Assessing Appropriate Conservation Strategies for Carpet Sharks

By

Maryam Nakhostin

Submitted in partial fulfillment of the requirements for the degree of
Master of Marine Management

at

Dalhousie University
Halifax, Nova Scotia

November 28th, 2022

Abstract

Although there is considerable momentum for expanding protected area coverage under the 30x30 paradigm, there is key criticism of the existing targets in that they are not linked to conservation outcomes and marine biodiversity loss continues despite the rise in protection efforts. The success of different forms of conservation strategies is contingent on species-specific characteristics, such as behavior, life-history traits, migratory range, as well as the nature of existing threatening processes. Due to their small average size (<10 km^2) Marine Protected Areas (MPAs) can be more beneficial for endemic species that are localized to smaller regions, than for larger and pelagic migratory species that inhabit and travel over larger ranges. This research develops a conservation classification scheme for the threatened species of the order of carpet sharks, Orectolobiformes, that considers the species based on their distribution, biology, and threats to their populations. This group was chosen due to the large diversity in the size and traits of the species it encompasses; ranging from the Halmahera Epaulette Shark that reaches a maximum length of 70 cm and inhabits a geographic range of 14,446 km^2 versus the significantly larger Whale Shark that can grow to a length of 21 meters and migrates over 171,000,000 km^2. The findings reveal that only a third (39.3%) of the threatened Orectolobiformes would benefit exclusively from site-scale protection whereas the other 60.8% require either a combination of MPAs and broad-scale measures, or solely the latter; illustrating that MPAs might not be the solution for protecting all marine biodiversity. Furthermore, almost no direct relationship was discerned between the species' geographic ranges, habitat types or threats to their populations, and the conservation categories they were classified in; further signifying that conservation actions must match the individual species they are intended for.

Keywords: Carpet sharks, Orectolobiformes, Biodiversity, Marine Protected Areas, Conservation, Geographic Range, Site-scale, Broad-scale

Table of Contents

List of Acronyms

ABNJ - Areas Beyond National Jurisdiction

AOO - Area of Occupancy

CBD - United Nations Convention on Biological Diversity

CITES - Convention on the International Trade of Endangered Species

CMS - The Convention on the Conservation of Migratory Species of Wild Animals

DD - Data Deficient

EEZ - Exclusive Economic Zone

FAO - United Nations Food and Agriculture Organization

ICCAT - International Commission for the Conservation of Atlantic Tunas

IPOA- International Plan of Action

IUCN - International Union for the Conservation of Nature

LC - Least Concern

LSMPA - Large-Scale Marine Protected Area

MPA - Marine Protected Area

RFMOs - Regional Fisheries Management Organizations

UNCLOS - United Nations Convention on the Law of the Sea

UNCED - United Nations Conference on the Environment and Development

UNEP- United Nations Environment Program

List of Figures

List of Tables

Acknowledgements

I would like to express my sincere gratitude to each and every one who has supported me throughout my research and encouraged me in the pursuit of my master's degree.

To my academic supervisor, Dr. Nick Dulvy, thank you for your continued support, valuable and honest feedback, and above all, your enthusiasm for my graduate research project. I've valued all your insight and expertise throughout the process.

To my internship host, DFO National Head Quarters Marine Planning and Conservation, and particularly my supervisor Melissa Desforges, thank you for cultivating an exciting and supportive environment to carry out my internship in. The energy and passion of the team, even virtually, made every day an adventure.

To my second reader Marty King, thank you for taking the time to review my work. I appreciate your expertise and interest on this topic and appreciate your insights.

To my MPA course professor, mentor, and friend, Maxine Westhead, thank you for believing in me and guiding me in my path to gain a career in marine conservation.

To the MAP faculty, thank you for providing me with a stimulating learning experience, and the opportunity to grow throughout this program by gaining a well-balanced perspective of the socio-economic world as well as that of the ecological and biological one.

Lastly, to my family and friends, thank you for being supportive of all my endeavors and always pushing me to achieve my goals.

Chapter 1: Introduction

The rapid rise in global human population accompanied by continuous technological advancements has translated to a surge in consumption and need for resources (Vitousek et al., 1997). This in turn threatens terrestrial and marine ecosystems and has led to a decline in global species biodiversity (Chapin et al., 2000). In contrast to terrestrial systems, threats to marine environments are particularly challenging to understand, measure and manage (Maxwell, 2015). The emerging evidence suggests that population declines, and extinction risk of marine species are primarily due to overfishing, habitat loss and degradation (Hutchings & Reynolds, 2004; McClenachan, Cooper & Dulvy, 2012). As a result, the urgency to respond to declines in marine biodiversity has improved significantly from the international community, and many nations have committed to combat these threats (Selig et al., 2014). Previous and present management efforts to address threats to marine biodiversity can be categorized into two main classes of conservation including non-specific threat reduction and conservation through site-based protected areas, and species-specific broad-scale initiatives, such as fisheries and trade regulation (Vincent et al., 2014; Hilborn et al., 2020). Consequently, there has been a rise in the overall area of oceans conserved through marine protected areas as well as fisheries and trade regulations (Vincent et al., 2014; Hilborn et al., 2020; Simpfendorfer & Dulvy, 2017). Nevertheless, despite the increased efforts to mitigate threats to marine ecosystems, marine diversity continues to decline – the Pressey paradox (Pressey, 2013). Thus, there has been rising recognition of the need to connect management, particularly site-based management, to biodiversity outcomes (Butchart et al., 2015; Davidson & Dulvy, 2017; Grorud-Colvert et al., 2021). This gives rise to a key question in conservation of what measures are best needed to save individual species. This concept of diagnosing the problem and providing a specific treatment is central to medical and veterinary sciences, yet marine conservation seems surprisingly devoid of such thinking with the general assumption that more and/or larger MPAs will be the solution for everything (Dulvy, 2013; Kaiser, 2005; Butchart et al., 2015).

A notable exception is a global conservation triage conducted by Boyd et al., in 2008, which revealed that necessary conservation actions vary for different species depending on species-specific traits and threatening processes (Boyd et al., 2008). This paper classified 4,329, mainly terrestrial species into four classes of conservation action spanning from site protection to broadscale conservation, using the IUCN Red List Assessments as a consistent information source (Boyd et al., 2008). Our study takes advantage of the recent reassessment of the class Chondrichthyes (hereafter 'sharks and rays') to apply this approach and to identify plausible conservation strategies for the diverse order of carpet sharks (Orectolobiformes). Next, I introduce (1.1) the Boyd et al. (2008) conservation triage approach, (1.2) the major threats facing marine biodiversity, (1.3) the specific threats facing sharks and rays, and (1.4) conservation through spatial protection, and (1.5) broad scale initiatives. Finally, I lay out this paper's objectives and approach (1.6).

1.1 Boyd et al. (2008) Conservation Triage Approach

Using the International Union for Conservation of Nature (IUCN) Red List Assessments as a consistent and comparable source of information, Boyd and team classified 4,239 globally threatened (mainly terrestrial) species into two broad classes of conservation (Boyd et al., 2008). The first class included two types of spatial protection measures: local site scale protection (Figure 1A= category 1) and protection of multiples of sites with ecological connectivity (i.e., protected area networks, Figure 1B=category 2). The second class included a combination of site-scale and broad-scale measures (Figure 1C=category 3), and broad-scale conservation strategies alone (Figure 1D=category 4). Their analysis revealed that approximately 82% of the species can benefit from protected areas (category 1), such as the frog (*Eleutherodactylus corona)* and the Tamarin Lion Monkey *(Leontopithecus chrysopygus),* whereas most of the remaining species (18%) would require a combination of broad-scale and site-scale conservation (category 3; Boyd et al., 2008). For example, the Leatherback Turtle (*Dermochelys coriacea*) has nesting sites on beaches that require site protection, but subadult and adult turtles are also at risk of accidental bycatch by fisheries and must be managed in the high seas (Boyd et al., 2008). Less than 1% of the species were determined to not benefit from any form of site protection and would require broad-scale conservation only (category 4), such as the Indian Vulture (*Gyps indicus*) which requires actions at the policy level to eliminate the veterinary drug diclofenac from its diet dominated by cattle carcasses (Boyd et al., 2008).

Despite being a valuable step towards conservation of global biodiversity, Boyd et al.'s study included only 119 marine species, from which most species were air-breathing fauna such as marine reptiles (e.g., turtle), mammals including sirenians and cetaceans, and seabirds (Boyd et al., 2008). Even though the largest habitats and longest evolutionary history belong to the world's oceans, there are a very limited number of peer-reviewed studies available on marine species and fishes exclusively (Dulvy et al., 2014; Boyd et al., 2008). In 2001, fewer than 6% of the world's fishes were assessed by IUCN (Reynolds et al., 2005); and by 2011, there were less than 10 conservation related papers per species of sharks and rays compared to the 194 papers per species of marine turtles (McClenachan, Cooper & Dulvy, 2012). As a result, concerted attention has been allotted to including marine species on the IUCN Red List and to studying changes in their biodiversity (Miranda et al., 2022; Dulvy et al., 2014). It is imperative to deliberate on what species-specific traits must be considered and prioritized to classify and conserve marine species. Prior to that however, we must understand the major threats to marine species and biodiversity, and the resultant impacts on their habitats and populations.

1.2 Major Threats Facing Marine Biodiversity

In 2016, Arthington and team conducted an analysis on the status of freshwater and marine fish and investigated the major threats to species biodiversity in both ecosystem types (Arthington et al., 2016). Their results revealed that the main threats to North American marine fish populations are overfishing and habitat destruction (Musick et al., 2000). Specifically, overfishing was discovered to be responsible for the threatened status of 55% of North American marine fishes, with habitat loss and destruction the second most significant threat affecting 38% of the populations (Musick et al., 2000). Local and regional population extinctions of marine species were mainly driven by overfishing implicated as the key threat for 60% of marine species considered, with habitat loss and destruction likely responsible for extinction of 5% of marine fish species (Dulvy et al., 2003). A more recent analysis of charismatic coral reef species, in addition to overfishing and habitat loss and degradation also revealed the emergence of climate change as a key threat (McClenachan, Cooper & Dulvy, 2012).

1.3 Specific Threats Facing Sharks and Rays

The most recent comprehensive survey of a class of marine fishes reveals that overfishing affects all 391 threatened sharks and rays, with 66% threatened only by overfishing, with the other 34% threatened by overfishing in combination with other threats (Dulvy et al., 2021).

Habitat loss in combination with other threats affected 31.2% of sharks and rays with climate change in combination with overfishing and habitat loss affecting 10.2% of sharks and rays (Dulvy et al., 2021). Though they can be major drivers of extinction in terrestrial and freshwater ecosystems, other threats such as climate change, pollution, and invasive species are too minor to be considered when addressing marine conservation (Arthington et al., 2016; Dulvy et al., 2021).

