Human-wildlife conflict regarding shark nets in Richards Bay, South Africa

Seeking solutions

by

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Declaration

I declare that this thesis submitted for the degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg, is my own work. It has not been submitted before for any degree or examination at any other University.

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Abstract

In the mid-1900s, shark bites in KwaZulu-Natal, South Africa, impacted bathers and tourism, and the authorities set gillnets to reduce shark numbers. This quintessential human-wildlife conflict was exacerbated by incidental catches of non-target species (bycatch). Sharks are now threatened globally, yet KwaZulu-Natal continues to use lethal bather protection gear (nets and baited hooks) to reduce shark populations. I aimed to map KwaZulu-Natal's bather-shark conflict, engage stakeholders and work with them in a productive, learning space that bridges research and implementation to improve the conservation status of sharks without compromising bathers. To map the human-wildlife conflict - identify and characterise the social and ecological elements of the system and their interactions - I used various philosophical perspectives and a multifaceted approach. First, I reviewed the ecological impact of KwaZulu-Natal's lethal gear and found that 88% of the catches were not the three target shark species, many were threatened species and 73% of the animals died. Second, I modelled the numbers of sharks, bycatch and bathers at a high-catch beach to predict temporal overlap between them. The findings yielded trade-offs to consider when striving for a positive impact on biodiversity without impacting the risk to bathers. Third, I characterised the social dimensions of the conflict using interviews, questionnaires and the literature, focussing on stakeholders whose work intersects with the bather-shark conflict. There were multiple stakeholders, varying in influence over decisions and interest in the bather protection programme, but communication flows were limited. Publications about the social and policy context describe the complexity of the conflict but studies of the economic impact are lacking. Fourth, I used a qualitative, constructionist approach to understand these stakeholders' perspectives of changing the lethal gear. Narratives of the obstacles were mostly centred around governance issues whereas opportunities were about technology, research and education. Finally, I used transdisciplinary learning to engage these stakeholders, leveraged their knowledge of different parts of the bather-shark conflict system and together, we designed a preliminary strategy to support the Sharks Board in moving away from lethal methods. My findings have illuminated multiple perspectives of the bather-shark conflict and exposed the stakeholders to these varied perspectives, improving our shared understanding. This should aid change agents in planning to implement change that would allow both humans and sharks to swim safely in KwaZulu-Natal.

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I dedicate my PhD to my daughter, Erin Lily Atkins, my budding animal whisperer. You have helped and inspired me in uncountable ways.

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Glossary and List of Abbreviations

(*Full references provided in the chapters*)

AIC: Akaike's Information Criterion (Anderson and Burnham, 2002).

Baited hooks: large hooks that are baited with fish and set to catch potentially dangerous sharks (Cliff and Dudley 2011).

Bather: a person in the ocean, especially swimmers and surfers.

Bather protection programme: public safety measures that are implemented at popular bathing beaches to reduce the chances of sharks biting bathers.

Bather protection fishing gear: shark nets and/or baited hooks.

Bather-shark conflict: a human-wildlife conflict that occurs between bathers and sharks and indirectly affects other humans that are not at the beach and other species.

Betweenness centrality: a metric describing a structural property of a network, the number of shortest paths (here, shortest chains of communication) that pass through a given stakeholder (Freeman, 1979).

Bycatch: incidental catch, i.e. animals that are caught in fishing gear set to catch a different species.

Chatterfall: the simultaneous sharing of personal reflections as text messages during online meetings that use video communication software.

Closeness centrality: a metric describing a structural property of a network, how 'close' individuals are in the network via their connections (the reciprocal of the sum of the length of the shortest paths between the node (stakeholder) and all other nodes in the graph) (Newman 2008)

Communication network: a set of nodes linked by interactions where the nodes consist of actors (in my case, the stakeholders/interviewees) and the edges denote interactions where information is communicated (Aggarwal 2011).

Connectance: a metric describing a structural property of a network, the proportion of realised edges (communication links between stakeholders) relative to the maximum number of edges possible (Newman 2008).

CPUE: Catch Per Unit Effort: number of catches relative to the quantity of nets.

CR: Critically Endangered (IUCN Red List Category).

DFFE: (National) Department of Forestry, Fisheries and the Environment.

Drumlines: a colloquial term for baited hooks set to catch potentially dangerous sharks (Cliff and Dudley 2011).

EDTEA: (Provincial) Department of Economic Development, Tourism and Environmental Affairs.

Effort: quantity of nets (usually measured in length).

EKZNW: Ezemvelo KwaZulu-Natal Wildlife, a provincial conservation entity.

EN: Endangered (IUCN Red List Category).

F=0: the magnitude of fishing mortality at which there was no potential for population growth (Dudley and Simpfendorfer 2006).

Fishing gear: shark nets and/or baited hooks.

Generation length: a time-scalar in the Red List as a way of accounting for differences in species' life-histories, quantified as the average age of parents of the current cohort (i.e. new born individuals) in the population (Cooke et al 2018).

GLMM: Generalised Linear Mixed Models.

Human-wildlife conflict: a protracted conflict that occurs when actions by people and wildlife have an adverse effect on the other, including threats (actual and perceived) posed by wildlife to human life, economic security, or recreation, human safety, health food or property which frequently involves human–human conflicts over conservation and resource use (Nyhus 2016).

IUCN Red List: an inventory of the global conservation status of biological species, providing comprehensive and scientifically rigorous information about the extinction risk of species (https://www.iucnredlist.org/).

IUCN: International Union for Conservation of Nature.

Key informant: Interviewees with specific, first-hand knowledge about certain aspects of the community.

Knowledge café: a type of meeting in which people are invited to discuss a topic of mutual interest in several rounds in small groups whose composition changes periodically (Steier et 2015, Brouwer et al 2019).

KZN: KwaZulu-Natal Province on the east coast of South Africa.

Leverage point: key point in a system where interventions can result in disproportionately large changes (Meadows 1999).

Modularity: a metric describing a structural property of a network, the existence of densely connected subgroups (Newman 2006).

Network: a set of nodes linked by interactions where the nodes consist of actors (in this case, the stakeholders/interviewees) and the edges denote interactions where information is communicated (Aggarwal 2011).

NPOA2: South Africa's second National Plan Of Action for the conservation and management of sharks (DFFE 2022).

NT: Near Threatened (IUCN Red List Category).

r: intrinsic rate of population growth (Dudley and Simpfendorfer 2006).

R/NT: Least Risk/Near Threatened (IUCN Red List Category).

Red list: an inventory of the global conservation status of biological species, providing comprehensive and scientifically rigorous information about the extinction risk of species (https://www.iucnredlist.org/).

Research-implementation gap: an implementation crisis in which there is a lack of progression from the scientific evaluation of valued elements of nature to the activities required to maintain or enhance those elements (Knight et al 2006).

SAAMBR: South African Association of Marine Biological Research.

SANBI: South African National Biodiversity Institute, a national public entity.

Sardine Run: The annual migration of sardine *Sardinops sagax* and predators from the Agulhas Bank up the KwaZulu-Natal coast.

Shark nets: gillnets set to catch potentially dangerous sharks (Dudley 1997).

Social learning: the collective action and reflection that takes place among both individuals and groups when they work to understand a system (Cundill et al 2012).

Social learning platform: the opportunity to collectively act and reflect, as per social learning.

Social-ecological system: a system of people and nature (Colding and Barthel 2019).

Systems thinking: a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects (Arnold and Wade 2015).

Top predator: a predator at the top of a food chain, without many natural predators, e.g. sharks, dolphins, lions.

TOPS: Threatened or protected species, as per the Threatened or Protected Species Regulations, 2017, Government Gazette No. 40875.

Transdisciplinary learning: integrating knowledge from both scientific and non-scientific (societal) branches of knowledge (Lang et al 2012).

Chapter 1. An introduction to seeking solutions to the human-wildlife conflict around bather protection from sharks in KwaZulu-Natal, South Africa

Introduction

Research-implementation gaps pervade biodiversity conservation. Biologists that study threatened wildlife want the results of their work to be used to improve the conservation status of the species of interest. Yet frequently this does not occur and those scientific results are not converted into management actions (Knight et al 2006). An example of this occurred in KwaZulu-Natal, South Africa, when investigations of the interactions between Indian Ocean humpback dolphins *Sousa plumbea* and gillnets (shark nets) which are set to protect bathers yielded evidence that nets were affecting the conservation status of Endangered humpback dolphins (Keith et al 2013, Atkins et al 2013a, b, Atkins et al 2016, Plön et al 2016, Braulik et al 2017). However, no significant changes to the nets were made, even though the relevant management organisation was aware of the results. It became apparent that simply presenting scientific evidence that the shark nets were causing a conservation problem was inadequate and more was needed to elicit conservation action.

The research gap

The gap that I will address in this PhD was not a gap in theory, nor was it a gap identified from the literature – the gap was between research and implementation in a conservation issue which triggered the question: how do we induce people to take conservation action when it is challenging but clearly necessary for a threatened species?

In designing an approach to consider this gap based on the scientific literature and creating my theoretical framework, I was guided by three concepts: an operational model for implementing conservation action (Knight et al 2006); navigating the space between research and implementation in conservation (Toomey et al 2016) and managing human-wildlife conflicts (Redpath et al 2013).

Operationalising conservation action

The research-implementation gap is described as an implementation crisis in which there is a lack of progression from the scientific evaluation of valued elements of nature to the activities required to maintain or enhance those elements (Knight et al 2008). These authors point out that although there is much science that informs where we need to focus conservation efforts, there is less scientific input on how to go about achieving these efforts. Where operational models do exist, they tend to be oversimplified and too narrowly focused on the biological entities rather than viewing the bigger picture. Five hallmarks of effective operational models to bridge the research-implementation gap were identified (Knight et al 2006:

- Links to an appropriate conceptual framework;
- Pays attention to social learning and action research;
- Includes stakeholder collaboration;
- Includes the development of an implementation strategy; and
- Links with existing governance instruments.

Based on these ideas, I aimed to find an appropriate conceptual framework and ensure that my approach included social learning and stakeholder collaboration. Social learning is defined as the collective action and reflection that takes place among both individuals and groups when they work to understand a system (Cundill et al 2012).

Exploring the research-implementation space

Toomey et al (2016) use a simpler definition of the research-implementation gap: a process by which "scientific information accumulates, but is not incorporated into management actions" (Matzek et al 2013, p. 208). They question the prevailing framing of the (linear) research-implementation relationship in which conservation scientists provide answers in the form of empirical information which must be translated by practitioners into applied solutions. An important part of this framing is that these scientists are not a part of society where the problems and everyone else are situated (Figure 1A). If the "gap" between research and implementation (which has negative connotations and suggests a deficit) were reframed as a "space for interaction" (with more positive connotations), this would lend itself to new ways of thinking about connecting research and implementation. They advocate for a far more inclusive set of stakeholders to participate in the space connecting science and governance generally (Figure 1B). They argue that although conservation science literature frequently calls for things like

stakeholder collaboration, breaking down disciplinary barriers, and integration of local, traditional, indigenous and scientific knowledge systems, these objectives are undermined by the prevailing linear conceptualisation used for translating research into action. Conservation is not a discipline that is completely within the realm of science (and neither is resolving human-wildlife conflicts). Social issues and contexts (values, norms, institutions, organisations and human well-being) underpin almost all of the opportunities and constraints for implementing conservation action (Cowling and Wilhelm-Rechmann 2007). In an example of successful eliciting conservation action, Arlettaz et al (2010) attribute social and political factors ahead of scientific factors (though the scientific factors did have an important role to play). Conservation science needs to be embedded into collaborative social and decision-making processes because conservation is a social process that engages science, not a scientific process that engages society (Balmford and Cowling 2006).

Based on these ideas, I wanted to embed my research in the social processes that exist, collaborate with others outside of my field of study and outside of science. It became important to engage different knowledge types and to explore people's experiences and perceptions of my research. This type of learning is designated transdisciplinary learning - integrating knowledge from both scientific and non-scientific (societal) branches of knowledge (Lang et al 2012). In transdisciplinary learning, actors from science, policy and practice come together to develop their understanding of a social–ecological issue together, reconcile their diverse perspectives and co-produce appropriate knowledge to serve a common purpose (Roux et al 2017).

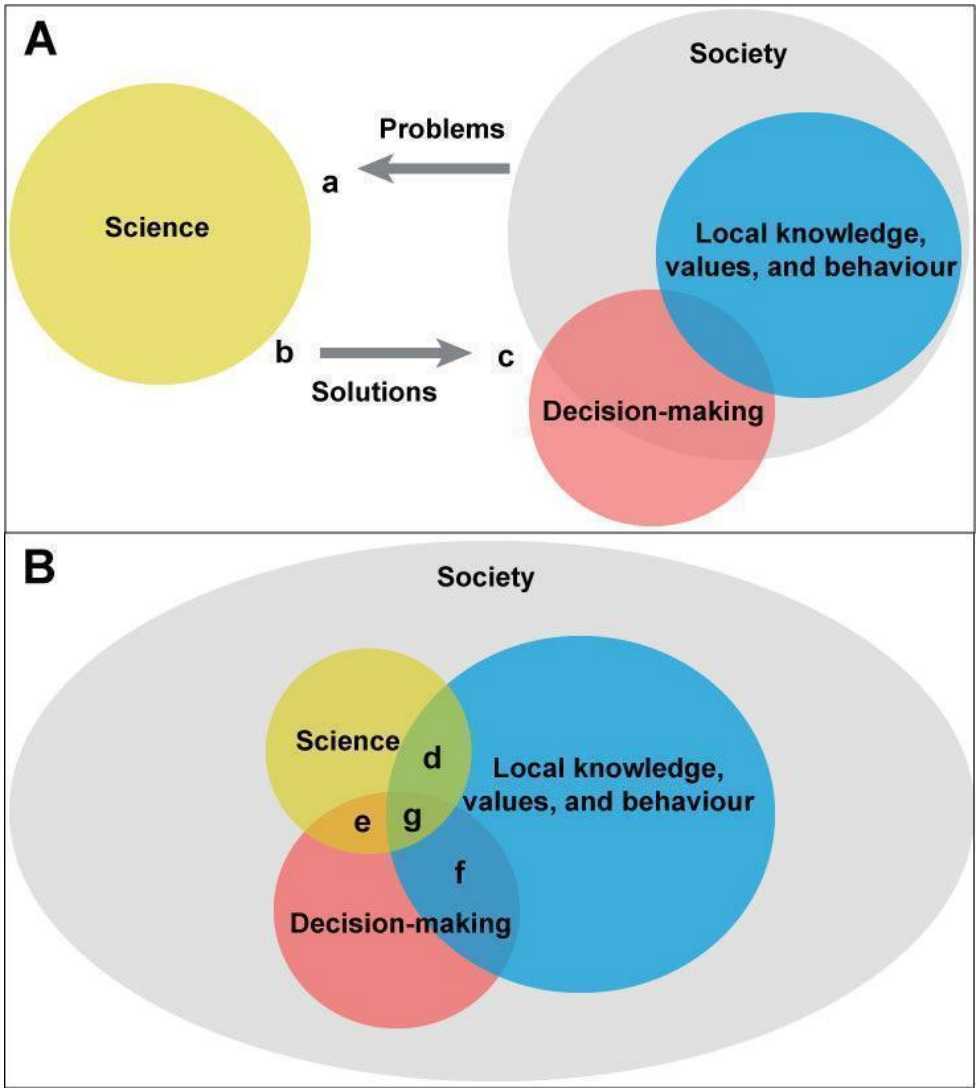

Figure 1. The research-implementation gap, reconceptualised as a productive space. Modified from Toomey et al (2016). A The conventional conceptualisation of research-implementation gaps in conservation: (a) communicating societal concerns to science; (b) translating scientific information into applicable recommendations; and (c) disseminating scientific recommendations for policy-makers. (B) Research-implementation spaces: (d) public engagement in science, e.g. citizen science, (e) boundary work and organisations, (f) environmental activism, community-based conservation, (g) participatory action research, sustainability science.

Human-wildlife conflicts

Both of the studies above discuss the need to view the bigger picture of the conservation situation. My previous research had focussed on the interactions between the shark nets and just one species, the humpback dolphin, and had been framed as a bycatch issue (Atkins et al 2013a, b, 2016). I had to expand my focus to include the sharks against which the nets were set and the people involved. Kock and O'Riain (2015) alluded to shark-human interactions as a human-wildlife conflict and this seemed a valid and appropriate conceptual framework, which was one of the hallmarks of an effective operational model identified by Knight et al (2006).

Human-wildlife conflict is a well-known phenomenon and has a vast literature (Peterson et al 2010, Pooley et al 2017). Effective management of such conflicts is a two-part process - understand the conflict, then manage it (Redpath et al 2013). The idea of understand-manage is similar to research-implementation but it is not framed as a gap and could potentially provide a way to think and work in the research-implementation space. Redpath et al's (2013) roadmap clearly articulated steps to be taken to understand the conflict (Figure 2):

- Identify the stakeholders;
- Map their values, attitudes, goals and positions;
- Identify economic, social and ecological impacts;
- Understand wider socio-political context (e.g. legislation); and
- Then, ask: do the stakeholders wish to discuss with other parties?

In the second stage, the steps to manage the conflict comprise:

- Identify the appropriate process;
- Agree on the aims;
- Negotiate positions;
- Identify alternative solutions and trade-offs;
- Agree on a resolution mechanism; and
- Test the mechanism; and
- Manage adaptively

They emphasised that conflict management requires parties to recognise problems as shared, and engage with clear goals, a transparent evidence base, and an awareness of trade-offs (Redpath et al 2013).

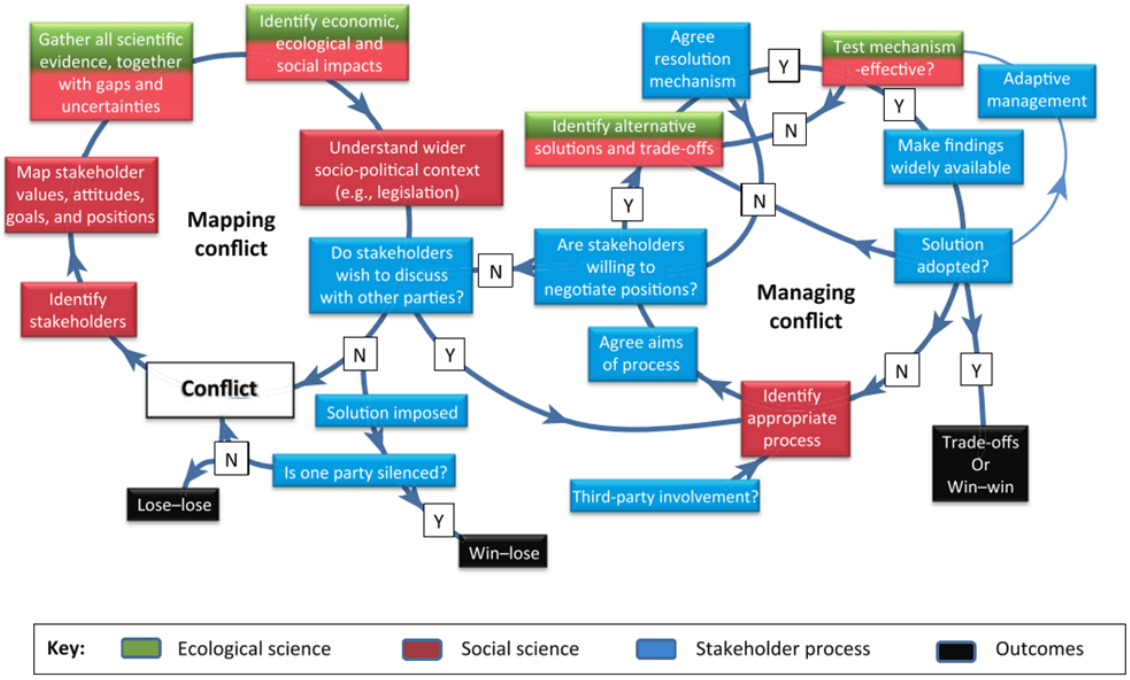

Figure 2. Roadmap to guide effective management of conservation conflicts (Redpath et al 2013).

My PhD was designed to work predominantly in the first phase: understanding the conflict. It deviates from the suggested process because I decided to engage the stakeholders early on, during the first phase rather than waiting to engage them only in the second phase, for two reasons: to enhance the chances of embedding the research in social and policy-making processes and to strengthen the recognition of the shared nature of the issues.

Social-ecological systems and change

The roadmap to understand human-wildlife conflicts refers to both social and ecological components and, although Redpath et al (2013) do not specifically say so, all human-wildlife conflicts are necessarily social-ecological systems. There are many, varied definitions of social-ecological systems, ranging from the broad “a system of people and nature” to the very specific “(1) integrated biogeophysical and socio-cultural processes, (2) self-organisation, (3) nonlinear and unpredictable dynamics, (4) feedback between social and ecological processes,

(5) changing behaviour in space (spatial thresholds) and time (time thresholds), (6) legacy behavioural effects with outcomes at very different time scales, (7) emergent properties, and (8) the impossibility to extrapolate the information from one social-ecological system to another"; a clear, unifying definition is yet to be settled upon (Colding and Barthel 2019). I use the term in the broad sense, i.e. a system of people and nature.

Using a systems framework yields useful systems tools and concepts. Systems studies have arisen in various scientific disciplines (and other non-scientific fields too), making it difficult to pin systems science down. A system is a set of components including the relationships between the components and between their attributes (Hieronymi 2013). Another important aspect of a system is "a complex whole" (Reynolds and Holwell 2010). Both the complexity and the "wholeness" are important attributes of systems within systems science. Studying the complexity of the problem in its entirety is important because solutions must match the complexity of the problem - panaceas are not realistic or helpful (Ostrom 2007).

Like systems in general, systems thinking has been difficult to define precisely. Systems thinkers have described it as: an art, a science, a discipline, a framework, a diagnostic tool, a philosophy and they often describe it in terms of its purpose (Arnold and Wade 2015, Goodman 1997). Arnold and Wade (2015) wrote a whole paper to define systems thinking and they settled on: systems thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects (Arnold and Wade 2015).

In systems thinking, the situation is considered as a whole and investigating the interactions among the elements of the system is key to discovering how something works, which is different to the general scientific approach of understanding something by pulling it apart - a reductionist approach (Reynolds and Howell 2010). Knight et al (2019) suggest we need to try a different approach to conservation to boost our chances of drastically improving our track record and recommend using systems thinking.

A particularly useful concept within systems thinking is that of leverage points – key points in a system where interventions can result in disproportionately large changes (Meadows 1999). Identifying leverage points can help in designing a strategy for change.

Conservation and the shark nets at Richards Bay, KwaZulu-Natal

Shark nets are deployed in KwaZulu-Natal Province in South Africa to catch and kill large sharks to reduce the number of sharks and thus reduce the risk of shark bites (Dudley and Cliff 1993). This culling practise ensures human well-being and safeguards tourism which is a valuable income-generator in the province (Dudley and Gribble 1999). It is a costly endeavour, both financially and environmentally. Systematically removing apex predators has negative impacts on marine ecosystems and their functioning over time (Myers et al 2007). Evidence has been presented that suggests that the impact is minimal (Dudley and Simpfendorfer 2006) but nearly 20 years have passed since that analysis and the conservation status of sharks in general has deteriorated (Dulvy et al 2014). In addition, the unintentional catches of other species (termed bycatch) are a concern.

Among the bycatch species is the Indian Ocean humpback dolphin *Sousa plumbea* (Cockcroft 1990, Cliff and Dudley 2011, Plön et al 2016). This species inhabits coastal waters from South Africa to the Bay of Bengal and is considered Endangered throughout its range due to its limited near-shore distribution, continuing decline in habitat quality, likely fragmentation of subpopulations, and anthropogenic-related mortality (Braulik et al 2017). In South Africa, the best-documented cause of humpback dolphin mortality is the shark nets, and the spatial distribution of this bycatch is skewed towards one of 37 netted beaches: Richards Bay (Atkins et al 2013). Patterns of residency, site fidelity and bycatch indicate that, because of these nets, Richards Bay may be an ecological trap for humpback dolphins (Atkins et al 2016). Conservation resources could be maximised by focussing efforts at Richards Bay with a potentially positive effect on the broader population of this Endangered species.

One way of reducing the impact of the bather protection programme on the humpback dolphin is changing the fishing method. Other types of fishing gear have lower rates of megafauna bycatch than gillnets (Read et al 2006, Lewison et al 2014), so changing fishing methods was considered a valid way to reduce humpback dolphin mortality. Baited hooks have been used successfully to prevent shark attacks in South Africa, Australia and Brazil and have a reduced bycatch compared to nets (Dudley et al 1998, Cliff and Dudley 2011, Hazin and Afonso 2014). In 2007, the KwaZulu-Natal Sharks Board (hereafter Sharks Board), who manage the bather protection programme, began to replace some gillnets on KwaZulu-Natal's south coast with baited hooks, colloquially known as drumlines (Cliff and Dudley 2011). In 2016, the Sharks Board intended replacing some of the Richards Bay nets with hooks and discussed this with the

local municipality (uMhlathuze) in September 2016 (personal observation; I was present at the meeting). Although there was verbal agreement with the proposed change, there was no formal response from the municipality in the two years following the discussion (personal observation, pers. comm. Geremy Cliff, Head of Research, KwaZulu-Natal Sharks Board). These circumstances triggered this research to fill the research-implementation space.

Is this a human-wildlife conflict?

Human-wildlife conflicts are protracted conflicts that occur when actions by people and wildlife have an adverse effect on the other, including threats (actual and perceived) posed by wildlife to human life and well-being, economic security, or recreation, which frequently involves human–human conflicts over conservation and resource use (Nyhus 2016). They have three characteristics (IUCN 2023):

1) Human-wildlife conflicts involve interactions between people and wildlife that are direct and recurring.
2) Human-wildlife conflicts are almost always underpinned by social conflicts between people over the management of wildlife.
3) Human-wildlife conflicts tend to involve species of conservation concern that are negatively affecting human interests.

Does the situation with bathers and sharks in KwaZulu-Natal match these characteristics?

1) In KwaZulu-Natal, in the 1940s there was a spate of shark bites causing injury or death to 58 people in 22 years and a loss of vital tourism from the province (Davies 1962). People's response was to set gillnets to catch and kill sharks, reducing their numbers and thus the risk to bathers; thousands of sharks have been killed since these shark nets were first set in 1952 (Dudley 1997; Cliff and Dudley 2011). The direct interactions between sharks and humans where humans are seriously or fatally harmed are historical because the use of shark nets (and more recently, baited hooks) has drastically reduced the risk of a bather interacting with a shark. The regular entanglement and removal of sharks from the nets and hooks are direct and recurring human-shark interactions. The adverse effect is currently drastically skewed against sharks, with very few humans suffering shark bites in the province (none fatal). However, if the current lethal bather protection method were removed and the shark populations began to recover, it is likely

that the risk of shark bites would go up in KwaZulu-Natal again (in the absence of alternative methods of bather protection) as South Africa is a hotspot for shark and shark bites, even with the current lowered shark bite rate in KwaZulu-Natal (Derrick et al 2020, Midway et al 2019). Thus, there are direct and recurring interactions (currently and potentially) between people and sharks.

2) Sharks are among the least liked, most misunderstood animals yet they are extremely valuable to ecosystem health (George et al 2016, Hammerschlag et al 2019). Thus, there is contention over the potential long-term impacts and the ethics of managing bather-shark interactions using lethal methods (Gibbs et al 2020, Sheridan et al 2021). In the past, most people thought humans needed to be protected from sharks but now more and more people think sharks need protection from humans (Simpfendorfer et al 2011). There are social conflicts between people over the lethal management of sharks.
3) Large coastal sharks have an elevated risk of extinction (Dulvy et al 2014; Pimiento et al 2020).

Although it's not one of the stipulated criteria, "perceptions of conflict" are an important part of human-wildlife conflicts (Nyhus 2016, IUCN 2023). People's fear of sharks and misconceptions of the risk of shark bites play an extremely important role in the conflict (Crossley et al 2014). It is also important to note the indirect impacts of shark bites which further fuel the conflict. Shark bites are rare but sensationalised events (Bombieri et al 2018) and do not only affect the person who was bitten but have a ripple effect on tourism because of the negative publicity (Oelofse 2006). People tend to avoid areas where shark bites occur (Lemahieu et al 2017). Such avoidance has negative effects on local businesses and economies. Thus, the indirect effects are also considered among the threats posed by wildlife to economic security and well-being. According to Nyhus (2016), the bather-shark conflict is among the most negative and severe human-wildlife conflicts, despite the rare occurrence of interactions. There is another indirect effect of this conflict that should be considered: "bycatch as collateral damage". Shark nets and baited hooks are set to catch sharks but are indiscriminate and catch other large marine animals too. Their entanglements also constitute part of this human-wildlife conflict, even though the catches are incidental.

An unusual feature of this human-wildlife conflict is the directness of the conflict. Many human-wildlife conflicts occur due to competition between humans and wildlife over a shared biological resource. Redpath et al (2013) offer four examples of conflicts and in all of them, there

is a biological resource (e.g. fish, grouse, old-growth trees and crop plants) that is common to both human (fishermen, gamekeepers, loggers and farmers) and non-human predators/resource users (seals, hen harriers, owls, elephants). In the bather-shark case, there is no biological resource that we are competing with sharks for. It is a matter of spatial overlap - we enter their environment and, being tantamount to potential prey, we are vulnerable to direct interactions with them that can possibly injure or kill us.

Is it a human-wildlife conflict or a conservation conflict? Some suggest that “conservation conflict” is a more accurate designation since wildlife is not an antagonist and the conflicts are essentially between conservationists and people who are impacted by the wildlife. Conservation conflicts are defined as situations that occur when two or more parties with strongly held opinions clash over conservation objectives and when one party is perceived to assert its interests at the expense of another’ (Redpath et al 2013, 2015). There is utility in being explicit about the underlying human-human conflict to improve transparency and articulate goals (Redpath et al 2015). However, the phrase “conservation conflict” lacks specificity and could refer to conflicts regarding a variety of conservation issues, e.g. protected areas, hunting. Given the directness of the conflict between sharks and people and that the social aspect of the conflict has been incorporated into the definition of human-wildlife conflicts, it seems appropriate to use the term human-wildlife conflict. The term continues to be used in the literature (Su et al 2022). In this case, I find it useful to simultaneously draw attention to both components of the system - humans and wildlife.

Thesis problem statement

This human-wildlife conflict began in KwaZulu-Natal, South Africa, in the 1940s when there was a spate of shark bites causing injury or death to bathers and a loss of vital tourism income (Davies 1962). A new layer to the conflict was added when people’s response was to set gillnets to catch and kill sharks, reducing their numbers and thus the risk to bathers (Dudley 1997). The conflict is exacerbated by the fact that other animals in addition to the damage-causing sharks are also caught and killed, incidentally (Dudley and Cliff 1993). There is further conflict among people - those who think these animals should be conserved and those with other priorities. Effecting change to conserve threatened species in this complex social-ecological system is a challenge.

To manage the conflict such that there is less impact on the threatened wildlife, without impacting humans, we needed to understand the conflict and its many layers. We needed to examine the social and ecological elements - who is involved, what are the interactions among them, what are the impacts and the context. This would allow us to identify opportunities and obstacles to change and chart a way forward. I used a multi-faceted approach with tools from natural and social sciences and began to make the space between research and implementation productive by collaborating with the stakeholders.

Aim and objectives

My overarching aim was to map the human-wildlife conflict around shark nets at Richards Bay, KwaZulu, South Africa, involving stakeholders and social learning in the process, to identify obstacles and opportunities to facilitate changing the current system of culling sharks without unduly affecting bathers. Specifically, I have:

- Reviewed what is known about the ecological impact of the bather protection programme on KwaZulu-Natal's marine megafauna;
- Modelled the temporal patterns of sharks, bycatch and bathers at Richards Bay to predict their overlap and identify temporal obstacles and opportunities for change;
- Identified and characterised the stakeholders whose work intersects with the drivers and consequences of the use of lethal methods to protect bathers, and described the social context of the conflict;
- Interviewed the stakeholders to document their knowledge and perceptions of shark nets, with particular focus on obstacles and opportunities for change; and
- Provided a transdisciplinary, social learning platform to co-evolve stakeholders' understanding (i.e. influence each other in the process of understanding) and identify potential actions that can mitigate the conflict in the forthcoming years.

Scope

My study is focused on the primary (sharks, bathers, bycatch) and secondary stakeholders whose work intersects with the drivers (e.g. bather protection and tourism) and consequences (e.g. biodiversity loss) of the use of lethal methods to protect bathers. Richards Bay is the focal area of the study within the KwaZulu-Natal Province (Chapter 2, Figure 1, page 41).

Research questions

1) Ecological impact
   - What evidence exists that would allow an assessment of the impact of the bather protection programme on marine species?
   - What is the ecological impact of the use of shark nets and baited hooks in KwaZulu-Natal?
   - Is there cause for concern?

2) Temporal patterns
   - When are sharks and other animals caught in the shark nets at Richards Bay?
   - How many bathers use the beach at Richards Bay daily?
   - Can I predict when sharks, bathers and bycatch overlap to establish times of higher and lower risk to bathers and to bycatch to identify opportunities for change?

3) Stakeholders and context
   - Whose work intersects with the drivers and consequences of the use of shark nets at Richards Bay?
   - How interested and influential are these stakeholders?
   - What are the characteristics of the network they form?
   - What are the social, economic and political contexts in which this bather-shark conflict occurs?

4) Stakeholder knowledge and perspectives
   - What do the stakeholders know about how the shark nets work?
   - What are the stakeholders' perspectives about change?
     - Specifically, what are the narratives relating to what impedes or could facilitate change?

5) Social learning platform
   - Who would make use of such a platform?
   - Given the explicit and tacit knowledge of stakeholders that work in different parts of this social-ecological system, and what I learned in the previous stages about obstacles and opportunities to change, what should be done to elicit change that minimises the bather-shark conflict in KwaZulu-Natal?

Research contribution

My PhD attempts to address the research-implementation gap in conservation and in doing so

makes varied contributions. I use the human-wildlife conflict framework to view the problem of protecting bathers from sharks in KwaZulu-Natal with a new lens. The thesis adopts an interdisciplinary approach, examining ecological and social aspects of the relationships between 'sharks that bite, bather safety and bycatch'. Although I followed Redpath et al's (2013) roadmap to understand and manage human-wildlife conflicts, I deviated from the suggested protocol by engaging the stakeholders during the first phase (understanding the conflict) rather than waiting until the second phase (managing the conflict). To do this, I created a social learning platform and used a transdisciplinary approach to engage key stakeholders to improve our understanding of the social-ecological system and find solutions, thus enhancing the chances of embedding the research in social and governance processes and strengthening the stakeholders' recognition of the shared nature of the issues. My thesis bridges disciplines, methods, scales, and stakeholders. The holistic and integrative character of the thesis as a whole is an innovative contribution.

Thesis layout

- Chapter 1 provides the background, the research gap and the theoretical frameworks that form the basis of my research, as well as the aims, objectives and research questions.
- Chapter 2 explores the context of the human-wildlife conflict in KwaZulu-Natal, focussed on the wildlife aspect, mapping the biodiversity impacts over time. It lays out some of the history of the bather protection programme and its impacts on sharks particularly, as well as other marine megafauna.
- Chapter 3 focuses on one particular beach, the northernmost protected beach in KwaZulu-Natal that has a particularly high catch rate, and brings in the human element. It investigates and models the temporal overlap of the three elements - the sharks, the bathers and the bycatch, assessing the relative human-wildlife risks in an attempt to identify temporal opportunities to make changes.
- Chapter 4 broadens the view of the human elements beyond just the bathers, to understand who the parties are that are connected with this human-wildlife conflict. It characterises these stakeholders and their stakes, and the interactions among the stakeholders. It is focussed on the human dimensions of the conflict - and looks for obstacles and opportunities for change from the social, political and economic contexts.
- Chapter 5 elucidates one-on-one engagement with the stakeholders and investigates

how they understand the mechanism of the bather protection gear, and interrogates their perspectives, interpreting these with a focus on the narratives that exist pertaining to the obstacles and opportunities to change.

- Chapter 6 gathers the stakeholders together and feeds back the results of chapter 4 to the group creating an opportunity for them to recognise the multiple perspectives in the conflict and to collectively devise a way forward. Here, stakeholders from both the research and management sphere are engaged and work together to create a way forward.
- Chapter 7 pulls all the information of the chapters together and evaluates the whole approach, suggesting what should be done differently and what should be done next. It then draws a conclusion.

A separate reference list accompanies each chapter, and thus there is some overlap in referencing between chapters. All tables and figures are numbered sequentially per chapter, while page numbers are numbered sequentially throughout the thesis.

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Chapter 2. Review of the ecological impact of bather-protection fishing gear in KwaZulu-Natal, South Africa: an update

Abstract

A human-wildlife conflict exists in KwaZulu-Natal, South Africa, where in the past, sharks bit bathers which indirectly affected the local tourism industry. In response, humans set fishing gear (gillnets and baited hooks) to catch and kill sharks to reduce their numbers and thus the risk of shark bites. The gear also catches and kills non-target marine megafauna (bycatch). Sharks and these other apex predators (e.g. dolphins) are particularly vulnerable to extinction generally. Over the past 50 years, various measures have been taken to reduce the impact of the fishing gear. Managing human-wildlife conflicts effectively entails attempting to first understand the conflict, including the ecological impact. My aim was to review the ecological impact of this fishing gear by using existing information to assess the number of catches and mortalities of target and non-target species. I reviewed the literature and consulted species-specific Red List assessments to examine the longer term catch trends. The vast majority of the catches (88%) in the gear were not the three target species: Zambezi *Carcharhinus leucas*, white *Carcharodon carcharias* and tiger *Galeocerdo cuvier* sharks. Most (73%) of the animals died. The catch per unit effort (CPUE, number of sharks/amount of gear) was extremely high in the early years but species identification was poor so species-specific sampling began after the steepest declines. Still, population declines have been measured in nine of 14 shark species, 13 of which are threatened (including six Endangered and Critically Endangered). For five of these six species, the gear is responsible for >50% (mostly >75%) of South Africa's reported catches, although unreported catches are suspected but not accounted for. Replacing nets with hooks has had a positive impact on some threatened species (e.g. ragged-tooth sharks and humpback dolphins) but not others (e.g. dusky and scalloped hammerheads). Levels of concern are high for two of the 14 shark species (dusky and scalloped hammerhead sharks), medium for seven and low for five. Non-shark species of high concern are white-spotted wedgefish and two locally extinct sawfishes, humpback dolphins and leatherback turtles. All species legislated as threatened or protected were ranked at least as medium concern, except for tiger sharks which are increasing in numbers. We need to find a more targeted way to deal with the risk of shark bites, preferably using non-lethal solutions since there is concern about two of the three species of target sharks, the Zambezi and white sharks. Conservation concern for tiger sharks is relatively low since their populations are increasing but this might exacerbate future conflict.

Introduction

Human-shark conflict

In some parts of the world, the conflict between sharks and people is intense. Shark bites are rare but when they occur, they are often extremely traumatic and attract much attention (Crossley et al 2014, Midway et al 2019). These shark bites do not only affect the person who was bitten but there is often a ripple effect on tourism because of the negative publicity (Oelofse 2006). In KwaZulu-Natal in South Africa, during the 1940s and 1950s, the rate of bites was particularly high (Davies 1962). From 1940 to 1962, a period with a particularly high rate of shark bites in KwaZulu-Natal, 61 people were bitten and 24 of them died (https://www.sharkattackfile.net/spreadsheets/GSAF5.xls, accessed 12/11/2022). The coastal communities in KwaZulu-Natal demanded the authorities intervene. In response, the municipalities tried a few different methods and settled on an Australian solution of using gillnets (Davis et al 1995).