Sharks and rays are amongst the oldest and most ecologically diverse marine vertebrates, comprising more than 1,250 species, many species playing a key role as apex predators in marine ecosystems (Dulvy et al., 2014; Dulvy et al., 2021). Nevertheless, sharks and their populations are especially at risk of extinction due to their intrinsic sensitivity, and extreme life history traits including long gestation periods, slow maturation, and low reproductive rates (Pardo & Dulvy, 2022; Cortes, 2000). Other species that are at higher risk of extinction are those with smaller habitats and geographic ranges (Musick et al., 2011). In 2021, one-third (37.5%) of the 1,199 sharks and rays were listed or predicted to be threatened (Dulvy et al., 2021).

1.4. Conservation Through Spatial Protection

The following two site-scale protection measures are reviewed in this study: MPAs and MPA networks.

1.4.1 Marine Protected Areas (MPAs)

A protected area is defined by the International Union for the Conservation of Nature (IUCN) as "A clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values' (IUCN). These protected areas are designated with the purpose of protecting biodiversity through the removal and management of harmful human activities (Ward et al., 2001). They can vary in size, levels of protection (no-take versus multiple use), and governing legislation and policies (Ward et al., 2001). These components of protected areas depend on several conditions including their conservation objectives, the designating nations' economic and political capacity, and whether the MPAs are designated in countries' exclusive economic zones (EEZ) or areas beyond national jurisdiction (ABNJ); which will in turn influence the governing bodies responsible for monitoring and managing the protected areas (Dehens & Fanning, 2018). Past studies have revealed that no-take marine reserves, though rare, can help replenish depleted population biomasses of marine species particularly in well-managed remote coral reef habitats (Edgar et al., 2014). This mainly occurs through the buildup of biomass and subsequent 'spillover' outside park boundaries. For example, the spillover of groundfish such as Haddock (*Melanogrammus aeglefinus*) from Georges Bank MPA (Murawski et al., 2005) and coral reef fish from Apo Marine reserve in the Philippines (Abesamis et al., 2006). As a result of this spillover, monitoring of fisheries revealed higher average revenue per hour near the boundaries of the protected area on Georges Bank (Murawski et al., 2005) and in the catch rates outside by local fishers in the Philippines (Alcala et al., 2005). Site protection can also minimize destruction of sensitive habitats by restricting use of fishing gear such as trawls and drive-nets (Ward et al., 2001; Dinmore et al., 2003).

Due to their static nature and smaller sizes however, single MPAs can be more beneficial for endemic and benthic species that are localized to smaller regions (Davidson & Dulvy, 2017; Claudet et al., 2010). Whereas the same level of efficacy is not uniformly evident for highly mobile species that inhabit and migrate over larger expanses (Kaplan et al., 2010). As a result, some nations have turned to other forms of marine spatial protection such as single large-scale

MPAs (LSMPAs) and MPA Networks to combat these limitations, and to protect species with large geographic ranges, or with fragmented populations or habitats (Game et al., 2009).

1.4.2 MPA Networks

MPA networks are another form of spatial protection to improve connectivity and viability for wide-ranging populations. Different MPAs in a network can be designated with different degrees of protection, which collectively work to meet their conservation objective that could not otherwise be met with a single reserve (Cannizzo, Wahle & Wenzel, 2020). Protection measures for ecological connectivity through migratory corridors between "essential habitats" in the network can help maintain the population numbers of migratory organisms (Andrews, n.d.). MPA networks could potentially benefit adult individuals of species such as Nurse sharks that use a range of habitats, as they can be protected by individual MPAs in the network with corridors provided for the species to move between sites with a reduced risk of getting caught by fishing gear during migration (Rigby et al., 2019). These sites can be substantial for the species' spawning or nursery grounds, or other important life-history characteristics (Andrews, n.d).

Nonetheless, there are three main disadvantages associated with this form of spatial management which is why only 11% of the MPA networks in the world have been implemented based on ecological connectivity (Cannizzo, Wahle & Wenzel, 2020). Unlike terrestrial protected areas that can be linked with corridors, the nature of corridors is not as well-defined and clear in the oceans. Hence, extensive research is required for detecting and preserving the ecological connectivity of other forage species, zooplankton, benthic invertebrates, and plants that are crucial for creating a functioning ecosystem between the MPAs in the network (Cannizzo, Wahle & Wenzel, 2020). Second, while some species such as the Flatback Sea Turtle (*Natator depressus*) or the Humpback Whale (*Megaptera novaeangliae*) move in more predictable and linear patterns, comparative research of migratory species has revealed that others such as the Whale Shark (*Rhincodon typus*) have more dispersed swimming patterns (Pendoley et al., 2014). Therefore, static MPA networks might not be as beneficial for the latter species if they are not returning to the same sites consistently (Pendoley et al., 2014). Another obstacle in designating MPA networks includes complications with existing legal frameworks for marine conservation, as many do not acknowledge "connectivity as a necessary component of place-based management" (Cannizzo, Wahle & Wenzel, 2020).

1.5 Conservation Through Broad-scale Initiatives

Broad-scale conservation initiatives in the marine ecosystem primarily address fisheries management given that overfishing is the biggest threat to marine species, specifically Chondrichthyans (Dulvy, 2014). Over the past few decades, numerous international and national laws have been developed that govern fisheries and other marine affairs. Globally adopted by nations in 1982 and enforced in 1994, the United Nations Convention on the Law of the Sea (UNCLOS) encompasses numerous agreements that provide nations with international and national legislative frameworks for managing their waters (Grip, 2016). These agreements dictate the member states' rights and responsibilities towards the management of fisheries, maritime traffic and safety, response to climate change and its impacts, prevention and mitigation of pollution, and protection of biodiversity in their national waters, EEZ, and the high seas (Grip, 2016). An added layer to UCLOS is the 1992 UN Conference on the Environment and Development (UNCED) in Rio de Janeiro that led to other international agreements including the United Nations Convention on Biological Diversity (CBD) which specifically addresses the conservation and use of marine biodiversity (Grip, 2016).

Globally fisheries are managed by regional bodies and organizations (Regional Fisheries Management Organizations (RFMOs) such as International Commission for the Conservation of Atlantic Tunas (ICCAT)), particularly for pelagic and deep-sea fishes on the high seas, and by national governments within EEZs (Ewell et al., 2020; Shiffman et al., 2021; Heidrich et al., 2022). The reality is, however, that only a few target fisheries are managed for both teleosts and sharks, which are mainly in the Northeast Atlantic, USA, Canada, Australia, New Zealand, and South Africa (Hilborn et al., 2020; Simpfendorfer and Dulvy 2017). Whereas elsewhere, the species taken alongside these target species continue to decline due to undermanagement (Juan-Jorda et al., 2022). As a result, the best, most comprehensively assessed exploited group–sharks and rays–have declined by 70% in the pelagic ocean and more than one-third of all 1,199 species are threatened (Pacoureau et al., 2021; Dulvy et al., 2021).

In 1999, FAO initiated the International Plan of Action for Sharks (IPOA-Sharks) to improve conservation, monitoring and management of sharks, rays, and chimeras (Worm et al., 2013). However, this was a legally non-binding process and a review of the progress of IPAO-Sharks in 2013 by FAO revealed that only 13 of the 26 top shark fishing nations responded to the survey, and progress on meeting the 10 objectives was limited (Davidson et al., 2015; Davidson & Dulvy, 2017). Their study also indicated that despite the increased international efforts for shark conservation, there was very little change in the number of shark mortalities from 2000 to 2010 (63 million to 61 million sharks per year) (Worm et al., 2013). The Worm et al. team concluded that protective measures must increase considerably to tackle this lack of progress in mitigating shark mortalities (Worm et al., 2013).

Some in the biodiversity conservation community argue that the better broad-scale species-specific tool for biodiversity conservation is the Convention on International Trade in Endangered Species (CITES); given that a large portion of revenue from harvesting marine species includes their trade and there is a "stronger compliance regime" with CITES than there is with RFMOs (Shiffman et al., 2021; Vincent et al., 2013). First developed in 1976, this Convention is meant to manage and restrict international trade of wild plants and animals (Vincent et al., 2013). However, there were no marine fishes included in the Appendices until 2002, and a total of only three species of sharks were added by 2012 (Vincent et al., 2013). Therefore, CITES has been criticized for its slow pace in dealing with regulation of international trade for marine fishes (Vincent et al., 2013). Moreover, some nations' have voiced their concern regarding the capacity of their CITES Scientific and Management Authorities to adequately implement the marine fish listings (Vincent et al., 2013).

Marine vessel collisions are another threat to marine biodiversity, and particularly a risk to larger migratory marine mammals such as the North Atlantic Right Whale (*Eubalaena glacialis*) and fishes such as the Whale Shark (*Rhincodon typus*) (Schoeman et al., 2020; Womersley et al., 2022). Additional UN bodies including the International Maritime Organization (IMO) combat these threats to marine biodiversity by regulating human activities at sea including maritime traffic and shipping (Grip, 2016).

1.6 Research Objectives and Approach

A key limitation of the conservation triage approach of Boyd et al. was the paucity of marine species then listed on the IUCN Red List. Here I apply Boyd et al.'s approach to the 28 threatened species of the order Orectolobiformes, which were classified into four main conservation categories based on available data on their geographic range and distribution (including their Area of Occupancy), habitat types, aggregatory and migratory behaviour, and threats to their populations (Boyd et. al, 2008). This order of sharks was chosen for the study due to the large diversity in the size and traits of the species it encompasses. For example, the Halmahera Epaulette Shark (*Hemiscyllium halmahera)* grows to a maximum length of 70 cm and has a geographic range of 14,446 km^2, versus the Whale Shark (*Rhincodon typus*) which is the largest fish in the world and can grow up to 21 meters and has a geographic range of 171,000,000 km^2 (Ebert et al., 2021). This study aims to illustrate that the success of different marine conservation strategies is contingent on species-specific attributes and must be tailored to the individual marine species and habitats (Rigby et al., 2019). Specifically, I ask the following questions: (1) what percentage of carpet sharks can benefit exclusively from site protection? (2) is there a correlation between species' geographic range and their conservation category? (3) Is there a correlation between species' habitat type and their conservation category? (4) Is there a correlation between the type of threat to the species and their conservation category? (5) In comparison to the conservation categories the carpet sharks are classified in, what is the current conservation progress of these species in the oceans, and does it match what I recommend for them?