These gillnets and, much later, baited hooks (known colloquially as shark nets and drumlines) were set at popular beaches to catch and kill sharks, reducing their numbers and hence the probability of interactions between sharks and people (Dudley 1997, Dicken et al 2016). In other words, the gear fishes for sharks to reduce the risk of shark bites and it is sometimes described as a non-commercial fishery. It has been called a shark control programme but is usually known as a bather protection programme. Between 1978 and 2010, more than 50 000 sharks and other marine megafauna were caught in this fishing gear and most of them died (Cliff and Dudley 2011).

The interactions between humans and sharks in KwaZulu-Natal constitute a quintessential human-wildlife conflict where the activities of sharks harm humans and, in response, the activities of humans harm sharks (Nyhus 2016). There are direct effects, i.e. injuries and loss of life (to humans, sharks and other marine animals), and indirect effects, i.e. loss of tourism and livelihoods for humans and, for wildlife, loss of biodiversity and the impact on the ecosystem caused by the loss of top predators (Myers et al 2007).

Sharks are threatened

There are numerous threats to sharks globally and, as a group, they are particularly vulnerable to extinction (Dudley and Simpfendorfer 2006, Dulvy et al 2014, da Silva et al 2015, Roff et al 2018, MacNeil et al 2020, Pacoureau et al 2021). Fishing is by far the greatest threat to sharks and even on a relatively small scale, fishing can have a negative impact on large sharks (Dulvy et al 2014, Ferretti et al 2010, Simpfendorfer et al 2021a). In addition to commercial fishing and bycatch (when the species that were caught were not the ones being fished for), other threats include habitat loss, persecution and climate change (Dulvy et al 2014). Many other species of marine megafauna, like dolphins, turtles and seabirds are also vulnerable to extinction because of fishing practices (Lewison et al 2004). These animals are valuable, economically, culturally and ecologically, especially because they play a vital role in marine ecosystem health (Simpfendorfer et al 2021).

Measures to reduce the impact

Over the past four decades, various measures have been taken to reduce the impact of the bather protection programme on sharks and the bycatch in KwaZulu-Natal (Cliff and Dudley 2011, Dudley and Cliff 2010). Most of the description below is drawn from the summary and Figure 2 in Cliff and Dudley (2011). For the first 10 years, Durban (Figure 1) was the only town protected by shark nets and there was one beach with nets that covered 2 km. In the first year, more than 500 sharks were caught in this one installation. In the 1960s, other municipalities along the KwaZulu-Natal coast began deploying shark nets and by 1970, there were 39 protected beaches and 30 km of nets (Figure 1). In 1964, the Natal Anti-Sharks Measures Board (now the KwaZulu-Natal Sharks Board, hereafter Sharks Board) was formed to oversee the bather protection programme. During the following decade (1970s), the Sharks Board began to take over the servicing and maintenance of the nets. This drastically improved the collection of catch data and, since then, our biological knowledge of sharks and bycatch species. Also important is that the nets were inspected more frequently and so more animals were found alive. By 1980, the rate of installing new nets had slowed, resulting in 42 beaches with 36 km of nets. During the 1980s, most of the sharks that were found alive were released (i.e. not killed) and many of them were tagged. By 1990, there were 43 protected beaches and 43 km of nets in KwaZulu-Natal. During the 1990s, the Sharks Board reduced the large number of catches associated with the sardine *Sardinops sagax* run (an annual influx of huge shoals of sardines and their predators) by improving the timely removal of nets and increasing the duration of the

net removal. At the end of this decade, the Sharks Board began reducing the number of nets and by 2000 there were 38 beaches protected by 32 km of netting. During the 2000s, the first baited hooks replaced some of the remaining nets and, by 2010, the 38 beaches had 23 km of netting and 79 hooks. The baited hooks are more selective than the nets are and have a reduced bycatch (Dudley et al 1998). The gear change continued through the 2010s and currently, there are 13 km of shark nets plus 177 baited hooks at 37 protected beaches (KwaZulu-Natal Sharks Board 2022).

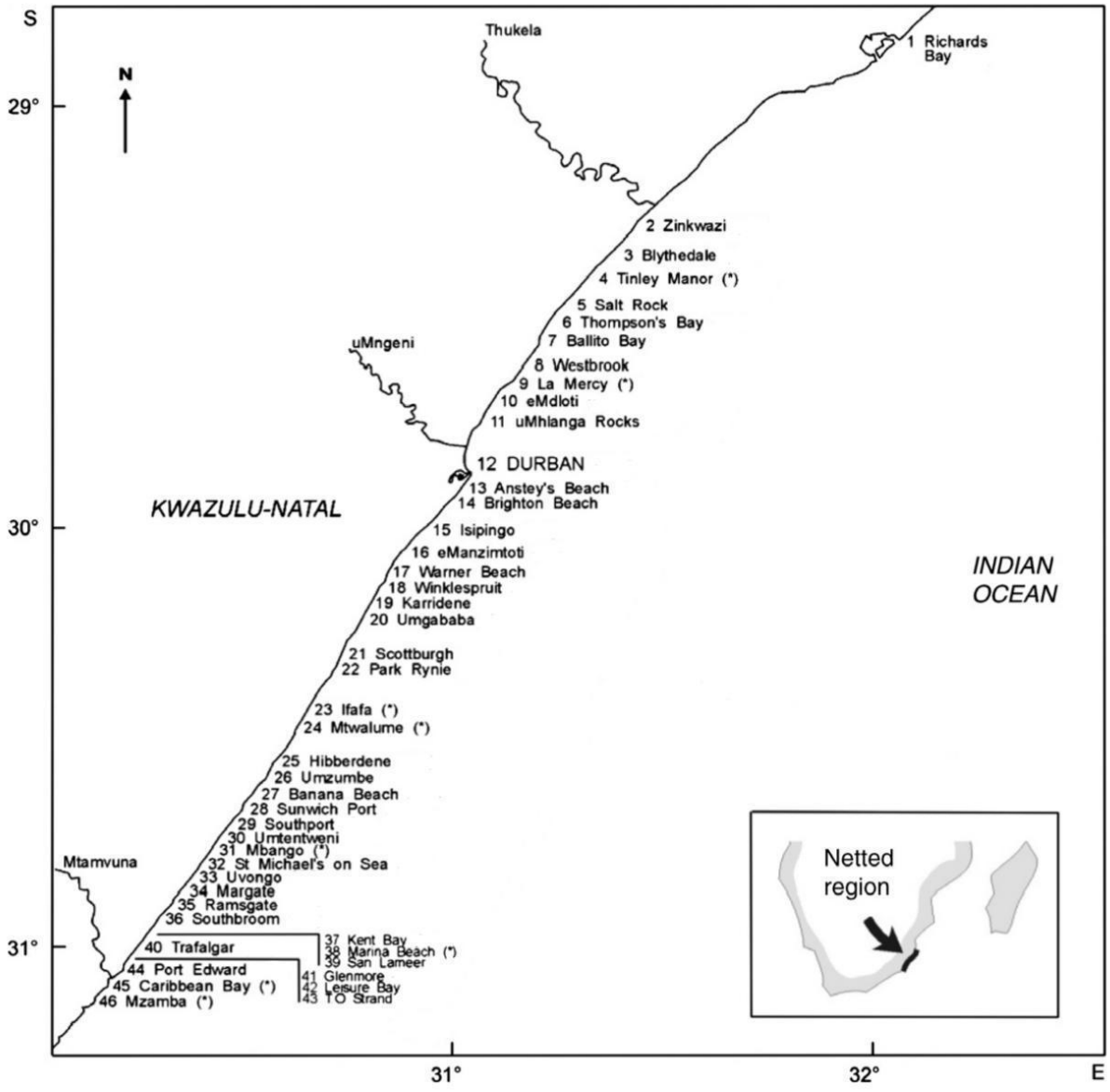

Figure 1. Beaches that have historically had bather protection fishing gear (gillnets and baited hooks) along the coast of KwaZulu-Natal, South Africa (inset). Several beaches no longer have gear (marked with the symbol: (*)). Map replicated from Atkins et al (2013).

Effectively managing human-wildlife conflicts requires first understanding them, including understanding the ecological impact of the conflict (Redpath et al 2013). My aim was to improve our understanding of the ecological impact of KwaZulu-Natal's human-shark conflict and review what is known about the ecological impact of the bather protection programme on KwaZulu-Natal's marine megafauna. I used existing information to assess the number of catches and mortalities of target and non-target species and reviewed the literature to assess the long term catch trends of species that are caught in the bather protection fishing gear.

Methods

To learn about the impacts of the bather protection fishing gear and the conservation status and trends of the species that are caught, I consulted four data sources: 1) the peer-reviewed literature; 2) the most recent IUCN Red List assessments; 3) national legislation (Threatened or Protected Marine Species Regulations, 2017); and 4) a publicly available report of the annual average number of catches and mortality rates in the bather protection gear between 2013 and 2017.

Fisheries impacts take four forms: impacts to habitats; bycatch species; threatened and endangered species; and ecological communities (Hobday et al 2011). I used the peer-reviewed literature to review what is published about any of these four types of impacts.
I searched the Web of Science database using multiple search terms: bather AND protection AND impact; shark AND net AND impact; protective AND gillnet AND impact; shark AND control AND impact. Although I did not limit my search to KwaZulu-Natal, I report only publications pertaining to this area to address the aims of the study.

I used the most recent IUCN's Red List assessments to obtain information of the past and current Red List categories of threat for each species and found that many of these assessments of the 14 species of shark listed in Dudley and Simpfendorfer (2006) included extensions of the trend data (up to 2019). I consulted South Africa's Threatened or Protected Marine Species Regulations, 2017, to identify which species have been flagged for special attention by the national government. In addition, for some aspects of the bycatch assessment, I used data that had been made publicly available on the Sharks Board's website (shark.co.za) because there are no recent published data reporting the number of catches and mortality rates

of all the species caught in KwaZulu-Natal following the replacement of many of the shark nets with baited hooks. These data consisted of an annual mean (between 2013 and 2017) of catches and releases of 18 species of sharks and seven groups of animals labelled as harmless to people, including turtles, harmless sharks, dolphins, whales, batoids, birds, and teleosts and can be found at https://www.shark.co.za/Pages/SharkCatchStats.

Results and discussion

Based on the titles and the abstracts of the outcomes of the search, there were seven relevant papers: Dudley and Cliff (1993); Dudley and Simpfendorfer (2006); Natoli et al (2008); Cliff and Dudley (2011); Brazier et al (2012); Atkins et al (2016); Plön et al (2020). From previous work, I knew of six additional papers that contained relevant information for one or more of the species, including Dudley (1997); da Silva et al (2015); Everett et al (2016); Daly et al (2020); Kock et al (2022); Bowlby et al (2022). In addition, chondrichthyan fisheries' catch data in South Africa is presented in South Africa's second National Plan of Action for the conservation and management of sharks (NPOA2; Department of Forestry, Fisheries and the Environment 2022).

None of the papers investigated impacts on habitat. Since the gear is stationary, there are unlikely to be any serious impacts on the substrate. Nets are usually taken out of the water prior to inclement weather, so lost nets are unlikely to be a problem. The gear is serviced about 18 times per month (Cliff and Dudley 2011) and the boats that are used to service the gear contribute to noise pollution in the area. This noise pollution could negatively impact animals that use the area. Because the boats only spend a few hours per month at the gear, the impact is unlikely to be substantial though this would need to be tested.

Ratio of target:non-target catches

Regarding bycatch, usually the bather protection catches are divided into two categories: sharks and harmless animals (e.g. Cliff and Dudley 2011). According to the Sharks Board's publicly available data from 2013-2017, an average of 796.8 animals (no range given) were caught per year, including 502.0 sharks and 294.8 harmless animals which suggests a target:non-target ratio of 1:0.6, many more target animals than non-target (another term for bycatch). However, only bull *Carcharhinus leucas*, (known locally as the Zambezi shark), white *Carcharodon carcharias* and tiger *Galeocerdo cuvier* sharks are responsible for serious shark bites (Cliff 1991) and just these three species should be considered the target species. An average of 92.8

individuals of the three target species were caught per year: 10.2 were Zambezi, 22.4 were white and 60.2 were tiger sharks (Figure 2). Reclassifying the other shark species as non-target species suggests that an annual average of 704.0 non-target animals were caught yielding a target:non-target ratio of 1:7.6, i.e. for every target shark caught, 7.6 non-target individuals are caught, which amounts to 88% of the total catches. Considering only mortalities, of the 578.0 animals that died per annum, and average of 59.6 were the three target species (8.0 Zambezi, 16.8 white and 34.8 tiger sharks) yielding a target:non-target ratio of 1:8.7 (90% of the catches). Target:non-target ratios in commercial fisheries are usually reported in terms of weight (non-target relative to total catch in tonnes) whereas the ratios expressed in my review are of the number of individuals. To provide some context, the global shrimp fishery is the most wasteful at 55% (i.e. just over half of the total weight of the catch was not the target species), and, for gillnet fisheries, ranged between 8% and 35% (Gilman et al 2020). Thus, the relative non-target catch in the bather protection programme seems extremely high compared to other fisheries.

Mortality rates

Using the same publicly-available data: Of the 796.8 animals that were caught on average annually between 2013 and 2017, 73% died (Figure 2). Of the three target shark species, 64% died in the nets and 36% were released alive. Of the non-target species, 74% died and 26% were released alive. Far fewer animals were caught and died in the bather protection programme recently compared to the 1980s when an average of 2071 animals were caught per year and 80% died (Cliff and Dudley 2011).

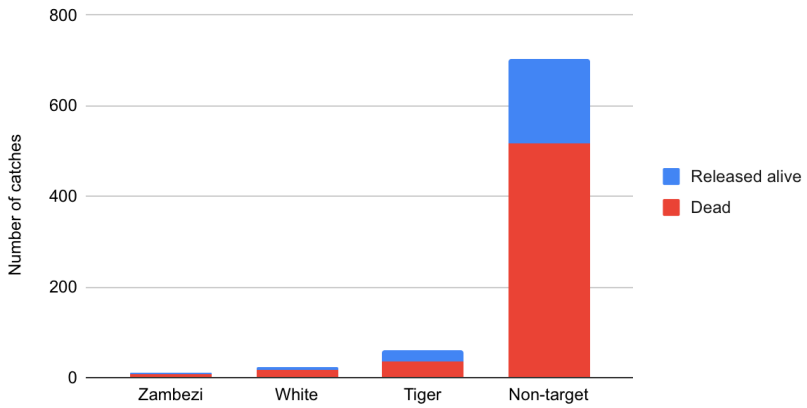

Figure 2. The number of catches and mortalities of target three shark species: Zambezi (bull) *Carcharhinus leucas*; white *Carcharodon carcharias*; and tiger *Galeocerdo cuvier*, and of non-target species of the bather protection gear between 2013 and 2017 (Data from https://www.shark.co.za/Pages/SharkCatchStats).

Interactions between humpback dolphins and the bather protection gear

For most of the species caught in the shark nets and on the hooks, little is known of the individuals that become caught, unless in the rare case that they are already tagged. Therefore, my previous studies of humpback dolphins *Sousa plumbea* at Richards Bay provide unique insights into some aspects of the interactions between marine animals and the bather protection gear.

Humpback dolphins are classified by the IUCN Red List as Endangered, and shark nets are considered a major threat to the species in South Africa (Plön et al 2016, Braulik et al 2017). Catches were first flagged as a concern in the 1990s (Cockcroft 1990, 1994) and the Sharks Board has taken measures to reduce the catches of this species, e.g. testing acoustic warning devices and encouraging research (Cliff and Dudley 2011). Between 1980 and 2009, 203 humpback dolphins were caught by shark nets in KwaZulu-Natal with a mean (± standard error) of 6.8±0.63; there was substantial variation in the annual number of catches and no declining trend (Atkins et al 2013). Had this species been assessed against the criteria used in Dudley and Simpfendorfer's (2006) assessment (see below), they would have concluded that the effect of the shark nets on the species was limited because 1) there was no declining trend, and 2) there were very few catches every year.

It is noteworthy that there was a strong spatial bias in humpback dolphin catches in KwaZulu-Natal, with 60% occurring at one beach, Richards Bay, which has just 5% of the province's nets (Atkins et al 2013). There, I investigated the residency, site fidelity and bycatch of humpback dolphins using photo-identification (Atkins et al 2016). There was evidence of a net loss of humpback dolphins from the local population and some of that loss could be attributed to mortalities in the shark nets. A significant proportion (8%) of the distinctive adults that were photo-identified and catalogued were killed in the nets. This far exceeds the International Whaling Commission's acceptable mortality rate of 2% for cetaceans (Perrin et al 1994). Therefore, even very few catches can impact a population negatively. In addition, I detected a

high short-term population turnover at Richards Bay and noted the immigration of transients from adjacent areas which could mask a local population decline (Atkins et al 2016). Richards Bay may be an attractive sink or ecological trap (Battin 2004), which is an area of high habitat suitability and high anthropogenic mortality. Populations that overlap with ecological traps might appear stable (even growing) through immigration from adjacent habitats (sources), but theoretical and empirical studies show such traps affect the demography in source habitats, and can drive local populations to extinction (Delibes et al 2001, Gundersen et al 2001, Whitehead and Gero 2015). Therefore, even though the catch rate did not decline over time and there were only a few individuals caught in the nets annually, the shark nets appeared to be negatively affecting the population at Richards Bay and further afield.

I analysed the spatial distribution of catches at Richards Bay and identified the nets with the highest catches (unpublished data). In 2005, half of the highest-catch net was replaced with three baited hooks. In the 10 years that followed, the catch rate of humpback dolphins at Richards Bay was reduced from 4.82 ± 0.71 to 2.90 ± 0.69 (Atkins et al 2019). In 2019, two more nets were replaced with hooks and currently Richards Bay has four nets (700m) and nine hooks, and during the whale migration in 2022, all nets were temporarily replaced with hooks (Greg Thompson, KwaZulu-Natal Sharks Board Head of Operations, personal communication). I anticipate further measurable reductions in the annual catch rate of humpback dolphins.

Impact on sharks

In KwaZulu-Natal, Dudley and Simpfendorfer (2006) conducted a comprehensive study of the trends of catches in the bather protection programme between 1978 and 2003 and the potential impact of the programme on the populations of 14 species of large sharks. This assessment investigated the catch data, biological data (the sizes of the sharks caught and life history patterns of the species, such as intrinsic rate of population growth (r)) and a knowledge of other potential impacts in the environment. They calculated the magnitude of fishing mortality at which there was no potential for population growth (Fr=0) as a quantitative measure to categorise the potential impact of the shark nets (high, medium or low potential impact) by species and then evaluated this relative to trends in catch rate, shark size and intrinsic population growth rates. Despite the result that catches and/or size declined in six of the species, the outcome was that the effect of the shark nets on the shark populations was limited for 13 of the 14 species; in the one exception, the effect of the shark nets on the Zambezi shark was regarded as “more

pronounced". It is worth noting that at this time, only two of the 14 species were considered threatened (both Vulnerable (VU)) and most of the others were Lower Risk/Near Threatened (LR/NT). Analyses of the trends in catch were extended by another 10 years in an assessment of the status and management of South Africa's chondrichthyan fisheries (da Silva et al 2015). Three of the 14 shark species continued to show declines in catches but there were changes in the trends of the others - some species had begun to show evidence of declines and some that had been declining were no longer declining (details below). da Silva et al (2015) concluded that, because the bather protection gear was permanently deployed at fixed locations, any decreases probably reflected localised rather than population-level effects.

It should be noted that the period of the analysis by Dudley and Simpfendorfer (2006) did not start when the nets were first installed but 26 years into the bather protection programme. There is good reason for their choosing 1978 as a starting date - prior to this, many shark catches were recorded but species identification was not sufficiently reliable. However, there was a trade-off in that all the catches from these first 26 years were not included in the trend analysis. In a similar assessment of the trends in the Queensland Shark Control Programme, Australia, Roff et al (2018) sacrificed species-specific data and used broad taxonomic groups so that they could use all data from the inception of their programme in 1962 to 2016. The results of Roff et al's (2018) study showed drastic declines in shark catches: 92% for white sharks, 92% for hammerhead sharks, 74% for tiger sharks and 82% for the group of requiem sharks of the family Carcharhinidae known as whalers (species that are common to both the Queensland and KwaZulu-Natal bather protection programmes include *C. amboinensis*, *C. brachyurus*, *C. brevipinna*, *C. leucas, C. limbatus, C. obscurus, C. plumbeus*). The speed with which the decline occurred for many species is notable (Roff et al 2018). The Catch Per Unit Effort (CPUE; the number of sharks caught relative to the amount of fishing gear in the water) had halved in just over 10 years and was at 75% 20 years later. Only the tiger sharks did not show exponential declines. In a figure produced by Roff et al (2018), (Figure 3), I have pencilled in red the time period, or window, that coincides with the KwaZulu-Natal analysis. Declines during that period were far less steep than the declines measured from the start of the programme. If Dudley and Simpfendorfer (2006) had had data going back to the beginning of the programme, their results are likely to have shown more drastic declines.

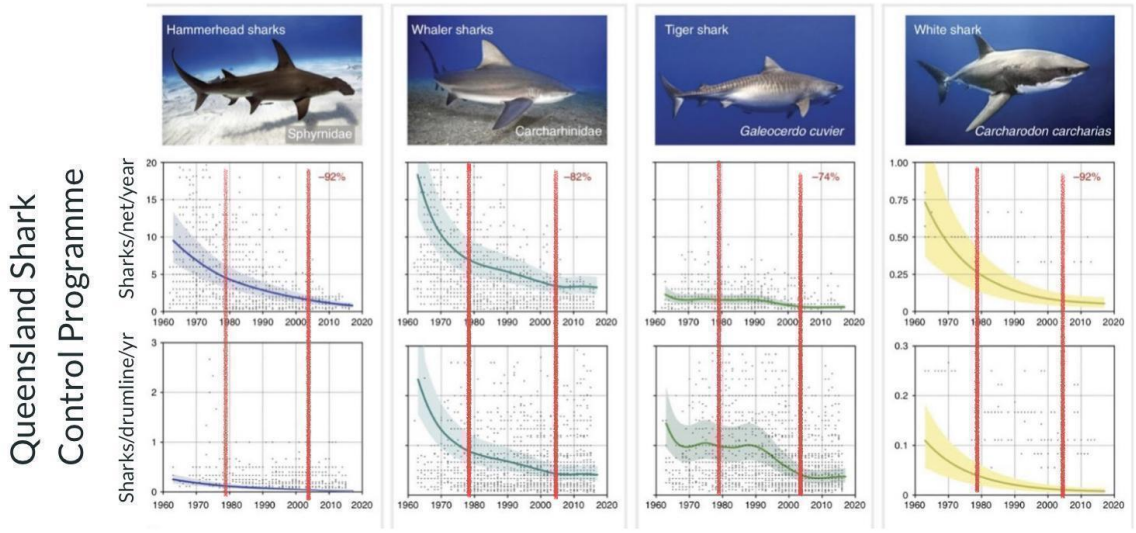

Figure 3. Declines in the number of sharks caught in Queensland, Australia's bather protection programme (Roff et al 2018) with Dudley and Simpfendorfer's (2006) window of analysis (1978-2003) that I delimited (in vertical red lines) for the KwaZulu-Natal programme which began in 1952 and intensified during the 1960s. Note that in the window of analysis used by Dudley and Simpfendorfer (2006), the declines for all species were not as dramatic as the two preceding decades. (Open source and used with permission from G. Roff.)

The fact that similar drastic declines have occurred since the start of the KwaZulu-Natal bather protection programme is borne out in Figure 4 which depicts CPUE for all sharks in the KwaZulu-Natal gear derived from the total shark catches and effort presented in Cliff and Dudley (2011). This is for the 14 species of sharks lumped together and is a minimum as "underreporting cannot be excluded" (p701). It seems likely that if Dudley and Simpfendorfer (2006) had access to accurate species data since the start of the programme, they may have found the impact of the KwaZulu-Natal bather protection programme to be "more pronounced" for more of the 14 shark species than just the Zambezi shark.

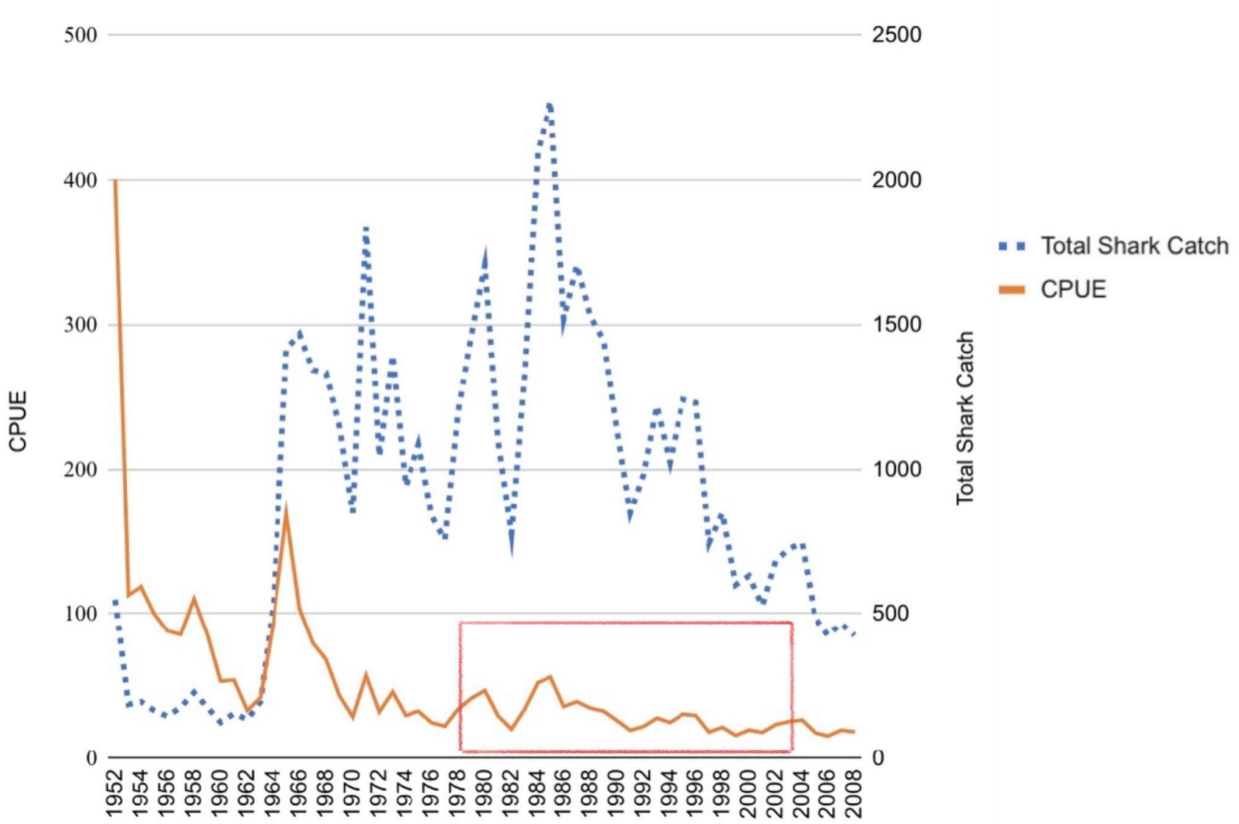

Figure 4. The number of catches and catch per unit effort (CPUE) for 14 shark species combined, caught in KwaZulu-Natal's bather protection fishing gear. Modified from Cliff and Dudley's (2011) total shark catches and effort. The window of analysis used by Dudley and Simpfendorfer (2006) is pencilled in as a red box.

There is some debate on how localised the effect of the bather protection gear is (Dudley and Cliff (1993). Dudley and Simpfendorfer (2006) and da Silva et al (2015) conclude that the effects are localised. Dudley (1997) notes that CPUE at adjacent protected beaches in both KwaZulu-Natal and Queensland were independent (suggesting localised effects). This was later tested explicitly in Queensland and, within regions, the initial CPUE in newly installed beaches were consistently similar to that of established beaches (Roff et al 2018). This implied that the scale of declines extended beyond the local protected beaches, and points to serial depletion of shark species that are caught (Roff et al 2018). It would be useful to conduct a similar analysis of beach-specific initial CPUEs in KwaZulu-Natal.

Species-specific assessments of 14 shark species

In what follows, I collate what is known for each species to assess a relative, species-specific level of concern about the impact of the bather protection programme (high, medium or low). For all of them I started with information from Dudley and Simpfendorfer's (2006) assessment, followed by the trends reported in da Silva et al (2015). The proportion of catches in the bather protection programme as a percentage of South Africa's total catch was published by da Silva et al (2015), including the number of other fisheries that are known or suspected to catch each species. Note that there were uncertainties about the data quality and reporting rates for many of the other fisheries compared to the good data collected by the Sharks Board (da Silva et al 2015). The conservation status and Red List Assessment trends were derived from species-specific global Red List Assessments which are referenced in the text. Comparisons of catch rates in the shark nets and on the baited hooks were sourced from Cliff and Dudley (2011). Any additional sources of information were cited in the text. Using these sources, I constructed a table of information to consider the current situation and the potential impact of the bather protection fishing gear on the 14 species of sharks (Table 1).

Table 1. The levels of concern of the impact of KwaZulu-Natal 's (KZN) bather protection programme proposed for 14 large shark species and other species. (r: intrinsic population growth rate; Fr=0: the fishing mortality at which r = 0; TOPS: Threatened or Protected Species; CR: Critically Endangered; EN, Endangered; NT: Near Threatened; VU: Vulnerable; SA: South Africa; IWC: International Whaling Commission; CPUE: Catch Per Unit Effort.)

Common name	**Species**	**Proposed level of concern**	**Reasons for concern**	**Reasons moderating concern**	**Other considerations**
Dusky shark	*Carcharhinus obscurus*	High	EN, very low r, large recent declines, bather protection catches >50% in SA, many more caught on baited hooks which are being used more frequently.	Many are juveniles.	Other fisheries are catching them (da Silva et al 2015 and G. Cliff KZN Sharks Board Head of Research (retired) pers. comm.).
Spotted ragged-tooth shark	*Carcharias taurus*	Medium	CR, very low r, small population, large catch, declining trends in catches, bather protection catches >75% in SA, ToPS.	Not caught on hooks, mark-recapture and genetic studies suggest they have not declined in SA (Dicken et al 2008, Klein et al 2020).	
Zambezi/ bull shark	*Carcharhinus leucas*	Medium	VU, low r, moderate catch, low Fr=0, declining.	Impact is likely to be localised (Dudley and Cliff 1993), and tagging suggests	Nursery areas, e.g. Lake St Lucia, have been

				fishing mortality in KZN is low (Daly pers. comm. in Rigby et al 2021b).	inaccessible to them due to prolonged closure of the estuary mouths.
White shark	*Carcharodon carcharias*	Medium	VU, low r, small population, moderate catch, steep declines in the past and bather protection catches >75% of known catches in SA, ToPS. Spatiotemporal study found shark net impact is likely to be high (Kock et al 2022).	Recent trend is increasing.	Wide ranging and therefore other sources of mortality are likely to have greater impact.
Scalloped hammerhead shark	*Sphyrna lewini*	High	CR, low r, large catch, very steep declines, bather protection catches >75% in SA, catch rate on hooks > nets, very poor survival rate in fishing gear. Pregnant females are caught in the northernmost nets (De Bruyn et al 2005). Concern at a national level (da Silva et al 2015), ToPS.	Fr=0 is moderate, catch is mainly of juveniles.	Travel outside of SA (G. Cliff pers. comm.).
Java/ pigeye shark	*Carcharhinus amboinensis*	Medium	There is limited information about this species, VU, declining globally, bather protection catches >75% of reported catches in SA, r and Fr=0 were unknown, limited nearshore distribution	Few catches in bather protection gear and other fisheries (<1t in 2012 and 2019).	

			(<60m depth, Simpfendorfer et al 2021).		
Copper shark	*Carcharhinus brachyurus*	Medium	VU, naturally low abundance , r and Fr=0 were unknown, despite increasing trend 1978-2003, CPUE declined between 2004-2019, catches on hooks higher than in nets and hooks now replace nets during the sardine run.	Catches only occur during sardine run.	Caught more frequently in other fisheries.
Spinner shark	*Carcharhinus brevipinna*	Low	VU, bather protection catches >75% in SA but declines are only slight.	Very high Fr=0, not caught on baited hooks.	
Blacktip shark	*Carcharhinus limbatus*	Low	VU, slight declines.	Common species, very high Fr=0, fewer catches on hooks.	
Sandbar shark	*Carcharhinus plumbeus*	Medium	EN, drastic declines, bather protection catches >75% of known catch in SA, low r, more catches on hooks than in nets.	Moderate Fr=0.	No commercial fishery targeting the species.
Tiger shark	*Galeocerdo cuvier*	Low	Bather protection catches >75% in SA, ToPS.	NT, increasing trends, high release rate.	Increasing trends may have negative implications for bathers.
Shortfin mako shark	*Isurus oxyrinchus*	Low	EN, declines detected, ToPS.	An oceanic, not neritic, species.	

Great hammer-head shark	*Sphyrna mokarran*	Medium	CR, drastic declines, bather protection catches >75% in SA, r and Fr=0 were unknown, very poor survival rate in fishing gear, ToPS, concern at a national level (da Silva et al 2015).	Edge of range of mobile species (Cliff 1995).	They are suspected to be taken in 3 other fisheries.
Smooth hammer-head shark	*Sphyrna zygaena*	Low	VU, very poor survival rate in fishing gear, r and Fr=0 were unknown.	Only juveniles were taken.	
White-spotted wedge-fish / giant guitar-fish	*Rhynchobatus djiddensis*	High	CR, though local risk assessment indicated a reduction of 65% over three generation lengths, ToPS.	High survival and release rate.	Taken in commercial fisheries in Mozambique where they reproduce (Daly et al 2021).
Largetooth sawfish	*Pristis pristis*	High	Locally extinct, ToPS.		
Green sawfish	*P. zijsron*	High	Locally extinct, ToPS.		
Loggerhead turtle	*Caretta caretta*	Medium	EN, ToPS.	CPUE increased, 50% released alive. Not caught on hooks.	
Green	*Chelonia*	Medium	EN, moderately large number of	Edge of their distribution and the	

turtle	*mydas*		catches, relatively high mortality rates, ToPS.	majority of the catch was immature. Not caught on hooks.	
Leatherback turtle	*Dermochelys coriacea*	High	CR, mortality rate was relatively high, ToPS.	Few individuals caught, CPUE fluctuated without declining - interpreted as stable. Not caught on hooks.	
Hawksbill turtle	*Eretmochelys imbricata*	Medium	CR, ToPS.	Occasional migrants, few catches. Not caught on hooks.	
Olive ridley turtle	*Lepidochelys olivacea*	Medium	VU, ToPS.	Occasional migrants, few catches. Not caught on hooks.	
Humpback dolphin	*Sousa plumbea*	Medium	EN, proportion of catches likely exceed IWC's acceptable mortality rate, ToPS.	Highest-catch nets replaced with hooks.	
Bottlenose dolphin	*Tursiops aduncus*	Medium	NT, population sizes are not known so catches cannot be assessed relative to stock size, ToPS.	No evidence of declining catches and expert judgement suggests stocks may be large.	
Humpback whale	*Megaptera novaeangliae*	Medium	ToPS.	LC, increasing population, not caught on hooks and most nets replaced with hooks during migration period.	
Southern right	*Eubalaena australis*	Medium	ToPS.	LC, not caught on hooks and most nets replaced with hooks during	

whale				migration period.	
Minke whale	*Balaenoptera acutorostrata*	Medium	ToPS.	LC, not caught on hooks, many nets replaced with hooks.	

More detailed characteristics of the various species and their interactions with KwaZulu-Natal's bather protection programme used to assess potential impact of the programme on sharks can be found in Supplementary Table 1.

Two species were flagged in Dudley and Simpfendor (2006) as having a potentially high impact by the shark nets: Dusky *Carcharhinus obscurus* and spotted ragged-tooth *Carcharias taurus* sharks.

Dusky sharks

In Dudley and Simpfendorfer's (2006) assessment of the impact of shark nets on sharks, the potential effect of the nets on dusky sharks was rated as high because of their very low r (intrinsic rate of population growth) but the actual effect was deemed limited because there were no declines. However, in the following 10 years, significant declines became evident. The bather protection programme was responsible for 50-74% of the catches in South Africa; catches in 6 other fisheries are documented (and a seventh is suspected). The conservation status in 2006 was LR/NT but now is EN (Rigby et al 2019a). The trend analysis in the Red List assessment used data from the bather protection fishing gear from 1978 but only until 2003; this indicated steep declines (50-79%) over three generation lengths (a time-scalar in the Red List as a way of accounting for differences in species' life-histories, quantified as the average age of parents of the current cohort (i.e. newborn individuals) in the population (Cooke et al 2018)). The catch rate was much higher on baited hooks than nets although it is generally of newborns and the survival rate was slightly higher on hooks (22% on hooks, 15% in nets). Hooks have replaced more nets and are used instead of nets more often increasing levels of concern. The 2013-2017 data used for the target:nontarget assessment above indicates that catches of dusky sharks are among the highest for all species. Thus, I conclude that concern for this species should be high.

Spotted ragged-tooth sharks

The potential effect of the nets for spotted ragged-tooth sharks was rated as high because of their very low r, small population, and large catch but the actual effect was deemed as limited because there were no declines and 39% of the catch was released alive. However, in the following 10 years, significant declines became evident. The bather protection programme is responsible for >75% of the catches in South Africa. Catches are reported in two other fisheries

and suspected in a third. The conservation status went from VU in 2006 to the current CR (Rigby et al 2021a). Red list assessment trend analyses that used the bather protection data between 1981-2019 suggested steep declines of 50-79% over three generation lengths but this was revised based on local expert judgements to 30-49%. This species is rarely caught on baited hooks which lowers the level of concern along with mark-recapture and genetic evidence that suggests that, in South Africa, this species has not declined (Dicken et al 2008, Klein et al 2020). It is listed among South Africa's Threatened or Protected Species (ToPS) Regulations, 2017. Therefore, I propose that the level of concern should be medium.

Three species had been flagged by Dudley and Simpfendorfer (2006) as having a potentially medium impact by the shark nets: Zambezi, white and scalloped hammerhead sharks *Sphyrna lewini*.

Zambezi (bull) sharks

The Zambezi shark has long been flagged for their steep declining catches and the potential effect of the nets was rated as medium because of their low r, moderate catch and low Fr=0, and this is the only species that was deemed to be affected by the shark nets. Reasons for this conclusion was the declining CPUE from 1978 - 2003 as well as the sharp declines that had been recorded in the 1960s with two moderating factors 1) few annual catches, and 2) other threats to the species. In the following 10 years, significant declines continued. Catches in South Africa have only been reported in the bather protection programme but are suspected to occur in five other fisheries and therefore the bather protection programme may catch 11-25% of South Africa's total catch of Zambezi sharks The conservation status of Zambezi sharks changed from LR/NT to VU (Rigby et al 2021b). Red list assessment trend analyses that used the bather protection data between 1981-2019 suggested steep declines of 50-79% over three generation lengths (supplementary data in Rigby et al 2021b suggests bull sharks in South Africa are EN) but this was revised based on local expert judgements to 30-49%. One reason for the revision was that the declines were influenced by "the marked drop in CPUE in the first few years of data collection, which is more a reflection of the high capture rates of more resident Bull Sharks at the netted beaches in the first few years of the program rather than a decline in the population of Bull Sharks in the region" (Rigby et al 2021b, in the section: Population). This does not seem accurate - in 1981 the bather protection programme was not new and Dudley and Cliff (1993) showed steep declines in the 1960s, not the 1980s. Moderating factors that reduce the level of concern include 1) the fishing effort by gillnets has been reduced and

Zambezi sharks are only rarely caught on the baited hooks and 2) the Red List assessment includes a personal communication from local scientists, R. Daly, that tagging studies in the KwaZulu-Natal area suggest that the fishing mortality rate in the province is low. Therefore, I propose that the level of concern should be medium.

White sharks

The potential effect of the nets on white sharks was rated as medium because of their low r, small population, and moderate catch but the actual effect was considered to be limited because only one of five measures of decline was significant and other threats were deemed to have greater impact. In the following 10 years, the declining trend was no longer evident. The bather protection programme was responsible for >75% of the known catches in South Africa. No other fishery reported catches, though they are suspected in a fishery on South Africa's west coast. Catch rate was similar in the nets and on the baited hooks. The VU conservation status did not change between 2006 and the most recent assessment in 2022. Steep declines in the 60s and 70s (Dudley and Cliff 1993) were not taken into account in the Red List trend analysis which used the bather protection data between 1978-2012 and suggested increases are most likely over three generation lengths (Rigby et al 2022). A study of the spatiotemporal distribution of white sharks relative to fisheries found that the bather protection programme had a greater than expected impact on this species (Kock et al 2022). In addition, Bowlby et al (2022) suggested that prevailing mortality rates in the bather protection programme may be limiting the potential for this population to recover, despite the protection afforded the species, e.g. on the 2017 TOPS list. It is difficult to decide the appropriate level of concern: perhaps concern for this species should be medium.

Scalloped hammerhead sharks

In the 2006 assessment, the potential effect of the nets was rated as medium because of their low r, large catch, moderate Fr=0 but the actual effect was deemed as limited because, although the CPUE declined, the high Fr=0 can sustain high catch rate. In the following 10 years, significant declines continued. The bather protection programme was responsible for >75% of the catches in South Africa, although catches were reported in three other fisheries and suspected in three more. The conservation status went from LR/NT in 2006 to CR (Rigby et al 2019b). The Red List assessment trend analysis that used the bather protection data from 1978 to 2003 suggested steep declines of >80% over three generation lengths. (Note that recent data were not included.) The catch rate on baited hooks was significantly higher than nets. Although

most catches were of juveniles, catches of pregnant females and mature males suggest that the fishing gear at Richards Bay was set in or close to a breeding ground and a nursery area (De Bruyn et al 2005). There is concern for this species at a national level (da Silva et al 2015). The 2013-2017 data used for the target:nontarget assessment above indicates that catches of this species are among the highest for all species. Therefore, I propose that the level of concern should be high.

The remaining nine shark species were considered to have a potentially low impact by shark nets by Dudley and Simpfendorfer (2006), including the great hammerhead *Sphyrna mokarran*, sandbar *C. plumbeus*, shortfin mako *Isurus oxyrinchus*, Java/pigeye *C. amboinensis*, blacktip *C. limbatus*, spinner *C. brevipinna*, copper *C. brachyurus*, smooth hammerhead *Sphyrna zygaena* and tiger.

Great hammerhead sharks

In 2006, the potential effect of the nets on great hammerhead sharks was rated as low because of the very small catch and the actual effect was deemed as limited because, although the CPUE declined, there were very few catches. (Note that r and Fr=0 were not known.) In the following 10 years, significant declines continued. The bather protection programme was responsible for >75% of the known catches in South Africa - it is the only fishery that reported catches of great hammerheads, although it is suspected that they might be caught in small numbers in the commercial and recreational line fisheries and pelagic longlines (da Silva et al 2015). The conservation status went from DD to CR and the threats to this species were all fisheries-related (Rigby et al 2019c). The Red List assessment trend analysis that used the bather protection data between 1978-2003 suggested steep declines of >80% over three generation lengths. Unlike most of the other Red List assessments, no new data were included following 2003. There is concern for this species at a national level (da Silva et al 2015). It is possible that, like humpback dolphins, few catches should not be assumed to equate to a small impact. However, KwaZulu-Natal is at the edge of their tropical distribution and they are not common close to shore (Cliff 1995). Therefore, I propose that the level of concern should be medium particularly because of the CR conservation status. However, the level of concern needs to be reconsidered as more information comes to light.

Sandbar sharks

The potential effect of the nets on sandbar sharks was rated as low because of the small catch and the actual effect was deemed limited because there were no declines and few catches (Dudley and Simpfendorfer 2006). In the following 10 years, significant declines were detected. The bather protection programme is responsible for >75% of the catches in South Africa; one other fishery reports catches and two more are suspected. The conservation status went from LR/NT to EN (Rigby et al 2021c). The Red List assessment trend analysis using the bather protection programme data from 1981 to 2019 suggested declines of >80% in three generation lengths but, because of the low catch rate, it was assumed that it is not the bather protection programme that caused the reductions and a “reduction in effort” was mentioned (Rigby et al 2021c). While there has been some reduction in effort over the analysis period, the replacement of some nets with baited hooks is not likely to be good for sandbar sharks which tend to have a higher (but non-significant) catch rate on hooks compared to nets. In addition, r is low for this species although Fr=0 is moderate (Dudley and Simpfendorfer 2006). And, as shown for humpback dolphins (above), few catches should not be assumed to equate to a small impact. Therefore, I propose that the level of concern should be medium.

Shortfin mako sharks

In 2006, the potential effect of the nets on mako sharks was rated as low because of the very small catch and the actual effect was deemed as limited because there were no declines and few catches. In the following 10 years, significant declines were detected. Only a small proportion of the catches in South Africa occurred in the bather protection programme (<1%). The conservation status went from NT in 2006 to EN (Rigby et al 2019d). There was no Red List trend analysis using bather protection data. This is an oceanic, not neritic, species (Rigby et al 2019d) and therefore the bather protection programme probably only catches vagrants. Therefore, I propose that the level of concern should be low.

Java sharks

This appears to be a poorly known, rare species and the potential effect of the nets was rated as low because of the very small catch and the actual effect was deemed limited despite the decline in sizes of both males and females. In the following 10 years, declines in catches were not evident. In South Africa, most of the catches (>75%) occurred in the bather protection programme. According to the Red List assessment, there is limited information on this species and there was no trend analysis using bather protection data, although global trend assessments suggest 30-49% declines, changing the conservation status from DD to VU

(Simpfendorfer et al 2021b). Early work suggested that the shark nets may have caused declines in this species (Cliff and Dudley 1991). It is difficult to decide the appropriate level of concern, so perhaps concern for this species should be medium.

Blacktip sharks

The potential effect of the nets was rated as low because of the very high Fr=0 and the actual effect was deemed to be limited despite the decline in CPUE and size (Dudley and Simpfendorfer (2006). In the following 10 years, declines in catches were no longer evident. In South Africa, catches occurred in many fisheries besides the bather protection programme which is responsible for 1-10% of catches. The conservation status went from LR/NT to VU and the Red List assessment trend analysis using the bather protection data between 1978-2019 suggested a likely decrease of <20% over three generation lengths (Rigby et al 2021d). Fewer blacktips were caught on baited hooks than in the shark nets (Cliff and Dudley 2011) and it is a common species and therefore I propose the level of concern could be low.

Spinner sharks

In the 2006 assessment of the impact of the shark nets, the potential effect of the nets on spinner sharks was rated as low because of the very high Fr=0 and therefore the actual effect was deemed limited. In South Africa, most (>75%) of the catches occurred in the bather protection programme though catches were suspected in three other fisheries. The conservation status changed from LR/NT to VU and the Red List assessment trend analysis that used the bather protection data between 1978-2019 yielded a likely decrease of <20% over three generation lengths (Rigby et al 2020). However, spinner sharks were not caught on the baited hooks and the gear change should improve the situation (Cliff and Dudley 2011). Therefore, I propose that the level of concern should be low.

Copper sharks

In 2006, the potential effect of the nets was rated as low because most of the catch occurred during the sardine run and at that stage, the shark nets were being removed temporarily to reduce the very high catches; also, there were no declining trends in CPUE or size. In South Africa, copper shark catches occur in many fisheries besides the bather protection programme which is responsible for <1% of catches. The conservation status went from NT to VU; the Red List assessment trend analysis that used the bather protection data between 1978-2003 suggested likely increases over three generation lengths but data from 2003-2019 showed a

steady decline in CPUE (Huveneers et al 2020). In recent years, rather than removing the nets during the sardine run, the Sharks Board temporarily replaced nets with baited hooks along most of the coast. Since copper sharks are caught on baited hooks at a (non-significantly) higher rate than in nets, this could be the reason for the change. The species appears to have a naturally low abundance across most of its range (Huveneers et al 2020). It is difficult to decide the appropriate level of concern: perhaps concern for this species should be medium (at least until there is a better understanding of the effect of the gear change to baited hooks during the sardine run).

Smooth hammerhead sharks

In 2006, the effect of the nets was considered low because the catch was almost exclusively of juveniles and there were no declines. In South Africa, catches occur in many fisheries besides the bather protection programme but it is unclear what proportion of the catches occur in this fishery. The conservation status went from NT to VU and the Red List assessment trend analysis that used the bather protection data between 1978-2014 suggested a likely increase over three generation lengths (Rigby et al 2019e). The catch rate was higher on hooks than in nets. Because of the likely increase, this species is of low concern.

Tiger sharks

In 2006, the effect of the nets was rated as low because of a medium r and increasing CPUE. The bather protection programme is the only fishery that reports catches of this species although catches in two other fisheries are suspected. Their survival rate was high, with 56% of the catch being released alive (Dicken et al 2016). The conservation status remained NT and the Red List assessment trend analysis that used the bather protection data between 1978-2003 suggested a likely increase over three generation lengths (Ferreira and Simpfendorfer 2019). The increase was also notable between 1978 and 2014 and Dicken et al (2016) stated that “it is possible that tiger sharks have a competitive advantage within a multispecies shark community influenced by a bather protection programme” (p294) which I interpret to mean that the increase in the number of tiger sharks may be because by lowering the number of sharks of multiple species, the bather protection programme may have created conditions that can be exploited by tiger sharks. If the bather protection programme is indirectly causing an increase in a species that is responsible for serious shark bites, it may be counterproductive since it aims to reduce the numbers of tiger, Zambezi and white sharks. Therefore, this species could be of low concern from a conservation perspective, even though it

is a TOPS species, but the impact should be carefully considered from a bather protection perspective.

Other species that are caught

Other elasmobranchs likely to be of concern

The white-spotted wedgefish, known locally as the giant guitarfish, *Rhynchobatus djiddensis*, is CR globally (Kyne et al 2019). On average, 79 were caught in KwaZulu-Natal's bather protection programme annually with a high release rate (72%). However, the CPUE declined (fourfold) and a risk assessment indicated a reduction of 65% over three generation lengths, implying that it should be considered EN in South Africa (Daly et al 2021). There are no targeted fisheries for this species in South Africa but there is an organised commercial fishery in neighbouring Mozambique where they are most likely to reproduce. Level of concern is high.

Largetooth sawfish *Pristis pristis* and green sawfish *P. zijsron* are both CR globally (Simpfendorfer 2013, Kyne et al 2013) but considered to be locally extinct in South Africa with the last recorded specimen released alive from the shark nets in KwaZulu-Natal in 1999 (Everett et al 2015). All sawfishes are protected in the Threatened or Protected Species Regulations, 2017. It is difficult to propose levels of concern for a locally extinct species but proposing a low concern does not seem appropriate. Therefore, using a conservative approach, the level of concern is high.

There are elasmobranchs listed on the Threatened or Protected Species Regulations, 2017, for which I have insufficient information: Vulnerable flapnose houndshark *Scylliogaleus quecketti* is endemic to KwaZulu-Natal and Eastern Cape Provinces; the whale shark *Rhincodon typus* is is Endangered (Pierce and Normal 2016). Manta and mobula rays of various species (which are VU and EN in the Threatened or Protected Species list, 2017) are caught in the bather protection programme although no specific details were reported (DFFE 2022).

Turtles

Catches of five turtle species in the bather protection fishing gear were assessed by Brazier et al (2012). A summary of Brazier et al's (2012) assessment follows. The gear was not considered to be a threat to any of the species although some concern was expressed about the

leatherback turtles *Dermochelys coriacea*. Endangered loggerheads *Caretta caretta* were the most commonly caught species, with a weak, but significant, increase in CPUE over time. The shark nets were not considered a major threat to the southern African loggerhead population as it appeared to be increasing along the East Coast and about 50% were released alive. Few leatherbacks (CR) were caught and the CPUE was variable but interpreted as stable. Shark nets were not considered to be a threat to the leatherback population in southern Africa since few individuals were caught in the nets. But, because they are CR and the mortality rate is relatively high, the authors expressed some concern about this species. Although EN green turtles *Chelonia mydas* occur in KwaZulu-Natal, it is at the edge of their distribution and the majority of the catch was immature. Despite a catch of moderate magnitude and relatively high mortality rates in the shark nets, the green turtle population in the South-West Indian Ocean is increasing, so the shark nets were not considered a major threat to this species. Hawksbills *Eretmochelys imbricata* (CR) and olive ridleys *Lepidochelys olivacea* (VU) are occasional migrants and catches were too small to have a significant effect on their populations.

The increased substitution of nets with baited hooks used is likely to minimise the impact on turtles (Cliff and Dudley 2011). This suggests levels of concern could be relatively low, except for leatherbacks for which it could be medium. However, all turtles are protected in the Threatened or Protected Species Regulations, 2017. Therefore, perhaps it would be more appropriate to raise the levels of concern to medium for most of the turtles and to high for leatherbacks.

Cetaceans

Concern was expressed about the effect of the shark nets on humpback dolphins and Indo-Pacific bottlenose dolphin *Tursiops aduncus* (Cockcroft 1990). Humpback dolphins were assessed in the first section (above) and I tentatively propose medium levels of concern while watching catch numbers of this species in the remaining shark nets at Richards Bay.
An assessment of the population structure of bottlenose dolphins using KwaZulu-Natal waters found low genetic diversity and possible population differentiation along the coast (Natoli et al 2008). This evidence considered with the high capture rate suggested care should be taken in managing the take from shark nets especially in the north coastal area of KZN where the population which showed a higher degree of differentiation (Natoli et al 2008). A recent publication found no evidence of a long-term decline in bottlenose dolphin catches but in the

absence of recent population assessments found it difficult to assess the impact of the bather protection gear on the populations off KwaZulu-Natal (Plön et al 2020). Expert estimates of population sizes suggest a relatively small impact of the bather protection programme (Plön et al 2020). The increased substitution of nets with baited hooks used is likely to minimise the impact on dolphins (Cliff and Dudley 2011). However, all dolphins are protected in the Threatened or Protected Species Regulations, 2017.

Whales are also entangled in the shark nets, predominantly humpback *Megaptera novaeangliae*, southern right *Eubalaena australis* and minke whales *Balaenoptera acutorostrata* (Meyers et al 2009). All three species are LC, even though trends in population size are unknown for southern right and minke whales (Cooke 2018a, b, Cooke and Zerbini 2018). Most (77% of the humpback and 89% of the southern right) whales that were found entangled in shark nets were released alive (Meyers et al 2009). Recently, many of the shark nets were temporarily substituted with baited hooks during the whale migration season (a preventative entanglement system), drastically reducing the whale bycatch (KwaZulu-Natal Sharks Board's Annual Report, 2022). This suggests that level of concern could be low. However, all whales are on South Africa's 2017 TOPS list, elevating the level of concern to medium.

Conclusion

I reviewed the ecological impact of the bather protection fishing gear on marine megafauna in KwaZulu-Natal and found high mortality rates and extremely high bycatch rates: 88% of the catches were not the target Zambezi, white and tiger sharks. It is apparent that the biggest impact occurred in the first year that shark nets were deployed and again from 1964 to 1990 and now population sizes are a small fraction of what they were historically. However, for much of that time, the species-specific data quality was poor and so most assessments necessarily ignore much of those data and sample from a shifted baseline, i.e. are measured relative to reference points which themselves represent significant changes from an earlier state of the system of interest (Pauly 1995, Pinnegar and Engelhard 2008).

It has been suggested that the bather protection programme impacts shark species minimally but reflects the general status of sharks in the area as fisheries-independent monitoring devices (Dudley and Simpfendorfer 2006). In other words, often the impact of fisheries is assessed using the data of that fishing operation (i.e. fisheries-dependent monitoring). Yet, it may be more

reliable to monitor impact using data that is collected independently of the fishing operation (i.e. fisheries-independent monitoring). Dudley and Simpfendorfer (2006) suggest that the catches in the bather protection programme provided data that monitored the effects of commercial fisheries on sharks independently of the commercial fisheries, as if the shark nets themselves had no impact on the shark populations. The situation for the 14 species of large sharks in KwaZulu-Natal has worsened since the 2006 assessment. At that time, only two species were threatened but now 13 of the 14 species are threatened and half of these are EN and CR. Trend assessments show declines for nine species using Sharks Board's data, even since 1978 which was well into the programme that began in 1952. The bather protection gear is responsible for >50% (mostly >75%) of South Africa's reported catches for five of the six species of large sharks that are EN and CR (dusky, ragged-tooth, sandbar, scalloped and great hammerhead), although unreported catches are suspected in other fisheries, e.g. the commercial linefishery (da Silva et al 2015). Threats such as climate change and habitat degradation are likely also affecting these species(Dulvy et al 2014). It is difficult to tease apart the causes of declines, especially when the declines caused by other threats are not as well quantified as in the bather protection programme.

Based on my in-depth study of humpback dolphin ecology and interactions with the shark nets (Atkins et al 2013, 2016), I question the assumption that a small number of catches per year equates to a small impact of the bather programme on a species. Changing gear (replacing nets with hooks) has a positive impact on catches of some species (e.g. ragged-tooth sharks and humpback dolphins) but other EN and CR species are more susceptible to catches on hooks (e.g. dusky sharks and scalloped hammerheads). I suggest that levels of concern could be high for six of the 27 species (i.e. dusky and scalloped hammerhead sharks, white-spotted wedgefish, leatherback turtles and two locally extinct sawfishes), medium for 16 (though two species are flagged for ongoing scrutiny: great hammerhead sharks and humpback dolphins) and low for the remaining 5. These trends are based on the shifted baselines and if I were to take those early years into account, the levels of concern would probably be much higher. Even if other threats add to (and possibly exceed) the impact of the bather protection gear, the extremely high bycatch rate indicates that we need to find a more targeted way to deal with the risk of shark bites that is posed by white, Zambezi and tiger sharks, preferably using non-lethal solutions.

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Appendix 1

Appendix Table 1. The characteristics of the 14 shark species and their interactions with KwaZulu-Natal's (KZN) bather protection programme used to assess potential impact of the programme on sharks. KZNSB: KwaZulu-Natal Sharks Board; % SA catches: the proportion of the total catch of that species in South Africa (SA) that is reported by the KwaZulu-Natal Sharks Board; # other fisheries (reported): the number of other fisheries that had reported catches of that species; # other fisheries (suspected): the number of other fisheries that are suspected to catch that species. Sources include: *Dudley and Simpfendorfer (2006), **da Silva et al (2015), ***Threatened or Protected Species (TOPS) Regulations, 2017, Government Gazette No. 40875, ****Cliff and Dudley (2011) and species-specific red-list assessments. Gen.: generation; med.: medium; r: intrinsic population growth rate; Fr=0: the fishing mortality at which r = 0; CPUE: Catch Per Unit Effort.

Shark	Species	Poten- tial KZN SB effect *	Reasoni ng of KZNSB effect *	Declinin g trend 1978 - 2003 *	Effect of nets *	Reason for “limited effect of nets” decision *	Red list in 2006	Trend 1978 - 2013**	% of SA catch -es **	# othe r fishe r-ies repo r-ted **	# other fisher -ies susp- ected **	ToP S ***	Red list in 202 2	Years with KZNS B data in the red list asses- sment	Likely declinin g trend over 3 generati on lengths in KZN?	Red List Ref.	More on baited hooks or nets? ****	Pro- pos- ed leve l of con- cern
Dusky	*Carcharhin us obscurus*	High	Very low r	No	Limited	Did not decline	LR/N T	Declinin g	50-7 5	6	1		EN	1978–2003	50-79%	Rigby et al 2019a	Hooks	Hig h
Spotted ragged- tooth	*Carcharias taurus*	High	Very low r, small populatio n, large catch	No	Limited	Did not decline and 40% are released alive	VU	Declinin g	>75	2	1	Yes	CR	1981–2019	50-79% but revised by expert judgem e-nt	Rigby et al 2021a	Nets	Med

														elicitation to 30–49%			
Zambezi /bull	*Carcharhinus leucas*	Med.	Low r, moderate catch, low Fr=0	Declining CPUE	More pronounced	Declining (and there were sharp declines in the 60s). But there are few annual catches (45). Other threats.	LR/NT	Declining	11-25 susp-ected	0	5		VU	1981–2019	50-79% but revised by expert judgeme-nt elicitation to 30–49%	Rigby et al 2021b	Nets	Med
White	*Carcharodon carcharias*	Med.	Low r, small population, moderate catch	Declining size	Limited	Other threats. Only 1 of 5 measures of decline was significant. But there were steep declines in the 60s and 70s.	VU		>75	0	1	Yes	VU	1978–2012	Increasing	Rigby et al 2022	Similar	Med
Scalloped hamme	*Sphyrna lewini*	Med.	Low r, large catch,	Declining CPUE	Limited	High Fr=0 can sustain a high catch	LR/NT	Declining	>75	3	3	Yes	CR	1978–2003	>80%	Rigby et al 2019b	Hooks	High

r- head			moderat e Fr=0			rate.											
Java/ pigeye	*Carcharhin us amboinensi s*	Low	Very small catch	Declinin g size	Limited	Very small catch.	DD		>75	1	2		VU	No KZNS B data	Globally , 30-49% suspect ed	Simpfe -ndorfe r et al 2021	-	Med
Copper	*Carcharhin us brachyurus*	Low	Most catch avoided by removing nets for Sardine Run	No	Limited	Catches now avoided by removing nets during Sardine Run	NT		<1	7	1		VU	+2003 –2019	Declinin g CPUE	Huven- eers et al 2020	Hooks	Med
Spinner	*Carcharhin us brevipinna*	Low	Very high Fr=0	No	Limited	Very high Fr=0	LR/N T		>75	1	3		VU	1978 to 2019	<20%	Rigby et al 2020	Nets	Low
Blacktip	*Carcharhin us limbatus*	Low	Very high Fr=0	Declinin g both (CPUE and size)	Limited	Despite declines in size and in catch rate, Fr=0 is very high.	LR/N T		1-10	2	3		VU	1981– 2019	<20%	Rigby et al 2021d	Nets	Low
Sandba r	*Carcharhin us plumbeus*	Low	Small catch	No	Limited	Very small catch.	LR/N T	Declinin g	>75	1	2		EN	1981– 2019	>80%	Rigby et al 2021c	Hooks	Med

Tiger	*Galeocerdo cuvier*	Low	Medium, increasing CPUE	Increasing	Limited	Increasing CPUE.	LR/NT	Increasing	>75	0	2	Yes	NT	1978–2003	Increasing	Ferreira and Simpfe-ndorfer 2019	Hooks	Low
Shortfin mako	*Isurus oxyrinchus*	Low	Very small catch	No	Limited	Very small catch.	NT	Declining	<1	5	2	Yes	EN	No KZNSB data	Globally, 50-79%.	Rigby et al 2019d	Similar	Low
Great hammerhead	*Sphyrna mokarran*	Low	Very small catch	Declining CPUE	Limited	Very small catch.	DD	Declining	>75	0	3	Yes	CR	1978–2003	>80%	Rigby et al 2019c	-	Med
Smooth hammerhead	*Sphyrna zygaena*	Low	Only take juveniles	No	Limited	Only take juveniles	LR/NT	Increasing	un-clear	5	1		VU	1978–2014	Increasing	Rigby et al 2019e	Hooks	Low

Appendix 2

Appendix Tables 1 and 2. Annual average catches in KwaZulu-Natal and releases, made publicly available on the KwaZulu-Natal's website. https://www.shark.co.za/Pages/SharkCatchStats

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Table 1: shark catches 2013-2017 (see how to read this table below).

Species		Annual averages 2013-2017			
		No. of animals		Percentage	Mortality
		C	R	released	No. of animals
DUSKY SHARK	*Carcharhinus obscurus*	92.4	13.8	14.9	78.6
SPINNER SHARK	*Carcharhinus brevipinna*	61.6	7.6	12.3	54
BLACKTIP SHARK	*Carcharhinus limbatus*	52	3	5.8	49
SCALLOPED HAMMERHEAD	*Sphyrna lewini*	68.8	0.8	1.2	68
TIGER SHARK	*Galeocerdo cuvier*	60.2	25.4	42.2	34.8
SMOOTH HAMMERHEAD	*Sphyrna zygaena*	48.8	0.8	1.6	48
RAGGEDTOOTH SHARK	*Carcharias taurus*	46.6	20	42.9	26.6
GREAT WHITE	*Carcharodon carcharias*	22.4	5.6	25.0	16.8
COPPER SHARK	*Carcharhinus brachyurus*	5.4	1.2	22.2	4.2
ZAMBEZI SHARK	*Carcharhinus leucas*	10.2	2.2	21.6	8
SANDBAR SHARK	*Carcharhinus plumbeus*	16.8	2.8	16.7	14
MAKO SHARK	*Isurus oxyrinchus*	5.2	0.6	11.5	4.6
JAVA SHARK	*Carcharhinus amboinensis*	5.4	0.2	3.7	5.2
GREAT HAMMERHEAD	*Sphyrna mokarran*	0.8	0	0.0	0.8
HAMMERHEAD	*Sphyrna sp.*	0.8	0.2	25.0	0.6
THRESHER - THINTAIL	*Alopias vulpinus*	0.2	0	0.0	0.2
SNAGGLETOOTH SHARK	*Hemipristis elongatus*	0.4	0	0.0	0.4
BIGNOSE SHARK	*Carcharhinus altimus*	0.2	0	0.0	0.2
SPECIES UNKNOWN		3.8	1.4	36.8	2.4
	Total	**502**	**85.6**	**17.1**	**416.4**

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Table 2: Catches of harmless animals 2013-2017 (see how to read this table below).

Species Group	Annual averages 2013-2017			
	No. of animals		Percentage released	Mortality No. Of animals
	C	R		
TURTLES	62.6	39.8	63.6	22.8
HARMLESS SHARKS (eg Angel or blackspot)	27.4	10.8	39.4	16.6
DOLPHINS	27.2	1	3.7	26.2
WHALES	8.6	6.4	74.4	2.2
BATOIDS (RAYS/GUITARFISH)	135.8	75.2	55.4	60.6
BIRDS (CAPE GANNET)	2.4	0	0.0	2.4
TELEOSTS	30.8	0	0.0	30.8
TOTAL	**294.8**	**133.2**	**45.2**	**161.6**

How to read this table (examples):

The annual average turtle catch for the last 5 years is 62.6 animals per year of which 39.8 animals (63.6%) were released alive.

The annual average mortality for turtles in the last 5 years is 22.8 animals per year.

Please note that some of the totals might not add up due to rounding of the figures.

Note also that these catch figures include animals that were discarded at sea due to their decomposed state.

Chapter 3. Sharks that bite, bather safety and bycatch: predicting temporal overlap to reduce the impact of shark nets on biodiversity at a high-catch beach, without compromising bather safety.

Abstract

The fear of being bitten by a shark is widespread, yet the risk of a bite is extremely low. In KwaZulu-Natal, South Africa, gillnets and baited hooks are used to cull potentially dangerous sharks at popular swimming beaches to reduce that risk further. This bather protection programme provides public confidence and protects the valuable tourism economy, but not without environmental costs. Although only 3 species of sharks are considered dangerous to humans, the non-selective gillnets and baited hooks have a high bycatch, killing many more animals that are caught unintentionally. The interactions between people, sharks and the bycatch can be framed as a human-wildlife conflict, the effective management of which requires understanding the social-ecological system they form together. My aim is to examine the temporal patterns of bathers, the three species of target sharks and bycatch species at one beach, Richards Bay, where the catch rate of sharks is particularly high. I used reported catches of sharks and other marine megafauna in the bather protection gear and counted bathers in the water at Richards Bay to build models to describe the occurrence patterns of each component of this conflict (sharks, bathers, bycatch). I then modelled the monthly numbers of each of these three components using Generalised Linear Mixed models to predict their abundance over time, and tested their temporal correlation to measure the degree of overlap. I considered the implications of the occurrence patterns and overlap in terms of when the risk of bycatch entanglement could be mitigated without impacting the risk of shark bites to bathers. My analyses reveal periods where co-occurrence of the three components is reduced and where species do not overlap temporally. These findings contribute to the ongoing efforts to decrease the mortality of marine species without affecting the current excellent levels of bather safety.

Introduction

A human-wildlife conflict has persisted in KwaZulu-Natal, South Africa, that began with a spate of shark bites in the 1940s and 1950s. A response to the shark bite incidents was a shark

culling programme where gillnets (shark nets) and, more recently, baited hooks (drumlines) are set to catch and kill sharks to reduce their numbers, and subsequently the risk of interactions between humans and sharks (Dudley and Gribble 1999, Dicken et al 2016). Three shark species caused the serious incidents: Zambezi *Carcharhinus leucas*, white *Carcharodon carcharias* and tiger *Galeocerdo cuvier* sharks (Cliff 1991). In addition to these species, many other species are caught in the non-selective gillnets and hooks; these incidental catches are called bycatch.

To improve the management of this human-wildlife conflict, we need to map it first (Redpath et al 2013). As the phrase suggests, all human-wildlife conflicts contain social and ecological elements. Many studies that have focussed on the issue of bather protection from sharks have considered only social, or only ecological, elements, for example, where public perceptions were measured (Crossley et al 2014, Lucrezi et al 2019) or shark biology was investigated (Cliff et al 1988, Dicken et al 2016). Increasingly, both social and ecological elements are considered together, for example, the spatial co-occurrence of people and sharks measured by Lemahieu et al (2017) and the interdisciplinary approach taken by Gibbs et al (2020). Viewing the social-ecological system more holistically could help to identify solutions that match the complexity of the problem (Ostrom 2007).

The human-wildlife conflict around the KwaZulu-Natal bather protection programme is considered particularly high at one beach, Richards Bay. This is the northernmost protected beach in the province; its distance to the nearest protected beach, as well as the catch and the catch per unit effort (CPUE) are much greater than most of the other beaches (Dudley and Cliff 1993, Atkins et al 2013). It has a relatively high catch rate of Zambezi sharks, as well as of critically endangered (CR) scalloped hammerhead *Sphyrna lewini* and (pregnant) dusky *Carcharhinus obscurus* sharks (Cliff and Dudley 1991, De Bruyn et al 2005, Dudley et al 2005). Now locally extinct in KwaZulu-Natal, the last sawfish *Pristis* spp. that was encountered in the province was found in the Richards Bay shark nets (Everett et al 2013). Therefore, this installation is of particular interest in this human-wildlife conflict. It is also particularly useful since it is a relatively new installation, first deployed in 1980, and species-specific catch data have been collected since the nets were first set.

By mapping the various social and ecological aspects of human-wildlife conflict around the bather protection programme in KwaZulu-Natal, my overarching goal is to find ways to resolve

the conflict. As part of this process, I aim to understand the temporal patterns of the various components of the conflict at Richards Bay, especially to identify obstacles and opportunities to mitigate the conflict. In other words, I searched for leverage points, i.e. small changes that can have disproportionate effects on facilitating changing the current system of culling sharks (Meadows 1999). It is important to explicitly include both the social and the ecological parts of the conflict, and here I did this by modelling the temporal occurrence of the three components of this conflict—sharks, bycatch and bathers. I used catch data of sharks and other marine megafauna in the bather protection gear and also counted bathers in the water at Richards Bay to build models that describe the occurrence patterns of each component of the conflict; then I used these to predict the monthly co-occurrence of each component and the overlap between them. I consider the implications of the overlap in terms of when it might be possible to mitigate the risk of bycatch entanglement without impacting the risk of shark bites to bathers.

Material and methods

Data sampling

The bather protection programme is managed by the KwaZulu-Natal Sharks Board (hereafter, the Sharks Board), a provincial entity that is mandated to safeguard bathers against shark bites in the province. To achieve this, they deploy two types of fishing gear: gillnets and baited hooks, called shark nets and drumlines. The shark nets are either 213 m or 319 m long x 6.3 m deep and are permanently anchored parallel to the coast beyond the surf, 300–500 m offshore, in 10–14 m of water. They are made of black multifilament polyethylene braid that is weaved to a stretched mesh size of 51 cm. Each baited hook (drumline) is anchored and consists of a single Mustad 4480DT 14/0 J hook (Gjøvik, Norway) suspended beneath a large float. The hooks are baited with fish (Scorpaenidae) that are bycatch from other fisheries. More details about the shark control programme and the gear are provided by Dudley (1997) and Cliff and Dudley (2011).

At Richards Bay, the fishing effort (the amount of fishing gear in the water over a given unit of time) has varied occasionally since the nets were first deployed in 1980. For shark nets, monthly fishing effort is calculated by multiplying the number of nets used by their length. For baited hooks, four hooks were considered to be equivalent to one 213m net (Cliff and Dudley 2011). Therefore, one hook is the effort-equivalent of 53.25 m of net and the number of hooks x 53.25m is added to the monthly shark net fishing effort. The annual fishing effort is the sum of

the monthly effort, divided by 12 months. Between 1980 - 2019, fishing effort ranged from 1.21 to 2.51 km/year, with a mean ± standard deviation of 1.59 ± 0.38 km/year.

The fishing gear is checked by Sharks Board staff 15–20 times per month and any animals caught are identified to species and removed. Most are found dead and, depending on the state of decomposition, carcasses are sent to the Sharks Board headquarters for research and educational dissections or are taken out to sea and dumped. If found alive, individuals are released, often tagged.

I used data collected by the Sharks Board from when they first deployed shark nets at Richards Bay early in 1980 until the end of 2019. For each animal recorded, I used the date of retrieval and species identification. The Sharks Board considers two categories of catches, large sharks (14 species of large sharks, see Appendix 1) and harmless species (cetaceans, turtles, batoids and other elasmobranchs). I recategorized these into target sharks (Zambezi (bull) shark *Carcharhinus leucas*, white shark *Carcharadon carcharias*, tiger shark *Galeocerdo cuvier*) and non-target species (all bycatch species other than the three target species).

To estimate the abundance of human bathers using the same environment of these species, I used an outdoor-mounted video camera overlooking the Richards Bay nearshore area. From July 2017 to January 2019, at noon each day, I recorded a 50-second clip to then manually count the number of bathers, hereby defined as surfers and swimmers in water that is deeper than 1m. Note that bathers were not individually identifiable due to the distance from the camera.

Data analysis

To investigate the temporal patterns of overlap in occurrence of each of the three components of the human-wildlife conflict, I assessed the relative numbers of target sharks, non-target animals (bycatch) and bathers for each month of the year. The relative numbers of target and non-target species were their summed catches for each month for the years 1980 to 2019. Due to technical and environmental issues, the number of days with clear recordings of bathers in a month varied, with a minimum of eight recordings in a month. To ensure the same sampling effort across months, each month was randomly subsampled to obtain eight days per month, and the bather counts in these eight samples were summed for the years 2017 to 2019.

To evaluate how each component of the conflict (target sharks, bathers, bycatch) varied over time, I built three independent Generalised Linear Mixed Models (GLMMs; Bolker et al 2009) with the abundance of each component as a function of the month (categorical) as the fixed effect, and the year as a random effect. I considered Poisson and Quasi-Poisson error distributions but since this type of count data are usually slightly overdispersed, to be conservative I considered a negative binomial distribution with log link function. As a benchmark, I built null models with only the intercept and the year as a random effect, and compared them to the corresponding GLMMs using Akaike's Information Criterion (AIC; (Appendix Table S1). When the level of support for the model (ΔAIC) was <2, the model with the highest AIC weight was considered the most probable model to explain data variation (Anderson and Burnham 2002). I used conditional and marginal R^2 for mixed effect models (Nakagawa and Schielzeth 2013) to assess goodness of fit and the importance of the random effects (Appendix Table S2). I used simulated residuals (n=1000; Hartig, 2018) to check the assumptions of the model in terms of dispersion, uniformity, outliers and temporal autocorrelation (Appendix Table S3).

Using each model, I predicted the monthly shark catches and bycatch, as well as the number of swimmers. I then used a Pearson's product-moment correlation to test for overlap between the monthly predicted shark catches and predicted bycatch, and also between the monthly predicted shark catches and predicted bather numbers. I used 1,000 permutations to estimate the 95% confidence intervals.

Results

Catches

In the 40 years since the nets were set at Richards Bay, there were 4824 catches reported at an annual mean$\pm$standard deviation of 120.6$\pm$49.0. Of these, 3497 (72%) animals died. The mean annual catch of target sharks was 6.1$\pm$4.7 for Zambezi, 4.5$\pm$2.6 for white and 1.6$\pm$1.6 for tiger sharks per year. For every target shark caught, 8.7 non-target animals were also caught.
The number of catches and bathers varied by month: for target sharks, June and July were predictably low while bycatch was predictably low from April to September (inclusive). Bathers were significantly different in all months (Figure 1).

Modelling

Using the Generalised Linear Mixed models with negative binomial error distribution, I analysed the number of sharks, bycatch and bathers for each month (Figure 2). For target sharks, the predicted number of catches per month ranged from 0.4 (with little variability) in June to 1.5 (with much variability) in December. The GLMM for the count of target sharks caught by the bather programme (*target ~ month + (1|year)*) suggested that the occurrence of these species was significantly low in the austral winter (Appendix Table S4), particularly June and July. For bycatch, the predicted number of monthly catches ranged from 4 (with little variability) in June to 17 (with much variability) in November. The GLMM for the count of bycatch (*non-target ~ month + (1|year)*) suggested that the occurrence of these species was lower from the middle of austral autumn (April) to the middle of austral spring (September) (Appendix Table S5). So the two months with predictably fewer catches of target sharks partially overlap with the six months with predictably less bycatch. Predicted numbers of bathers were very variable, ranging from 2 in September to 200 in January (Appendix Table S6). The models had more support than the null model (Appendix Table S1) except for the bathers model); all models showed moderate to sufficient explanatory power. Overall, the conditional R^2 were higher than the marginal R^2 indicating that together the fixed and random effects account for more variance than the fixed effect alone (Appendix Table S2). All the assumptions of the Generalised Linear Mixed models were within acceptable limits, i.e. suggesting that the models fit quite well (Appendix Table S3).