Chapter 2: Methods

In this section I first describe the sources of data used. Analogous to Boyd et al.'s study, I referred to data from the IUCN Red List Assessments for this analysis along with other sources exclusive to sharks in an effort to attain information pertaining to specific traits of all threatened species of Orectolobiformes (Boyd et al., 2008); which in turn, guided their categorization into optimum conservation categories. Next, I discuss further details on each of the four conservation categories with figures that illustrate how the categories differ from one another. I then provide an in-depth description of the significant attributes of the species examined for this study, along with that of the four conservation categories, to support the comprehension of how and why the traits were prioritized and used to sort the species into each of the conservation categories.

2.1 Sources of Data

Following the approach of Boyd et al. (2008) this analysis relied primarily on consistent sources of data including the IUCN Red List assessment and natural history field guides such as Sharks of the World, particularly since the disparity in the availability of peer-reviewed studies across this order is staggering. For example, there are 76,600 studies available on what could be considered as the more charismatic Whale Shark (*Rhincodon typus*), whereas only 13 studies are available on the Elongate Carpet Shark (*Parascyllium elongatum*), which was accumulated from a single specimen that was retrieved at the depth of 50m and from the inside the stomach of a School Shark (McClenachan, Cooper & Dulvy, 2012; IUCN, 2022). The absence of sufficient data on some species could also be attributed to the shortage of adequate resources or technology to access them or their habitats, and the ability to collect an ample number of specimens required for gaining a thorough understanding of their biology, ecology, population dynamics, and behavioural traits (Bland & Collen, 2016). Moreover, the geographic range of certain species of carpet sharks overlaps with nations that lack the economic or political capacity to study those species or are unwilling to share the data they have previously obtained on them with the rest of the scientific community (Davidson & Dulvy, 2017). This can be an additional challenge that limits our ability to accumulate the data needed to determine whether those species of carpet sharks require conservation measures and what are the ideal strategies to protect them.

2.2 Classifying Species Conservation Needs Based on Biological Traits, Threats, and Conservation needs

This study focused on seven key species-level attributes including their (a) geographic range, (b) area of occupancy (AOO), (c) the number of locations (d) habitat type, (e) migratory and (f) aggregatory behavior, and g) threats to their populations to support the classification of the species. Data available on present conservation measures received by the carpet sharks was also used to aid in the development of a holistic understanding of their individual biology, ecology, and status, and to facilitate categorizing them; particularly in instances where there was insufficient or no data available on the seven key characteristics. Table 1 lists these attributes and provides definitions and further explanations of what they entail.

The geographic range of a species is the area that incorporates the entirety of the range of the species. The data for geographic ranges of carpet sharks was obtained using IUCN Red List's calculations from the species' range maps (IUCN, 2022). Another significant aspect of a species' habitat distribution is its AOO. IUCN defines AOO as: "the area within a species' extent of occurrence, which is occupied by a taxon, excluding cases of vagrancy" (IUCN, 2022). The AOO differs from the species' geographic range in that a taxon does not always occur throughout its geographic range or extent of occurrence as the latter two might encompass unsuitable or unoccupied habitats (IUCN, 2001). The AOO of the species is therefore the smallest area of its geographic range that is required at any stage for the survival of its extant population (IUCN, 2001). The geographic range of some carpet shark species is spread across multiple locations, where location is defined as "a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present" (IUCN, 2022). The physical and biological nature of the type of marine environment the carpet sharks reside in (habitat) can be categorized into coastal, pelagic and deep water.

Though IUCN Red List data was used to determine the migratory behaviour of the carpet shark species, it is important to discuss what is considered as a migratory species; given that the definition of migratory versus non-migratory is an arbitrary human construct and determined using arbitrary thresholds. As an intergovernmental treaty created by United Nations Environment Program (UNEP) and signed in 1979, The Convention on the Conservation of Migratory Species of Wild Animals (CMS) defines migratory species as those where "the entire population or any geographically separate part of the population of any species or lower taxon of wild animals, a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries' (Pytka & Pauly).

In addition to their migratory behaviour, numerous shark species such as the Whale Shark and Zebra Shark also undergo aggregations (Venegas et al., 2011; Dudgeon et al., 2008). These species aggregate at specific sites in larger numbers for different purposes and life history events, including, feeding, breeding, nursing (Venegas et al., 2011; Dudgeon et al., 2008). Given the larger density of the species, these stopovers are more vulnerable to human activities such as directed fishing practices as they are more catchable, or are at higher risk of harm from site destruction due to fishing or construction activities etc. (Venegas et al., 2011).

IUCN defines direct threats as "the proximate human activities or processes that have impacted, are impacting, or may impact the status of the taxon" (IUCN, 2022). Threats to a species can be direct or indirect and they can differ in their timing, meaning they "can be past (historical, unlikely to return or historical, likely to return), ongoing, and/or likely to occur in the future." (IUCN, 2022). Moreover, the threats can be site-scale such as habitat degradation through destructive fishing practices (e.g., dynamite fishing) or broad-scale such bycatch by fisheries (e.g., trawls) or ship strikes in the high seas.

2.3 Description of Conservation Categories A-D

The four categories of in-situ conservation detailed in this analysis were primarily informed by Boyd et al., 's work (Boyd et al., 2008). Figure 1 visually demonstrates each of the conservation categories where category A (Figure 1A) is a single MPA for species where the entire population or most of their viable population can be preserved at a single site; where 'Site' is considered as a uniform area that can be defined and actually/potentially managed as a single conservation unit. (Boyd et. al., 2008). Despite the presence of several large-scale MPAs across the globe, in this study I considered the maximum scale of a single MPA for category A the same as the current median size of MPAs as of 2022 (<10 km^2), making it a more practical conservation option. Category B (Figure 1B) signifies a network of MPAs with ecological connectivity/biological corridors where the maximum size of each MPA in the network is the same as that of category A. Species placed in category C (Figure 1C) are those that require a combination of site-scale protection (MPA or MPA network) and broad-scale measures (fisheries management or other policy changes) given that either type alone will not adequately benefit the species. Lastly, at the other extreme is category D (Figure 1D) which signifies broad-scale conservation only and encompasses species that would not benefit from any site-scale protection.

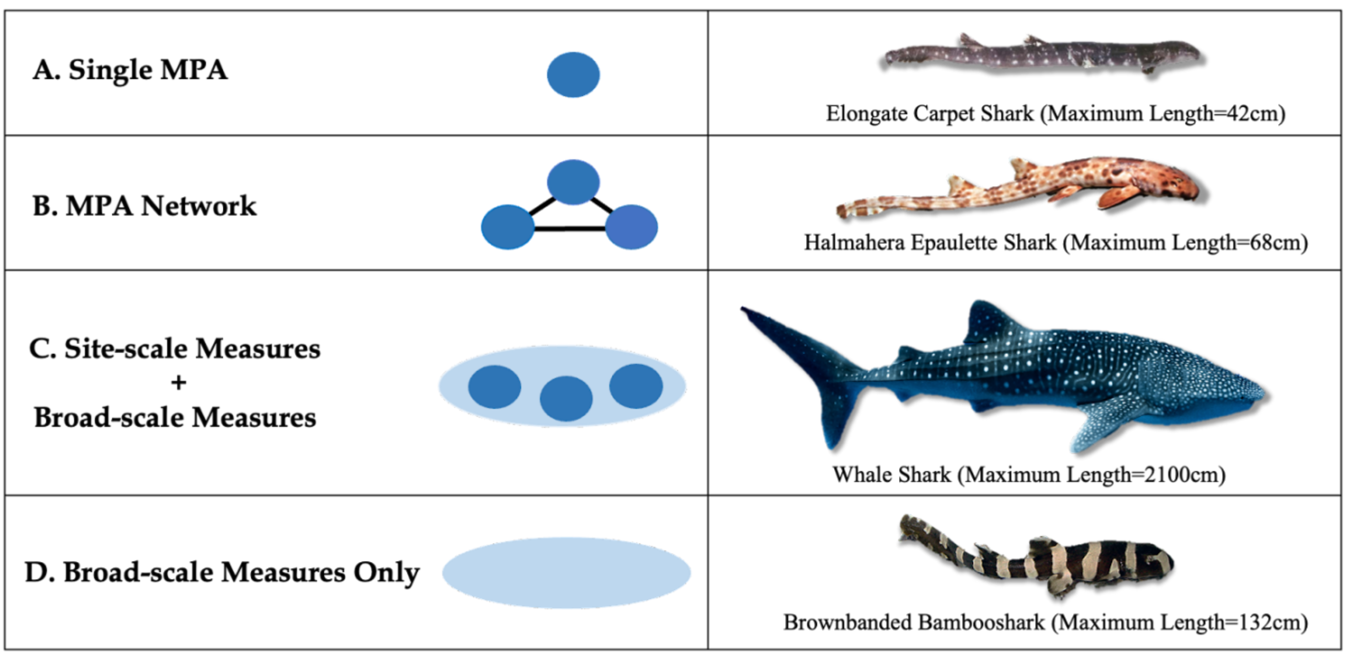

Figure 1. Conservation measures required for the protection of carpet shark species. A = single dark blue circle, a single MPA (e.g., Elongate Carpet Shark, *Parascyllium elongatum*); B = multiple connected dark blue circles, network of MPAs/sites (e.g. Halmahera Epaulette Shark, *Hemiscyllium halmahera*); C = dark blue circles in pale blue oval, combination of network of MPAs/sites and broad-scale conservation action (e.g., Whale Shark, *Rhincodon typus*); D = pale blue oval, broad-scale conservation action (e.g., Brownbanded Bambooshark, *Chiloscyllium*

punctatum). (Photographs are not to scale) Photographs by Australian National Fish Collection (Elongate Carpet Shark), M.V. Erdmann (Halmahera Epaulette Shark), B.J. Skerry (Whale Shark), and A. Murch (Brown Banded Bambooshark).

2.4 Stages of the Classification Process

I developed a step-by-step pattern central to the categorization process that takes into consideration the species' key characteristics in a precise order (Figure 2). The first stage involved asking if a single MPA can encompass the entirety of the species' AOO or geographic range (Figure 2a). If yes, the species was automatically placed in Category A. If not, the next stage was to ascertain if the species population is spread across multiple discrete locations (see Table 1 for the definition of 'location') and if so, the species was immediately placed in category B (Figure 2b). If not, however, I investigated the species' habitat type and whether it is dependent on a particular ecological feature (such as coral reefs, mangroves, seagrass beds, etc., Figure 2c). If the species does not rely on a specific habitat type, the species aggregating behaviour was used next to determine its conservation category (Figure 2d). If the species aggregates at specific sites, then a combination of site-scale and broad-scale conservation measures, or category C, would be the best fit for them. If the shark does not rely on a specific habitat and does not have specific aggregating sites, then it was placed in category D. Species in category D are those that do not tend to aggregate at specific sites (are highly nomadic), do not rely on specific ecological features/habitat types, or are impacted by threats that cannot be mitigated by closing off/protecting sites. If the species does in fact rely on specific ecological, physical, or biological features for its habitat, the next feature to consider was the type of threats to the species (Figure 2e). If threats are site-scale, then the species was placed in category B, if broad-scale then category D, and lastly, if there is a combination of both types of threats then category C seemed to best suit the shark. While the primary traits were commonly considered in that order, supplementary information about the species including the conservation measures they are currently receiving was used in instances where the key traits were not sufficient for a concrete decision about the category the species belonged to. Similarly, for some species, a secondary category was designated as the next best conservation strategy given that the information available on neither their primary nor secondary characteristics allowed for a clear-cut choice. Unknown data surrounding the species' life-history characteristics, biology, behaviour, the capacity of the governing bodies implementing the conservation measures, and other possible threats to the species can make one conservation option more effective than another.