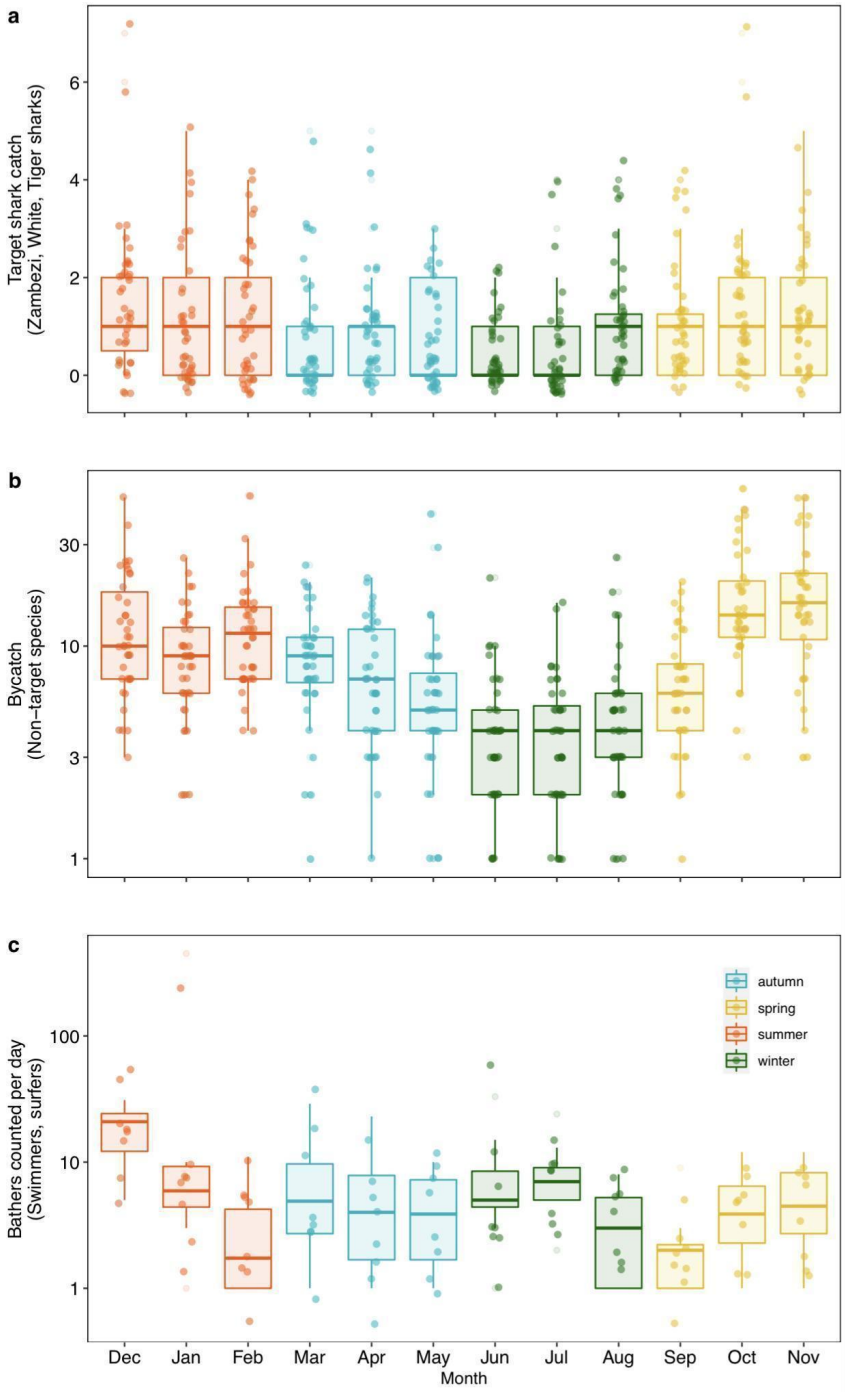

Figure 1. Temporal overlap of the three components of the conflict at Richards Bay, KwaZulu-Natal. Monthly counts of (a) target shark species (i.e. Zambezi, white and tiger) and (b) bycatch (all non-target species) caught in the bather protection programme; and the number of (c) bathers in waters >1m deep recorded in the video monitoring. In (a) and (b) data points show the summed catches per month, replicated by years (1980-2019); in (c) data points show the total count of bathers per day, replicated by months (July 2017 to Jan 2019).

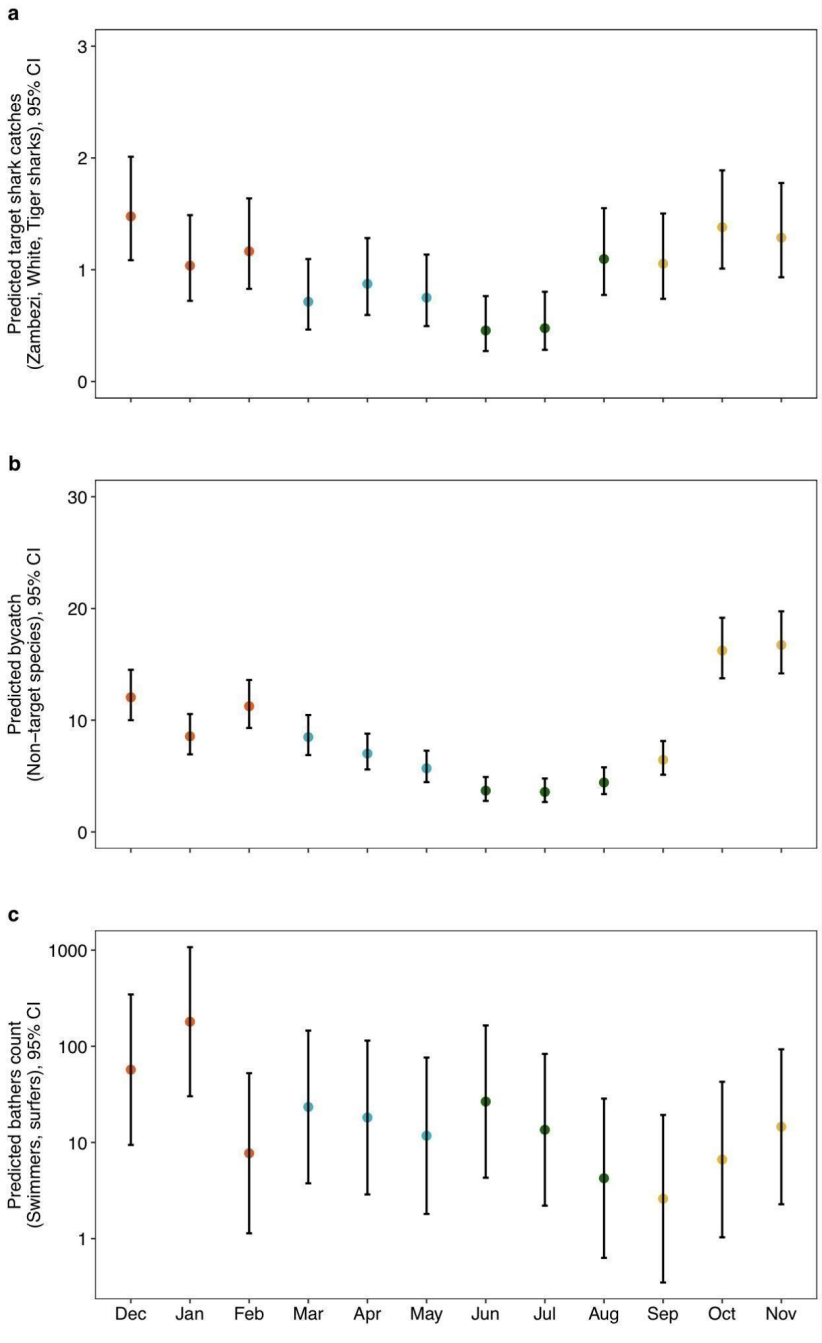

Figure 2. Predicted catches of target sharks and bycatch, and predicted counts of bathers for each month at Richards Bay, KwaZulu-Natal

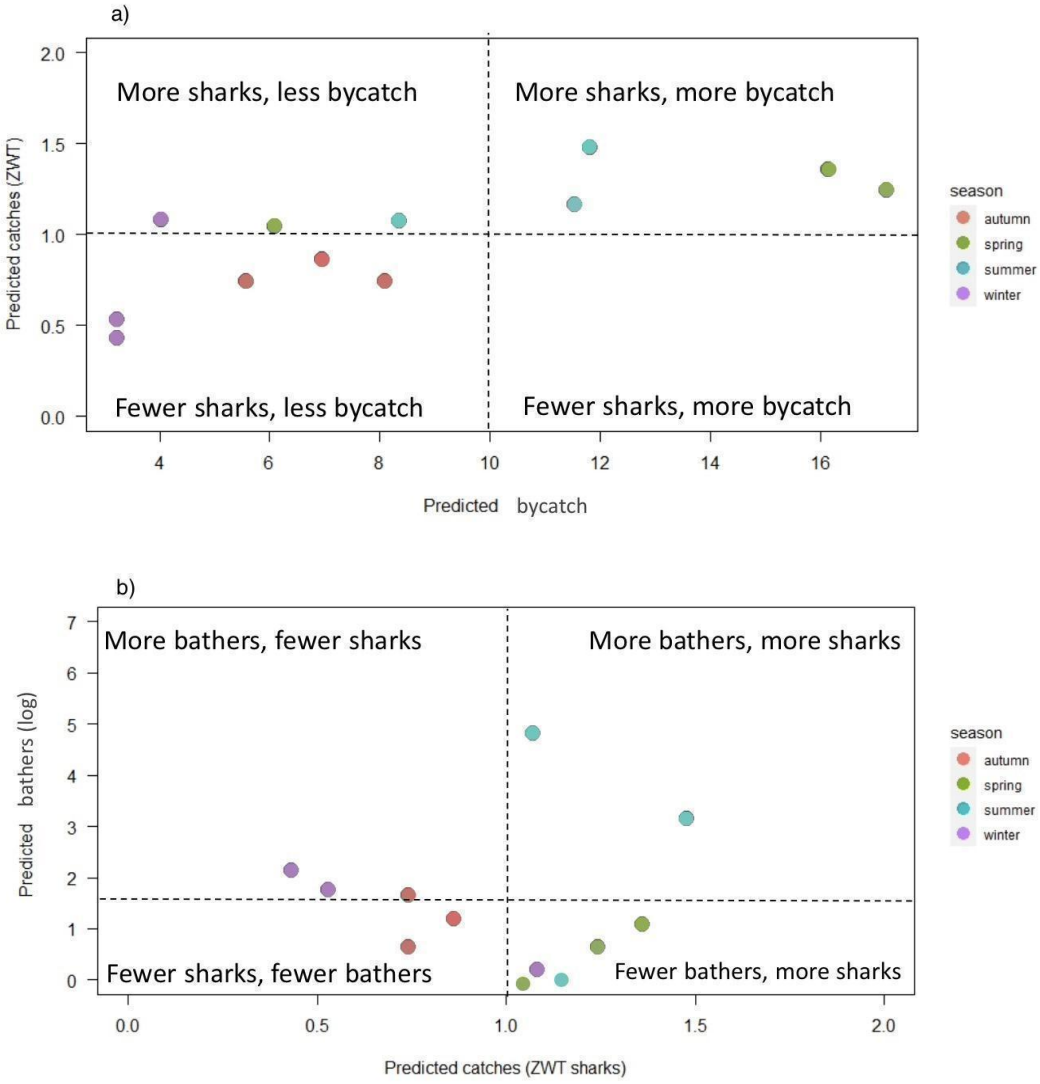

Figure 3. Predicted occurrence of target sharks, non-target species and bathers in Richards Bay, KwaZulu-Natal. (a) Predicted monthly catches of the target sharks (Zambezi, white and tiger; ZWT) versus non-target (bycatch) species were positively correlated. b) Predicted monthly catches of Zambezi, white and tiger sharks versus monthly bather numbers were not correlated. The graphs are divided into quadrants based on the relative numbers of bathers, sharks and/or bycatch for discussion of obstacles and opportunities to mitigate the human-wildlife conflict. (Note the log scale for bathers in (b) due to very high bather counts in December and January.)

Predicted numbers

The predicted monthly catches of target sharks and bycatch animals were correlated (Pearson correlation r = 0.773, t=3.85, df = 10, p-value = 0.003, 95%CI = 0.358 - 0.933; Figure 3a). On the other hand, the predicted monthly catches of target sharks were not correlated with the number of bathers (r = 0.127, t=0.41, df = 10, p-value = 0.693, 95%CI = -0.482 – 0.653; Figure 3b). However, the correlation between the counts of bathers and target sharks is highly influenced by the huge counts in the summer. If we omit the data from January and December, then the number of bathers is strongly negatively correlated with that of the target sharks (r= -0.681, t=-2.63, df = 8, p-value = 0.030, 95%CI = -0.917 – 0.09).

Discussion

We assessed the temporal overlap of the three components of the human-wildlife conflict around the bather protection fishing gear at Richards Bay, KwaZulu-Natal—target sharks, bycatch, and bathers—to identify obstacles and opportunities to reduce the impact on biodiversity without compromising the risk to humans. Catches of the three species of target sharks were predictably low in June and July while bycatch was predictably low between April and September. There was a high degree of temporal overlap in the occurrence of these two components of the human-wildlife conflict. Bather numbers were extremely high during December and January and quite high during the March/April and June/July school holidays, and were low during September. There was less overlap between the temporal patterns of target sharks and bathers and they were not correlated.

Bather numbers were low during August and September which are particularly windy months. This is likely to be a regular pattern. However, in August 2018, the low number of bathers were possibly influenced by two very unusual events: a province-wide labour strike was held by Sharks Board crew from 25 July to 02 August and, on 08 August, a tragic boat accident occurred while the Sharks Board crew was checking the Richards Bay shark nets and three of the five crew members were killed and the boat was damaged. Both events triggered the temporary removal of the gear which resulted in the “banning” of bathing — signs were erected and announcements were made prohibiting people from entering the water. However, many of the surfers did not heed the warnings. Following the accident, the gear remained out of the water until 05 October 2018.

Obstacles and opportunities

For the obstacles and opportunities to mitigate the conflict around the bather protection fishing gear at Richards Bay, the times when the risk of a shark bite was greatest for bathers were considered to be obstacles to change. These are likely to be times when the number of bathers and the number of sharks are highest in the same area. There are a variety of factors that influence the probability of a shark bite. The very least necessary condition for this type of incident is the co-occurrence of the conflict-causing shark species and people in time and space (West 2011, Chapman and McPhee 2016). Ecological and oceanographic conditions can increase the occurrence of these shark species nearshore at a given location (Chapman and McPhee 2016, Ryan et al 2019); and time of day and time of year can influence conditions suitable for shark occurrence and recreation and watersports that increase the human presence in the same habitats (Cliff 1991, West 2011). I divided Figure 3b into quadrants based on the relative number of bathers and catches of target sharks predicted, to assess the times when changes might predictably affect bathers' risks and when this is less likely. The first set of months that are worth noting, when there are more bathers and more sharks, are in two austral summer months (December and January)—this is when the conflict is highest but also when changes would be most likely to affect risks to bathers. The second set of months worth noting, when there are fewer bathers and fewer sharks, is during two months in autumn (April and May). However, during some years the Easter holidays occur in April and then there are likely to be more bathers. A finer resolution analysis should take the precise times of the holidays into account. A third time that is worth noting is that, although there were two months in winter (June and July) when bather numbers were intermediate, shark numbers were predictably low. Historically, only one of 46 shark bite incidents (2%) have taken place in KwaZulu-Natal in winter (Cliff 1991). These two months should be considered low risk months. Based on this, the period between April and July (though subject to the timing of the Easter holidays) could be considered low-conflict and low risk to bathers, even though winter school holidays occur in June and/or July.

The conflict between bathers and target sharks is highest in summer when both components are present in relatively high numbers and risk is greatest to bathers at Richards Bay. Historically, in KwaZulu-Natal, the number of shark bites was highest in January and February, which is different to the Eastern and Western Cape provinces, where incidents took place throughout the year (Cliff 1991).

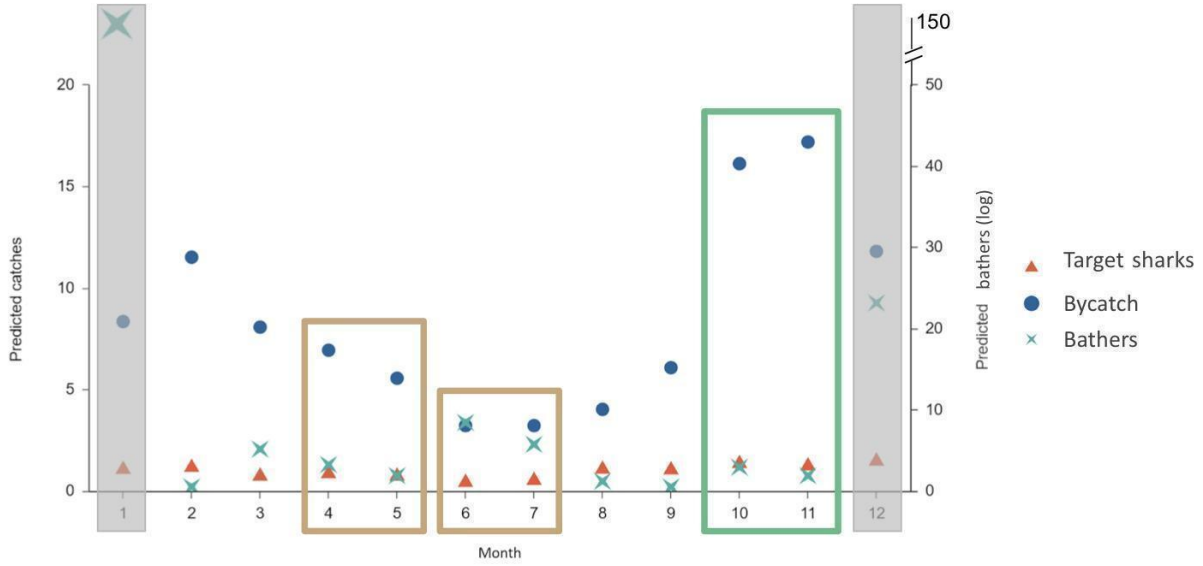

Figure 4. Assessing when there are opportunities to reduce the impact of the bather protection fishing gear on biodiversity at Richards Bay, KwaZulu-Natal, without impacting bather safety by considering predicted numbers of target sharks, bycatch and bathers by month. Greyed out months, January and December, are high conflict and high risk times with more bathers and more sharks. Months outlined in gold are relatively low conflict, low risk times because of predictably low shark numbers or combined fewer bathers, fewer sharks. However, impact on biodiversity would be relatively low since bycatches are also predictably low in all four months. Spring months, October and November (outlined in green) have high bycatches, so changes would have the greatest positive impact on the conflict. But, the relatively high number of shark catches in the months suggest that changes could impact bather risk.

Opportunities to maximise the positive impact on biodiversity would be when bycatch rates are greatest although risk to bathers must be taken into account. Bycatch rates are highest in two spring months (October and November) when predictions suggest 30 animals are likely to be caught. Target shark catches are also particularly high. It is worth noting that during these two months, the target:bycatch ratio was at its highest when >10 bycatch individuals occurred for every target shark caught. From the wildlife's perspective, this would be the best time to make changes. However, there are elements of increased risk to bathers because of the relatively high incidence of shark catches. Two summer months (December and January) also had high bycatch and shark catches but this period was considered a high risk to bathers. During autumn and winter months that were considered low risk because there were predictably few sharks

(June and July) or the combination of fewer bathers/fewer sharks (following the Easter holidays: April and May), bycatch was predictably low. Changes during this period would alleviate some pressure on biodiversity (saving seven animals in April, six in May and four animals in each of June and July) but the impact would be lower. However, across those four months, the catches of 21 bycatch animals are predicted and 2.5 target sharks might be spared.

These results suggest that we may not require protection from sharks all the time and frequently people suggest that it is only necessary to deploy bather protection gear during peak tourism seasons. However, the gear is set to reduce shark abundance and as such is considered a long-term approach. This precludes the use of the gear over short periods only. In the future, if alternative methods of bather protection are identified which act more immediately, these results could be used to identify particular times when protection is needed in the short term.

Conclusion

In conclusion, the most fundamental factor influencing the probability of shark bite incidents is the co-occurrence of sharks and people using the same place at the same time - the bather protection programme in KwaZulu-Natal operates under the premise that reducing the number of sharks can reduce the number of bites. Here, by assessing the degree of temporal overlap between the three components of the human-wildlife conflict at one beach, I identified trade-offs that need to be considered when attempting to mitigate the conflict. The best opportunity to reduce the impact on bycatch occurs at a time when risk to bathers is relatively high, low risk times have relatively few predicted bycatches and changes would only have a relatively small impact. By including the layer of human abundance to the temporal analysis of the shark catches at one particular location, I began to reveal the months when changes to this bather protection programme could be considered. My findings suggest that the current year-round lethal response to a seasonal threat could be changed during winter when target shark numbers are predictably low and should be changed during spring when bycatch is high. However, the relatively higher occurrence of people makes changes less likely in winter, and in spring, the higher occurrence of sharks makes this challenging despite the low occurrence of humans. The increased replacement of shark nets with baited hooks (see chapter 2) is likely to change some of these patterns.

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Appendix 1

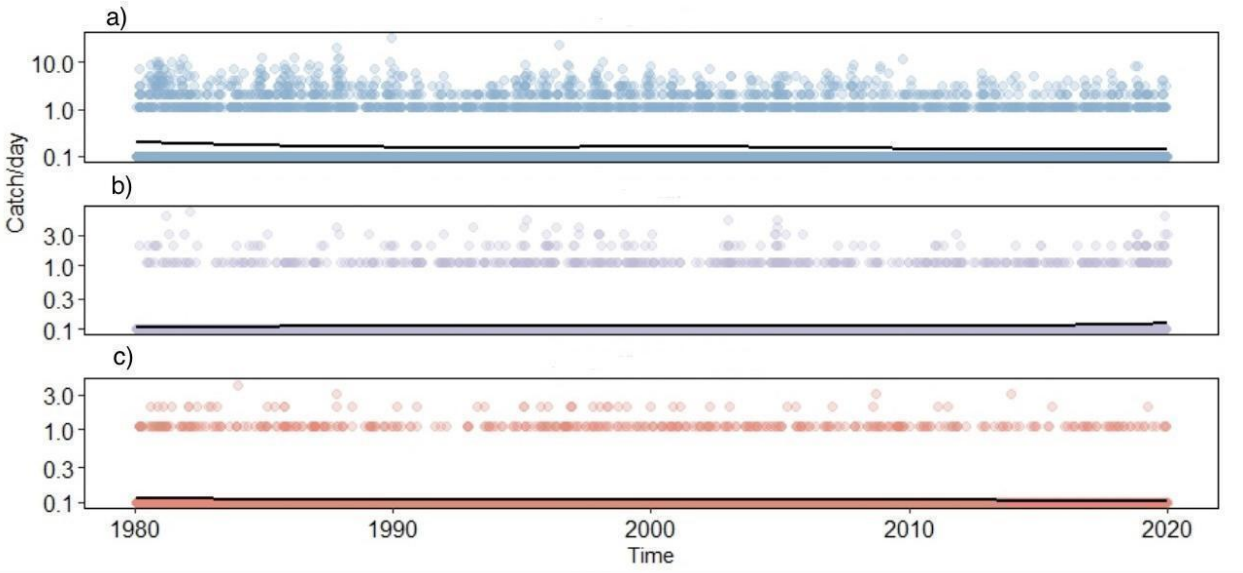

Figure S1. Daily counts of catches in the bather protection fishing gear at Richards Bay from 1980-2019: a) 14 species of large sharks including the three target species: Zambezi (bull) *Carcharhinus leucas*, white *Carcharadon carcharias*, tiger *Galeocerdo cuvier*, b) “harmless” species (cetaceans, turtles, batoids and other elasmobranchs), c) the three target sharks: Zambezi, white and tiger sharks only.

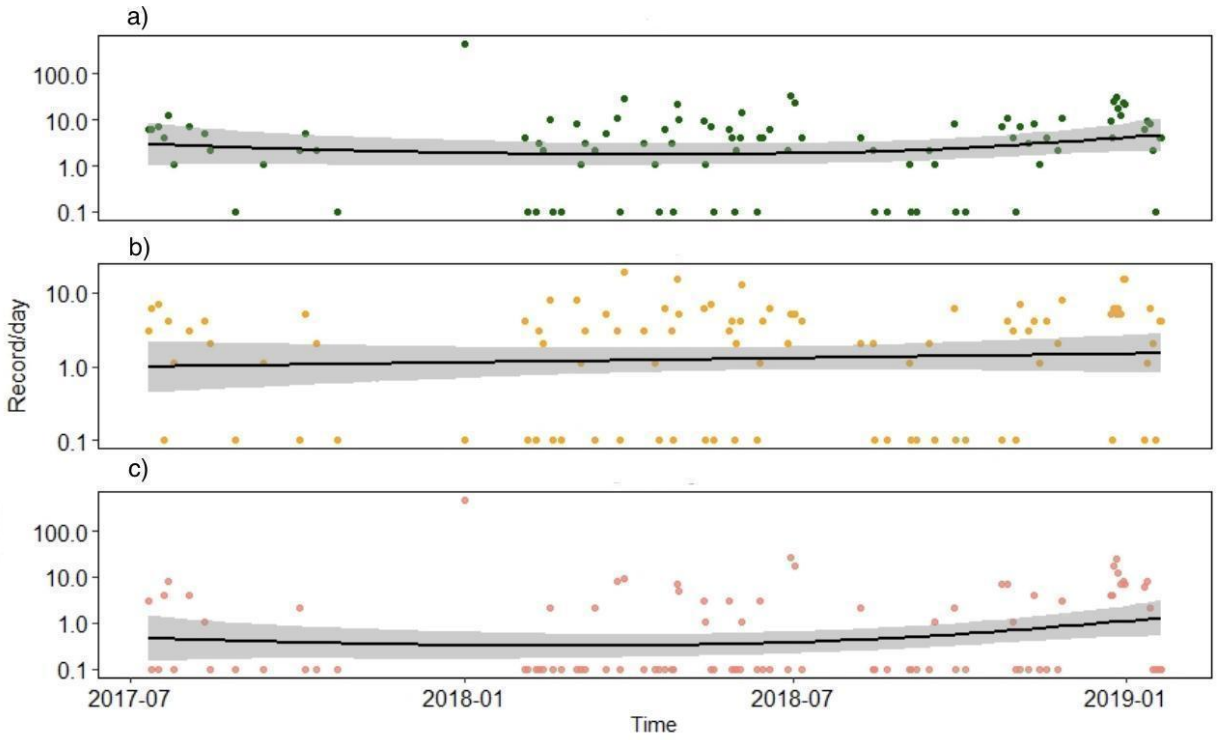

Figure S1. Daily counts of bathers at the beach at Richards Bay from July 2017 to January 2019: a) all bathers (i.e. swimmers and surfers) in water deeper than 1m, b) surfers and c) swimmers. Note the log scale for all bathers and for swimmers.

Table S1. Model rankings for Generalised Linear Mixed Models (GLMMs) for each component (target sharks, bathers, bycatch) with year as the random effect.

Component	Model	Intercept (month)	Family	df	logLik	AICc	delta	weight
Non-target *month + (1|year)*	**Negative binomial**	**2.123**	**nbinomial (log)**	**14**	**-1406.45**	**2841.8**	**0**	**1.00**
	QuasiPoisson	2.146	nbinomial1 (log)	14	-1429	2886.9	45.1	0.00
	Null	2.151	nbinomi	3	-1532.0	3070.2	228.37	0.00

			al (log)		6			
	Poisson	2.09	poisson (log)	13	-1657.71	3342.2	500.4	0.00
Target sharks *month + (1|year)*	**Negative binomial**	**0.07**	**nbinomial (log)**	**14**	**-644.7**	**1318.3**	**0**	**0.99**
	Poisson	0.06	nbinomial (log)	3	-652.885	1332.6	14.24	0.00
	Null	-0.06	poisson (log)	13	-663.628	1333.3	14.99	0.00
Bathers 8 *month + (1|year)*	**Null**	**3.78**	**nbinomial (log)**	**3**	**-85.89**	**179.6**	**0**	**1.00**
	Negative binomial	5.2	nbinomial (log)	14	-63.69	365.4	185.75	0.00

Table S2. Marginal and conditional R^2 (delta) for each component of the human-wildlife conflict around shark nets (sharks that bite, bycatch and bathers).

Component	R^2 marginal	R^2 conditional
Target sharks ~ *month + (1|year)*	0.09	0.15
Bycatch ~ *month + (1|year)*	0.38	0.52
Bathers ~ *month + (1|year)*	0.52	1.00

Table S3. Results of the tests used to check the assumptions of the model in terms of dispersion, uniformity, outliers and temporal autocorrelation against simulated residuals (n=1000).

Test used to check assumptions of negative binomial models against simulated residuals	Target sharks:	Bycatch:	Bathers:
DHARMa nonparametric dispersion test via sd of residuals fitted vs. simulated:	ratioObsSim = 0.99764, p-value = 0.99	ratioObsSim = 1.0476, p-value = 0.554	ratioObsSim = 0.6187, p-value = 0.794
To test uniformity, One-sample Kolmogorov-Smirnov test:	D = 0.047785, p-value = 0.2241	D = 0.04538, p-value = 0.2774	D = 0.48162, p-value = 0.0003766
To test outliers, DHARMa bootstrapped outlier test:	outliers at both margin(s) = 0, observations = 479, p-value = 1, outlier frequency (expected: 0.00114822546972 86) = 0, % CI: 0.000000000 to 0.004175365	outliers at both margin(s) = 1, observations = 479, p-value = 0.9, outlier frequency (expected: 0.00133611691022 964) = 0.002087683, % CI: 0.000000000 to 0.006263048	outliers at both margin(s) = 0, observations = 17, p-value = 1, outlier frequency (expected: 0.00705882352941 176) = 0,
To test autocorrelation, Durbin-Watson test:	DW = 1.9588, p-value = 0.6513	DW = 2.0022, p-value = 0.9806 and	DW = 2.1092, p-value = 0.8183
DHARMa Moran's I test for spatial autocorrelation:	observed = -0.0008739, expected = -0.0020921, sd = 0.0044100, p-value = 0.7824	observed = 0.00085744, expected = -0.00209205, sd = 0.00504769, p-value = 0.559	observed = 0.014877, expected = -0.062500, sd = 0.083741, p-value = 0.3555

Table S4. Results of Generalised Linear Mixed model with negative binomial error distribution for target sharks caught by the KwaZulu-Natal bather protection programme (target ~ month + (1|year)) suggested that the occurrence of these species was significantly low in the austral winter (June and July).

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.070	0.181	0.39	0.700
month02	0.086	0.242	0.35	0.724
month03	-0.367	0.266	-1.38	0.167
month04	-0.217	0.257	-0.84	0.398
month05	-0.368	0.266	-1.39	0.166
month06	-0.911	0.306	-2.97	**0.003**
month07	-0.705	0.290	-2.43	**0.015**
month08	0.009	0.246	0.04	0.970
month09	-0.024	0.247	-0.1	0.924
month10	0.238	0.236	1.01	0.314
month11	0.148	0.240	0.62	0.536
month12	0.321	0.235	1.37	0.172

Table S5. Results of Generalised Linear Mixed model with negative binomial error distribution for non-target (bycatch) species caught by the KwaZulu-Natal bather protection programme (non-target ~ month + (1|year)) suggested that the occurrence of these species was significantly low from mid-autumn to mid-spring (April to September).

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	0.836	0.165	5.06	**0.000**
month02	-0.146	0.221	-0.66	0.509
month03	-0.310	0.224	-1.38	0.167
month04	-0.786	0.243	-3.24	**0.001**
month05	-0.992	0.255	-3.89	**0.000**
month06	-0.805	0.245	-3.28	**0.001**
month07	-0.971	0.254	-3.82	**0.000**
month08	-0.913	0.251	-3.64	**0.000**
month09	-0.720	0.242	-2.97	**0.003**
month10	-0.335	0.228	-1.47	0.142
month11	0.085	0.215	0.4	0.692
month12	0.110	0.217	0.51	0.613

Table S6. Results of Generalised Linear Mixed model with negative binomial error distribution for bathers at Richards Bay, KwaZulu-Natal (bathers ~ month + (1|year).

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	5.195	0.695	7.48	0
month02	-3.160	0.245	-12.92	**<2.00E-16**
month03	-2.044	0.156	-13.08	**<2.00E-16**
month04	-2.298	0.172	-13.4	**<2.00E-16**
month05	-2.737	0.204	-13.41	**<2.00E-16**
month06	-1.915	0.149	-12.81	**<2.00E-16**
month07	-2.587	0.171	-15.1	**<2.00E-16**
month08	-3.735	0.252	-14.84	**<2.00E-16**
month09	-4.168	0.300	-13.9	**<2.00E-16**
month10	-3.298	0.213	-15.5	**<2.00E-16**
month11	-2.521	0.187	-13.48	**<2.00E-16**
month12	-1.148	0.119	-9.62	**<2.00E-16**

Chapter 4. Stakeholders in the shark-bather conflict at a high-catch beach: identifying and characterising them, their network and context.

Abstract

There is a human-wildlife conflict in KwaZulu-Natal Province, South Africa involving sharks and people. In response to a spate of shark bites here, the authorities deployed fishing gear to reduce shark numbers and hence the risk of shark bites. The situation at one beach at Richards Bay is of particular interest because it has a particularly high catch rate of some shark species and bycatch. Past research has focussed on the animals involved and the human bathers that they might interact with, but there are others with a stake in this social-ecological system. Managing human-wildlife conflicts effectively requires first mapping the elements of the conflict in the system. Therefore, I set out to map the human dimensions of bather-shark conflict with a focus on the Richards Bay region. I first identified the stakeholders whose work intersects with the drivers and consequences of the use of shark nets and their roles, relationships and interactions. Next, I investigated the wider social context of the conflict including the policy and economic contexts. I took a constructionist approach and used semi-structured interviews and consulted the literature to identify and characterise stakeholders and the social context of the bather-shark conflict. I asked key informants to rate their perceptions of the influence and interest of other stakeholders and their frequency of communication. Key players (high influence/high interest stakeholders) included the Sharks Board, national and provincial government, while local government was perceived as a Context Setter (high influence/low interest). Conservation and tourism organisations (both governmental and non-governmental) were perceived as Subjects (low influence/high interest). I found that the network of information flow about non-lethal alternative methods of protecting bathers was small and sparse. The economic impact of shark bites and its mitigation has not been studied. The important social context is the public's lack of knowledge about how shark nets work and the fact that many believed that it is the government's responsibility to offer protection. In the policy context, legislation assigns roles and responsibilities which help understand accountability.

Introduction

Human-wildlife conflict has been occurring for as long as there have been humans on the planet. This conflict occurs when actions by humans or wildlife have an adverse effect on the other, including when threats (real or perceived) are posed by wildlife to human life, economic security, or recreation (Nyhus 2016). There may also be related conservation conflicts that involve human interactions between those seeking to conserve species and those with other goals (Young et al 2010). Responses to these conflicts vary, as does who should be accountable for taking action (Pooley et al 2017; Young et al 2016). As our society has become more highly structured, accountability in human-wildlife conflict has probably also changed.

There is a human-wildlife conflict in KwaZulu Natal Province, South Africa that involves sharks, people and other marine megafauna. In the 1940s and 1950s, there was an increase in the number of shark bites, and people demanded that the authorities intervene (Davies 1962). The proposed solution was to deploy shark nets (gillnets) that were set to catch and kill sharks reducing their numbers to reduce the risk of shark bites (Dudley 1997). Besides the targeted sharks, many other species are caught in the bather protection fishing gear (which now includes baited hooks) (Cliff and Dudley 2011). This is a quintessential human-wildlife conflict, where the activities of sharks have an adverse effect on humans and the activities of humans have an adverse effect on sharks (Nyhus 2016). There are direct effects: injuries and loss of life to humans, sharks and other marine animals. There are indirect effects: for humans, these potentially include the loss of tourism and livelihoods; for wildlife, these potentially include the increased risk of extinction and the impact on the ecosystem caused by the loss of top predators – which ultimately affects humans negatively (Myers et al 2007). Currently, many species of marine megafauna are threatened with extinction and therefore this lethal method being used to protect bathers must stop (Dulvy et al 2014, MacNeil et al 2020). However, although biodiversity loss is an ecological problem that affects wildlife and humans, solving the problem is a largely social process.

Managing human-wildlife conflicts is considered as a 2-phase process (Redpath at al. 2013). The first phase entails mapping the conflict. It is crucial to study stakeholders' roles, their relationships and interactions, as well as the way in which these various representations are produced, negotiated and conveyed (Coz and Young 2020). The second phase involves engaging stakeholders to find and implement solutions. There is evidence that participatory processes are significantly more likely to lead to information gain, learning and enhanced trust

and thus reduced conflict (de Vente et al 2016). Elucidating how power, which is synonymous with influence, is distributed among stakeholders can be useful because the manner in which power dynamics are managed can contribute to the success or failure of conflict resolution (Reed et al 2018).

I aimed to investigate the human dimensions of bather-shark conflict to identify the main stakeholders and their roles and relationships and to investigate the wider social context of the conflict, including the policy and economic contexts. I set out to identify who is accountable for people's safety and the wildlife's safety. I consulted the literature, conducted interviews and used questionnaire surveys to establish which organisations were involved and to investigate their influence, interest and their interactions (relative to the methods used to protect bathers) and to describe the social (including political and economic) context. Beyond just documenting the human dimensions, I note obstacles and opportunities to accelerate change in the lethal method currently being used.

Methods and materials

Because conservation issues invariably host a variety of differing perspectives, and many of them are valid, this study is grounded in social constructionism that posits that various understandings and interpretations of the world coexist and are co-constructed (Knight et al 2019; Coz and Young 2020). I used a variety of tools to gather information - scientific and other types of published documents, local knowledge of the system of people who work therein and the self-reported perceptions and experiences of key informants.

Stakeholder analysis

The point of departure for a stakeholder analysis is to clearly identify the issue under investigation so that the boundaries of the social and ecological phenomena can be established (Reed et al 2009). In my study, the issue under investigation was the system that encompasses those interactions between humans and sharks that involve the risk of injury or death to either humans or sharks and mitigating those risks in KwaZulu-Natal. An important part of the issue under investigation was the specific focus on opportunities to change the system to reduce the impact on sharks and other marine megafauna without undue risk to people. I set out to identify stakeholders who are most likely to be engaged in the system - those whose work intersects with either the drivers of the conflict (e.g. tourism and bather protection) or with the

consequences of the conflict (e.g. conservation of sharks and marine biodiversity). Central to the issue is the use of lethal methods to reduce the impact on bathers which then increases the impact on some marine species.

I identified the stakeholders using a combination of key informant and purposive sampling (Bernard and Bernard 2013). I started with the staff at the organisation that manages the bather protection operation (the KwaZulu-Natal Sharks Board) and the municipal Beach Manager at Richards Bay (as the municipalities pay the Sharks Board for their services). Richards Bay is one of the 37 beaches in KwaZulu-Natal that has bather protection fishing gear and I selected this focal area for study because more animals are caught there than at other beaches (Dudley and Cliff 1993). I asked all interviewees who else they perceived as stakeholders (within and outside of their organisations), these stakeholders' roles, and others I should interview. Based on their suggestions, I invited others to participate. My purpose was to sample a range of roles within each organisation and at different levels within the organisations' hierarchies.

To preserve anonymity, I do not cite which interviewee offered the information in the results but the information about each stakeholder organisation and their stakes came from the representatives of the organisation, or occasionally from the Sharks Board interviewees. I also consulted the available literature on policy documents and annual reports.

Interest and influence

Various attributes can be considered when characterising stakeholders and I chose an assessment of interest and influence which makes power dynamics explicit (Reed et al 2009). I asked key informants (at least one person within each stakeholder organisation) about their perceptions of the influence and interest of other stakeholders. This assessment involved a brief questionnaire emailed to 13 key informants from nine organisations. I asked: "For each of the stakeholder positions presented, please rate out of 10 (1 lowest and 10 highest), your perceptions of their influence (the capacity to affect what type of methods are used to protect bathers) and their interest (in a variety of methods of bather protection); and I presented a list of 20 stakeholders. These stakeholders were identified by their position within organisations rather than by their name, e.g. Head of Research, KwaZulu-Natal Sharks Board; Beach Manager, uMhlathuze municipality; Project Manager (Sharks), WildOceans. All 13 key informants were on the list, plus seven other stakeholders that I had interviewed at that stage. I received replies

from eight interviewees, representing seven organisations. Using the key informants rating, I calculated a mean ± standard deviation (SD) score for the influence and interest of each organisation. The graph was divided into 4 equal-sized quadrants (along the two dotted lines) and labelled as Key Players, Context Setters, Subjects, and Crowds following the approach described by Reed et al (2009).