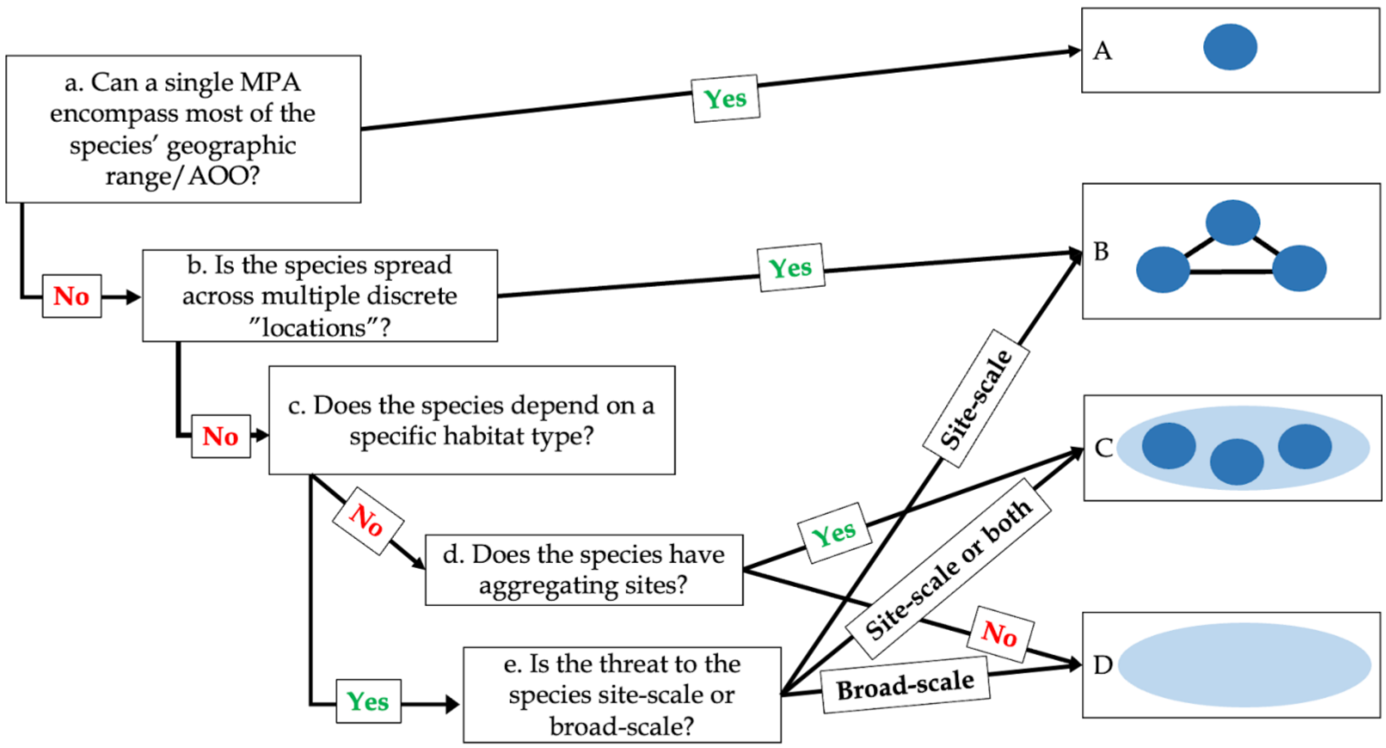

Figure 2. Central order of questions asked and answered (using the sharks' key attributes) to categorize the species into each of the four conservation categories. Depending on the availability of data on the species and their traits, supplemental questions regarding other traits (current conservation measures received by the species) were asked to facilitate categorizing the species.

Chapter 3: Results

3.1 What Percentage of Carpet Sharks Might Benefit from Spatial Protection?

As demonstrated by Figure 3, of the 28 species of Orectolobiformes that were investigated, only three species (10.7%) were classified as requiring site protection through the designation of a single MPA (category A) and only 5 (17.9%) were broader-ranging and were categorized as needing conservation across multiple sites through a network of MPAs (category B). Hence, together only one-third (28.6 %, *N*=8) of the threatened species would benefit exclusively from MPA-style conservation, whereas more than half of the sharks cannot be adequately protected by site-scale conservation measures alone. 12 species (42.9%) were analyzed as requiring a combination of both site-scale and broad-scale protection (Category C), and the remaining 8 (28.6%) species were sorted into category D; given that analysis of their traits revealed that they would likely not benefit from any site protection, requiring broad-scale measures taken at the policy level. For most species sorted into category D fisheries management is the most suitable conservation measure given that the main types of threats to the species were broad-scale and as a consequence of fishing practices. These numbers also include species that were listed as Data Deficient on the IUCN Red List.

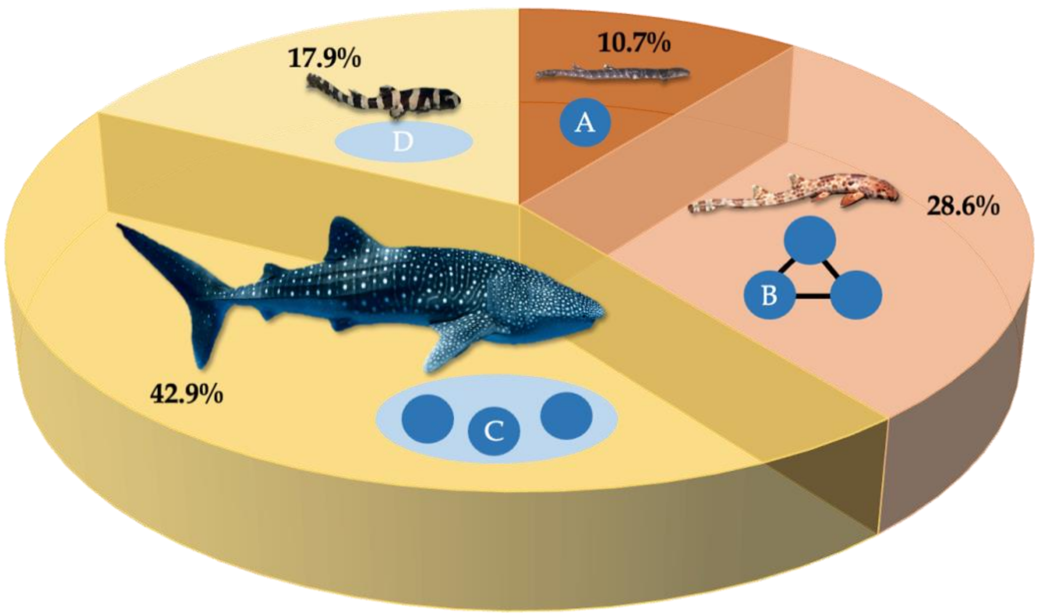

Figure 3. Percentages of carpet sharks classified into each of the four conservation categories. Dark orange = Category A, single MPA, Pale orange = Category B, MPA Networks, dark yellow = Category C, combination of site-scale and broad-scale measures, pale yellow = Category D, broad-scale measures only. Photographs by Australian National Fish Collection (A-Elongate Carpet Shark), M.V. Erdmann (B-Halmahera Epaulette Shark), B.J. Skerry (C-Whale Shark), and A. Murch (D-Brown Banded Bambooshark).

3.2 Correlation Between Species' Geographic Range and Their Conservation Category

As displayed by Figure 4, an investigation of the relationship between the frequency of species in each of the four conservation categories and their respective geographic ranges revealed that all species in category A (single MPA) have geographic ranges of less than 3000 km^2 and this category encompasses the carpet shark with the smallest geographic range of 172 km^2 (elongate carpet shark). While I expected species in category A and B to be those with the smallest geographic ranges (given that the primary species attribute used to classify them in those categories was their geographic range and habitat distribution), the more even distribution of species in category C and D across the geographic range scale was unpredicted. The species with the largest geographic range (Whale Shark=171,329,722 km^2) is in category C, whereas two of the species in category D (*C. expolitum*= 3,384 km^2 and *C. fomosanum*=3,433 km^2) have geographic ranges smaller than species in category B that can be protected by site protection alone (MPA network).