Communication network

Understanding interactions among stakeholders may also be important when analysing and characterising stakeholders and I investigated the communication network in this human-wildlife conflict. A communication network is defined as a set of nodes linked by interactions where the nodes consist of actors (in this case, the stakeholders/interviewees) and the edges denote interactions where information is communicated (Aggarwal 2011). I asked the same key informants (above) to report two aspects of the frequency with which they communicated with the other stakeholders. I asked, “For each of the stakeholder positions presented: 1) How often do you communicate with this stakeholder? 2) How often do you communicate about the use of non-lethal methods to protect bathers? They could choose categorical measures of frequency: Daily, weekly, monthly, annually, never, other. These measures were then converted to numeric measures: “daily” was converted to 365, “weekly” to 52, “monthly” to 12, “annually” to 1, “never” to 0; “Other” included reports of “quarterly”, “biannually”, “occasionally” and “as needed” which were converted to 4, to 2, 0.5, and NA. Using each of these self-reported frequencies of communication, I constructed two directed, weighted networks in which nodes representing individual stakeholders were linked by edges whose direction indicated who cited whom, and the thicknesses were proportional to the cited frequency of communication between them. Nodes were then differentiated by colour according to their organisations (see Results).

To investigate the structural properties of the networks, as well as the role of individuals and organisations on the flow of the networks, I used four network metrics (detailed in Newman 2018). First, to estimate how dense the communication networks were, I calculated their connectance as the proportion of realised edges (communication links between stakeholders) relative to the maximum number of edges possible. High connectance indicates highly connected networks, through which information can potentially flow quickly and more directly than in sparse networks (e.g. Cantor and Whitehead 2013). Second, to estimate levels of network clustering and subgroup interconnectivity, I calculated network modularity (Q) and

tested statistical significance with a null model approach. Modularity informs about the existence of densely connected subgroups (Newman 2006); in this case, subsets of stakeholders that communicate more with each other than with the rest of the network. I used a swapping algorithm to generate an ensemble of 1000 permuted networks of the same size of the originals by shuffling edges among nodes (Gotelli and Entsminger 2003), and calculated modularity to all of them to create a theoretical distribution of Q-values to which I compared the observed modularity. Modularity was considered significant when falling outside of the 95% confidence interval (CI) of this distribution. Third, to measure the degree of cohesiveness of the networks, I calculated closeness centralisation, a summary of centrality by closeness (Freeman, 1979), for the whole network. Closeness centrality is the reciprocal of the sum of the length of the shortest paths between the node (stakeholder) and all other nodes in the graph, and it informs about how 'close' individuals are in the network via their connections, and therefore are best placed to influence the entire network. I also calculated the node-based closeness centrality for each stakeholder in the communication network about non-lethal alternatives. Finally, I calculated another metric of social centrality, betweenness centrality (Freeman, 1979), to consider the number of shortest paths (here, shortest chains of communication) that pass through a given stakeholder. Stakeholders that are peripheral in the communication network have zero betweenness, while individuals who connect otherwise discrete subgroups have particularly high betweenness, and so have a particularly high influence on the spread of the information. All network analyses were performed in R software (R Core Team, 2014) using the package igraph (Csardi and Nepusz 2006).

The broader context

As part of my investigation of the human dimensions of this human-wildlife conflict, I investigated the broader context in which the conflict was set, in particular the social-political context, and what has been published in the literature about the economic impact of the bather-shark conflict. As part of the mapping process, Redpath et al (2013) suggested understanding the legislation and therefore I report on the Acts, Regulations and policy documents that were referred to by the interviewees, the Sharks Board's Annual Reports and references within those documents. I focused on biological and ecological policy, even though the Sharks Board is governed by others, e.g. financial, labour and shipping legislation, and so on.

For the economic impact and social context I conducted literature reviews. I searched a multi-disciplinary database – Web of Science. For the economic impact, I used the following search terms: “Econom* AND shark* AND (bite* OR attack*) AND (Natal OR KwaZulu-Natal OR South Africa)”. This yielded 3 publications and none were from South Africa; therefore, I dropped the location terms. I searched titles only, then broadened it to topics, then to author keywords and “keywords Plus”.

For the social context, I used similar search terms: (Social OR human) AND shark* AND (bite* OR attack*) AND (Natal OR KwaZulu-Natal OR South Africa). Searching titles yielded no results, whereas searching topics yielded 18 publications. Only three were on the topic of interest about the human dimensions of shark bites but were studies from Australian or Reunion island. Based on these, I broadened the first search term to (Social OR human OR public OR perceptions OR attitudes). I searched titles only, then broadened it to topics, then to author keywords and “keywords Plus”. Within the publications that were relevant to KwaZulu-Natal, I considered the literature cited for other publications pertinent to KwaZulu-Natal.

Results

Stakeholder analysis

For the stakeholder analysis, I conducted 28 interviews with 13 organisations. An additional six people were approached but declined to be interviewed or did not reply to my emails. The stakeholder organisations are presented in Table 1. For the three levels of government (local, provincial and national) and Ezemvelo KZN Wildlife (see below for details about each stakeholder organisation), I spoke to at least one official higher up in the hierarchy in a “strategic” position and at least one official “on the ground”. For the Sharks Board, I spoke to two heads of departments but the “on the ground” staff declined to be interviewed. For the remaining organisations, I interviewed one representative each. We discussed the stakes of the organisations they represented and their roles within the organisations, related to the bather-shark conflict. We discussed the roles of others within their organisations, of others they interacted with outside of their organisations and generally who they perceived to have a stake. The interviews yielded the stakeholder analysis results below and in Table 1. I have not attributed specific information to specific interviewees as anonymity was called for by my University’s ethics committee but the information about each stakeholder organisation below

was from the interviewees representing that organisation or from the Sharks Board interviewees. Information derived from the literature is cited.

Table 1. The KwaZulu-Natal (KZN) bather-shark conflict stakeholders organisations, the type of organisation and their stakes, with focus on the Richards Bay area. The primary stakeholders provided bather protection and beach amenities, as well as providing financial support of the bather protection programme. Other stakeholders are mostly interested in conservation of biodiversity, tourism and research.

Organisation	**Type of organisation**	**Stake**
KZN Sharks Board (KZNSB)	Provincial entity	Mandated with providing environmentally-sensitive bather protection in KZN.
uMhlathuze Municipality	Local government	Mandated with providing beach amenities, pay Sharks Board for bather protection services rendered.
KZN Dept. Economic Development, Tourism and Environmental Affairs	Provincial government	Sharks Board's "controlling department", covers 2/3 of the costs of the bather protection programme.
KZN Treasury	Provincial government	Allocates funds to provincial departments and entities.
Ezemvelo KZN Wildlife	Provincial entity	Conserves nature in KZN.
Tourism KZN	Provincial entity	Promotes tourism in KZN.
Dept. Forestry, Fisheries and Environment: Biodiversity and Coastal Research	National government	Provides scientific information to other departments, including Oceans Conservation Strategies.
Dept. Forestry, Fisheries and Environment: Oceans Conservation Strategies	National government	Issues an operating permit to Sharks Board. Administers the Shark Biodiversity Management Plan.
South African (SA) National Biodiversity Institute	National government	Mandated to act as an advisory and consultative body on matters relating

	entity	to biodiversity
Various - SA Association for Marine Biological Research, Wildlife Environment Society SA, WildOceans, Endangered Wildlife Trust	Non-governmental organisations	Conserve biodiversity (and sustainable tourism in some cases).
SouSA Consortium	Consortium of researchers	Studies the conservation biology of endangered humpback dolphins.
SharkSpotters	Non-profit organisation	Reduces interactions and conflict between bathers and sharks.
SharkSafe Barrier	Pty Ltd	Developed an alternative bather protection method.
City of Cape Town	Local government	Drafted bather protection policy and strategy.
Various universities and research institutions	Academic	Study the animals involved and people's perceptions

More detailed information about each of the stakeholder organisations follows, as explained by the stakeholder representing each organisation.

KwaZulu-Natal Sharks Board and provincial government

The KwaZulu-Natal Sharks Board (hereafter, the Sharks Board) is mandated to protect bathers from the risk of shark bites while minimising environmental impact. The objectives of this Board are to undertake, initiate, control and approve measures for safeguarding bathers against shark attack in the province and perform the powers, duties and functions that pertain to this objective (KwaZulu-Natal Sharks Board Act, 2008). It is a provincial public entity and falls within the Department of Economic Development, Tourism and Environmental Affairs (EDTEA), in the Environmental Management section, and almost two thirds of the Sharks Board's income is granted by the provincial government (KwaZulu-Natal Sharks Board 2015-2022). The Member of the Executive Council (MEC) representing EDTEA, is ultimately accountable as the executive authority. The MEC appoints a Board of Directors to be the accounting authority and the Board appoints a Chief Executive Officer who is responsible for the administrative and financial

management of the Board, and the appointment and management of staff (KwaZulu-Natal Sharks Board Act, 2008). In 2021, there were 170 staff members in five divisions: Operations; Corporate Services; Finances; Research, Planning and Development; and Business Development (KwaZulu-Natal Sharks Board 2022).

The main activities of the Sharks Board staff include: 1) providing bather protection; 2) conducting research into the biology of sharks and other animals caught and developing alternative methods of protecting bathers; and 3) conducting public education and outreach programmes on sharks, safe bathing and the activities of the Sharks Board (KwaZulu-Natal Shark Board 2022). The divisions most closely tied to decisions about the methods being used to protect bathers are Operations and Research, Planning and Development. Both divisions are overseen by the Board's Research and Shark Repellent Technology committee. The education programme falls within the Business Development division (overseen by the Board's Business Development committee). Operations are spread out along the coast at 11 base stations. The research and education facilities are housed at the Sharks Board's headquarters. At the headquarters, there is a small museum, filled with displays of newspaper articles about shark attacks and life-like replicas of sharks and visitors can attend an audio-visual presentation and a shark dissection. They offer boat tours from the Durban harbour. In addition, an outreach programme visits about 50 schools per year (KwaZulu-Natal Shark Board 2022). They exhibit at events and trade shows and advertise and promote their activities.

Local government

Another primary stakeholder is the local government (local municipalities). Providing beach amenities is a mandated function of the local government (Integrated Coastal Management Act, 2008) and in KwaZulu-Natal, the coastal municipalities contract and pay the Sharks Board to provide bather protection from sharks. In KwaZulu-Natal, there are five coastal municipalities and their combined "meshing fees" constitute about one third of the Sharks Board's annual income (KwaZulu-Natal Shark Board 2015 - 2022). Originally, in the 1950s, 60s and early 70s, it was the municipalities who deployed the shark nets or contracted fishermen to do so but in 1974, the task was assigned to the Natal Anti-Shark Measures Board, now the KwaZulu-Natal Sharks Board (Dudley and Cliff 1993, Powell 2017).

Because of my interest in the bather protection fishing gear at Richards Bay, the focal municipality in this study was the uMhlathuze municipality. Within the municipal structure, the Community Services section is responsible for beaches and engages the Sharks Board and pays them monthly fees. It receives monthly operational reports and a report of the number of animals caught listed by species. The Beach Manager and lifeguards interact with the Sharks Board's boat skippers and area managers at least weekly. Within the Community Services portfolio committee, the bather protection programme is discussed frequently by officials at all levels of the hierarchy from the beach manager to the deputy municipal manager. In addition to the protection afforded to the residents and the tourists who use the protected beaches, an important consideration for the municipality is their occupational health and safety policy which compels them to consider the safety of the lifeguards, including the risk of shark bites. The Department of Economic Development Facilitation (which includes Tourism) also has interests in bather protection, as does the department of Spatial and Environmental Planning. Their focus has been on developing additional beach nodes where they would like to offer bather protection from sharks.

National government

The South African National Environmental Management: Biodiversity Act, 2004 provides for the management and conservation of biological diversity and for governance in biodiversity management and conservation. Related to this, the Threatened or Protected Marine Species Regulations, 2017 regulate specific restricted activities involving specimens of listed threatened or protected marine species. The Sharks Board's use of gillnets and baited hooks involves the restricted activities: catching, releasing and being in possession of some species that are listed in these regulations. Therefore, the Sharks Board applies to the Department of Forestry, Fisheries and the Environment's (DFFE) Ocean Conservation Strategies annually for a permit for the operation. Research permits may also be issued by DFFE's Biodiversity and Coastal Research. Other interactions between the two organisations include reports of catches, e.g. South Africa's second National Plan of Action for the conservation and management of sharks reports prepared by DFFE's Fisheries Management section and includes the Sharks Board's chondrichthyan catches (Department of Forestry, Fisheries and the Environment 2022), as well as reports to the International Whaling Commission about cetacean catches. The Sharks Board scientists sit on various national Working Groups and have participated in the national Red List assessments for elasmobranchs. The Sharks Board has been contracted as consultants to the

department to conduct research and advise on matters pertaining to shark bites outside of the KwaZulu-Natal province (e.g. at Port St. Johns, Eastern Cape Province). In the past, DFFE has provided funding for research on the use of baited hooks (drumlines) to reduce bycatch. Scientists from both organisations collaborate to publish in the peer-reviewed literature (e.g. Wintner and Kerwath 2017, da Silva et al 2015).

The national public entity, South African National Biodiversity Institute (SANBI), is another organisation (linked to the national government) that is interested in the Sharks Board's activities. It is mandated to assess and monitor the state of South Africa's biodiversity. It has published two National Biodiversity Assessments and both included information about KwaZulu-Natal's bather protection programme (Sink et al 2012, 2019).

Ezemvelo KZN Wildlife

As the provincial agents of DFFE, Ezemvelo KZN Wildlife (EKZNW) is also a stakeholder. They are a provincial public entity that falls under EDTEA's Environmental Management section. They are mandated with nature conservation in the province and are thus responsible for the conservation indigenous fauna and flora in KwaZulu-Natal, including sharks and marine fauna (KwaZulu-Natal Nature Conservation Act 1999). They have a formal policy that describes their stance when it comes to shark nets (Ezemvelo KZN Wildlife 2004). The Sharks Board informs them about matters pertaining to the bather protection programme. There has been a national mandate to rationalise provincial entities and EKZNW is likely to absorb the objectives, functions and powers of the Sharks Board, and the KwaZulu-Natal Sharks Board Act (2008) is currently being redrafted as part of the KwaZulu-Natal Environmental, Biodiversity, Protected Areas and Human-wildlife Interaction Management Bill, 2022.

Others

The tourism industry is an important beneficiary of the bather protection programme. Within the provincial department of EDTEA, the Tourism Development section interacts occasionally with the Sharks Board, mainly with the Business Development staff. Tourism KZN is a provincial public entity within the Tourism Development section although they are very rarely involved directly with the Sharks Board's activities. However, they are interested in issues that affect the reputation of the province (which potentially includes shark bites) and therefore have a stake.

Environmental and sustainable tourism NGOs that aim to conserve sharks, other marine megafauna and their habitat are also stakeholders of the bather protection issue. For example, WildOceans has been running an awareness campaign to inform people of the imperilled status of sharks and their threats, including shark nets. The Endangered Wildlife Trust worked with the Sharks Board to research strategies to mitigate the bycatch of the endangered humpback dolphin (*Sousa plumbea*). The South African Association of Marine Biological Research (SAAMBR) has run education programmes to inform the public about the use of shark nets. The Wildlife and Environment Society of South Africa, which implements the Blue Flag Beach certification system, engaged the Sharks Board in an attempt to reduce the environmental impact. A consortium of researchers focused on humpback dolphin conservation in South Africa (the SouSA Consortium) is a stakeholder since shark nets constitute a major threat to the humpback dolphin population (Plön et al 2016, Vermeulen et al 2018, Plön et al 2021).

The City of Cape Town, Western Cape Province, South Africa has grappled with the issue of environmentally-sensitive bather protection (Nel and Peschak 2006) and has drafted a bather protection policy and strategy. They use the services of the SharkSpotters (Kock et al 2012). The SharkSpotters is a shark safety and research organisation that uses visual surveillance by trained observers to detect sharks and signal water users to leave the water when sharks are spotted; it also deploys a non-lethal exclusion net that physically separates sharks and bathers. A private, for-profit company, SharkSafe Barrier (Pty) Ltd, sells a non-lethal alternative bather protection system using visual bio-mimicry and magnetic repellents (O'Connell et al 2018). There are many academics that study species that are caught in the shark nets and use samples and carcasses of the animals for research (Lane et al 2014, Daly et al 2020). The above organisations are all stakeholders that interact with the Sharks Board in their professional capacities, at various levels.

There are other stakeholders, i.e. the residents, businesses and tourists in KwaZulu-Natal, that benefit from the reduction in the risk of shark bites in KwaZulu-Natal, directly and indirectly in terms of protection of the tourism industry. Specifically, interviewees included bathers (swimmers, surfers, triathletes), lifesaving clubs (they are different to the professional lifeguards who fall within the municipal structures), fishermen and angling clubs. No interviews were conducted with these stakeholders because my focus was on the stakeholders that were involved in the bather-shark conflict professionally.

Influence and interest

The brief questionnaires that were sent to the key informants from the above organisations yielded individual ratings of the perceived influence and interest of many of the stakeholders by their position within the stakeholder organisations (e.g. Ezemvelo KZN Wildlife: Regional Manager). When these were averaged by organisation, it showed how the mean (±standard deviation) influence and interest of the organisations varied (Figure 1). The Sharks Board and the three levels of government were perceived to have high influence on the types of methods used to protect bathers and high high interest in a variety of methods of bather protection too, except for local government which was perceived as less interested. The conservation and tourism organisations were perceived to have high interest but low influence. There were more stakeholders that were interested but lacked influence than stakeholders that were influential but lacked interest.

There was variability in perceptions (i.e. the standard deviation which was shown using the coloured lines in Figure 1), e.g. perceptions of the influence of the Sharks Board were quite consistent whereas perceptions of their interest were more variable. This was true generally in that there tended to be greater variability in perceptions of interest than influence.

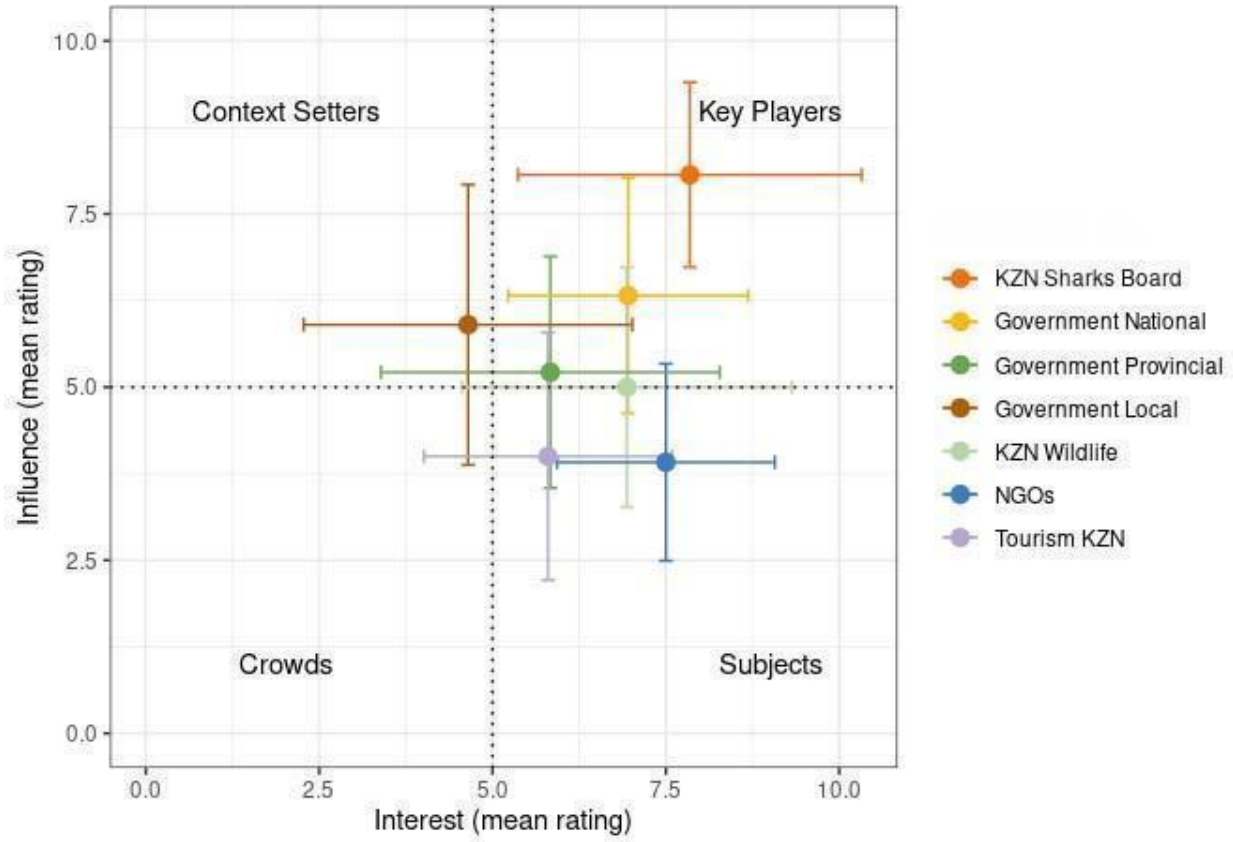

Figure 1. The perceived influence and interest of the stakeholder organisations (mean±standard deviation) (NGOs have been combined) suggest that Key Players (with high influence, high interest) were the KwaZulu-Natal (KZN) Sharks Board, and national and provincial government. The local government was perceived as a Context Setter (with high influence but low interest). The conservation-focused organisations such as Ezemvelo KZN Wildlife and the (combined) non-government organisations (NGOs) were perceived as Subjects (with high interest but low influence).

Below the results are presented within the framework set out in Reed et al (2009) in which high influence, high interest stakeholders are categorised as “Key Players”; high influence, low interest stakeholders are “Context Setters”; low influence, high interest stakeholders are “Subjects”; and low influence, low interest stakeholders are “Crowds”.

- Key Players.The stakeholder community perceived three stakeholder organisations with high influence in the types of methods used to protect bathers and high interest in a variety of methods of bather protection. The Sharks Board was consistently perceived to

have the highest influence although there is variability in perceptions of their interest in a variety of methods of bather protection. The next most-influential was the national Department of Forestry, Fisheries and the Environment. The provincial Department of Economic Development, Tourism and Environmental Affairs was also perceived as both influential and interested (there was high variability in perceptions of their interest).

- Context Setters. The local government was perceived to have the lowest interest, despite their high influence, which placed them in the Context Setters' quadrant.
- Subjects. The stakeholder community perceived three Subjects with high interest but low influence. The combined NGOs were second only to Sharks Board in interest but lowest in terms of influence and they were consistently rated as such. Perceptions of Ezemvelo KZN Wildlife were quite variable, they appeared to be relatively influential but less interested than the NGOs. Tourism KZN was also rated to be in this quadrant.
- Crowds. No one within the stakeholder community was perceived as lacking both influence and interest.

Communication network

The brief questionnaires that were sent to the key informants also yielded reports of the frequency with which these key informants communicated with other interviewees in their own, and other organisations, again by their position within the organisation e.g. EDTEA: Environmental Affairs: Control Environmental Officer. The weighted, directed network of the reported frequency of general communication among the stakeholders I had interviewed (Figure 2a) was a benchmark against which to consider the weighted directed network of communication about non-lethal alternatives specifically (Figure 2b). In terms of the density of the communication network (which I measured as connectance (C)), there were 63 communication links (edges) among 19 of the 20 interviewees resulting in a low connectance (C=0.184), i.e. <20% of the possible edges (communication links between stakeholders) were realised generally. By contrast, there were only 24 communication links specifically about non-lethal alternative methods of protecting bathers and these occurred among only 12 interviewed stakeholders. While connectance of this smaller network is similar (C=0.181), I was not interested in the connectance within this smaller network but I was interested in the connectance with regard to non-lethal methods within the benchmark network of general communication. Considering the maximal number of edges in the general (benchmark) communication network containing all interviewed stakeholders, the connectance of the network

of communication about non-lethal alternatives is much lower (C=0.07). These findings suggest that the overall communication is relatively low, especially regarding non-lethal alternatives methods of protecting bathers.

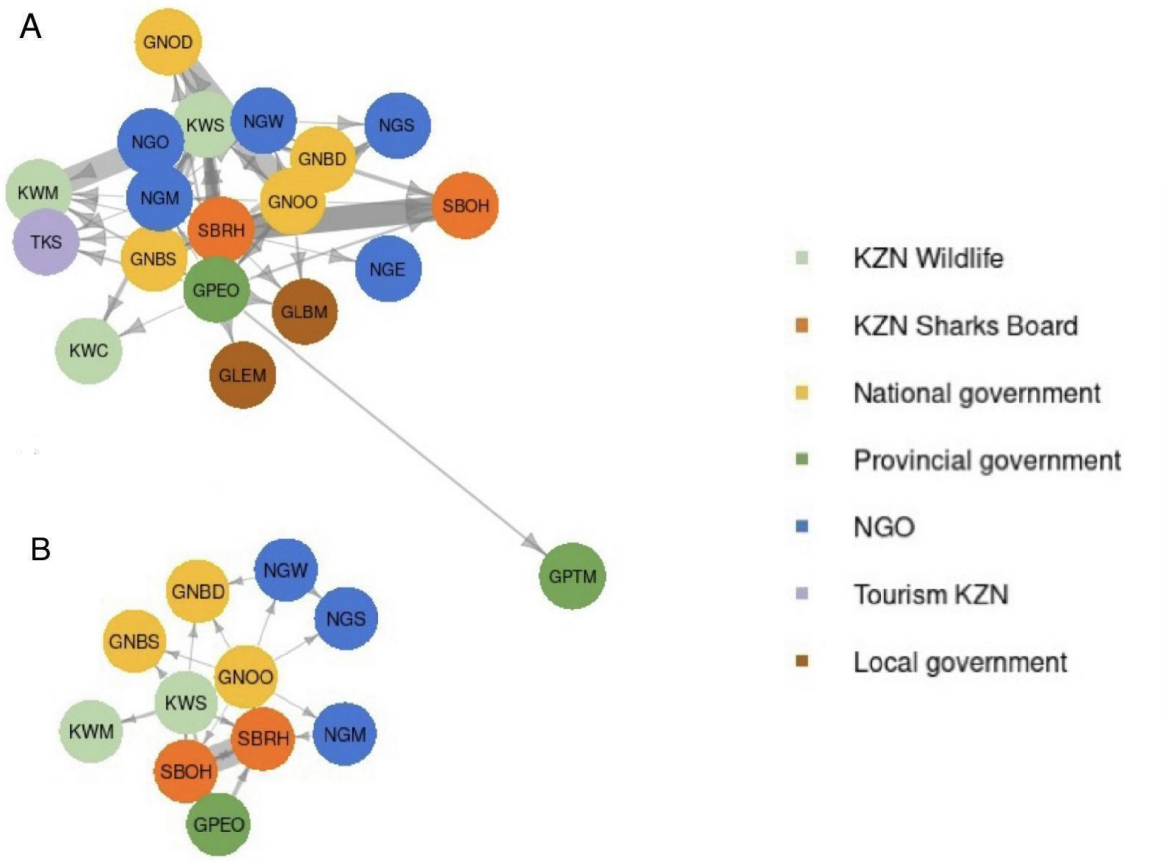

Figure 2. Networks depicting communication flows among the interviewees as reported by key informants: (a) general communication and (b) communication that is specifically about non-lethal alternatives to bather protection fishing gear in KwaZulu-Natal, South Africa. The thickness of the connections (i.e. the edges) indicates the relative frequency of communication. Abbreviations are found in table 2.

In terms of subgroup connectivity (i.e. levels of clustering into subgroups measured using modularity (Q) with 95% confidence intervals (CI)), I found high and significant modularity of the benchmark network (Q = 0.542, 95%CI = 0.132 - 0.279), which suggested a reliable division (Q>0.3; Newman 2006) of the network of general communication into seven clusters. In contrast, the communication network about non-lethal alternatives did not have reliable divisions, as the modularity was low and nonsignificant (Q = 0.132, 95%CI = 0.125 - 0.353).

In terms of the degree of cohesiveness of the network, i.e. network centrality, the network-level closeness centralisation (Cc) of the benchmark communication network (Cc = 0.51) was a small fraction of the theoretical maximum of the most centralised network with the same number of nodes, which would be 8.74. For the network of communication about non-lethal alternatives, the centralisation is 0.54, i.e. it is slightly more organised around a few nodes, particularly DFFE's Ocean Conservation Strategies' Control Environment Officer, followed by Sharks Board's Head of Research and Ezemvelo KZN Wildife's Marine Scientist (Table 2, Figure 2b). Regarding the network position of individual stakeholders from different organisations in influencing the communication flow, I found that those from the Sharks Board and the National Government had a disproportionately high betweenness centrality both in the benchmark communication network (Figure 3 a) and in the communication network about non-lethal alternatives (Figure 3b). These individuals occupying more central positions were followed by individuals from the Local Government and, to a lesser degree, from NGOs (Figure 3). All other stakeholders and organisations can be considered at the periphery of these communication networks, with little to no participation in the communication flow, as they had zeroed betweenness centrality (Figure 3).

Table 2. The closeness scores of individuals within the sub-network of positions that communicate about non-lethal methods of bather protection in KwaZulu-Natal (KZN)

Position Initials	Organisation and position	Closeness scores
GNOO	Government, national: Ocean Conservation Strategies: Control Environmental Officer	0.048
KWS	KZN Wildlife: Marine Ecologist	0.042
SBRH	KZN Sharks Board Head of Research	0.040
SBOH	KZN Sharks Board Head of Operations	0.039
GNBD	Government, national: Biodiversity and Coastal Research: Director	0.038
GNBS	Government, national: Biodiversity and Coastal Research: Scientist	0.037
NGW	NGO: Wildlife and Environmental Society of SA	0.036
NGS	NGO: SharkSpotters	0.034
NGM	NGO: SA Association for Marine Biological Research	0.034
GPEO	Government, provincial: Environmental Affairs: Control Environmental Officer	0.013
KWM	Ezemvelo KZN Wildlife: Regional Manager	0.013

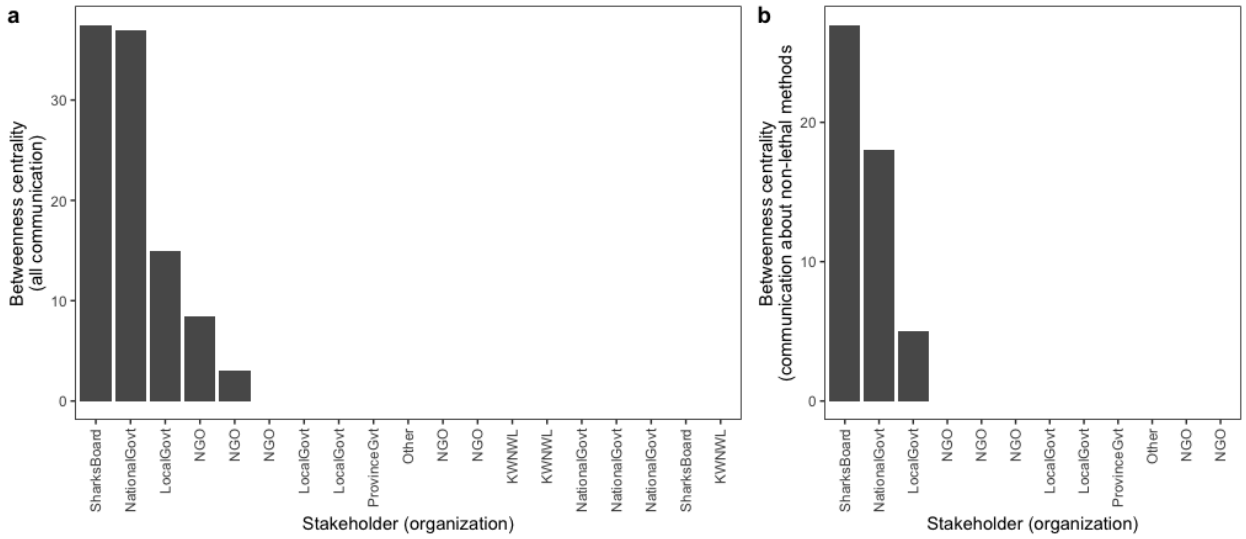

Figure 3. Betweenness centrality of individual stakeholders in the networks depicting communication flow about (a) general information and (b) specifically about non-lethal alternatives to bather protection fishing gear in KwaZulu-Natal, South Africa. Stakeholders are anonymized and categorised by their organisation type.

The broader context

Policy context

Using the Acts, Regulations and policy documents that were referred to by the interviewees and the Sharks Board's Annual Reports, I have extracted or summarised the most pertinent aspects that should be considered by those seeking to understand the context of the bather-shark conflict.

The KwaZulu-Natal Sharks Board Act (2008) sets out the powers, duties and functions of the Sharks Board which I have summarised as:

- to research, develop, install and maintain schemes, devices or measures necessary to safeguard bathers in the Province against shark attack;
- consider existing or proposed schemes in terms of efficacy of reducing the risk of shark attacks, including endeavouring to introduce schemes that will -
    - reduce negative impact on all biodiversity; and
    - enhance the survival of caught sharks and other marine animals;

- undertake research to assess the feasibility of different methods and their environmental impact
- consider relevant scientific and technical research of others;
- create awareness to bathers about
    - the measures that have been taken
    - safety precautions bathers should take;
- assist or place its services at the disposal of any municipality, in connection with aquatic issues, life-saving and emergency services, research and surveys;
- in exercising its powers and functions it must
    - promote biodiversity and ecological integrity by striving to avoid, mitigate and reduce any negative environmental impact;
    - do anything in its power to promote the sustainability of marine life;
    - endeavour to use all dead sharks and other marine animals caught by the schemes implemented for scientific research;
- where possible, release all live marine animals, including sharks, caught or affected by the schemes implemented;
- keep accurate records of all sharks and other marine animals caught or otherwise affected by the schemes implemented; and
  investigate and make recommendations to and advise the responsible Member of the Executive Council regarding any matter related to the protection of bathers against shark attacks in the Province.

The activities of the Sharks Board require a permit from DFFE because they handle animals that are specified as Threatened or Protected Species (ToPS) in terms of the National Environmental Management: Biodiversity Act, 2004 and Marine Threatened or Protected Species Regulations, 2017, and because some bather protection installations are set within Marine Protected Areas (MPAs) (National Environmental Management: Protected Areas Act, 2003). The elasmobranchs (the group comprising sharks, rays, skates) that are specified in the 2017 ToPS regulations that are caught in the bather protection programme include white *Carcharodon carcharias,* tiger *Galeocerdo cuvier*, spotted ragged tooth *Carcharias taurus*, shortfin mako *Isurus oxyrinchus* and whale sharks *Rhincodon typus*, scalloped hammerhead *Sphyrna lewini* and great hammerhead *S. mokarran*, flapnose houndshark *Scylliogaleus quecketti*, manta rays *Manta spp*; in addition, all cetaceans, turtles, seabirds and seals are protected. The Marine Living

Resources Act (MLRA) (1998) stipulates that chondrichthyans may not be landed, transported, transshipped or disposed of with their fins removed without a permit.

The Protection of Animals Act, 1962 includes in their definition of “animal” as a wild animal in captivity or under the control of a person and states that one may not confine, chain, tether or secure any animal in such a manner or position as to cause that animal unnecessary suffering or in any place which affords inadequate ventilation (*inter alia*). It also stipulates that if one has laid a trap or device, it must be inspected or cleared at least once each day.

In 2011, South Africa signed the Shark Memorandum of Understanding under the Convention on Migratory Species. This triggered the Shark Biodiversity Management Plan (SBMP), 2015, with the purpose of attaining and maintaining a favourable conservation status for resident and migratory sharks within South Africa, taking into account the socio-economic value of these species. The SBMP includes legislative, strategic and research-related aims for the conservation and management of sharks. Threats to sharks are categorised as: 1) Lack of co-ordinated legislative framework and governance (domestic, regional and international). 2) fishing (directed and bycatch;. 3) other anthropogenic impacts (non-consumptive uses, habitat degradation, trophic level impacts and climate change, plus the shark control programme); and 4) insufficient data and uncoordinated research and monitoring.

Within the Plan, there are three objectives pertaining to the shark control programme.
1) minimise bycatch of shark species that pose little or no threat to bathers;
2) minimise impacts on all shark species; and
3) raise public awareness on bather safety and shark control programs
The first two objectives were high-priority and aimed to start within a year of the plan’s publication (2015) and were the responsibility of the Sharks Board. It specified replacing more shark nets with baited hooks and researching non-lethal alternatives. The third objective was a medium-priority and was set to start within 2 years of the plan date.

One of the recommendations in the plan was that information about bather protection impacts on sharks should be added into the local governments’ Integrated Development Plans (IDP). I could not find any reference to the bather protection programme in uMhlathuze’s IDP (confirmed by a representative of uMhlathuze’s Environmental department 2021/12/03), nor in eThekwini’s IDP (the municipality of Durban, KwaZulu-Natal’s biggest city).

The Food and Agriculture Organisation's Committee on Fisheries developed an International Plan of Action for the Conservation and Management of Sharks (IPOA-Sharks) in 1998 within the framework of the Code of Conduct for Responsible Fisheries, to which South Africa is a signatory. This triggered a National Plan of Action (NPOA) for Sharks which was recently updated (NPOA-Sharks 2) which includes reports of the shark catches in the bather protection fishing gear (DFFE, 2022). This plan did not issue any actions to the Sharks Board, and it states that the bather protection catch represents *"only 2.4% of South Africa's total shark catches, much of which is released alive"* (DFFE, 2022, page 8). It also reports extensive testing of non-lethal alternatives to fishing gear using an electrical barrier system.

A KwaZulu-Natal Beach Tourism Policy (no date available) exists and assigns three roles to the Sharks Board: to assist the municipalities with compliance with tourism policy, especially with regard to safety and security issues, incorporate tourism policy implementation into their Annual Action Plan, and assist municipalities with tourism awareness.

It must be noted that in South Africa, ecological impact is considered relative to our national imperatives as set out in South Africa's National Development Plan 2030 and Medium Term Strategic Framework 2019-2024, which are socially-biased. It is people-centred rather than resource-centred and promotes sustainable use as opposed to control (Celliers et al 2009). This is evidenced by provisions such as that in the Shark Biodiversity Management Plan: "*taking into account the socio-economic value of these species*" when articulating the conservation purpose of the plan. In other words, when weighing up the impact on the environment versus impact on people and economy, the government will prefer to err on the side of the people.

<u>Economic impact</u>

There was one result in the literature survey of economic impact that had all three search terms in the title. Entitled "Sharks take a bite out of seaside economy", this was not a study investigating the economic aspects of shark bites but a news report/opinion-piece reporting on a series of shark bites in Recife, Brazil (Miller 1995).

There were 17 results in which all three search terms (Econom* AND shark* AND (bite* OR attack*)) appeared in the abstract. Seven of them were irrelevant (e.g. sharks biting submarine cables, cetaceans or fishermen's catches). Of the remaining 10 that were relevant to shark bites

and people, none were studies of the impact of shark bites on economic variables. In fact, only one of these studies included any economic variables in their investigation. This was a study examining the effect of several demographic, economic and socio-environmental factors on the quality of knowledge about and perceptions toward sharks in a Brazilian area with a high incidence of shark bites (Afonso et al 2020). Regarding economic level effects, they found that people's knowledge and affinity for sharks were positively correlated with economic level and that prejudice was inversely proportional to economic level (Afonso et al 2020). It is interesting to note that of the 10 papers, five used the term economic in the first sentence, four used it in the second and third sentences and one used it in the last sentence. Clearly, the economics of the situation is being used to justify the importance of various studies on the topic of shark bites.

There were no results in the literature survey in which the search terms appeared in keywords.

Social context

The literature survey of social context yielded no titles with the social context search terms which were (Social OR human OR public OR perceptions OR attitudes) AND shark* AND (bite* OR attack*) AND (Natal OR KwaZulu-Natal OR South Africa). The search terms appeared in the abstracts of 23 publications. Of these, only four were about social issues regarding the risk of shark bites and its mitigation, and only one of them was conducted in KwaZulu-Natal (Sheridan et al 2021). The other three relevant papers were focussed on Australia or Reunion island. The remaining 19 publications that contained the social context search terms were not relevant and were about shark biology, methods or programmes of protecting bathers from sharks, investigations of shark bite incidents and global trends thereof. There were no results in the literature survey in which the social context search terms appeared among keywords of publications.

The single relevant study investigated perceptions of different methods of protecting bathers held by beach recreationists in KwaZulu-Natal compared to the Western Cape Province, South Africa (Sheridan et al 2021). They surveyed bathers after their emerging from water in Durban, KwaZulu-Natal, at two beaches where shark nets and baited hooks are set, and in Cape Town, Western Cape, where the Shark Spotter programme uses non-lethal methods to reduce the risk of bites. They assessed knowledge and perceptions of lethal versus non-lethal methods of protecting bathers. Few respondents understood that shark nets (10% of 205 respondents in

Durban, and 8% of 370 Cape Town respondents) and baited hooks (23% of Durban's respondents) are designed to catch and kill sharks to reduce the risk to humans. Almost all respondents opposed the use of lethal methods of bather protection. However, there was significantly less opposition among those at Durban beaches compared to Cape Town (Sheridan et al 2021).

Sheridan et al (2021) referred to a study that pertained to social issues regarding the risk of shark bites and its mitigation conducted in South Africa, including in KwaZulu-Natal. Lucrezi et al (2019) tested causative and moderator effects in human perceptions of sharks, their control and framing. They surveyed visitors (not exclusively water-users like Sheridan et al (2021)) at five beaches with differing approaches to bather protection including two in KwaZulu-Natal, uShaka and Ballito, that use lethal shark nets and baited hooks to protect bathers. Most respondents (71% of 1138) were South African, the remainder were foreign tourists. They found that most respondents knew that sharks do not hunt humans. Views were mixed about whether sharks are dangerous. More respondents asserted that preventing human-shark interactions is the responsibility of the government though most ultimately believe it is one's personal responsibility to make sure it is safe to enter the water. Only a quarter selected their beach destination based on locally adopted bather protection measures. Most did not think that "shark attack" is a good expression to describe human-shark interactions. Many felt that the media talks about human-shark interactions in an improper way. Modelling results suggested that 1) knowledge about sharks made people less dependent on bather protection from sharks, 2) perceived intent in shark bite incidents can instigate both fear of sharks and support for lethal shark control policies, and 3) perceived danger from sharks can be a predictor of lower tolerance of sharks among the public (Lucrezi et al 2019). These authors concluded that a primary strategy to improve support for shark conservation would be to enhance the acquisition of knowledge by the general public.

Lucrezi and Gennari (2021) extended their investigation and compared beach visitors' perceptions of bather protection in Durban and Cape town. At the Durban beach, 43% of the 257 respondents were local inhabitants, 51% domestic tourists and 6% international tourists whereas at the Cape Town beach, 33% of the 586 respondents were local inhabitants, 23% were domestic tourists and 44% were international tourists. In Durban, 75% of the respondents had used the water compared to just half in Cape Town. More Durban respondents could name at least one species of shark and they named a greater variety of species than in Cape Town. In

both places, almost half of the beach visitors claimed to be afraid of sharks, yet most believed that sharks do not represent a risk to water users locally. In Durban, 55% of beach visitors reported that there was bather protection at the beach (including a small proportion who identified shark nets, but not baited hooks, as the method used) compared to 39% in Cape Town (where a similarly small proportion identified the SharkSpotter programme). Those using the water were more aware of the protection programmes. Perceived effectiveness of the programmes varied and more people in Durban believed lethal methods were effective and more people in Cape Town believed non-lethal methods were effective. South African beach visitors were significantly more inclined to perceive lethal strategies as effective, compared with foreign visitors. There was much uncertainty around the harmfulness of bather protection to sharks, in both locations and for both lethal and non-lethal methods (Lucrezi and Gennari 2021).

Discussion

This multidisciplinary approach revealed unprecedented details about the human dimensions of the bather-shark conflict in KwaZulu-Natal, South Africa. By characterising the key stakeholders and the social context of the conflict, my analyses strengthened the idea that the most influential and interested stakeholder was Sharks Board, a provincial public entity that is mandated in provincial legislation to protect bathers in KwaZulu-Natal from the risk of shark bites and conduct research and education pertaining to this issue. They provide this bather protection service to the local municipalities who were perceived as influential but lacking interest. The programme is heavily subsidised by the provincial government - perceptions of their influence and interest were variable but were generally rated as high. Some of the species caught by the Sharks Board are Threatened or Protected Marine Species and a permit is issued by the national government which was perceived as the second-most influential and interested stakeholder organisation by the stakeholders in my study. The great interest of most of the conservation organisations (provincial and NGOs) was recognised, as was their lack of influence. Few stakeholders communicated regularly about alternative methods of bather protection, and among these, again the Sharks Board and the National Government occupy a central role in the communication flow. The high priority of shark conservation is recognised in South Africa's legislation but national development imperatives are apparently socially-biassed and favour economic growth. There were no published studies of the economic impact of shark bites or mitigating them, even though such an impact is commonly used to justify other research. The majority of bathers actively using the ocean in Durban, KwaZulu-Natal did not

know that the gear intentionally kills sharks and they were generally opposed to the idea of using lethal methods, but less so than bathers where non-lethal methods are used. Beach visitors believed that the government should protect them.

Stakeholder and network characterisation

There was high interest among most of the stakeholders in which methods are used for bather protection. Six of the seven stakeholder organisations were perceived as interested compared to four of the seven perceived as influential. Only the local government appeared to lack interest — their key informant did not respond to the survey. Perhaps respondents tend to score their own interest relatively high or perhaps their lack of response is confirmation of their lack of interest. In the interviews, at least two of the three municipal representatives reported conducting informal research to learn about potential alternatives to the current lethal methods being used which suggests they do have some interest. Perceptions of the influence and interest of the provincial government were quite variable, many of the stakeholders did not appear to be aware of their important financial role.

Assessing influence and interest individually and numerically provides novel insights about variability in perceptions. Often, stakeholder identification and characterisation are conducted in a group setting such as a workshop or focus group and stakeholders are mapped qualitatively with just a single point (Sandroni et al 2022, Reed et al 2009). For my assessment, key informants independently rated influence and interest numerically which allowed me to assess the variability in general perceptions. The greatest variability in perceptions of interest were of the provincial government's interest and this may be because many of the stakeholders were not aware of their important financial role in terms of the annual grant. On the other hand, the greatest consistency was in the perceptions that NGOs struggle to influence this system despite their great interest. Reed et al (2009) suggest that forming alliances can increase influence; this is an opportunity to promote change.

For the flow of information pertaining to non-lethal alternatives, the number of communication links was low—few stakeholders were discussing alternatives. Although the general network itself was quite modular (i.e. there are fairly distinct subgroups that communicate more often with each other), there were no subgroups when it came to communication about non-lethal alternatives, likely because this was a small fraction of the general network. Although the

general network was not particularly centralised as a whole, there were stakeholders from key organisations occupying central positions in the communication flow. Regarding general communication, individuals within the Sharks Board and the National Government featured as more influential. The communication about the non-lethal methods, specifically, was more centralised around the Control Environmental Officer at DFFE's Ocean Conservation Strategies, who administers the Shark Biodiversity Management Plan. This may be a sign of the utility of tools such as Biodiversity Management Plans in raising the profile of conservation issues.

One caveat of my approach is that the communication networks depict only a subset of the social landscape around this human-wildlife conflict. Thus, the resultant networks do not perfectly represent the real situation, since I did not ask every node in the network about their communication, and of those that I did ask, not everyone responded. Based on the qualitative data from the interviews, I know that there are some positions within the stakeholder organisations that were not interviewed but which do communicate with one another. For example, interviewees from the Sharks Board and the municipality mentioned that the Sharks Board's boat skippers and crew communicate regularly with municipal officials that work at the beach. It is possible that they may discuss alternative methods of bather protection. Although I did not interview every stakeholder, considering that I interviewed the relevant heads of departments, directors, and the few stakeholders that deal with any aspect of alternative methods of bather protection, it is likely that I interviewed most of the influential and interested people that are engaged with, and thinking about, the human-wildlife conflict around bather protection and the methods used.

Context and impact

Legislation delegates the roles and responsibilities of the organisations involved in various aspects of the bather-shark conflict in KwaZulu-Natal. There are legislation and policies in place to protect sharks and other marine animals, and national plans to improve the situation for sharks specifically, like the Shark Biodiversity Management Plan. Two of the three shark species targeted by the bather protection fishing gear are protected by national legislation (ToPS Regulations 2017), along with many other species caught, yet a permit is issued for the operation. Since the marine ToPS regulations were published in 2017, more recent Red List assessments indicate that 13 of the 14 species of large sharks are Vulnerable, Endangered or Critically Endangered (see chapter 2). The one exception is the tiger shark which already

appears on the ToPs list. Therefore, it is likely that all 14 species of sharks listed in chapter 2 will be included on the ToPS list in the next revision.

There was no literature aiming to quantify the economic effect of the risk of shark bites. We do not need rigorous science to verify that these incidents have economic consequences but a scientific approach might help to quantify the size of the effect. The main economic impact is likely to be in the form of lost opportunity for local businesses and lost opportunity of tourism more generally but it would be challenging to unravel the many, interconnected factors that determine destination choice. Safety is among the many factors that motivate tourists in their destination choices (Van der Merwe et al 2011) although safety from sharks is just one of a variety of safety issues (other examples include e.g. crime, disease). Shark bites do affect the spatial patterns of ocean-users, usually as displacement, rather than cessation of beach use (Lemahieu et al 2017). However, this displacement may manifest differently for local inhabitants and tourists.

Much of the literature that pertains to sharks and tourism was focussed on sharks as an attraction (e.g. Gallager and Hammerschlag 2011, Vianna et al 2012). This gives rise to an interesting dilemma where the same species simultaneously attract some tourists but repel others. According to the interviewees from the Sharks Board, the cost of the bather protection programme is very small compared to the income generated by the beach tourism it protects. Protecting such sources of income is vital because KwaZulu-Natal is among the poorest of South African provinces and has particularly high rates of unemployment (Maluleke 2020). It would be useful to have an independent, objective assessment of the economic impact of the risk of shark bites on tourism and the cost of removing sharks from the ecosystem.

Most people seem to be afraid of sharks (La Busque et al 2019) and sharks are among the least popular animals on the planet, mainly because they are perceived as dangerous (and “unlovable”) (Driscoll 1995; George et al 2016). While people in KwaZulu-Natal expressed ambivalence about the danger of sharks, those who believed that sharks act intentionally to harm people tended to have higher levels of fear and were more likely to support the use of lethal means to control sharks (Lucrezi and Gennari 2021). Overall, very few people were comfortable with the concept of killing sharks; however, people in KwaZulu-Natal were slightly less opposed to lethal methods than people in the Western Cape (Sheridan et al 2021). Very few people on the beach understood that the nets and hooks are intentionally catching sharks or

even harmful to sharks (Sheridan et al 2021, Lucrezi and Gennari 2021). This is despite the Sharks Board's awareness programme. It is stipulated in the scientific literature that the nets are set to lower shark populations near beaches (Dudley 1997), yet the discourse around the function of the nets has not been clear in the public domain and it is not common knowledge how the bather protection gear works, possibly because most people are opposed to the use of lethal methods.

Many people believe that it is the government's responsibility to protect bathers from sharks (Lucrezi 2019). If sharks continue to be framed primarily as perpetrators of risk, policy responses will likely remain unfavourable to shark conservation (Muter et al 2013). However, people's perceptions of sharks are changing and public opposition to these lethal shark control programmes is mounting, especially in Australia (McCagh et al 2015, La Busque et al 2019, Gibbs and Warren 2015, Whatmough et al 2011, Gibbs et al 2020). Education and knowledge affect perceptions of sharks (Afonso et al 2020) and therefore the Sharks Board's education programme is an opportunity to improve people's perceptions, though it may benefit first from an assessment of its accuracy and efficacy.

Accountability

Accountability is largely a question of defining roles and responsibilities; a minimum requirement for accountability in this sense is that the responsibility—for actions and effects—should rest with those with the power to make decisions (Mikalsen and Jentoft 2008). The KwaZulu-Natal Sharks Board Act has delegated the power to the Sharks Board to conduct research and make the decisions about which method of bather protection is appropriate. They are accountable for both the safety of the bathers and the impact on the environment although the language in the act prioritises the safety of the bathers. It is the Sharks Board's Operations staff that decides what methods should be used in consultation with its research department, subject to approval by the Board. They are the designated experts and all three levels of government (local, provincial and national) in South Africa rely on their expertise to make decisions about bather protection. However, they must operate within the budget constraints that are imposed by the provincial government. They also must operate within the permit conditions that are set out by the custodians of South Africa's biodiversity, i.e. the national government. When deciding the permit conditions, the potential ecological impact is not considered in isolation and national imperatives with strong social biases form part of the considerations.

Legislation defines the local government's role in providing beach amenities. However, in KwaZulu-Natal, the bather protection amenity has been delegated to the Sharks Board. Although the uMhlathuze municipality (at Richards Bay) and its Executive Committee have invested much time in the discussion of bather protection from sharks, my perception is that their decision-making is limited to whether they want protection from sharks or not and even that is a foregone conclusion, given the fear of liability and the displacement of tourists to other, protected beaches.

Ezemvelo KZN Wildlife are not delegated any serious role or responsibilities, although they are consulted by the national government and informed by the Sharks Board of some of their decisions. The tourism section of the provincial department of EDTEA, and other tourism organisations, such as Tourism KZN, do not actively participate in any of the decisions about bather protection, and do not have any designated roles or responsibilities associated with bather protection. NGOs have no formally designated roles and responsibilities although they do have a strong interest in the conservation of marine biodiversity.

Conclusion

I contributed to the mapping of the social elements of this bather-shark conflict by identifying stakeholders that are invested in this social-ecological system, the capacity in which they are invested and how they interact, especially around the concept of alternative methods of protecting bathers. I now have a more holistic understanding of the role players and the policy environment which has helped to elucidate accountability among the stakeholders. This knowledge creates an opportunity for change agents to design strategies to mitigate the bather-shark conflict in the future.

Politics and power imbalances pervade many conservation initiatives and so articulating, revealing and negotiating power dynamics can provide an opportunity for successful conservation (Knight et al 2019). There is growing recognition that restricting influence to politicians and those who "use" resources is part of the problem rather than the solution (Mikalsen and Jentoft 2008). While top-down strategies can work to manage conservation conflicts, more collaborative approaches can too. Decision-making should be collaborative, participatory and involve communities (Redpath et al 2017), although much work must first be

done to clarify the many misconceptions about sharks and mitigating shark bites. It seems prudent to involve a variety of people to solve this problem since diverse groups are more likely to solve problems than just highly intelligent problem solvers (Hong and Page 2004).

Few stakeholders communicated regularly with each other about alternative methods of bather protection. Changes in connectivity can have a pronounced effect in small networks (Cantor et al 2021). Providing opportunities for increased information flow within the network could be an opportunity to increase the chances of conservation action. Changing how information flows within a system is considered a particularly “deep” leverage point (where a small shift may lead to fundamental changes in the system as a whole) that potentially affects the design of the system (Abson et al 2016, Fischer and Riechers 2019).

I have also peeked into the social context of the conflict but this is very limited as little science has been conducted on the social context of this conflict in KwaZulu-Natal and there is scope for more investigation of what people know, think, and feel about sharks, the risk of shark bites and how it is mitigated. There is a complete absence of scientific information on the economic impact of shark bites and its mitigation, despite its importance, and this area should be explored.

This bather-shark conflict is mired in fear of sharks and misconceptions and there is a lack of public knowledge about how the nets work. Despite the Sharks Board’s education programme, the public lacks accurate information on sharks and reducing the risk (Sheridan et al 2021, Lucrezi et al 2019, Lucrezi and Gennari 2021). The Sharks Board should evaluate the efficacy of their education programme (the messaging and/or the communication technique) because the KwaZulu-Natal public lack accurate information about how the bather protection achieves its goal of reducing shark attacks. Others (e.g. NGOs) can fill the gap but inconsistent messaging causes further confusion.

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Chapter 5. Stakeholder perceptions reveal obstacles and opportunities to change lethal methods of protecting bathers from sharks.

Abstract

Shark nets and/or baited hooks are set to catch and kill sharks to protect bathers at popular beaches in four of the world's countries. This lethal practice contributes to human well-being and safeguards beach tourism, a valuable income-generator. However, culling is costly—financially and environmentally. Here, I identify obstacles and opportunities to change this lethal bather protection system in the South African province of KwaZulu-Natal by assessing the knowledge and perceptions of people closely involved with the use of shark nets. I conducted semi-structured interviews of 29 stakeholders from the government entity responsible for the nets (KwaZulu-Natal Sharks Board), three levels of government (local, provincial, national), and affected tourism and conservation organisations. Half of the interviewees were unaware that shark nets are set to intentionally reduce shark populations. Barriers to changing the 70-year *status quo* included: mindsets pertaining to sharks and managing shark bites in KwaZulu-Natal (compared to other places); the sense of liability among government officials; the political nature of the decisions; the lack of proven alternatives; the high cost of potential alternatives; the difficult high-energy surf conditions in KwaZulu-Natal; and the slow progress of innovation. However, stakeholders saw opportunities in promising technology, research and in education that can rectify misconceptions. I recommend an assessment of the obstacles to and opportunities for change to the local social structures (institutions, policies, systems and infrastructure) in order to implement a programme that accelerates the development and testing of alternatives in KwaZulu-Natal coupled with a well-designed communication campaign. Ensuring human well-being and sustainable tourism should remain a priority, but not at the cost of losing sharks. It is crucial to revisit this long-standing protection programme to make it safe for both people and sharks since human-wildlife conflicts cannot be solved by protecting only one of the parties.

Introduction

As human populations grow and spread across the globe, human-wildlife conflicts escalate (Nyhus 2016), both in the terrestrial and the marine realms. Human-wildlife conflicts can be mutually detrimental and result in injuries and death of people and animals, and loss of livelihoods, biodiversity and ecosystem functioning. A prime example is conflict caused by the

risk of human-shark interactions. Many (but not all) interactions between sharks and humans are negative for at least one party—for example, directed fishing of sharks, unintentional catches in fishing gear, competition between sharks and humans for resources, shark “attacks” (hereafter referred to as shark bites) and human response to these (Simpfendorfer et al 2021). Human fascination with shark bites is high (Muter et al 2013), even though the real risk of shark bites is low (Midway et al 2019). They are low-probability, high consequence events (Crossley et al 2014), which makes them quintessential human-wildlife conflicts.

South Africa has a particularly high shark biodiversity and is a hotspot for human-shark interactions, both positive (it has one of the highest numbers of non-consumptive shark ecotourism operators) and negative (it has one of the highest incidences of shark bites) (Derrick et al 2020, Midway et al 2019, Gallagher and Hammershlag 2011). Human-shark conflict is particularly high in the province of KwaZulu-Natal where a spate of shark bites in the 1940s to 1960s resulted in a fishing programme where gillnets and more recently baited hooks are set at popular beaches to reduce the number of sharks (Cliff 1991, Cliff and Dudley 2011). Theoretically, reducing the population of sharks reduces the probability of shark-human interactions (Dudley 1997). (There is also a bycatch - non-target species (dolphins, turtles, etc) are also caught and killed incidentally.) This method of bather protection adds to the list of other threats (e.g. overfishing, habitat degradation) that is resulting in a drastic decline in the number of sharks and other large marine species (Roff et al 2018, Pacoureau et al 2021, MacNeil et al 2020, da Silva et al 2015). In fact, sharks are one of the most threatened taxa on the planet (Dulvy et al 2014) and sharks in the Indian Ocean are particularly impacted (MacNeil et al 2020; Pacoureau et al 2021). In the KwaZulu-Natal bather protection programme, there has been a steady decrease in the number of nets set and the associated catch (~500 sharks killed annually in 23 km of nets in the 2010s) compared to previous decades (~1300 sharks killed annually in 44 km of nets in the 1980s) (Cliff and Dudley 2011; KwaZulu-Natal Shark Board unpublished data). Yet, even on a relatively small scale, fishing can have a negative impact on large sharks which are slow to mature, slow to breed and key to connecting marine ecosystems (Ferretti et al 2010, Simpfendorfer et al 2021). As apex predators, sharks are vital for healthy marine ecosystems as their removal causes community restructuring (Myers et al 2007). We cannot continue to systematically catch and kill large sharks as a method to reduce the risk to bathers for ethical reasons, for biodiversity conservation and to prevent further disruption of ecosystem functioning. We need alternative strategies.

Finding a better way to manage the human-shark conflict is imperative. However, change is difficult. Successfully managing a conflict requires an understanding of not only the conflict but also the social-ecological system around it (Redpath et al 2013). A vital part of this process involves elucidating the knowledge and understanding the perceptions of stakeholders. Previous research has addressed the knowledge and perspectives of beachgoers and ocean-users (e.g. Gibbs and Warren 2014, Crossley et al 2014, Lucrezi et al 2019) but to date no one has examined the views of the network of people involved in this bather-shark conflict at a professional (occupational) level. When trying to effect changes to reduce conflict, a starting place is to pinpoint the obstacles to and the opportunities for change.

In this study, I investigate the knowledge of and attitudes towards shark nets of stakeholders in the bather protection programme in KwaZulu-Natal. The stakeholders of interest are those whose occupations intersect with bather protection directly or indirectly. I draw on discussions held individually with these stakeholders about bather protection generally and the work they do that relates to bather protection specifically. This research aimed to identify the narratives that predominate around three issues: 1) how the shark nets work; 2) the advantages and disadvantages of using shark nets; and 3) the obstacles and opportunities to change the bather protection programme in KwaZulu-Natal. Ultimately, my goal was to understand the conditions that hinder changing the use of this lethal method and those that might facilitate change.

Material and Methods

The philosophical basis of the research

My philosophical position was oriented towards critical theory, which aims to challenge and bring about change (Moon and Blackman 2014). The research focused on the stakeholders whose work intersects with the bather protection system. My broad aim was to understand people's perspectives within this social-ecological system and the research is rooted in a constructionist epistemology, i.e. it assumes that reality is tied to the human experience (Moon et al 2019). I explored the stakeholders' knowledge and perceptions of the shark nets (and other methods to protect bathers).

Data collection

To identify potential respondents, I used a combination of key informant and purposive sampling, starting with the staff at the KwaZulu-Natal Sharks Board (the organisation that manages the bather protection operation, hereafter Sharks Board) and an official from the local government who manages one of the protected beaches - Richards Bay (where the bather protection fishing gear catches more animals than at most other beaches). Between March 2019 and April 2021, I invited 40 stakeholders via e-mail to participate in individually-conducted, semi-structured interviews. Of these, 33 consented and seven declined or did not respond to the request. Most (88%) interviews were conducted in-person and three were conducted virtually.

The interview guide was based on Kansky et al's (2016) questionnaire, a standard set of survey questions that have been used to understand the context of human-wildlife conflicts. We modified it to be open-ended and more appropriate for the context of our study. I asked respondents about how their work related to shark nets. We asked knowledge-based questions pertaining to how the shark nets work and about alternative methods to protect bathers. I elicited respondents' opinions about the use of shark nets and possible alternatives. Based on their work, four interviewees did not meet the criterion of sufficient recent intersection with the bather protection programme and, although the interviews were continued to completion, their data were not included in the analysis. The final sample included 29 respondents.

Data analysis

All but two of the interviews were voice-recorded and transcribed verbatim. For the two who preferred not to be recorded, notes were taken during the interview and then sent to the interviewees for approval and correction to ensure that their answers had been captured accurately. I formulated codes to analyse the data (Erlingsson and Brysiewicz 2017). During the initial stages of coding, multiple codes were identified to capture as many ideas on three specific subjects of interest: 1) how each stakeholder described, or referred to, the mechanism of the shark nets; 2) what they perceived to be the pros and cons of the current method; and 3) any mention of changing the situation or of alternative situations (i.e. bather protection in the past, future or in places other than KwaZulu-Natal). I coded the data and these codes were assessed by a social science expert and collaborator, Dr Judy Mann-Lang. The codes were then reviewed and refined, i.e. I used debriefing for triangulation (Moon et al 2016). Codes that shared a commonality were grouped into categories (Graneheim and Lundman 2004) which were then

identified as obstacles or opportunities to change or neutral (i.e. neither obstacles nor opportunities). Non-neutral categories were then placed within themes. All individual data were anonymized for analyses and presentation.

Results

I spoke to a variety of stakeholders

The respondents worked for various organisations, including the Sharks Board (n=3), local government (n=4), provincial government (n=3), national government (n=6), the provincial conservation entity (Ezemvelo KZN Wildlife, n =4), environmental NGOs (one respondent each from WildOceans, Wildlife and Environment Society of South Africa, the Endangered Wildlife Trust, the South African Association for Marine Biological Research, SharkSpotters) and some others, which included one respondent from each of: the provincial tourism entity (Tourism KZN); a company that is developing an alternative method of bather protection (SharkSafe Barrier Pty. Ltd); a consortium of humpback dolphin biologists in South Africa (SouSA Consortium); and a biologist who dissects the dolphins that are caught in the shark nets.

Many stakeholders are unaware of how shark nets work

When it came to describing the mechanism of the shark nets, I identified three categories of stakeholders' perceptions on how shark nets work: shark nets as fishing gear; shark nets as barriers; and those who were unsure. The Sharks Board respondents, and others (in total: 14 out of 29), described shark nets as fishing gear (e.g. "*They are fishing nets*") or talked about removing, killing, culling or reducing the number of sharks, sometimes linking the reduction in numbers with a reduction of risk (of encounters, bites or attacks) (e.g. "*They are designed to capture sharks and essentially reduce the local population in that area and thereby reduce the risk*."). Most of the remaining respondents (11 out of 29) described the shark nets as barriers (e.g. "*Sharks won't go through them*", "*They stop sharks from coming towards the shore*") though some of them stated that the barrier is permeable (e.g. "*There is still opportunity for sharks to get through that barrier*", "*I'm aware that a lot of sharks get through anyway*."). A few respondents (4 out of 29) talked around the issue without answering the question, including one who admitted: "*I just know they are there*."

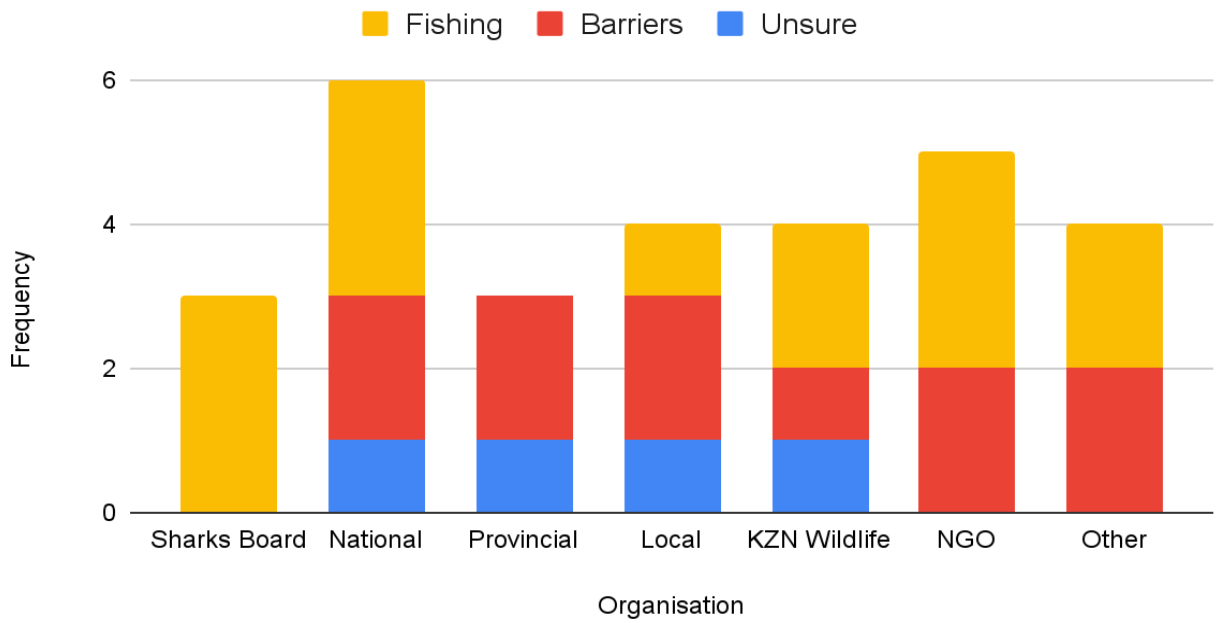

Figure 1. Knowledge of how shark nets work relative to the number of respondents within each organisation type. The 29 respondents described the shark nets as fishing gear or physical barriers or were unsure how they work. “Other” includes Tourism KZN, SharkSafe Barrier Pty Ltd, and university academics.

The pros of shark nets were safety and tourism while the cons were loss of marine life

Two main themes emerged in response to the question “What are the pros of having shark nets?” - tourism and safety (not mutually exclusive).

Tourism was mentioned most frequently, e.g. “*One - they actually do reduce the chances of people being bitten and - two - they give a sense of security and that sense of security translates into a tourism plus.*” Sometimes the economic benefits of tourism to KwaZulu-Natal were specified, e.g. “*Shark nets provide a safe bathing environment which supports maybe a billion rand tourism industry with hundreds and hundreds of thousands of jobs. So, the economic sustainability to a large part, certainly the coastal areas in KwaZulu-Natal, are a tribute to the shark nets.*”

The safety theme included four categories of responses that were mutually exclusive:

- Perceived safety: The shark nets conferred a psychological sense of safety, e.g. “*It puts confidence in a person.*”

- Actual safety: The shark nets reduced probability of shark bites, e.g. "*Shark nets provide a safe bathing environment.*"
- Both perceived and actual safety, e.g. "*I think families get a lot of reassurance knowing that if they come to one of our 37 protected beaches the risk of shark attack is very low.*"
- Perceived safety but actual safety questioned: Some made reference to the psychological safety but questioned or were sceptical about the efficacy of the shark nets at reducing the risk, e.g. "*It's in the minds of the people that it protects bathers. Whether it does or not... I don't know if that's ever really been tested.*"

Other themes included: "there are no pro's", e.g."*From an ecological perspective, there are none. In an ideal world you just wouldn't have them.*"; "Miscellaneous", e.g. "*maintaining the country's reputation*", and the valuable biological knowledge that the programme has yielded, jobs and some vague answers.

Looking at the pro's relative to the knowledge of the shark nets (i.e. whether they described nets as fishing gear, barriers or were unsure) was interesting. All four safety categories included statements from both Fishing-gear respondents and Barrier respondents (Figure 2). But it was clear that respondents who described the nets as fishing gear were inclined to value both the actual and perceived safety conferred by the nets, e.g. "*They do catch large sharks in the inshore environment and reduce the numbers and that gives the public a good deal of confidence.*" whereas those who described nets as barriers tended to doubt that the nets provide actual safety e.g. "*People believe that they are actively keeping the sharks out of the bathing area of the beaches so...I'm not so sure about that. Probably one of the biggest assumptions is that they work and that they protect us.*"

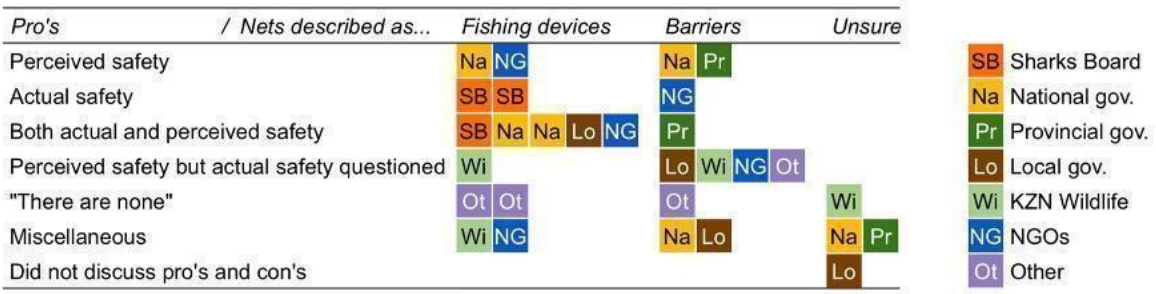

Figure 2. Proffered pro's of shark nets grouped according to respondents' description of the shark nets as fishing gear, barriers or unsure. Gov. = government, KZN = KwaZulu-Natal, NGOs = non-government organisations.

All stakeholders, except three, described the cons of having shark nets as the loss of marine life. There were subtle differences among the answers which were categorised as:

- Deaths of animals: Many talked about "killing," "deaths" or "loss" of life, species and animals (Figure 3), e.g. "*The cons are massive. Dying of other species, sharks especially. There's unnecessary killing of marine life which probably could be avoided if there wasn't a net there.*"
- Impact on the ecosystem: A different set of respondents talked about "impact", "effect" or "pressure" on marine life, populations or the ecosystem (Figure 3), e.g. "*We know that it's having an impact on not just the shark populations but possibly also the turtles and we know the dolphins. They're most likely not sustainable, the catches.*"

Some pointed out the ecological implications, e.g. "*The main con is that you reduce the number of top predators.*" Others expressed concern that some of the species are threatened with extinction, e.g. "*If we were to use government language they're on the TOPS list, the threatened or protected species list, such as your Sousa. And with some of these species one death is one too many and I believe when it comes to those kinds of issues shark nets are a bit problematic but Sharks Board, to be fair, they have tried to intervene.*"

Only two respondents mentioned both animal losses and ecosystem impacts, e.g. "*Animals are caught. This can impact the broader ecosystem. The shark nets are non-specific in their catch and this is of concern to the Department of Environment. We don't want animals to be killed.*"

The three interviewees who did not specifically refer to the loss of marine life referred to the non-selective, out-dated nature of the shark nets and were likely referring to the loss of marine life indirectly. For example, "*It's indiscriminate, catches anything. It is a gillnet, a fishing device.*" and "*In terms of international, contemporary best practice, it's considered to be a very archaic view of trying to deal with perceived threats.*"

An interesting perspective was raised about how sharks are being framed because the method is lethal, and the consequences of this on our relationship with sharks. "*One of the big cons is it still projects sharks as these sorts of killing machines that are out to get humans. It's 'us versus them' and we need to take whatever means are available to protect ourselves from them because they are out to get humans.*"

Figure 3. A word cloud of the cons of shark nets. The relative height of the words represent the frequency of respondents that used the word, i.e. taller words were said by more interviewees.

Obstacles pertained to governance and technology and there were few opportunities

Obstacles to change were divided into two: 1) general obstacles and 2) those specific to alternative methods (Table 1).

General obstacles were mainly governance issues:

- The political nature of decisions: many respondents referred to the political nature of the decisions that are made, e.g. "*When it's political, then factual information about declining species always loses.*"
- Sense of responsibility/liability: the government officials talked about the unacceptable repercussions if a shark bite followed any change. This was a mix of a sense of personal responsibility and formal liability, e.g. "*It's not the kind of thing you experiment with. People responsible for that feel a significant sense of responsibility. What people, general public or activists, don't get is that: If you are in a position of making decisions and you make a decision that even indirectly results in a young kid being killed, that's a*

difficult thing to internalise." Subtly different but in the same category: "*If the tourists are attacked by sharks then they will sue the department or the country.*"

- Status quo: it is difficult to change the *status quo*, e.g. "*Nets have been in the ocean for more than 50 years, the municipalities just take them for granted.*"

One general obstacle was a social issue. Quite a few respondents referred to the mindsets of people, especially in KwaZulu-Natal compared to those in other provinces, e.g. "*It's a much more healthy conversation whereas in KwaZulu-Natal it feels like it's been brushed under the carpet. We have shark nets. We will always have shark nets and we don't talk about it anymore.*"

There was an interesting obstacle posited by a few respondents that if a shark bite were to occur following the removal of nets, the public would demand a level of protection that exceeds current levels. "*I'm very confident that we would have an attack without the shark safety gear and what will happen… we won't go back to having 37 beaches protected but (I think we've got currently 12 km of nets in the water) I can guarantee that if you removed all the gear and someone was bitten it would be 50 beaches protected with 100 kms of nets in the water because we need to show a reaction to protect bathers. I think that's a very important point to note.*"

Much of the discussion around change pertained to alternative methods of protecting bathers. Respondents mentioned between 0 and 10 alternative, non-lethal methods of protecting bathers, with a mean (+SD) of 3.04+2.70. The electrical shark barrier was mentioned most frequently (11 times) followed by SharkSpotters (9), electrical personal protection devices (7) and exclusion nets (7). Other methods are listed in decreasing frequency of mentions: Vague references to "electric", SharkSafeBarrier, barriers, tidal pool, magnets/rare earth metals, education (i.e. risk reducing behaviours), drones, helicopters, kelp mimicry, bubble curtails, chemical repellents, lasers, radar, coral pool, balloons with cameras, SMART drumlines, "*something involving natural predators*". Most of the discussion fell into three categories:

- Technological: Respondents perceived a lack of alternatives that have been proven to be effective e.g. "*I don't think there is anything available to us to say a hundred percent that we can take liability for bather safety.*"; and expressed frustration about the slow progress of innovation, in general (e.g. "*The Sharks Board, they've been trying. They've been trying for decades. And it's not just Sharks Board. The Australians have been trying*

for decades too!"), and the electrical shark repellent cable in particular, e.g. "*But the Sharks Board's electronic device has been twenty years in the making ...I'd like to see some real progress on that front.*"

- Physical environment: Many respondents talked about the challenging physical environment along KwaZulu-Natal's coast, especially the large surf e.g. "*Is it even possible at a KwaZulu-Natal beach with its high energy and so forth?*" and
- Economic: about the high costs of alternatives e.g. "*Every time I ask about it I get told about the cost implications of deploying such technology on full scale.*"

There were far fewer references to opportunities (Table 1). Opportunities that were noted included:

- Social: education and awareness can change people's perceptions, e.g. "*Probably the most important thing we should do is build communities that understand the risks and that know how to mitigate against those risks.*" Often this included specific reference to how this might influence politicians, e.g. "*People need to be educated because we need buy-in from our politicians. They need to be educated about the importance of protecting these species.*"
- Technological: there are some promising alternatives being developed, e.g. "*There are quite a few projects on the go at the moment, looking at alternatives, trying not to use lethal methods.*"
- Research: research can help to understand the situation and design solutions e.g. "*We support all research undertaken to look at alternatives for shark nets.*" Other discussion about research pertained to what is still required (including shark behaviour and ecology, shark's responses to specific alternatives, the potential impact of the alternatives on sharks, and the spatial and temporal variation in the risk of shark bites).

Table 1. The main categories (mentioned by five or more respondents) within the themes of obstacles and opportunities to change the lethal methods used to protect bathers in KwaZulu-Natal (KZN), South Africa, the number of respondents who mentioned the category and the organisations they represented.