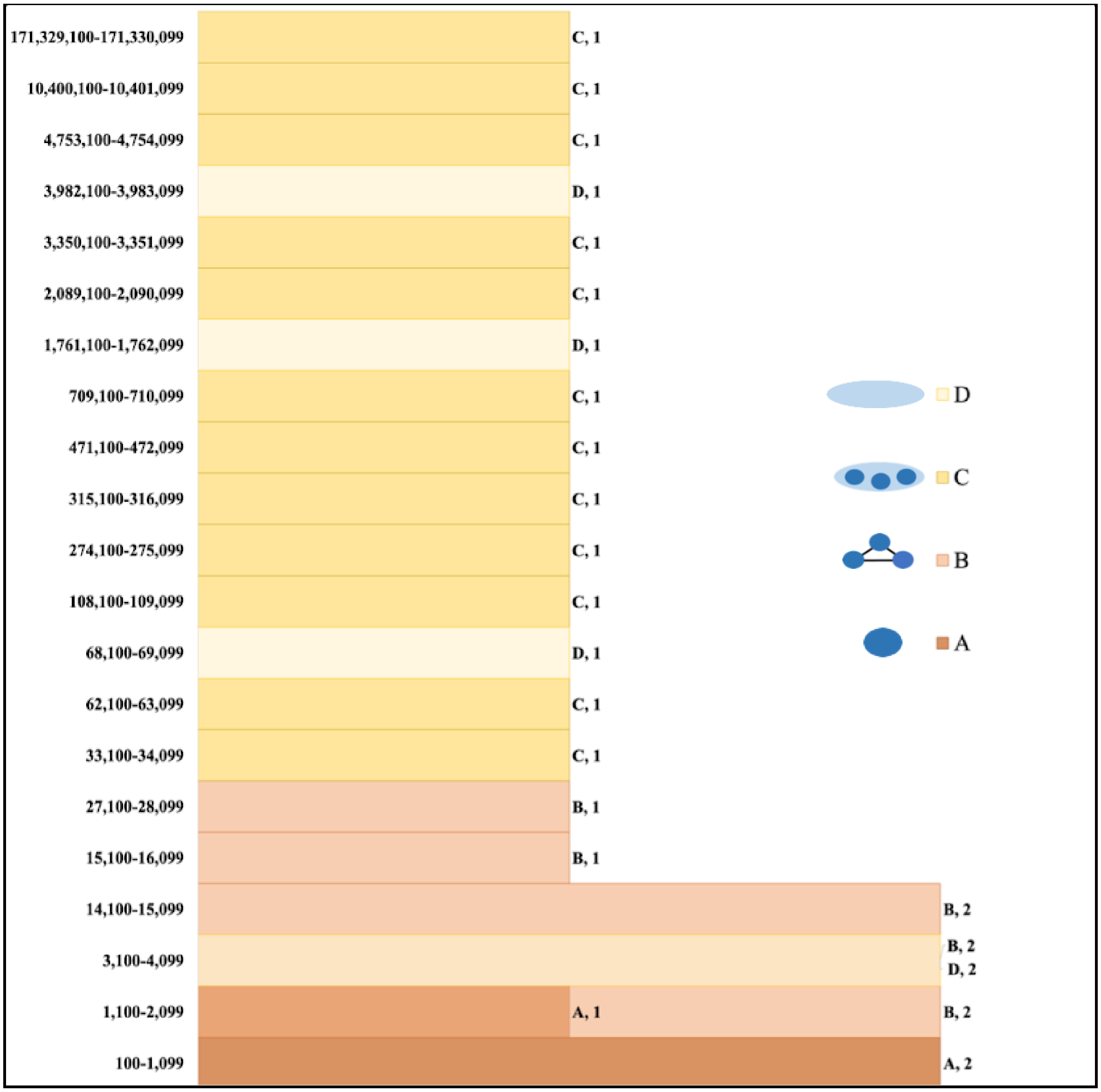

Figure 4. Geographic range and conservation classification. Number of species in each of the four conservation categories and their respective geographic ranges. Category A (dark orange, N=3), category B (pale orange, N=8), category C (dark yellow, N=12), category D (pale yellow, N=5).

3.3 Correlation Between Species' Habitat Type and Their Conservation Category

Similar to species' geographic ranges, comparison of their habitat types across all four conservation categories showed a relatively random distribution. All species in category B (100%, N=8) and category D (100%, N=5) live almost exclusively in coastal habitats and rely on biological features such as mangroves, seagrass beds, coral reefs etc. Similarly, two of the three species in category A (66.7%) reside in coastal habitats and rely on biological features such as mangroves, seagrass beds, coral reefs etc., whereas the other species in this category-Ginger Carpetshark (*Parascyllium sparsimaculatum*)-resides on the upper continental slope and in deep waters. While all species in category C have coastal habitats (100%, N=12), the Whale Shark (*Rhincodon typus*) relies on coastal habitats as well as pelagic environments. Available information on all Orectolobiformes indicates that the Whale Shark is the only carpet shark that resides in pelagic waters. Overall, almost all (96.4%) of the 28 threatened carpet sharks inhabit coastal environments despite being classified into different conservation categories. These ratios are depicted in Figure 5.

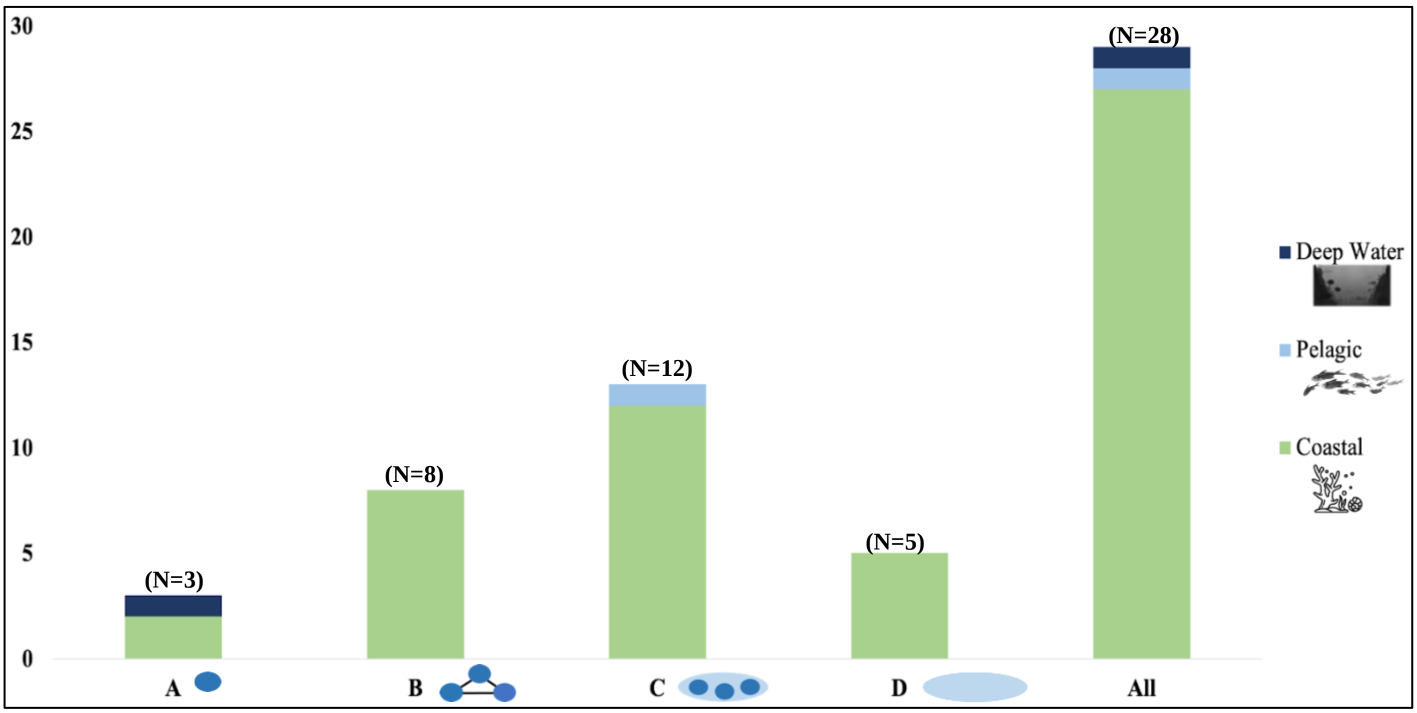

Figure 5. Habitat type and conservation classification. Percentages of carpet shark species in each of the conservation categories that inhabit coastal environments (light green), pelagic environments (pale blue), and deep waters (dark blue). *Whale Shark (*Rhincodon typus*) classified in category C resides in both coastal and pelagic habitats.

3.4 Correlation Between the Types of Threats to the Species and their Conservation Category

As demonstrated by Figure 6, the threats to carpet sharks were divided into four main types which include species with unknown threats (fourth category). This analysis did not include species that were listed as 'Least Concern' on IUCN. Threats to two of the three species in category A (66.7%) are unknown. While the other species in this category (*Parascyllium sparsimaculatum*) is unlikely to be threatened by fishing efforts due to its habitat (deep water), individuals can still be unintentionally harvested during demersal fishing practices and so the species is included amongst the species impacted by broad-scale threats. Of the eight species in category B, all (100%) are threatened by site-scale threats including habitat loss and degradation and pollution (e.g., seepage from mining) activities due to human activities such as dynamite fishing, palm oil cultivation and construction activities for tourism development. 16.7% of the 13 species in category C are threatened by broad-scale threats (e.g., caught directly by trawls or gillnets in commercial fishing or caught as bycatch) while the rest (10, 83.3%) are threatened by both site-scale and broad-scale threat types. Lastly, three of the five species in category D (60%) are affected by broad-scale threats and the remaining two (40%) are impacted by both types of threats. Overall, almost half (42.9%) of the 28 carpet sharks are threatened by both of broad-scale and site-scale threats.

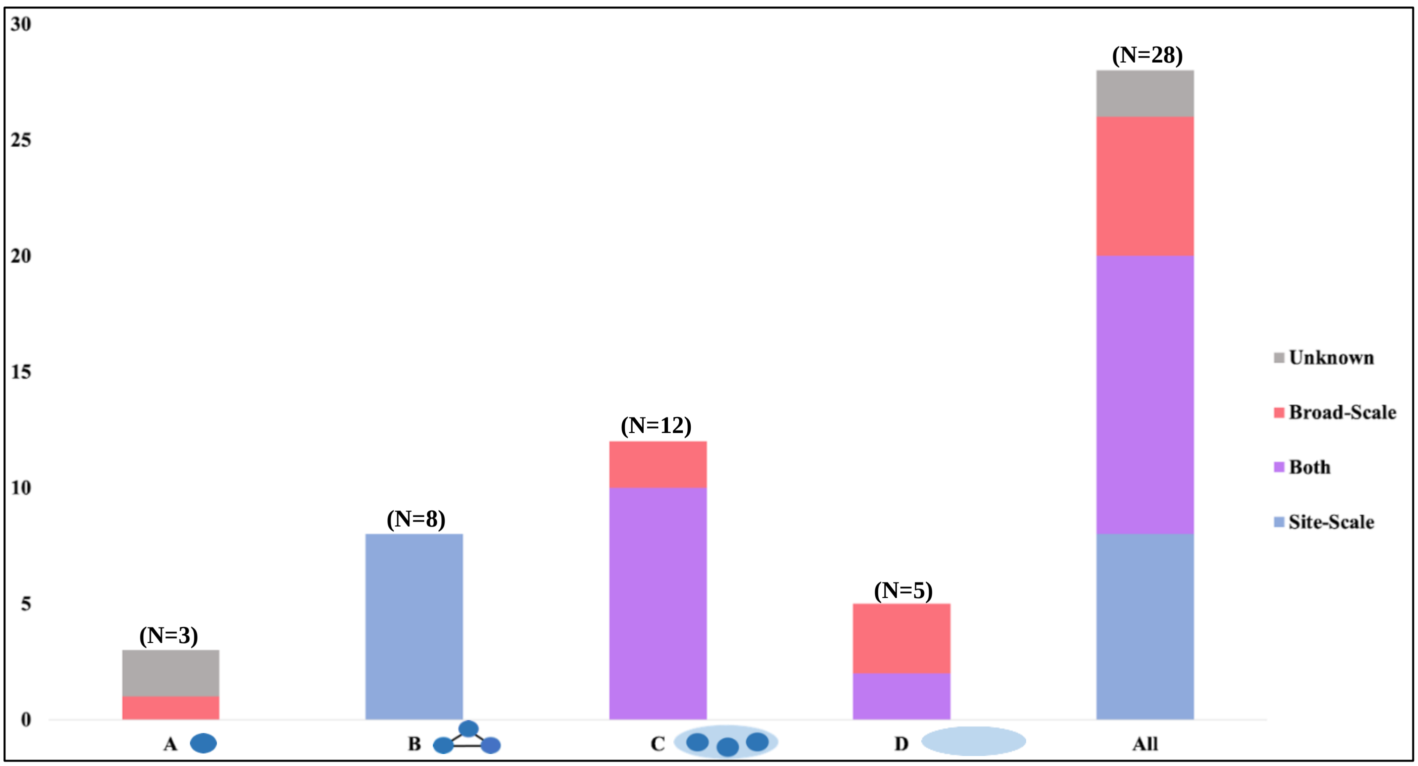

Figure 6. Threat types and conservation classification. Percentages of carpet shark species in each of the conservation categories threatened by site-scale threats (blue), broad-scale threats (red), both types of threats (purple), and unknown threats (gray).