Theme	Category	Type of issue	n	Organisations
Obstacles to change (general)	The political nature of the decisions	Governance	10	Sharks Board, National, Provincial, Local, KZN Wildlife, NGO, Other

	Sense of liability of government officials	Governance	8	Sharks Board, National, Provincial, Local, NGO
	Mindsets in KZN (compared to other provinces)	Social	8	National, Local, KZN Wildlife, NGO, Other
	Status quo	Governance	6	Sharks Board, National, Provincial, Local, NGO
Obstacles to change (alternative methods)	Lack of proven alternatives	Technology	9	Sharks Board, National, Provincial, Local, Other
	Difficult surf conditions	Physical environment	9	National, Provincial, Local, NGO, Other
	High cost of alternatives	Economic	5	National, Local, KZN Wildlife, NGO, Other
	Slow progress of innovation	Technology	5	National, Local, KZN Wildlife, NGO
Opportunities to change	Education can change minds	Social	9	National, Provincial, NGO, Other
	Research		7	National, Provincial, Local, KZN Wildlife, NGO
	Promising technologies	Technology	6	National, Provincial, Local, KZN Wildlife, NGO

Discussion

I interviewed representatives from most of the stakeholder organisations and my findings revealed that among these diverse stakeholders whose work intersects with the shark nets, directly or indirectly, there were many who were not aware of how the shark nets work. While those directly involved in deploying shark nets described them as fishing gear—in other words, set to catch and kill sharks— half of the remainder of the interviewed stakeholders mistakenly explained shark nets as barriers that prevent the movement of sharks, or were uncertain about how they work. Discussions around their advantages and disadvantages indicate that

stakeholders were aware that animals die in the fishing gear but they believed the deaths were accidental. Perceived obstacles to changing the current method of bather protection were predominantly social issues (mindsets in KwaZulu-Natal), governance issues (the sense of liability of the government officials, the political nature of the decisions and it is the *status quo*), and logistical issues relating to alternatives (no proven alternatives, the high cost of potential alternatives, difficult surf conditions, slow progress of innovation). There were fewer perceived opportunities to change shark nets as bather protection—methodological (promising technologies), social (education can change perceptions), and research opportunities. Below, I first discuss the general lack of awareness about the function of the shark nets, and then discuss three sets of obstacles and opportunities for changing the bather protection methods.

Lack of awareness of how shark nets work

Many people are unaware of how the shark nets work and my interviews reinforce how pervasive this lack of awareness is. Only half (48%) of the interviewed stakeholders described the shark nets as fishing gear for catching and killing sharks. Compared to the level of awareness in the general public - only 10% of people using the ocean at a Durban beach accurately described how the nets function (Sheridan et al 2021) - this is relatively high. However, the other half of the stakeholders did not describe the shark nets as fishing gear, including people from 1) the institution that issues the annual operating permit, 2) the local government that pays for the service in their area, and 3) the provincial government department that covers the costs of management, administration and research). Despite the lack of understanding of the fishing mechanism of shark nets, all the stakeholders were aware that animals (sharks and other species) die in these nets though many believe that the deaths are incidental, as one of the respondents articulated "*Remember, it is not their intention, it is caught by accident*." It is clear that many stakeholders did not know that the nets are set with the intent to kill sharks and reduce the local population.

While an understanding that the nets are set to deliberately catch sharks may not be sufficient to instantly stop the use of the lethal method of bather protection, the clarity may provide impetus to change by motivating those institutions that fund the Sharks Board's research and development to increase the amount and consistency of funding allocated to research and innovation.

Social obstacles and opportunities

The first obstacle to changing the use of shark nets for bather protection is a social one: the mindset in KwaZulu-Natal. Stakeholders explained that the attitudes of people in KwaZulu-Natal towards sharks seem to be more negative than other places. Attitudes to sharks can differ by place (Acuña-Marrero et al 2018) and it is likely that people in KwaZulu-Natal have more negative attitudes. Shark bites are low-risk, high-consequence events that generate much media attention and there have been multiple shark bites in KwaZulu-Natal in living memory (Cliff 1991). Popular beaches in KwaZulu-Natal all have signs that remind people of the danger of sharks and whenever nets are not in place (due to bad weather or to temporarily lower the environmental impact), bathing is immediately banned and people are not allowed to enter the water (Figure 4). This is likely to heighten people's perception of risk. This type of communication to the public over 70 years has probably distorted the perceived risk of shark bites. Although most ocean-users were against killing sharks, those in KwaZulu-Natal were slightly but significantly less against the practice (Sheridan et al 2021). Two of our interviewed stakeholders talked about how using this fishing method, which people know results in the deaths of many marine animals, has a subtle influence on how people perceive sharks because it suggests that they are so dangerous that we need to protect ourselves from them at all costs. To test the accuracy of this assumption that the attitudes of people in KwaZulu-Natal to sharks tend to be more negative than other provinces, future studies could conduct surveys in different provinces, or use content analysis of media articles (Bombieri et al 2018).

Figure 4. An example of communication with the public around the risk of shark bites. Note the dire consequences of contravention. This signboard was photographed on the beach at Richards Bay, KwaZulu-Natal, in 2018.

The social opportunity to change was evident in the stakeholders' confidence that educating people about sharks would change their perceptions. Studies have linked greater knowledge of sharks to more positive attitudes and behaviours towards sharks and their conservation (Giovos et al 2021; Acuña-Marrero et al 2018, Parsons and Rose 2018). A public awareness campaign that focused on the behaviour and ecology of sharks, furnished by relevant, local research following a series of shark bites, reduced public outcry in Hawaii and changed the state's support of shark hunts (Holland et al 1999, Dudley, 2006, Curtis et al 2011). It is not surprising that people who are more exposed to sharks perceive them in a more multi-dimensional way, and fear is less likely to predominate (Gibbs 2020). Important information that may support the development of more positive attitudes towards sharks includes the lack of intentionality of most bites, the basic biology of sharks, and the vulnerability of sharks (Lucrezi et al 2019). Misconceptions about the risk of shark bites should also be addressed (Crossley et al 2014). As Lucrezi et al (2019) conclude, while public support can be an important driver for shark bite mitigation and conservation, it is just one of many drivers. Education is sometimes considered a weaker option compared to a focus on regulations (Chan et al 2020). A reductionist focus on individual-level changes that can be brought about using education is more likely to be transformative when integrated with holistic, system-level changes that focus on governance (Naito et al 2022).

Governance obstacles and opportunities

The second obstacle to change is a governance issue around the political nature of the bather protection decisions. This issue revolves predominantly around obtaining the support of the politicians and their constituents. This is a major obstacle to conservation changes globally—without public support to influence political support, conservation is assigned low priority (Rose et al 2018). The solution proposed by the world conservation scientists, practitioners and policy people is to mainstream conservation and change the attitudes of policy-makers in favour of pro-environmental, long-term decision-making (Rose et al 2018).

One might wonder why the issue of reducing the risk of shark bites is within the political realm. Shark bites are traumatic, high-consequence events and an incident is usually not only an issue

of safety for the individual at the beach, it impacts broader issues such as tourism, business and economy at larger scales (Oelofse 2006). In response, the public exerts pressure on the government (e.g. public safety, law enforcement, fisheries agencies) to prevent future attacks (McCagh et al 2015, Curtis et al 2011, Dudley 2006). Some of the stakeholders noted that "*politics trumps facts*", alluding to short-term political gain being prioritised over long-term conservation imperatives. Legal scholars in human-wildlife conflict suggest that scientific information is useful at the risk assessment stage but is less so at the risk management stage when the political, social and economic contexts must be included in the deliberations (Hamman et al 2017).

The second governance obstacle is the sense of responsibility/liability. Many of the interviewed government officials stated they would not like to make a recommendation to a decision-maker that resulted in injury or death to a person, and some feared litigation. Once they are part of the decision-making process that affords bather protection, fears around the consequences of their recommendations are understandable for high-consequence events like shark bites. This sense of liability was contrasted with responses from stakeholders who were not responsible for decision making such as those from NGOs, Ezemvelo KZN Wildlife and academics. These stakeholders were convinced that when bathers enter the water, they are taking their own risk. In a South African study, more beach-users (40%) felt that it is the government's responsibility to prevent shark bites than not (20%) (Lucrezi and Gennari 2021). There were no documented instances of litigation following shark bites in South Africa or internationally prior to 2006 (Oelofse 2006), nor has there been any litigation since then (determined from a google-search for news items with combinations of two sets of search terms: shark/shark bite/shark attack and litigation/legal action/lawsuit/sue on 2022/02/12).

The third governance obstacle to change is the *status quo*. Once responsibility has been assumed by the authorities, it appears to be difficult to change. This "status quo" obstacle seems at least in part to be related to the liability issue—it is easier to leave things as they are rather than make changes in the face of uncertainty. Despite the many obstacles to change that are related to governance, there were no common categories that could be considered governance opportunities. Two stakeholders saw the national government's Shark Biodiversity Management Plan as a useful tool and this could be considered a governance opportunity as it does include elements of the bather protection programme with a goal to reduce the number of catches and increase awareness. In addition, there is a national process to reduce government

expenditure (a “rationalisation” process) in which it is likely that the Sharks Board’s functions will be absorbed by the province’s conservation agency, Ezemvelo KZN Wildlife, since both deal with animals. This process could be taken as a governance opportunity to accelerate conservation change. Beyond that, I consider some potential governance opportunities by consulting the literature on transformative change. I note the relational values demonstrated by the government officials to do no harm to others which yields the sense of responsibility/liability to make good decisions and suggest extending it from an interpersonal context to emphasise their responsibility to the non-human animals that are harmed by the operation (Chan et al 2020). Another potential way around these obstacles may be to scrutinise the governance structures that exist, i.e. examine the institutions, policies and socio-economic systems, to identify obstacles and opportunities at that large scale. Integrating a holistic, system-level view with the reductionist focus on individual-level changes yielded using education should theoretically enable transformative change (Naito et al 2022).

Methodological obstacles and opportunities

The last set of obstacles and opportunities are methodological and logistical issues related to the non-lethal alternatives to shark nets. Many stakeholders mentioned the lack of proven alternative methods to protect bathers. There is a paucity of published data about the efficacy of most of the non-lethal methods but, of 20 non-lethal alternatives reviewed by McPhee et al (2021), nine have been tested (and proved effective in peer-reviewed studies) on at least one, or sometimes two, or all of three shark species of interest here (Zambezi *Carcharhinus leucas*, white *Carcharodon carcharias* and tiger *Galeocerdo cuvier* sharks). While it is true that none of the alternatives will ever be able to detect or deter sharks 100% of the time, neither do lethal methods (McPhee et al 2021, Dudley 1997). The second perceived logistical issue was the difficult surf conditions along the KwaZulu-Natal coast: many of the stakeholders know that the physical characteristics of the environment make it difficult to deploy and maintain equipment in the surf or detect sharks in the water. Indeed, KwaZulu-Natal has a high-energy coastline with coarse-grained, sandy reflective to intermediate beaches with steep slopes and large-amplitude swells, with average wave heights of about 1.65m, and extreme significant wave heights measuring 8.5m (Smith et al 2010, Corbella and Stretch 2019). Water clarity in the region is about 4.5m in winter and 2.9m in summer, approaching zero in summer at estuary mouths (Dudley 1997), which make it very difficult to observe sharks in the water, precluding shark-spotting programmes. The respondents also cited the high costs involved in implementing alternative methods. Finally, the respondents discussed the typical slow progress of innovation

around these alternatives. For instance, in 1958, shortly before the Sharks Board was established, scientists in the province began experimenting with electrical shark repellents (Powel 2017). There have been significant developments since then, most notably the effective electrical personal protection devices (Huveneers et al 2018), but the Sharks Board is still developing this technology to use at a beach-wide scale (KwaZulu-Natal Sharks Board 2019). Despite these difficulties and frustrations, there were times that the stakeholders referred to alternatives as potential opportunities.

The methodological opportunity for changing the KwaZulu-Natal bather programme that the stakeholders talked about was the potential of promising alternatives. This included a general hope that suitable alternatives are possible in the future and specific reference to two alternatives that are currently being developed in South Africa. The Sharks Boards' electrical shark repellent cable, mentioned above, and the SharkSafe Barrier are both non-lethal alternatives that are being developed for beach-wide use (McPhee et al 2021). The nexus of technology, innovation and investment is considered an important leverage point on the pathway to sustainability (Chan et al 2020). Stakeholders talked about three considerations of this nexus (Appendix results 6). The lack of profitability of bather protection endeavours leads to a lack of investment in research and innovation by the private sector resulting in a dependency on already-constrained government funds . In cases where bather protection does become profit-driven, there could be changes in motivation/decision-making. Competition has a role to play in spurring innovation and new ideas.

Research as an opportunity for change

The final category within the theme of opportunity for change was research. National and provincial government stakeholders felt they were providing a supportive environment for research. Broadly, stakeholders suggested that useful research would include shark behaviour and ecology and the spatial and temporal variation in the risk of shark bites to identify hotspots where mitigation was required and how to mitigate the risk of shark bites in various contexts. They suggested research to yield measures of efficacy (sharks' responses to alternative methods) and impact (the effect of alternatives on sharks and the environment). These studies should be supplemented with studies of the social, cultural and economic implications of different conservation actions, and investigations into what underlies this human-wildlife conflict (such as competing interests, attitudes, values and beliefs) and research into new methods to

deal with conflict (Simpfendorfer et al 2021). It would also be useful to investigate better ways to communicate about the risks associated with sharks.

Conclusion

We interviewed stakeholders and identified the narratives around how the shark nets work, the advantages and disadvantages of using them, and around changing this method of protecting bathers. We did this to understand the conditions that hinder, or could help to facilitate, changing to a non-lethal method of bather protection. The narratives revealed few opportunities and many obstacles to change. The governance and social issues are perceived to be major obstacles to change. However, the decision-makers at the Sharks Board have made potentially unpopular decisions in the past when they felt sufficiently confident that the changes were unlikely to reduce people's safety. In 1998, they reduced the number of shark nets in KwaZulu-Natal by 25% and in 2007, they began to replace some of the shark nets with baited hooks (Cliff and Dudley 2011). Both of these changes were made to reduce the environmental impact of the gillnets. The baited hooks were especially unpopular as many people believed (mistakenly) that they attract sharks into the bathing area (Guyomard et al 2020). In both cases, the Sharks Board had gathered sufficient evidence to be confident that the changes would not increase the risk to bathers. Therefore, these governance and social obstacles are not insurmountable.

The biggest obstacle to changing to non-lethal alternatives is probably the difficult surf conditions in KwaZulu-Natal. These surf conditions drastically limit viable alternatives and increase the costs. For the electrical shark repellent, erratic government funding has delayed the development of this alternative (KwaZulu-Natal Sharks Board 2017, 2019). Therefore, an important way to accelerate change would be to attract support for the Sharks Board in their investigation and development of alternatives. The social and political obstacles do need to be addressed in order to increase and ensure the steady funding and capacity needed to accelerate the development and testing of alternatives in KwaZulu-Natal. Therefore, a good education campaign is required in KwaZulu-Natal that uses both information and emotion to support positive attitudes to sharks.

Human well-being and a thriving tourism industry should remain priorities, but we suggest that these priorities can no longer be achieved at the cost of harming shark populations and the ecological services they provide. Ultimately, we must work towards mainstreaming conservation, building capacity, responsible investment in technology and other types of solutions and unleash

latent values around coexisting with sharks to minimise the human-wildlife conflict (Rose et al 2018, Chan et al 2020). We need to ensure the safety and well-being of coastal residents and visitors—both people and sharks.

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Appendix 1

Additional themes regarding how the shark nets work

In addition to the main themes pertaining to the mechanism of shark net protection, there were other narratives around how the nets work. Many respondents included the assertion that most sharks are caught leaving the bathing area, i.e. “caught going out rather than coming in.” Many respondents offered a description of the physical attributes/position/layout of the nets, eg “two staggered rows”, “don’t go down to the sea floor”. Quite a few questioned the efficacy of the nets. Subtly different, quite a few mentioned that it doesn’t completely eliminate the risk of shark bites. Some called the nets deterrents that discourage sharks. Some talked about how the shark nets are not there to protect sharks.

Ambiguous obstacle/opportunity for change

Two categories of discussion about change were not placed within the themes of obstacles or opportunities to change due to ambiguity.

Risk varies in space and time

There was some discussion about the fact that risk varies in space and time “*we can’t just ignore the dangers that they can present in certain coastal areas, possibly at certain times and that we need to take the most appropriate measures.*"

Different areas, different solutions

Respondents often talked about the fact that different areas and conditions require different solutions - a method for Cape Town (for example) may not be feasible in Durban, e.g. “*It’s not a "one size fits all" kind of approach.*”

The innovation-research-finances nexus

Three different respondents had views worth noting about research, innovation and finances One respondent felt the lack of drive to innovate is because the Sharks Board is the legislated, sole service-provider, with no competition: “But are they innovative enough to have that responsibility and why, why do they have exclusive provision of this service? Why is it not like any other service the government tendered out or given to other companies to at least grow the

competition so that those companies who have other innovative ideas are able to bring the solutions or the technology to the table."

Another noted that deploying shark safety measures is not profitable and so there is little investment from the private sector so it is up to government and researchers: "There's not money to be made out of this and so the development of alternatives has to be generally led by researchers or government agencies and there is less and less scope from a budget point of view to do that so there's not a lot of innovation that's being driven."

A third respondent pointed out that patented, commercialised products are profit-driven which also has drawbacks: "And I think with both those products, they're patented and then let's talk about who is going to get the money...and then it becomes "how are we going to make money out of this?" And then it's a whole different ball game … because then you are going to make decisions based on how much money you can make rather than "can we remove the shark nets and replace them with an alternative?""

Chapter 6. Navigating transdisciplinary waters to protect both sharks and bathers in KwaZulu-Natal: diverse stakeholders propose potential actions.

Abstract

Shark nets and baited hooks (drumlines) are set at 37 beaches in KwaZulu-Natal, South Africa, to protect bathers and the province's valuable tourism industry. Sharks die in this gear and, as a group, they are particularly vulnerable to extinction. The KwaZulu-Natal Sharks Board has strived to minimise the impact of the operation and in recent decades has reduced the number of shark mortalities by >50%. This human-wildlife conflict is a complex problem and balancing the risks to both bathers and sharks is challenging. I engaged stakeholders whose work intersects with conserving sharks and/or protecting bathers to co-evolve our understanding of the issues, to hear diverse perspectives and work together to consider how we might reduce and ultimately prevent shark mortalities in KwaZulu-Natal's bather protection programme without compromising KwaZulu-Natal's vibrant coastal tourism. I invited these transdisciplinary stakeholders (from science, policy and management) to an online knowledge café to identify practical next steps to leverage change. Their suggestions included: initiate a working group to support this process moving forward; collate and share existing research to identify ways to mitigate the human-wildlife conflict; communicate with decision-makers to offer support and identify a champion among them to mainstream the issue; begin in designated Marine Protected Areas; engage with the internationally-recognised Blue Flag beach programme; and conduct beach-specific cost/benefit analyses, factoring in tangible and intangible aspects of social, ecological and environmental factors. In addition, they recommended assessing and prioritising alternative bather protection strategies for testing in KwaZulu-Natal. Lastly, other suggestions were to explore different funding models and align the process with a national framework, such as the Shark Biodiversity Management Plan. These suggestions constitute further transdisciplinary learning to assist the Sharks Board, to work together to find solutions and offer safe swimming in KwaZulu-Natal for both people and sharks.

Introduction

Shark nets and baited hooks (known colloquially as drumlines) are set at popular beaches in KwaZulu-Natal Province, South Africa, to reduce the risk of shark bites (Dudley 1997, Dicken et al 2016). Shark bites (emotively but mistakenly referred to as shark attacks) are rare but, when they occur, are often extremely traumatic and attract much media and public attention (Crossley et al 2014, Midway et al 2019). A shark bite does not only affect the individual who was bitten as there is often a ripple effect on tourism because of the negative publicity (Oelofse 2006).

Protecting bathers from sharks in KwaZulu-Natal has been an on-going matter since at least 1907 (Powell 2017). In Durban in the 1940s, there was a spate of shark bites with 21 incidents over nine years (2.3 incidents/year), seven of which were fatal (0.7 fatalities/year) (Cliff and Dudley 1992). A tipping point was reached and the community demanded the authorities intervene. In 1952, the Durban municipality deployed shark nets (an Australian solution) and Durban beaches have not experienced another serious incident ever since (Dudley 1997). A few years later, another spate of shark bites occurred, this time on KwaZulu-Natal's south coast with four incidents in December 1957 (two of them fatal). Again, a tipping point was reached and people demanded the same protection afforded to Durban beaches. With the development of outboard motors in the 1960s, it became feasible to operate small craft through the surf and other coastal municipalities also began deploying shark nets to fish for sharks. The Natal Anti-Shark Measures Board (now KwaZulu-Natal Sharks Board, hereafter referred to as Sharks Board) was formed to oversee (and subsequently manage) the bather protection programme (Davis et al 1995).

By the 1990s, there were 44 km of shark nets fishing at 40 beaches and nearly 1500 sharks of 14 species were caught each year and another 500 animals were caught incidentally (called bycatch), most of which were dolphins, whales, turtles and rays (Cliff and Dudley 2011, Plön et al 2020). Over the past four decades, various measures have been taken by the Sharks Board to reduce their impact on sharks and the bycatch. For example, in the 1970s, they started releasing all animals found alive. In the late 1990s, they reduced the number of nets by 25% and began evaluating the efficacy of baited hooks (Dudley et al 1998, Cliff and Dudley 2011). The baited hooks are more selective than the shark nets and substantially reduce the bycatch, particularly of whales and dolphins (Cliff and Dudley 2011). Once confident that the baited hooks would afford the same levels of protection to bathers as the shark nets, the Sharks Board replaced the remaining half of the shark nets with baited hooks, rolling out the change between

2005 and 2019 (KwaZulu-Natal Sharks Board 2007, 2019). They used to remove shark nets temporarily during the annual Sardine Run but more recently, they temporarily replaced the shark nets with baited hooks during the Sardine Run (June and July) and part of the whale migration period (June to October) (KwaZulu-Natal Sharks Board 2022). Currently, for most of the year, there are 12km of shark nets plus 177 baited hooks at 37 protected beaches (KwaZulu-Natal Sharks Board 2022) and the most recent publicly available data suggest that the annual number of animal mortalities has been reduced to 580 (420 sharks and 160 bycatch) with 220 animals released alive (90 sharks and 130 bycatch) (https://www.shark.co.za/Pages/SharkCatchStats). These reductions and changes have not increased the rate of shark bites at netted beaches (KwaZulu-Natal Sharks Board 2022).

There are numerous threats to sharks globally and, as a group, they are particularly vulnerable to extinction (Dudley and Simpfendorfer 2006, Dulvy et al 2014, da Silva et al 2015, Roff et al 2018, MacNeil et al 2020, Pacoureau et al 2021). Even on a relatively small scale, fishing can have a negative impact on large sharks (Pinnegar and Engelhard 2008, Garcia et al 2008, Simpfendorfer et al 2021). Many of the shark and bycatch species that are caught in this shark fishing/bather protection operation are threatened with extinction according to the IUCN's Red List assessments. A few examples include two of the most frequently caught species: the Endangered dusky shark, *Carcharhinus obscurus*, and the Critically Endangered scalloped hammerhead shark, *Sphyrna lewini*; the Vulnerable white shark, *Carcharodon carcharias* and the Critically Endangered whites-potted wedgefish, *Rhynchobatus djiddensis* (Ferretti et al 2015, Kyne et al 2019, Rigby et al 2019, 2022). Sharks are valuable, ecologically, economically and culturally (Simpfendorfer et al 2021), and therefore, to reduce the risk of extinction of various marine species, it would be beneficial to remove an ongoing source of mortality like the shark nets.

This is a quintessential human-wildlife conflict where the activities of sharks harm humans and the activities of humans harm sharks (Nyhus 2016). There are direct effects (injuries and loss of life - to humans, sharks and other marine animals) and indirect effects. Indirect effects for humans potentially include the loss of tourism and livelihoods and, for wildlife, indirect effects potentially include the loss of biodiversity and the impact on the ecosystem caused by the loss of top predators – which ultimately affects humans negatively (Myers et al 2007).

Figure 1. Conflicted. Used with permission. © Mandy Coppes-Martin.

One of the protected beaches, Richards Bay, has a particularly high bycatch of Endangered Indian Ocean humpback dolphins, *Sousa plumbea* (Atkins et al 2013, Braulik et al 2017) and research has shown that the shark nets have a negative impact on their population (Atkins et al 2016). In 2016, the Sharks Board aimed to replace some shark nets at Richards Bay with baited hooks to reduce the bycatch of humpback dolphins and other species. Eighteen months later, there was still no change[1]. This triggered a project that aimed to navigate the space between research and management in conservation (following Knight et al 2006, Toomey et al 2016) by engaging the relevant stakeholders to better understand the social issues and accelerate changes to the shark safety gear. A stakeholder analysis was conducted to identify stakeholders whose work intersects with the drivers and consequences of using shark nets at Richards Bay and these stakeholders were interviewed to gain an understanding of their points of view (Atkins, in prep).

The next step was to share what we had learnt with the community of stakeholders who intersect with the bather-shark conflict professionally and provide the opportunity for them to share their different points of view to improve the collective understanding of the opportunities and obstacles to reduce and ultimately prevent shark mortalities in KwaZulu-Natal's bather protection programme without compromising bathers. Thus, this study aimed to create a social learning platform for stakeholders to share their perspectives and to collaboratively identify practical potential next steps. My underlying research question was how to garner support and develop an effective strategy to leverage change that reduces shark mortalities?

[1]In 2019, three of the highest-catch nets at Richards Bay were replaced with baited hooks.

Methods

The philosophical basis of the research

The philosophical principles and theoretical assumptions of scientists can affect the design, execution and interpretation of research and therefore should be reported in social science publications (Moon et al 2016). I used Moon and Blackman's (2014) guide to understand these social science principles. My research ontology was structural realism in which I posit one reality exists but how it is defined, measured and so on makes it elusive. Conservation generally is a social issue, replete with values and culture, which influence our understanding and therefore I suggest that meaning is constructed from interplay between the subject and the object (epistemology: constructionism). My theoretical perspective was participatory, i.e. I was not a detached scientist observing from afar but participated in the process while I learned and harnessed the explicit and tacit knowledge of the other participants.

Since this study was an extension of the previous phase of the project (the one-on-one interviews in chapter 5), the sample selection process had already occurred. To summarise, I had conducted both purposive and key informant sampling to identify stakeholders whose work was related to some aspect of the drivers and consequences of the use of lethal bather protection methods with a focus at Richards Bay (chapter 5). Initial key informants were Sharks Board staff and a municipal official that manages the Richards Bay beach. In addition to those interviewed in the previous phase, I invited a social scientist and three biologists (based on their knowledge of the target sharks and the KwaZulu-Natal coastal ecosystem), an MSc student, a fine artist (who creates pertinent artwork, e.g. Figure 1) and a communications specialist to participate in this study.

Knowledge café

I organised a stakeholder engagement (social learning platform) in the form of a knowledge café, which is a type of meeting in which people are invited to discuss a topic of mutual interest in several rounds in small groups, whose composition changes periodically (Steier et al 2015, Brouwer et al 2019). With knowledge cafés, the gathering takes place in a comfortable, relatively informal setting, the topic is introduced and the meeting etiquette is explained. A question or subtopic is posed about one aspect of the main topic and the group is split into several smaller, break-away groups to discuss this aspect. Periodically, group membership

changes and a new aspect of the topic, or question, is discussed. The larger group is reconvened (either after each round or at the end of the meeting) and insights about the key questions are shared with everyone. The knowledge café encourages the cross-pollination of ideas through several rounds of discussion, allowing the sharing of information in an equitable and non-threatening manner, building relationships and fostering collaborative learning (Fouché and Light, 2011; Singh, 2017).

Our meeting was held on an online video conferencing platform (Zoom Video Communications Inc., 2016) on 2022/03/01 between 9:00 and 13:00. A team of four professional facilitators hosted and facilitated the meeting. They created a “thinking environment" (Kline 1999) with emphasis on the principles of attention, equality, ease and appreciation. We held discussions in three rounds (Figure 2). Each round was made up of about 25 minutes of discussion in four smaller groups (each with 6-8 participants), followed by a brief opportunity for individual reflection (see chatterfall below), followed by 15 minutes together as the large group where feedback was presented by one or more representatives of each of the smaller, break-away groups.

Data sources and analyses

The large-group sessions were video-recorded (with permission from attendees at the start of the meeting or upon entry into the meeting) and transcribed. During the smaller group break-away sessions, participants captured notes on their discussion in a shared Google drive document. In addition, individual reflections were solicited by the facilitators at various stages using a process called chatterfall: participants were given a short time to consider their perspectives which they typed into the “chat” function and when the majority were ready, everyone simultaneously pressed “enter” and shared their thoughts. The video recording, transcription, notes and chatterfall were all analysed qualitatively. The meeting was considered the unit of analysis and we dealt with the manifest content, i.e. what was said, without trying to interpret the underlying meaning or latent content (Graneheim and Lundman 2018). I used an inductive approach, creating codes from the data rather than creating a pre-existing coding frame (Braun and Clarke 2006).I distilled and condensed what was said by the participants who were reporting back to the large group (Graneheim and Lundman 2018). This was triangulated with the notes that had been captured by the smaller groups and the chatterfall. No analytical software was used. I do not report any quantitative metrics, e.g. the proportions of stakeholders

that expressed particular ideas, because ideas that are expressed by only one participant were not considered less valuable than ideas expressed by more than one participant.

I report the results of who attended, what type of change attendees were considering and the suggested next steps.

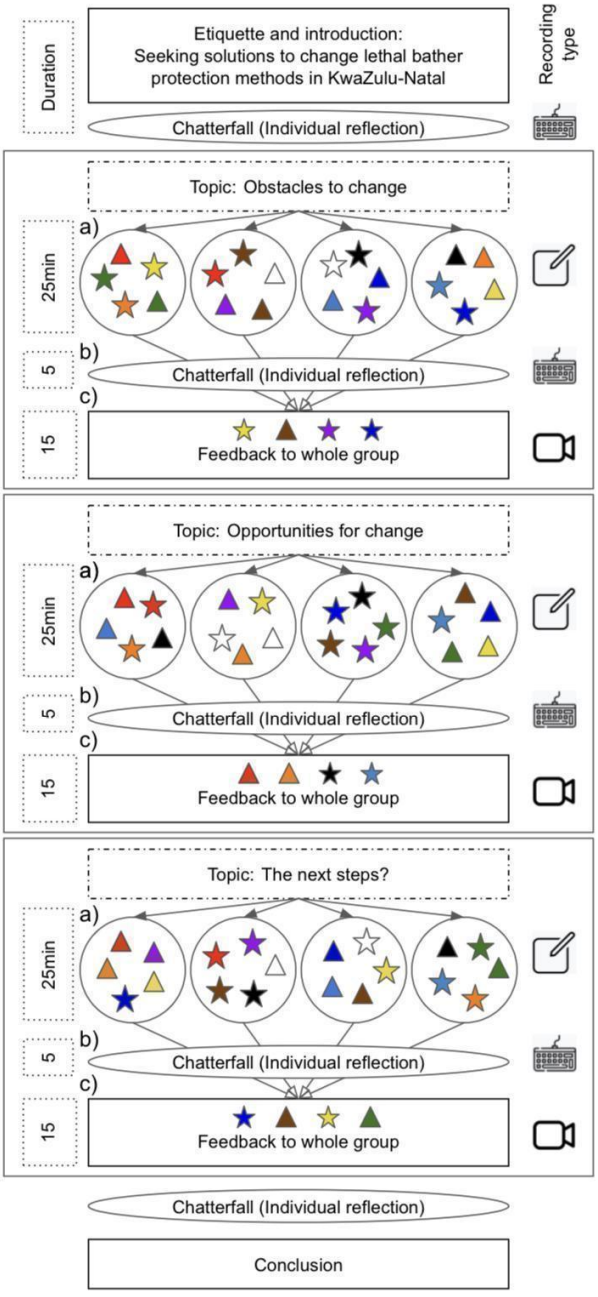

Figure 2. The knowledge café process and data sources in this study. Each shape/colour represents a meeting participant and shows how group membership changed in rounds. Following an introduction, discussions were held in three rounds. Rounds were composed of a) 25 minutes in four small groups (notes were scribed in a shared Google doc), b) a brief opportunity for individual reflection which was captured in Zoom's chat facility (called chatterfall), and c) 15 minutes of feedback by small-group representatives to the whole group (video recorded and transcribed). The composition of the small groups changed in each round. A final opportunity for reflection was followed by the conclusion and thanks.

Results

Who attended?

Forty-three people from 21 organisations were invited. Of these, 29 people from 17 organisations attended, including five who represented invitees who could not attend. The participants represented the Sharks Board, which manages the bather protection programme, three levels of government: local (uMhlathuze municipality - which pays for the service provided by the Sharks Board), provincial (Department of Economic Development, Tourism, and Environmental Affairs (EDTEA) - which covers the majority of the Sharks Board's annual costs) and national (Department of Forestry, Fisheries and the Environment (DFFE) - which issues a permit for the operation and is responsible for the administration of South Africa's Shark Biodiversity Management Plan and the National Plan of Action for Sharks), Ezemvelo KwaZulu-Natal Wildlife (the provincial conservation entity), three non-governmental organisations (NGO) concerned with conservation and sustainable tourism; academics from six South African universities or research institutes, two organisations involved in the use of non-lethal methods of protecting bathers, a professional fine artist, and a communications specialist. Invitees from some organisations were unable to attend or send representation. These organisations were: South African National Biodiversity Institute (which researches, monitors and reports on the state of biodiversity in South Africa), Tourism KwaZulu-Natal (which develops, promotes and markets tourism in the province), one environmental NGO and the City of Cape Town (which uses non-lethal methods of bather protection).

What kind of change?

The intention was to focus on what the participants felt were the next steps to address the human-shark conflict in KwaZulu-Natal. However, some of the discussions indicated that there were differences in opinion as to what kind of change should be the goal in resolving the conflict. There were three trains of thought.

1. Some considered a continuation of the current trajectory to be the goal with the sustained reduction in the number of shark nets (and the amount of time the nets spend in the water), replacing as many as possible with baited hooks for as much of the time as possible.
2. A few considered the current slow, phased removal of nets to be acceptable but the end-point should be the removal of all bather protection ("anti-shark devices").

3. Some considered a compromise between the two strategies above to be best, with the replacement of the lethal methods (shark nets and baited hooks) with more benign alternatives.

What are potential next steps?

Initial discussions revolved around opportunities and obstacles to changing the current method of bather protection (see Appendix 1 for the main points) and culminated in discussion about the potential next steps that could be taken to leverage change. We enjoyed a genuinely collaborative, solution-focused atmosphere (see Appendix 2) and all attendees contributed ideas about the next steps. The potential next steps are listed and summarised below. Note that they are not prescriptive or binding to any of the participating organisations but are potential actions that are worth considering, actions that various organisations might undertake together in various combinations. Not everyone present necessarily agreed with every suggestion but these are the collective ideas of those who spend more time than most people seriously considering the situation. There was no specific discussion about what order the steps should follow.

In total, there were 10 potential next steps, proposed by diverse stakeholders whose work intersected with the bather-shark conflict, to accelerate changing KwaZulu-Natal's lethal methods of bather protection to conserve sharks without compromising bathers:

- Initiate a working group
- Collate and share existing information
- Communicate with decision-makers
- Identify a champion to mainstream the issue
- Begin in Marine Protected Areas
- Use the Blue Flag programme
- Conduct beach-specific cost/benefit analyses
- Assess the feasibility of alternative strategies
- Consider funding options
- Align with a national framework

Initiate a working group

Several participants suggested initiating a working group or expert panel that includes a variety of people, from a variety of organisations and disciplines. It would be ideal if it included representatives from the Sharks Board, various levels of government, non-governmental organisations, experts in shark biology, conservation, human-wildlife conflict, communication, policy, tourism, economy, risk management, marine engineering, and other key stakeholders. The broad objective of the group would be to support a move away from the use of lethal methods of bather protection in KwaZulu-Natal.

Collate and share existing information

There was discussion about whether there was useful, existing, empirical data to support decisions, and many felt that there is but that perhaps the data is not readily available. Therefore, participants suggested collating existing local, national and international research to answer questions that would be relevant to decision-makers. These potentially include: 1) “What is known about alternative ways of considering this human-wildlife conflict, including existing non-lethal alternatives being used or tested elsewhere?” 2) “What is known about sharks, bathers and the environment that could be useful to mitigate risk to bathers and to sharks in a cost-effective manner?” 3) “What are the differences between KwaZulu-Natal and the other provinces in South Africa that result in the use of lethal bather protection methods here? 4) “Where are the major gaps in our knowledge of this social-ecological system?” These results should be shared with decision-makers and other relevant parties through various platforms, e.g. social learning platforms (meetings/workshops) and a dedicated website.

Communicate with decision-makers

Communication was discussed frequently during the knowledge café and generally focussed on communication with the public (see Appendix 1); but when considering potential future actions to be taken, it was focussed on communication with decision-makers. The suggestion was to open the channels of communication with key decision-makers to support them in their decision-making. The manner in which the communication is conducted is important and is carefully considered in the discussion.

Identify a champion

Involving a person who supports and promotes an environmental cause (a champion) can improve the success of such an endeavour (Pasquini et al 2015). One of the participants raised the human-shark conflict in Cape Town, reporting that only non-lethal methods of bather protection are used there (SharkSpotters and an exclusion net) and that this policy was driven by a "champion" within the municipality. Therefore, a suggestion was made to identify one or more champions at the Sharks Board, among the municipalities and/or at a provincial level.

Begin in Marine Protected Areas

As a starting point, focus could be on changing the system where shark nets and baited hooks are inside Marine Protected Areas (MPA). The MPA status has been used previously by the Sharks Board to reduce their impact, e.g. removing the shark nets from Park Rynie beach. At least seven installations of "shark safety gear" (i.e. shark nets and baited hooks) are inside MPAs: Zinkwazi and Blythedale in uThukela; Karridene, Umgababa and Scottburgh in Aliwal; and San Lameer and Trafalgar beach in Trafalgar (CoastKZN https://maps.coastkzn.co.za/CoastKZN/). The installations at Zinkwazi and Blythedale have particularly high catches of sharks and other species (Dudley and Cliff 1993, Allen and Cliff 2000, de Bruyn et al 2005, Dudley et al 2005) and changing the situation at these beaches may maximise the conservation return. Trafalgar is also a full-status Blue Flag Beach which has additional implications (see below).

Use the Blue Flag programme

The Blue Flag Beaches, Marinas and Tourism Boats Programme is an internationally-recognised certification system awarded to beaches that maintain high environmental, educational, safety, and accessibility standards (Lucrezi et al 2015). The Blue Flag implementation agent in South Africa – the Wildlife and Environment Society of South Africa (WESSA) – made an offer to use the Blue Flag platform to conduct research, test innovations and communicate with stakeholders that are common to both programmes. For example: 1) in their existing questionnaires, include questions to investigate beach users' perceptions of human-shark interactions; 2) pilot changes at Blue Flag beaches and run concurrent social media campaigns to monitor people's reactions; 3) engage beach managers at Blue Flag workshops; and 4) use Blue Flag's progressive environmental management

requirements to incentivise municipal decision-making to test and/or adopt alternative strategies.

Conduct beach-specific cost/benefit analyses

According to an uMhlathuze municipality representative, financial cost is a major factor when considering bather protection. Yet no formal cost/benefit analyses of bather protection has been conducted. This may be true for the other municipalities too. Each beach is unique in terms of its suite of ecological, physical and social characteristics (though they are all exposed to the high energy surf which makes bather protection difficult). The suggestion was to work with beach managers (and MPA managers) in small teams to assess economic and environmental costs versus economic and social benefits of using shark nets and baited hooks. Pertinent data to assess beach-specific circumstances could include: the presence and behaviour of target sharks, bathers, tourists and bycatch; plus the local environmental conditions. People's attitudes to human-shark interactions should be included in these assessments, especially bather perceptions, lifeguard perceptions, and local community perceptions, because intangible costs and benefits are important aspects of wildlife tolerance (Kansky et al 2016).

Assess the feasibility of alternative strategies

There was frequent discussion about the urgent need to test alternative methods of bather protection in KwaZulu-Natal. Alternative methods of detecting and deterring sharks exist, although none of them is an obvious silver bullet (McPhee et al 2021). A well-known example is the electrical shark repellent cable, an electrical barrier to sharks that has been developed by the Sharks Board and described by them as "a non-lethal solution to the use of nets and drums, which are designed to catch and kill sharks" (KwaZulu-Natal Sharks Board, 2021). Other examples include Shark Spotters (Kock et al 2012, Engelbrecht et al 2017) and technologies such as the SharkSafe Barrier™ (O'Connell et al 2014), and drones (Colefax et al 2020). To identify options worth trying, small teams could weigh up the feasibility of each available alternative against the beach-specific circumstances using relevant information, such as effect on bathers, sharks and other animals, costs, durability. More than one alternative should be tested.