3.5 Conservation Progress of Threatened Carpet Sharks

3.5.1 The Relationship Between the Recommended Conservation Strategy for Threatened Species and the Existing Conservation Measures in Place

To understand the progress made in the conservation of Orectolobiformes, the conservation measures that carpet shark species are currently receiving (both directly and indirectly) were compared with the conservation strategy that was recommended for them in this analysis (the strategy associated with the conservation category they were assigned to) (Figure 7). This comparison conveyed that none of the three species in category A are receiving the conservation actions decided to be best suited for them (single MPA), whereas conservation measures applied for more than half of the species in category B (62.5%, MPA networks) are equivalent to the those that are recommended for them in this study. Of this 62.5% however, only one species is afforded species-specific conservation. Similarly, more than half of the species in category C (58.3%, combination of site-scale and broad-scale measures) are receiving conservation measures that match what I recommended for them. Of the 58.3%, more than half (57.1%) meet some degree of species-specific conservation. Lastly, conservation efforts received by less than half (40%) of the species assigned to category D (broad-scale measures) concur with the strategies indicated by their conservation category; of which none of the conservation measures are species-specific. Overall, half of the threatened carpet sharks are meeting conservation measures that meet what I recommended for them, however, only 17.9% are receiving conservation measures that were implemented specifically for them.

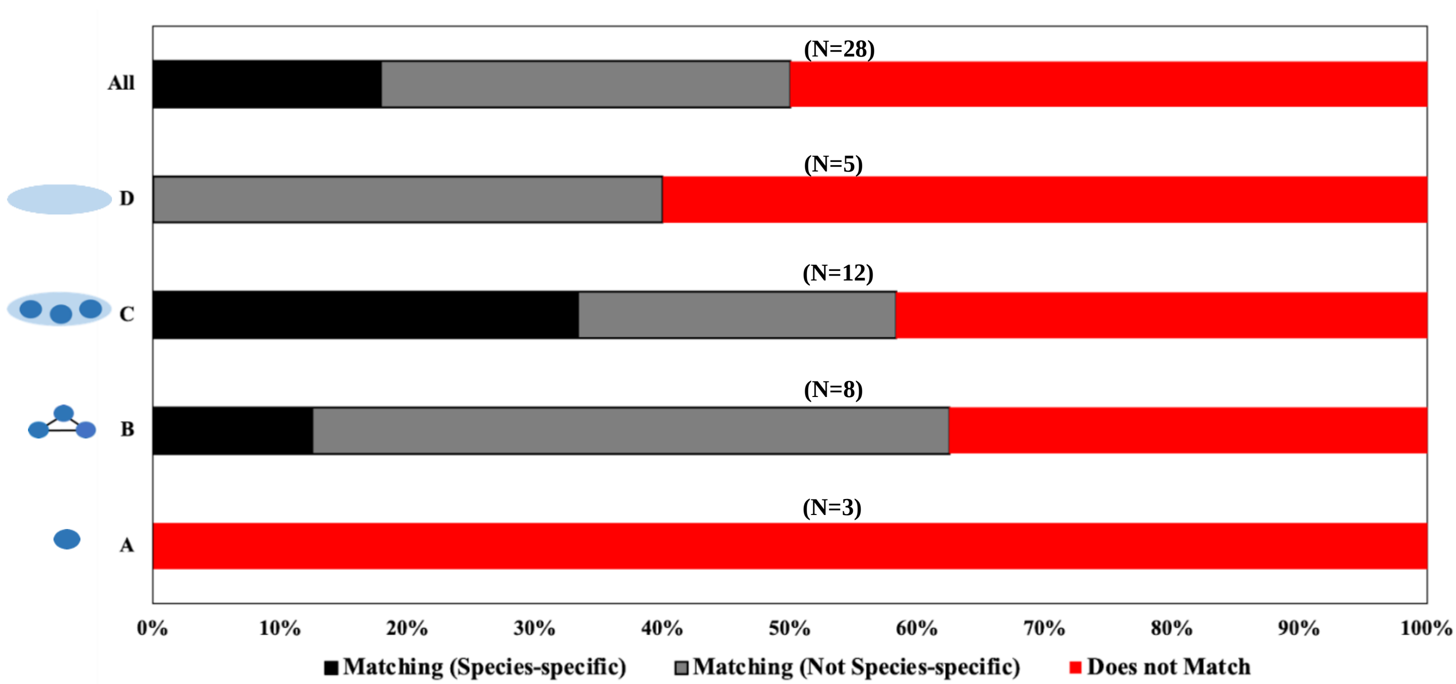

Figure 7. Conservation progress of threatened carpet sharks: percentages of carpet shark species in each of the conservation categories that are presently receiving the conservation measures that match their recommended category (species- specific=black, not species-specific=gray), in comparison to those of species that are not receiving the recommended conservation measures (red).

3.5.2 Percentage of the Species in all Threatened Carpet Shark Genera that are Presently Receiving the Conservation Measures Recommended for Them

Figure 8 illustrates the percentage of the threatened carpet shark species across all genera that are currently receiving the conservation measures that I have recommended for them. All species in four of the genera including that of the Saddle Carpet Shark (*Cirrhoscyllium japonicum*), Whale Shark (*Rhincodon typus*), Zebra Shark (*Stegostoma tigrinum*), and the Tawny Nurse Shark (*Nebrius ferrugineus*) are currently receiving the conservation measures I assessed to be most appropriate for them. Whereas only 37.5% of *Chiloscyllium*, 50% of *Ginglymostoma*, and 71.4% of *Hemiscyllium* are receiving optimum conservation measures. Lastly, none of the species in genera *Brachaelurus*, *Pseudoginglymostoma*, *Parascyllium*, or *Orectolobus* are receiving conservation measures that match what I recommended for them in this study.

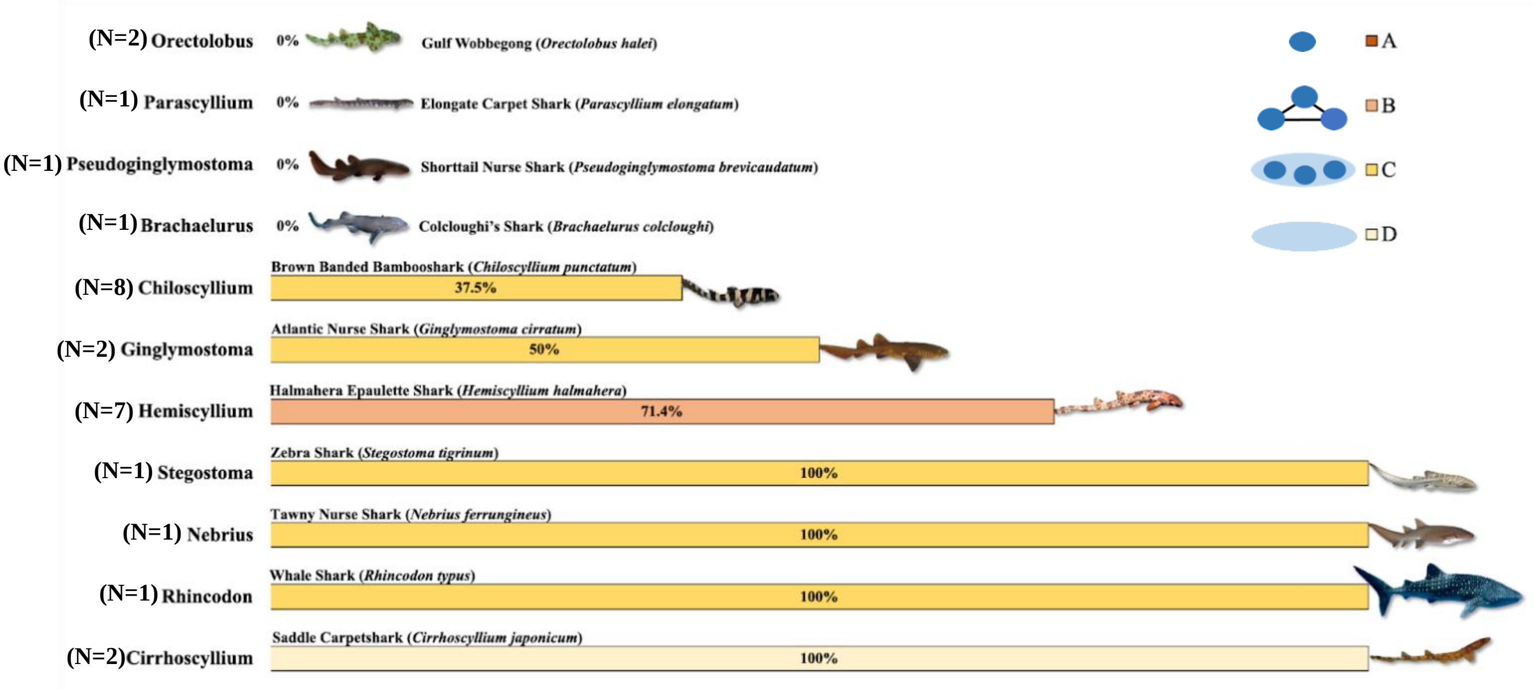

Figure 8. Conservation progress: percentages of threatened carpet shark species across all genera that are presently receiving the conservation measures that match their recommended and their category conservation categories. Species in category A (dark orange), category B (pale orange), category C (dark yellow), and category D (pale yellow). Species in category A (dark orange), category B (pale orange), category C (dark yellow), and category D (pale yellow). (Photographs are not to scale). Photographs by Creative Commons (Saddle Carpetshark), B.J. Skerry (Whale Shark), K. Marks (Tawny Nurse Shark), Georgia Aquarium (Zebra Shark), M.V. Erdmann (Halmahera Epaulette Shark), G.R. Allen (Atlantic Nurse Shark), A. Murch (Brown Banded Bambooshark), N. Marsh (Colcloughi's Shark), ORA (Shorttail Nurse Shark), Australian National Fish Collection (Elongate Carpet Shark), and D. Harasti (Gulf Wobbegong).