It should be noted that not everyone agreed with the principle of using alternative methods. Some pointed out that a tremendous amount of research has been conducted on alternative methods over many decades, in South Africa and internationally. It has been slow and expensive and has not yielded any applications suitable for KwaZulu-Natal's high-energy surf. They favoured a strategy of continued, slow, phased removal of shark nets (and all anti-shark devices), together with a major concurrent awareness programme that aims to increase tolerance of sharks and ultimately resilience to the impact of rare shark bites. They said: "*We've got to look at it more holistically. We've got to look at what is wrong with the current system and develop a strategic plan on how to bring in a better, more sustainable system in future.*" They were suggesting we shift the paradigm and minimise the conflict by changing human perceptions rather than by managing sharks. Therefore, in addition to the technical alternatives mentioned above, I expand the suggestion to consider other, non-technical strategies such as education to minimise this human-wildlife conflict in KwaZulu-Natal.

Consider funding options

The costs of the bather protection programme are borne by both the provincial and local government (KwaZulu-Natal Sharks Board's Annual Reports). The funding required for the next steps proposed here should be sourced from other institutions. Suggestions were made about considering potential funding models, such as international charitable or conservation organisations and/or the tourism industry.

Align with a national framework

A recommendation was made to identify a framework that already exists, one drawn up by the national government, and align the "next steps" strategy with the existing framework. The Shark Biodiversity Management Plan includes objectives of reducing shark catches by the bather protection programme and finding non-lethal methods to protect bathers, and therefore, it is sensible to align with this framework. But alternative policies could be considered, e.g. tourism policies. It is also important to consider provincial frameworks.

At the conclusion of the meeting, 14 attendees from 12 organisations volunteered their time to begin a nascent working group to begin taking these next steps. Most of them were scientists and there were representatives from provincial and national government.

Discussion

A variety of people representing a diversity of institutions participated and made use of the social learning platform we created. I invited stakeholders whose work intersected with the bather-shark conflict and two-thirds of those invitees attended, representing 80% of the invited organisations. This suggests a high level of interest in finding ways to support the Sharks Board to leverage change and improve the conservation status for sharks while still protecting people in KwaZulu-Natal. These participants voiced their different perspectives, listened to one another amicably and shared their professional opinions about how change might be leveraged. Generally, their ideas pertained to collaborating, using what exists and weighing up costs and benefits. Specifically, suggestions about *collaborating* included working more closely among us (the stakeholders whose work intersects with protecting sharks and/or protecting bathers) and also collaborating more with decision-makers, including consciously searching for decision-makers who have a strong conviction about protecting both sharks and people and working even more closely with them. The suggestions about *using what exists already* pertained to sourcing existing information that would be useful to mitigate the bather-shark conflict, using existing conservation legislation (Marine Protected Areas), an existing sustainable beach tourism programme (Blue Flag) and an existing national framework (e.g. Shark Biodiversity Management Plan). The suggestions about *weighing up the costs and benefits* pertained to critically analysing the advantages and disadvantages of our current circumstances and of potential alternatives and how we might finance the actions proposed here. Ultimately, half the participants indicated they are prepared to volunteer their time and expertise and work together in a coordinated fashion to find solutions.

Who did not attend?

It is interesting to note who did not attend the meeting. Among those who had been interviewed in the previous research phase but did not attend the meeting were the more senior representatives, e.g. department directors and heads from DFFE and Sharks Board (though some sent representatives in their stead). There were fewer representatives from the municipality, although in this instance the representative who did attend was a senior position (acting Deputy Municipal Manager). There were no representatives from provincial tourism. Where reasons for not attending were offered, they included: reluctance to be exposed to the potential for conflict; other, higher priorities; and technical difficulties with the online platform.

We made a start to transdisciplinary learning

The activities that took place at the meeting could be considered transdisciplinary learning. The stakeholders were transdisciplinary as they came from diverse institutions (e.g. governmental, non-governmental, academia) and had backgrounds across scientific and societal bodies of knowledge including science, policy or practice (Lang et al 2012). These stakeholders made a start to reconciling their diverse perspectives and co-evolving their understanding of this social-ecological issue and co-produce appropriate knowledge to create systemic change, as per the recommendations by Roux et al (2017). I tapped into the knowledge (explicit and tacit) of the various stakeholders who understand different parts of this human-wildlife system to co-produce knowledge which is defined by Armitage et al (2011) as ‘‘the collaborative process of bringing a plurality of knowledge sources and types together to address a defined problem and build an integrated or systems-oriented understanding of that problem’’ (page996).

All attendees contributed some ideas to the discussion about the next steps although not everyone agreed with every suggestion. The bather-shark conflict is an emotive issue and views are often polarised, yet in this case exchanges were amicable and participants remained open-minded, tolerant of different opinions and were more forward-focused than retrospective. The feedback from the participants about their experience of this social learning platform was positive (Appendix 2). They noted their appreciation that there are others that are trying to find solutions to this human-shark conflict, and they appreciated the opportunity to engage others, hear different perspectives and learn new things. They admired the general willingness of the community to work together.

Some transdisciplinary learning principles to guide the nascent working group

Nearly half of the participants volunteered to help start the working group. Many of the volunteers were scientists although there were some non-scientists. Groups of diverse people are more likely to solve problems than groups of very clever people (Hong and Page 2004) and therefore the group should strive to be transdisciplinary. Recommendations for effective transdisciplinary learning for systemic change include ensuring that groups are composed of experts in their fields, novices (e.g. students and interns) and bridging agents who are skilled at social facilitation, interfacing between various parts of the network and different transdisciplinary

knowledge types (Roux et al 2017). It is also important that participants have “appropriate agency”, able to relay messages over space and time and act on new knowledge within their mandates (Roux et al 2017).

The human-shark conflict is a complex problem and the decisions that are to be made are rarely clear-cut but require balancing and trading-off one risk against another (Game et al 2014). The decision-makers tend to operate in a political arena and must assess various risks - social, political, economic *and* ecological. Politically, conservation of biodiversity is frequently a low priority and this is a major barrier to conservation action (Rose et al 2018). When supporting the decision-makers who are tasked with trading off these risks, the working group should be aware of the pitfall of the perceived superiority of scientific knowledge and empirical data because others may be inhibited about sharing their knowledge if they perceive potential issues around data legitimacy and also because decisions often involve emotional as well as logical components (Reynolds 2011, Roux et al 2017). We must avoid the old-fashioned concept of unidirectional knowledge transfer from scientists to decision-makers. Effectively navigating the research-management space likely requires knowledge sharing, i.e. learning *with* the decision-makers, reciprocally (Roux et al 2006, Toomey et al 2016), especially because conservation issues frequently involve multiple, valid perspectives and we must engage constructively with the values, cultures, politics, and histories of others (Knight et al 2019). Recommendations for scientists wanting to influence environmental policy and management are to interact with the decisions-makers and a) identify and understand the audience, (b) clarify the need for evidence, (c) gather “just enough” evidence, and (d) share and discuss the evidence (Fisher et al 2020).

Conclusion

The staff at the Sharks Board has demonstrated their commitment to reduce the impact of the shark nets and drumlines on the environment. They are world leaders in the field of bather protection and have decades of experience of conditions on the KwaZulu-Natal coast. However, it is also clear that there is a need for even more change in light of the vulnerability of sharks to overharvesting and the ongoing environmental impact of shark nets and drumlines on threatened species (Dulvy et al 2014, Atkins et al 2016, Kock et al 2022). I approached the research-implementation “gap” not as a linear concept but embedded within society and positioned our science to overlap with local knowledge and decision-making (Toomey et al

2016). I hope that by improving the links between various types of knowledge, socio-political conditions and governance at multiple scales (Van Kerkhoff and Lebel 2015), we have developed an effective strategy while garnering support for its implementation to improve the situation for sharks without compromising people's wellbeing.

I would like to reiterate that these proposed next steps are not instructions but rather constitute proposed actions and interactions that this community of organisations should consider and could take collaboratively. Many of the participants indicated they are prepared to volunteer their time and expertise to work together in a coordinated fashion to assist the Sharks Board to reduce and ultimately eliminate the mortalities of sharks and other marine animals in its mandate to protect bathers in KwaZulu-Natal.

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Appendix 1

Prior to the discussions about potential next steps, we spent time discussing various opportunities, obstacles and things to consider. These are summarised below.

Communication/education

We will have to identify the different types of people/segments that we want to talk to. We will have to manage each stakeholder group differently and have specific plans for each group. Follow the process of stakeholder management. Three broad stakeholder groups identified so far: 1) the public, especially bathers and other users of the ocean, who need to know more about sharks, our interactions with sharks (like the risk of shark bites and how we prevent interactions with bathers) and the interlinked nature of the ecosystem. Education around how the shark nets and baited hooks work could be improved. Could we make people self-sufficient in terms of bather safety rather than us dictating terms? 2) Politicians, who need improved communication from technical people to help them to get the balance right between the needs of the people, the economic costs, the needs of future generations and the animals.

We believe that public perceptions can change political will. Must address both.

3) Beach managers might be a good communication focus - they will communicate up the chain of command.

Perceptions are really important and our communication strategy will have to be very deliberate with careful management of the narrative. Shark bites and protection from them are very emotive subjects. We have to communicate effectively around the concept of emotions. First, we need to research how best to communicate this type of thing.

We must be aware that people can be “blind” to things that they don’t want to see. We must be careful of unintended consequences. Once people are sensitised to an issue they might start noticing things they hadn’t seen before and that might be negative.

Social media can be an obstacle to change, especially because of the great speed at which negative incidents like shark bites are shared. But it can also be an opportunity because it can reach so many people.

Fear and change

It is important to recognise that there is a fear of this change. There is a fear of the perceptions that are associated with shark incidents and how they potentially impact tourism.

There is still a lot of fear around sharks, fear about changing status quo, fear about making decisions, fear of perceptions of racial inequalities around safe access to the coast. We must be cognisant of this when navigating the issues.

Assess the situation relative to other provinces

Look at benchmarking cases in other coastal provinces. What is so fundamentally different from the Eastern Cape where they do not have nets? What is different about Western Cape? And why does KwaZulu-Natal need anything? What can we learn from other provinces and places, which could be applied to KwaZulu-Natal?

Some important research questions

How current is our understanding of shark behaviour in KwaZulu-Natal? How has shark behaviour changed since the 50s and 60s when the shark attacks happened? Will sharks naturally migrate to protected areas that are established for them? Is there data showing how effective shark nets and baited hooks are at preventing shark bites? Is there research on effective communication around sharks? Work has been conducted in other parts of the country and the world, can we apply it to KwaZulu-Natal?

Past - present - future

In terms of the number of shark nets being used, looking at where we have come from - to where we are currently at - to where we need to go. Historically KwaZulu-Natal had 44 km of shark nets at 40 bathing beaches. Currently there are 12.5km nets across the 37 beaches + 177 baited hooks, and some of those nets are replaced by baited hooks temporarily (during the sardine and whale migrations). How much further can that net reduction be? Also new beach nodes are being developed, e.g. near Port Durnford in uMhlathuze municipality. Could those new nodes be opportunities for trying a different approach or alternative, non-lethal methods?

Coastal access and social justice considerations

Increasing coastal access is a key provision of the Integrated Coastal Management Act and bather safety is considered part of this. It is vital to consider potential impacts on all people, without discrimination on any measure of diversity, with social justice in mind.

Merger with Ezemvelo

There is a possibility that Sharks Board and Ezemvelo KwaZulu-Natal Wildlife will merge. This could be seen as an opportunity to reshape the shark management paradigm and improve the conservation aspect of Sharks Board's mandate (i.e. to protect bathers with minimal impact). Ezemvelo could consider appointing a key communicator to engage on shark measures with beach managers.

Whose responsibility is it?

We don't really know who actually makes those decisions around changing the shark nets. It is the Sharks Board but not only them. And within the organisations it is not very clear who makes which decisions. The question was alluded to: can accountability be spread to include others, i.e. can it become a more collective responsibility?

People seem to perceive their rights and responsibilities differently in the ocean and on land. On land, people tend to take responsibility for their own safety but in the ocean (in KwaZulu-Natal) they expect someone else (the government) to take responsibility for their safety. For example: in uKhahlamba/Drakensberg, there is the potential to be bitten by poisonous snakes like the puff-adder and this risk is greater than the risk of being bitten by a shark. People still choose to walk there, but they ensure they wear the right shoes and they watch where they are walking. Yet in the ocean, they expect the authorities to protect them.

Things happen behind the scenes

There is a lot that happens behind the scenes which we are not aware of, for example there are pressures on Sharks Board and decisions that need to be made about potential new installations of shark nets and baited hooks. We must be more understanding of the Sharks Board's situation.

No job losses

it is imperative that any changes do not result in job losses. KwaZulu-Natal's unemployment rate is amongst the highest in the country (Maluleke 2020). Changes to the bather protection programme should see a redeployment of staff to other tasks.

Appendix 2

Anonymised chatterfall (comments entered simultaneously) in response to “What I appreciated the most about our time together today is...” at the end of the knowledge café.

- Meeting such a lot of like-minded people
- That everyone is willing to work together towards a common goal 🦈
- Level headed discussions with intelligent inputs. Very refreshing to attend such a meeting.
- We are making steps towards protecting sharks, those marvellous creatures that deserve our care. I hope these steps will take us places. We all need to put in our efforts and go the extra mile to make the change.
- Meeting so many people from [sic]
- Good to see the passion around this contentious subject of killing sharks to protect people
- Engaging with people that care about sharks, people and marine life and want to make a positive change
- That so many minds are trying to find solutions to protecting people and marine wildlife, for a sustainable future!
- Great to hear the diversity of perspectives, thoughts and ideas.
- There appears to be a willingness for change and doing it better, let's take that energy forward!
- How invested everyone is to find working solutions. To hear different views from industry players.
- Some clear opportunities for change - that do not require years of research to action.
- We need and can do it
- Constructive passionate discussion forum for positive change
- Willingness to learn new things
- Wonderful experience and opportunity to make a difference
- Listening to such a diverse group of people with years of combined knowledge. I have learned a lot

Chapter 7. Conclusion

My approach

Studies on the conservation biology of the Endangered humpback dolphin *Sousa plumbea* yielded evidence of the impact of the shark nets set to protect bathers at Richards Bay, in KwaZulu-Natal Province, South Africa (Atkins et al 2013, 2016). Implementing conservation change was challenging and slow. Therefore, I set out to research and begin to bridge the notorious "research-implementation gap" and find a way to elicit conservation action to improve the situation for humpback dolphins and other species that are caught in the bather protection programme without compromising the well-being of people. I found literature on an operational model for implementing conservation action (Knight et al 2006), about understanding and managing human-wildlife conflicts (Redpath et al 2013) and about re-conceptualising the "gap" as a positive and productive "space" to work in with other role players (Toomey et al 2016). These three publications influenced my approach in the thesis.

The first piece of advice Knight et al (2006) offered was to use an appropriate conceptual framework. The human-wildlife conflict framework seemed appropriate and included a useful roadmap of how to understand the conflict, a vital precursor to managing the conflict (Repath et al 2013). The three studies stressed the importance of working with others who are not biologists or scientists. Toomey et al (2016) argued that using a strictly data-driven approach would not suffice because people tend to use other factors besides evidence while making decisions, for example beliefs, mental models, experiences and concerns. Clearly, I needed more than just quantitative data—mine was a multi-faceted problem that would require a multi-faceted approach, and I would have to collect different sorts of information and data using different philosophies and techniques. I had previously just focussed on one small part of the problem, the conservation biology of humpback dolphins, but I knew the problem was much more complex. A more holistic view of the whole social-ecological system was necessary. There is one more important thing to note: I did not simply want to document the problems, it was important to be solution-focused, so I was constantly attentive to issues that might help or hinder change. Thus, my aim was to map KwaZulu-Natal's bather-shark conflict and identify obstacles and opportunities to improve the conservation status of large marine animals without unduly affecting the risk to humans.

How the findings are related

The elements of my thesis are interrelated mainly as layers: I began with some background on the Indian Ocean humpback dolphin *Sousa plumbea* and proposed the need to look beyond just one species and see the bigger picture. From the starting point that involved one species, the humpback dolphin, and its interactions with the shark nets, I added a detailed layer that included many other (non-human) species that are involved in this human-wildlife conflict – i.e. the sharks and other marine megafauna - and their interactions with the shark nets and baited hooks. The questions and answers about the temporal distribution of sharks, bycatch and bathers built on the ecological impact analysis by adding a new layer - bathers, the humans that are potentially directly affected in this human-wildlife conflict. In the focus on the social dimensions, another layer of complexity was added by considering humans beyond the bathers. In this stakeholder analysis, I focussed particularly on stakeholders who were most likely to enact changes to the system - those whose work intersected with the bather-shark conflict. The field of view was further widened and the context in which the conflict is embedded was described. I then built on the results of the stakeholder analysis by documenting the perspectives of these stakeholders, studying what they knew and thought about the method being used to protect bathers. Lastly, I used the results from the study of the stakeholders' perspectives as a reason to gather together the stakeholders identified in the stakeholder analysis, adding further complexity by introducing interactions among the stakeholders. In doing this I broadened the view from the narrow focus on one species to many species, and from my single perspective as a conservation biologist to include the many perspectives of other stakeholders involved in the bather-shark conflict. In doing so I have heeded Knight et al's (2006) calls to avoid oversimplifying and focussing just on the biological entities. I have engaged and collaborated with stakeholders using a social learning platform, I have crossed disciplinary boundaries and embedded my work in social, as well as scientific, processes.

The most important research findings

My first question was about the ecological impact of the bather protection programme on marine species and whether there was reason to be concerned. I found that there was reason to be concerned (chapter 2). The shark nets and baited hooks, that are set to protect bathers, catch far more non-target animals than the three species of target sharks (Zambezi *Carcharhinus leucas*, white *Carcharodon carcharias* and tiger *Galeocerdo cuvier* sharks) that could cause harm to people, and most of these animals die. Some Endangered and Critically Endangered

species are caught in high numbers, and is a major cause for concern. As stated in the legislation presented in chapter 4, damage to the environment caused by the bather protection programme must be minimised. Although changes have been made that have decreased the number of catches and deaths, the high ratio of target:non-target catches and high mortality rates suggest that the damage is not minimal, especially considering how many of the caught species are threatened or protected. Highlighting these parameters of the social-ecological system could be useful leverage points. In my assessment of the impact, it may have been better to use the raw catch data from the start of the programme to date, rather than to stitch data from published studies together. An obstacle would be the poor species identifications before 1978 but it may be worth trying to find a modelling technique to account for these issues. It could also be important to include more literature from bather protection programmes in other countries when assessing the impact. For example, Australian shark nets may have impacted genetic diversity of tiger sharks *Galeocerdo cuvier* (Manuzzi et al 2022). Future work that investigates the ecological impact at the Richards Bay site specifically could be conducted using the data in chapter 3 for the temporal analysis of catches. Such an analysis would form part of the beach-specific cost/benefit analysis suggested by stakeholders, as documented in chapter 6 on transdisciplinary learning.

My second question (chapter 3) broadened the view beyond just the wildlife in this human-wildlife conflict by including the humans most directly affected, the bathers. It was prompted in part by the local government: they asked when their bathers were most at risk and when bycatch was most likely. In my search for temporal leverage points, I found that the overlap between the three elements - the sharks, bathers and bycatch - was relatively high and a series of trade-offs would need to be considered. For example, in spring when many of the bycatch animals were caught, there were more sharks and possibly a greater risk to bathers. In winter, when there were predictably fewer sharks, and hence a lower risk to bathers, there were also fewer bycatch animals so changes might prevent a few animal deaths but not that many. In chapter 6, some stakeholders suggested that the next steps in seeking solutions to this human-wildlife conflict should include beach-specific cost/benefit analyses and this chapter (3) shows how some aspects of such an analysis could be carried out.

With the simplification of the temporal overlap analysis, I necessarily assumed that the risk of a shark bite is simply a “numbers game”: risk to bathers is affected only by the number of sharks and humans in the water at the same time. This is reasonable because the premise of the

bather protection fishing gear is the reduction in shark numbers reduces the risk to bathers (Dudley 1997). Yet, there are other factors at play, such as the behaviour of the people and the sharks and the many processes that may affect the risk of shark bites, both environmental (e.g. water temperature, rainfall, distance from a river, the presence of other marine animals in the area) and anthropogenic (e.g. type of water-based activity (swimming, surfing), time of day in the water) (Lagabrielle et al 2018, Ryan et al 2019). I used month as the sample unit yet there might be other resolutions and time-scales that might yield more precise, or less complex, answers. Similarly, it may be useful in the future to analyse data for only the bycatch species with high levels of concern as identified in chapter 2. Out of necessity, I did not consider the stakeholders other than the sharks, bathers and the bycatch. Had I considered the issue more holistically and included impacts on stakeholders that were identified in chapter 4, there would be additional factors requiring consideration. For example, seasonal changes to the bather protection programme could potentially impact the employment patterns of people by the KwaZulu-Natal Sharks Board (hereafter Sharks Board) and any negative impacts on employment patterns may not be acceptable to a government-linked organisation in a poor province. In the future, it might be useful to investigate the spatial patterns of overlap between sharks and bathers at a fine scale—I hypothesise that there is a very small area overlap between bathers and sharks and mapping it may yield new ideas for mitigating the bather-shark conflict. Additional factors could be added, as proposed by White et al (2009) who quantified the intensity of biodiversity conflicts by mapping ecological, social and economic factors spatially.

My third set of questions (chapter 4) was about human stakeholders beyond just the bathers that were considered in chapter 3. I used a multi-faceted approach to identify the stakeholders that work in this system, and to characterise these stakeholders and their interactions, and to investigate who is accountable, as well as to learn more about the social, economic and political contexts in which this bather-shark conflict occurs. The Sharks Board which manages the operation is obviously the most powerful stakeholder since it is mandated with bather protection and conducts research and decides which methods to use. They are also charged with educating people about the risk of shark bites and how they reduce risk. Also powerful, the provincial government pays for two-thirds of the operation, and the national government issues a permit that allows the operation to interact with the Threatened or Protected Species that are caught. Bear in mind that it is the national government's responsibility to conserve biodiversity, and they administer a Shark Biodiversity Management Plan which is an instrument that could be seen as an opportunity to accelerate a change of methods. Other government stakeholders are

the local municipalities which are responsible for bather protection in other provinces but, in KwaZulu-Natal, legislation assigns the responsibility and decision-making to the Sharks Board. Stakeholders interested in conservation (the provincial Ezemvelo KZN Wildlife and NGOs) are interested but lack power to influence the decisions that are made around the bather protection programme. Tourism organisations do not engage much with the issue of bather protection from sharks. Although many of these stakeholders do interact with one another generally, very few communicate often about alternative ways of dealing with the risk of shark bites. When it came to the social, political and economic context, I could not find any studies of the economics of bather protection, which highlights an important gap in the shark-bather conflict. Local studies of the social aspects showed that the public is not aware that the shark nets and baited hooks are intentionally fishing for sharks but there is strong opposition to the notion of using lethal methods to protect bathers (Sheridan et al 2021). Most people do believe that it is the government's responsibility to provide bather safety (Lucrezi et al 2019, Lucrezi and Gennari 2021). I had a sample size of 30 stakeholders that, by the standards of quantitative scientists, may seem small. I did not engage with all the people whose work intersects with the bather-shark conflict, but I interviewed a significant portion of the officials who participate in the decision-making process and of the other stakeholders who take the issues very seriously. However, when it comes to the perceptions of influence, interest and communication among stakeholders, the sample size was indeed small and my method only allowed me to measure perceptions of key informants, and not the actual levels of communication. I would argue though that the result is a reasonable reflection of the actual levels of communication and that perceptions are important since they influence the beliefs, attitude and behaviour of stakeholders which in turn impact the conflict (Coz and Young 2020). Regarding the policy context, I would suggest that future studies on the legislation be conducted in collaboration with policy practitioners—to avoid the possibility of missing or misinterpreting relevant information. Regarding the economic impact, it may be necessary to broaden the search beyond the formal literature. In retrospect, it may have been valuable to include in the semi-structured interview questionnaire some additional questions designed by an economist. There is a rich literature on the social aspects of bather protection in other places, particularly in Australia, that may have added some value to our understanding and future studies should report on this, even though there may be differences in culture, socio-economic levels etc compared to KwaZulu-Natal. The results of this chapter yield multiple leverage points. Those aiming to mitigate the human-wildlife conflict and improve the situation for sharks could focus on two organisations: the Sharks Board and the national government, and that the Shark Biodiversity Management Plan and possibly

the permitting conditions could be useful instruments. There is also the potential to leverage at the design level of the system by improving the flow of relevant information within the network of stakeholders. The public should be made aware of how the nets and baited hooks work.

My fourth set of research questions (chapter 5) interrogated the stakeholders identified in chapter 4 to investigate their knowledge and perceptions of the method being used to protect bathers and to capture the narratives around changing the method. To my surprise and concern, I found that, like the general public, many of these stakeholders did not know that the nets and hooks are intentionally fishing for sharks. Ensuring that all the stakeholders have accurate information about the method being used is potentially a leverage point. There were three types of narratives about obstacles to change: governance, social and environmental. Governance obstacles included the fact that decisions were politically driven, officials did not want to feel or be held responsible if someone was bitten, and it was difficult to make decisions to change a practice that has been occurring for 70 years. Stakeholders perceived a social obstacle in the attitude of people in KwaZulu-Natal which seems to be worse compared to other provinces. In my opinion, the environmental conditions they referred to, the big surf and the turbid water on the KwaZulu-Natal coast, is the biggest obstacle because it is difficult (perhaps impossible) to use visual cues to detect sharks or to maintain any equipment in the surf zone that might deter sharks from the bathing area or detect sharks using other (non-visual) means. The governance and social obstacles had not prevented change in the past, like when the number of nets were reduced in the late 1990s and when the baited hooks were introduced in the late 2000s, but the challenges of the physical environment limit the options available and make everything more expensive. There were few narratives about opportunities and they comprised promising technologies that could be useful, the belief that education can change attitudes and the hope that research could yield alternative strategies. Like in the previous chapter, a sample size of 30 may seem small, but again, I engaged with a significant portion of the officials who participate in the decision-making process and others who consider the issue as part of their work. Looking forward, it is imperative that everyone working in this system have accurate information and know that the nets and hooks are set to catch and kill sharks to reduce their numbers. It may also be that an integrated framework that simultaneously attends to social and governance structures could be useful to change individual's knowledge perceptions and attitudes and system's norms (Naito et al 2022). Another leverage point could be helping to source funding for a local programme of innovation in which a variety of alternative methods are researched and

tested in KwaZulu-Natal to identify what can withstand the conditions and reduce the risk to bathers.

The last set step in the process (chapter 6) involved the all-important collaboration with the stakeholders. I invited the stakeholders identified in chapter 4 to reflect together on the results of chapter 5 about the obstacles and opportunities to change and how we use this knowledge to design a way forward. I had an additional aim to provide the opportunity for everyone to hear the perspectives of others so that they too would be exposed to the multiple perspectives and might take the alternative perspectives into account when they consider the bather-shark conflict in the future. I hosted a meeting to harness the collective knowledge and experience of the people working in different parts of this social-ecological system. Together, we designed a strategy to collaborate amongst ourselves and with others (decision-makers) to use what already exists (data, programmes, legislation and policy frameworks) to weigh up first the costs and benefits of the current circumstances at each beach and then potential alternative strategies to mitigate the human-wildlife conflict. Each of these could be a leverage point and together the suggested strategy could be considered a precursor to an implementation plan—an important part of Knight et al's (2006) operational model for implementing conservation action. Developing this further into a firm implementation plan that details actions to be taken, who is responsible for them and which instruments should be used is an important future activity. To consider how well the meeting met the objective of creating a social learning platform, I evaluated it against Roux et al's (2017) transdisciplinary learning principles. It was quite successful because 1) people from across the transdisciplinary (science and society) network were involved, including experts, novices and bridging agents, 2) we discussed concepts that promoted an aspirational common future, and 3) we made effective use of the concept of the third space. There was room for improvement in terms of 1) recruiting participants with agency (to carry out potential changes), 2) learning one another's histories, values and existing knowledge, and 3) using boundary objects better. (A boundary object is information, such as specimens and maps, that is used in different ways by different communities that allow people to work together without consensus through interpretative flexibility (Leigh Star 2010).) The social learning platform provided a good opportunity to work in the space engaging both science and management (research and implementation). It began the process of consolidating the network of people engaging with solutions to the conflict and provided a springboard for future collaboration and tightening of the network because half of the stakeholders present volunteered to form a group to continue the work.

Compared to other studies

Other studies have used interdisciplinary approaches to understand the bather-shark conflict. For example, Gibbs et al (2020) investigated social and ecological factors that contribute to the outcomes of the bather protection programme in New South Wales, Australia, and suggest that multiple factors are important when considering the effects and effectiveness of the programme. Shabtay et al (2020) presented a case to include bather protection in marine spatial planning, a process that includes assessing both social and ecological components - and consultation with stakeholders. Many of the steps in the marine spatial planning process are similar to those I used to understand the conflict and, as in my process, they decided to engage stakeholders early on in their process. A major difference is that there was much emphasis on spatial aspects of the conflict and conservation frequently has a spatial aspect to it (e.g. marine protected areas are an important "tool" in the conservation toolbox). However, I believe there is value in taking a broader approach in these initial explorations of KwaZulu-Natal's bather-shark conflict because spatial solutions may not be useful in this instance. Another difference is that the public were also involved in the marine spatial planning process in the Shabtay et al (2020) study - a step I have not reached yet.

In a similar, terrestrial human-wildlife conflict involving jaguars *Panthera onca*, Marchini et al (2021) and Sandroni et al (2022) were also interested in understanding and managing human-wildlife conflict but framed it more positively as planning for human-wildlife coexistence. They too worked to involve the stakeholders from the beginning of the "mapping" process, not just at the final step as per Redpath et al's (2013) roadmap. In their planning, they conducted a thorough stakeholder analysis as a transdisciplinary exercise at a workshop composed of people whose work intersected with the human-jaguar conflict: government officials, conservationists, and natural and social scientists (Sandroni et al 2022). They too characterised the stakeholders based on their influence but, rather than "interest", they assessed the relative support of the stakeholders for conservation. In the next stage of the project, they designed a workflow process and their focus was on change in every step of the process (Marchini et al 2021). In phase one, they identified the current positions in terms of the social and ecological impacts for each stakeholder group and wildlife species, and the future desired position. In phase two, they identified the causes of the problem (using systems thinking) and then designed their theory of change with reference to each of the causes. In phase three, they showed how involving the stakeholders in the research process should ensure that questions

and results are relevant to the stakeholders and guide action at a stage that is normally plagued with a gap between knowledge and implementation – that is they recommended using transdisciplinary learning to navigate the space between research and management. There are elements in common with Redpath et al's (2013) roadmap in terms of integrating ecological and social sciences and including stakeholder involvement. I tweaked the roadmap to include opportunities and obstacles to change, and I appreciate how Marchini et al's (2021) model explicitly incorporates change and forward thinking, as well as systems thinking with its leverage points, and transdisciplinary learning. I propose that the working group that was started at the end of chapter 6's knowledge cafe should use Marchini et al's (2021) model.

Conclusion

Ultimately, my intention was to learn more about how to bridge the gap between research and implementation in conservation. Knight and his team gave advice on how to operationalise implementing conservation action which led me to use Redpath and his team's roadmap to understand and manage conservation conflicts. Toomey and her team changed my perspective about how to think about and navigate that gap. All three drew my attention to viewing the whole system, rather than just parts, and they emphasised focusing on the multiple valid perspectives beyond my own. Based on this, my aim was to map the human-wildlife conflict around shark nets at Richards Bay, KwaZulu, South Africa, involve stakeholders and social learning in the process, to identify obstacles and opportunities to facilitate change. I have provided a rich description of the conflict, embedded the work within social processes, facilitated a general awareness of the multiplicity of perspectives and identified various potential leverage points in the system.

How do these findings bridge the gap?

The findings of this study point to the complexity of the bather-shark conflict. They portrayed important aspects of the conflict and described many of the stakeholders beyond just the obvious ones which were the wildlife that interact with the bather protection gear, the bathers and the Sharks Board who manages the gear. These results helped me to identify the three organisations with the most power and other organisations with an interest in accelerating change in the lethal methods being used. By identifying these stakeholders, I became aware of who I needed to engage, and this information is now more readily available to other change agents. In engaging the stakeholders, I learned about the roles of the various people and

organisations and what is important from their perspectives. I learnt about some important gaps in the stakeholders' - and the public's - knowledge about the current system and we now know that we need to ensure that accurate information reaches people, especially the people that work for the powerful organisations. The mapping process also resulted in the identification of some opportunities to promote a change in the lethal method being used, most importantly I identified a deep leverage point that could potentially transform this human-wildlife system - improving the flow of information generally and about alternatives specifically could elicit the change we need.

Was this the correct approach?

Because the bather-shark conflict is complex and finding and implementing solutions may take a long time, it is difficult to assess the success of my approach. During my study, changes were made to the shark nets at Richards Bay. In 2019, some nets were replaced with baited hooks, i.e. the original conservation actions were eventually implemented but these occurred before the majority of the stakeholders were interviewed and I cannot claim that they were due to the research presented here. Yet, I believe that the process I followed in this project was useful. The main justification I have for this is that already some stakeholders might have better information because of what they heard and learned when attending the social learning platform. Undoubtedly, some of the stakeholders have begun to think about the bather-shark conflict differently because of the one-on-one engagements and the social learning platform.

Also, I can see how mapping the conflict and engaging the stakeholders is more likely to achieve conservation action and more likely to have a positive effect on many species than if I had continued to study the ecology and behaviour of humpback dolphins in the Richards Bay area in a similar manner to Atkins et al (2004, 2013, 2016) without any reference to the social layers of the conflict.

Can the findings be implemented in conservation?

The approach documented here could be replicated and extended in other human-wildlife conflicts. In fact, it could be used for any biodiversity conservation issue as they invariably have both ecological and social layers and multiple valid perspectives and would therefore benefit a process of learning about these various aspects - and stakeholders should be involved from early on. In some instances, one could engage the public as stakeholders as well. But on this

emotive subject, there are so many misconceptions about sharks, the risk of shark bites and mitigating the risk that it may be sensible to delay engaging the public until we have better data on how to deal with these misconceptions. It makes sense to first spend time and effort engaging with the people who work within the system professionally, particularly as they are most likely to implement any conservation actions.

What would make it better?

In many ways, it feels like I have only observed the tip of the iceberg (or just the fin of the shark sticking out of the water) while much remains yet unseen beneath the surface. I would like to have involved the stakeholders in more aspects of the stakeholder analysis, e.g. in understanding the legislation and the economics better. It would be better to have learnt more about the policy and economic aspects by teaming up with an economist and a legal professional. There are many other aspects of the social impact and context of shark bites that are important. In the future, a wider set of search terms and a more diverse literature type (e.g. not only peer-reviewed literature) could yield more studies that are useful to understand context. I would recruit a wider variety of social scientists, e.g. psychologists, anthropologists, political ecologists and others, e.g. economists.

Next steps

My recommendation is that we do as the stakeholders suggested during the transdisciplinary learning of chapter 6: form a working group, collaborate among ourselves and with decision-makers, use what already exists (data, programmes, legislation and policy frameworks) to weigh up first the costs and benefits of the current circumstances at each beach and then potential alternative strategies to mitigate the human-wildlife conflict. This should be designed as a formal implementation plan. As a starting point, an assessment should be conducted that tells us for each beach the catch rates of target sharks, of Threatened or Protected Species (2017), noting whether the beach is in a Marine Protected Area and whether it is part of the Blue Flag programme. We should assess each municipality's perceptions of the bather protection gear and their openness to changing the lethal methods being used. Using these data we could prioritise which beaches are the best starting points. In the absence of such a study, I recommend three focal beaches as starting points: Richards Bay is an obvious choice as it was the focus of my study, it is a high-catch beach, and the municipality is relatively open to change;

Zinkwazi which is also a high-catch beach and is set within a Marine Protected Area; and Trafalgar which is a Blue Flag beach set in a Marine Protected Area. At the chosen beaches, we should engage the local stakeholders and the decision-makers, begin to understand the current beach-specific situation focussing on behaviour of the bathers, sharks and bycatch, and investigate the ecological, social, economic and policy context and impacts. We should identify potential alternative strategies of bather protection, and for each focal beach, prioritise them and begin to test them.

I recommend that change agents focus on the flow of information within the network of stakeholders identified in my study. We should create opportunities to discuss the current bather protection method being used, and alternative strategies. We must ensure that all the stakeholders who work in this bather-shark system have accurate information about how shark nets and baited hooks work to intentionally lower the number of sharks, that only three large shark species should be considered targets and the rest are bycatch, and about more about alternative methods, including the challenges of using them in the KwaZulu-Natal waters.

Similarly, we need to work on the knowledge and perceptions of the public. Change agents should work with the Sharks Board to investigate how to adapt their education messaging so that people have accurate information about sharks and the shark nets and baited hooks. But first we need to understand what exactly their knowledge and perceptions are and we need good information on how to communicate about emotive and misunderstood subjects such as shark bites and the fishing operation. I would very much like to investigate the stakeholders' suggestion that the attitudes to sharks and risk mitigation in KwaZulu-Natal is different to those of people in other places. I would like to figure out how they differ and why - perhaps it is due to the collective trauma of the shark bites in the 1940s and 1950s, or perhaps it is due to the drastic reminders of the possible danger as soon as the nets are not in the water.

Among the first steps that should be taken next, we need to work with policy experts to refine our understanding of the policy environment and assess potential changes in the legislation. This is particularly urgent as the Sharks Board's absorption by Ezemvelo KZN Wildlife is imminent and the rewriting of the KwaZulu-Natal Sharks Board Act, 2008, is underway, creating a window of opportunity. The bather protection programme no doubt contributes to KwaZulu-Natal's beach tourism and I would also recommend working with economists to investigate the economic impacts, context and variables in KwaZulu-Natal generally and in Richards Bay specifically. In such a study, we should include an assessment of the current risk of shark bites, given the drastic reduction in the number of sharks over the 70 years since the

historical spate of shark bites.

One of the clauses in the Threatened or Protected Marine Species Regulations, 2017, requires that a risk assessment is conducted when restricted activities involve critically endangered species: “13 (1) Before issuing a permit, the issuing authority must require a risk assessment for— (a) restricted activities involving wild specimens of listed critically endangered marine species” (Page 27). Several species would qualify for such assessments since the recent publications of the Red List Assessments as described in chapter 2. In addition, I recommend that the endangered dusky shark *Carcharhinus obscurus* is included, given that it is already caught in large numbers and this is likely to have increased with increase in the number of baited hooks deployed over the last decade. I would also like to flag the fact that the impact of the bather protection gear on sharks cannot be adequately assessed when data prior to 1978 is excluded. It is important that we avoid the “shifting baseline” problem (Pauly 1995, Pinnegar and Engelhard 2007) and explore statistical models or other methods that might deal with the trade-offs between using the whole dataset and data that is accurate with regards to species identification.

We need a programme of innovation in KwaZulu-Natal to find alternative strategies to protect bathers. It is unlikely that there is a single alternative that can reduce the risk to bathers and therefore a suite of alternative methods and strategies need to be considered and tested in collaboration with the experts who are mandated with bather protection at minimal environmental cost - the Sharks Board. It is imperative that we stop systematically catching and killing sharks and find alternative solutions so that humans, sharks and other marine wildlife can swim safely in KwaZulu-Natal.

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