Chapter 4: Discussion

I found that only about a third (39.3%) of the threatened carpet sharks could potentially benefit from site protection alone (categories A and B). Whereas almost half of the species (42.9%) including the Whale Shark (*Rhincodon typus*) and Zebra Shark (*Stegostoma tigrinum*) need site protection and are "area demanding" (for significant habitats or important aggregating sites and life history events) but must also be managed at policy level in the high seas (category C) (Ebert et al., 2021; Boyd et al., 2008). I discovered therefore that the remaining threatened carpet sharks (17.9%) would not benefit from any site protection (category D) and require broad-scale measures only. Additionally, I discerned little to no correlation between the species' geographic ranges, habitat types, or threats to their populations, and the conservation categories in which they were classified. This indicates that a single biological trait or attribute of species alone cannot be used to elect the optimum conservation measures for them. Thus, an individual species and all its attributes should be considered collectively so that it can be provided with optimum conservation measures. Lastly, I observed that precisely half (50%) of the threatened carpet sharks are not meeting the conservation measures that I determined would best benefit them. These encompass all the species in the genera *Pseudoginglymostoma*, *Brachaelurus*, *Orectolobus*, and *Parascyllium* (IUCN, 2022). Moreover, the existing conservation measures met by more than half of the other 14 threatened carpet sharks (64.3%) are not "species-specific" and were not implemented with the primary objective of conserving these species (Edgar et al., 2014; IUCN, 2022). This shortcoming in the existing conservation efforts for the order Orectolobiformes is a small, yet striking representation of the situation with most species of marine fishes and sharks across the globe (IUCN, 2022, Dulvy et al., 2014).

Next, I consider the dispersal patterns of carpet sharks and how they can inform the configuration of protected networks and alternative solutions for site protection including large-scale MPAs (LSMPAs). I will then provide recommendations for prioritizing future research and data collection that can help solidify decisions made concerning the most effective conservation initiatives for all carpet sharks and other marine species.

4.1 Dispersal and Network Configuration

4.1.1 Ecological connectivity and Movement Patterns of Carpet Sharks

When discussing MPA networks and ecological connectivity, it is important to distinguish between protected networks in terrestrial versus marine environments (Carr et al., 2003). Whether a species classified in category B (MPA network) will require or benefit from implementation of ecological corridors between the protected sites in an MPA network is dependent on its biological characteristics including dispersal behaviour (Bergstrom et al., 2022). Ecological connectivity integrated between protected sites through creation of corridors is much less concrete in aquatic environments than it is on land (Carr et al., 2003). As mentioned earlier, challenges regarding species' biological traits, and the political and socio-economic capacity of nations to maintain and enforce connectivity between protected sites in the ocean make it particularly complicated to designate effective MPA networks with migratory corridors (Pendoley, 2004). In aquatic environments, species either migrate actively as adults or juveniles, or their eggs, larvae, spores, seeds, and fragments passively disperse to sustain connectivity (Bergstrom et al., 2022). For highly mobile species such as the Whale Shark that swim in the marine pelagic zone and do not disperse collectively, integrating migratory corridors that protect majority of their swimming route is difficult (Sequeira et al., 2013). Conversely, coral reef associated species such as the Halmahera Epaulette Shark *(Hemiscyllium Halmahera)* that reside in these shallow habitats are restricted to smaller areas due to their slow movement which prevents them from to dispersing across longer distances (Jutan et al., 2018). Hence, it is unclear if corridors implemented between individual sites to protect their habitats will promote demographic connectivity and mitigate impacts of habitat destruction and fragmentation on their populations.

4.1.2 Network of MPAs versus a Single Large-Scale MPA (LSMPA)

Classification of some carpet shark species such as Michael's Epaulette Shark (*Hemiscyllium michaeli*) was more straightforward, whereas narrowing down the optimum conservation category for other species in this order such as Halmahera Epaulette Shark *(Hemiscyllium halmahera)* was more challenging. Due to the latter species' biological traits and distribution of its habitats and populations, selecting between category A (single MPA) and category B (MPA network) formed a dilemma. While the six habitat locations of *H. michaeli* are distinct and distributed linearly along the coast of Papua New Guinea, the locations (1-10) of extant residents in the geographic range of *H. halmahera* (Figure 9b) are not as clear-cut and are scattered around Halmahera, Indonesia (IUCN, 2022). Therefore, I deliberated on whether this species should be protected by a network of MPAs or a single large-scale MPA (LSMPA) that would cover all or most of its geographic range. The contrast in the geographic distribution of *H. michaeli* and *H. halmahera* is exhibited with the side-by-side comparison of their geographic range maps (retrieved from their IUCN Red List Assessments) in the figure below (Figure 9).

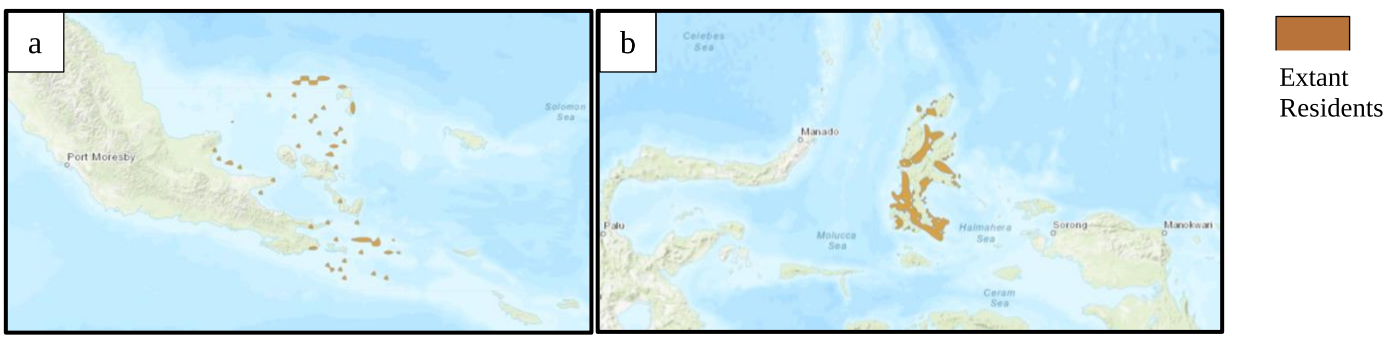

Figure 9 Geographic Range Maps of Michael's Epaulette Shark (*Hemiscyllium michaeli* = a) and Halmahera Epaulette Shark (*Hemiscyllium halmahera* = b). The distribution of extant residents is marked by the brown shading. Maps by IUCN, 2022.

IUCN defines 'large-scale MPAs' as MPAs that exceed an area of 150,000 km^2, where the entire region is protected and under active management (IUCN, 2017; Gallagher et al., 2020). Since the designation of the first LSMPA in 1975 (Great Barrier Reef Marine Park in Australia), there have been 33 LSMPAs of the same magnitude or larger implemented around the world (Toonen et al., 2013; IUCN, 2017). By covering greater expanses of the ocean this spatial management strategy can benefit species with larger geographic ranges by a) conserving significant pelagic ecosystems and critical habitats and b) protecting large portions of their migratory routes (Gallagher et al., 2020; Wilhelm et al., 2014). Although this is not the case with all LSMPAs (Magris & Pressey, 2018).

There are four main challenges regarding the current implementation of LSMPAs. Firstly, global threats such as climate change and marine pollution cannot be mitigated by MPAs (Wilhelm et al., 2014). For example, the remote Motu Motiro Hiva Marine Park around Easter Island, centred in the South Pacific Subtropical Gyre collects debris and microplastics from the

South Pacific Rim (Wilhelm et al., 2014). Another criticism of LSMPAs is that successful protected areas can displace fishing effort and concentrate it outside the boundaries of the protected area (Wilhelm et al., 2014). As a result, the MPA could have a larger negative cumulative impact on the vulnerable marine ecosystem than prior to its designation (Kaplan, 2013). This was observed in the case of over exploited tropical tuna stocks in the Indian Ocean's large marine reserves (Wilhelm et al., 2014; Kaplan, 2010). Furthermore, some authors speculate that LSMPAs can become a target for IUU (illegal, unreported, and unregulated) fishing activities due to the higher biomass of fish inside the MPA (Wilhelm et al., 2014). Lastly, to expand the overall percent coverage of protected areas to meet their international commitments, nations' focus has been on increasing the designation of these super-sized MPAs, LSMPAs which have largely become paper parks (Friedlander et al., 2016). Yet, in spite of these efforts to meet the Aichi target of protecting 10% of the marine area by 2020, the median size of MPAs was ~2 km^2 in 2017 and remains smaller than 10 km^2 in 2022 (Novaczek et al., 2017; unpublished data based on the PP). Consequently, the scale of MPA protection is unlikely to encompass a significant fraction of many species' geographic ranges. For example, Agardy et al. argued that despite covering an area of 344,400 km^2, the Great Barrier Reef Marine Park is inadequate for protecting the leatherback sea turtle as it does not cover all the critical habitat areas for the species (Agardy et al., 2011).

The effectiveness and feasibility of the conservation initiatives provided for *H. halmahera* from the two debated options for site protection (single LSMPA or MPA networks) depend on a) the socio-economic capacity and geo-political realities of the nation (Indonesia) responsible for the designation and enforcement of the site protection (IUCN, 2022; Wilhelm et al., 2014; Davidson & Dulvy, 2017) and b) the minimum viable population of this species that must be encompassed by the protected sites to effectively conserve and replenish its populations (Allison et al., 1998). Additionally, the presence of different stakeholders (e.g., fisheries) with varying types and degrees of reliance on the areas within the geographic range of the carpet shark can influence the practicality and ultimate choice between the two types of site protection (Pita et al., 2020). I discuss the minimum viable population of species and other significant species-specific characteristics, that can affect our decisions regarding appropriate conservation strategies in the following section.

4.2 Recommendations for Priority Data Collection

For several species of carpet sharks such as the Shorttail Nurse Shark (*Pseudoginglymostoma brevicaudatum*) that are connected to sites (coastal habitats) and are threatened by habitat loss (site-scale threats), but whose geographic ranges are too big (*P. brevicaudatum* = 62,786 km^2) to be conserved by protected areas I also asked: can the species still be placed in an MPA network if it protects most, but not all its population and habitat? (IUCN, 2022) If so, what is the minimum percentage of the population that must be encompassed by the protected sites for the MPA network to be effective in preserving the species' population and mitigating the risk of extinction? Uncovering the minimum viable population for these species of carpet shark is essential for answering these questions and must be prioritised during future research on these marine species (Hilborn et al., 2004; Allison et al., 1998). Knowledge of minimum viable population of species can also aid with assessing the efficacy of conservation measures and the best strategies monitoring it (Hilborn et al., 2004).

Another significant data gap for Orectolobiformes is their AOO, given that information on AOO of only six of the carpet sharks was available for our study. The geographic ranges of all three species placed in category A (single MPA) exceed the global median size of single MPAs (172 km^2, 375 km^2, 1,736 km^2); yet these species had the smallest geographic ranges amongst all the other carpet sharks (IUCN). I assumed therefore that their AOO and range of habitat they rely on would be even smaller and could potentially be protected by a single site. However, learning this key attribute of these species could prompt us to change the classification of these three species or any of the other threatened carpet sharks.

Addressing the data uncertainty concerning other attributes of carpet sharks including their habitat types, aggregatory behaviour, and degree of threats to their populations, can also help better inform the status of these species' population, and possibly result in a change of their IUCN Red List Assessment. From the 45 species of carpet sharks, the species listed on the IUCN Red List as 'Least Concern' (LC) were not included in our calculations and results. Nonetheless, given the lack or outdatedness of the available data for most carpet sharks and marine species and their populations, I classified these 17 sharks to get an idea of what conservation measures would best benefit them if they were to become endangered. For example, the status of the Speckled carpet shark (*Hemiscyllium trispeculare*) was last assessed in 2015 as LC, yet while the species is considered to be at minimal risk from fishing pressure in Australian waters, threat levels to the species are not known in Indonesian waters (IUCN, 2022). These species are suspected to be at risk of unsustainable fishing practices and habitat destruction in these waters (IUCN, 2022).

To tackle the data insufficiency on some of the key species-specific attributes of the carpet shark species listed as Data Deficient (DD) such as the Elongate Carpet Shark (*Parascyllium elongatum*), as well as several of the threatened species, these species were also classified into a secondary conservation category. *P. elongatum* was classified into category A (single MPA), but category B (MPA network) was elected as its secondary category, so that if a single MPA would not adequately cover the species' geographic range, a network of multiple protected sites can instead be an efficient conservation alternative for the species. Considering alternative conservation strategies for carpet sharks and all other marine species which are missing information on many of their biological traits and life-history characteristics can be viewed as adaptive management or preparation against unforeseen and rapid declines to their populations (Katsanevakis et al., 2020). Nevertheless, efforts must be placed towards prioritizing collection of data on the missing key attributes of these species to ensure their effective conservation.

Chapter 5: Conclusions

Here, I demonstrate that protected areas alone can be useful conservation tools for only a small portion of the carpet sharks (39.4%). They cannot be our solution for protecting all of them; given that more than half of sharks would require either a combination of site-scale and broad-scale initiatives (42.9%) or broad-scale initiatives such as fisheries management only (17.9%). These findings contrast with the findings of Boyd et al. (2008)'s analysis of mainly terrestrial vertebrates, which concluded that more than 99% of the globally threatened tetrapods require site protection as the main strategy for their conservation (Boyd et al., 2008). Second, while different species in the same order or genus might have multiple attributes in common such as their geographic range, habitat type, or threats to their population, this will not necessarily mean that they will benefit from the same conservation strategy. This was supported by the random relationship observed between these three attributes of the threatened carpet sharks and their conservation category. Furthermore, the conservation strategy implemented for carpet shark species can differ depending on the economic and political capacity of the nation whose waters they inhabit. Hence, we must tailor conservation measures for each marine species by individually considering their ecological, physiological, and behavioural traits, and with regard to their geographic distribution. To remove the gap in available data on most species of carpet sharks, the focus of scientific research and funding must be reallocated to the less charismatic, under-represented, and minimally studied species so that appropriate conservation measures can be implemented before their populations are depleted beyond the possibility of recovery. Nonetheless, to mitigate extinction risk and further loss of biodiversity, and to ensure the progression of effective conservation measures, policymakers and scientists must make prompt decisions for the threatened carpet sharks and all other marine species. Governing bodies and experts must therefore produce robust frameworks to help make decisions, despite the present data deficiency.

References

A. Pardo, S., & Dulvy, N. K. (2022). Body mass, temperature, and depth shape the maximum intrinsic rate of population increase in sharks and Rays. https://doi.org/10.1101/2021.03.02.433372

Abesamis, R. A., Acala, A. C., & Russ, G. R. (2006). How much does the Fishery at Apo Island Benefit from Spillover of Adult Fish from the Adjacent Marine Reserve? *Fishery Bulletin*, *104*(3), 360–375.

Agardy, T., di Sciara, G. N., & Christie, P. (2011). Mind the gap: Addressing the shortcomings of marine protected areas through large scale Marine Spatial Planning. *Marine Policy*, *35*(2), 226–232. https://doi.org/10.1016/j.marpol.2010.10.006

Alcala, A. C., Russ, G. R., Maypa, A. P., & Calumpong, H. P. (2005). A long-term, spatially replicated experimental test of the effect of marine reserves on local fish yields. *Canadian Journal of Fisheries and Aquatic Sciences*, *62*(1), 98–108. https://doi.org/10.1139/f04-176

Allison, G. W., Lubchenco, J., & Carr, M. H. (1998). Marine reserves are necessary but not sufficient for marine conservation. *Ecological Applications*, *8*(1). https://doi.org/10.2307/2641365

Andrews, S. Migratory species - and Marine Protected Areas. Retrieved from https://www.oceanoculus.com/news-from-the-sea/migratory-species-marine-protected-areas

Arthington, A. H., Dulvy, N. K., Gladstone, W., & Winfield, I. J. (2016). Fish conservation in freshwater and marine realms: Status, Threats and Management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*(5), 838–857. https://doi.org/10.1002/aqc.2712

Berkström, C., Wennerström, L., & Bergström, U. (2022). Ecological connectivity of the Marine Protected Area Network in the Baltic Sea, Kattegat and Skagerrak: Current knowledge and management needs. *Ambio*, *51*(6), 1485–1503. https://doi.org/10.1007/s13280-021-01684-x

Bland, L., & Collen, B. (2016). Species loss: Lack of data leaves a gap. *Nature*, *537*(7621), 488–488. https://doi.org/10.1038/537488c

Boyd, C., Brooks, T. M., Butchart, S. H., Edgar, G. J., Da Fonseca, G. A., Hawkins, F., Hoffmann, M., Sechrest, W., Stuart, S. N., & Van Dijk, P. P. (2008). Spatial scale and the conservation of threatened species. *Conservation Letters*, *1*(1), 37–43. https://doi.org/10.1111/j.1755-263x.2008.00002.x

Butchart, S. H. M., Clarke, M., Smith, R. J., Sykes, R. E., Scharlemann, J. P. W., Harfoot, M., Buchanan, G. M., Angulo, A., Balmford, A., Bertzky, B., Brooks, T. M., Carpenter, K. E., Comeros-Raynal, M. T., Cornell, J., Ficetola, G. F., Fishpool, L. D. C., Fuller, R. A., Geldmann, J., Harwell, H., … Burgess, N. D. (2015). Shortfalls and solutions for meeting national and Global Conservation Area targets. *Conservation Letters*, *8*(5), 329–337. https://doi.org/10.1111/conl.12158

Carr, M. H., Neigel, J. E., Estes, J. A., Andelman, S., Warner, R. R., & Largier, J. L. (2003). Comparing marine and terrestrial ecosystems: Implications for the design of Coastal Marine Reserves. *Ecological Applications*, *13*(sp1), 90–107. https://doi.org/10.1890/1051-0761(2003)013[0090:cmatei]2.0.co;2

Cannizzo, Z., Wahle, C., & Wenzel, L. (2020). *Ecological Connectivity for Marine Protected Areas*. Marine Protected Areas.

Chapin III, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., Hobbie, S. E., Mack, M. C., & Díaz, S. (2000). Consequences of changing biodiversity. *Nature*, *405*(6783), 234–242. https://doi.org/10.1038/35012241

Claudet, J., Osenberg, C. W., Domenici, P., Badalamenti, F., Milazzo, M., Falcón, J. M., Bertocci, I., Benedetti-Cecchi, L., García-Charton, J.-A., Goñi, R., Borg, J. A., Forcada, A., de Lucia, G. A., Pérez-Ruzafa, Á., Afonso, P., Brito, A., Guala, I., Diréach, L. L., Sanchez-Jerez, P., … Planes, S. (2010). Marine reserves: Fish life history and ecological traits matter. *Ecological Applications*, *20*(3), 830–839. https://doi.org/10.1890/08-2131.1

Cortés, E. (2000). Life history patterns and correlations in sharks. *Reviews in Fisheries Science*, *8*(4), 299–344. https://doi.org/10.1080/10641260008951115

Davidson, L. N., & Dulvy, N. K. (2017). Global Marine Protected Areas to prevent extinctions. *Nature Ecology & Evolution*, *1*(2). https://doi.org/10.1038/s41559-016-0040

Davidson, L. N., Krawchuk, M. A., & Dulvy, N. K. (2015). Why have global shark and Ray landings declined: Improved Management or overfishing? *Fish and Fisheries*, *17*(2), 438–458. https://doi.org/10.1111/faf.12119

de la Parra Venegas, R., Hueter, R., González Cano, J., Tyminski, J., Gregorio Remolina, J., Maslanka, M., Ormos, A., Weigt, L., Carlson, B., & Dove, A. (2011). An unprecedented aggregation of whale sharks, Rhincodon typus, in Mexican coastal waters of the Caribbean Sea. *PLoS ONE*, *6*(4). https://doi.org/10.1371/journal.pone.0018994

Dehens, L. A., & Fanning, L. M. (2018). What counts in making Marine Protected Areas (mpas) count? the role of legitimacy in MPA success in Canada. *Ecological Indicators*, *86*, 45–57. https://doi.org/10.1016/j.ecolind.2017.12.026

Dinmore, T. A., Duplisea, D. E., Rackham, B. D., Maxwell, D. L., & Jennings, S. (2003). Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities. *ICES Journal of Marine Science*, *60*(2), 371–380. https://doi.org/10.1016/s1054-3139(03)00010-9

Dudgeon, C. L., Noad, M. J., & Lanyon, J. M. (2008). Abundance and demography of a seasonal aggregation of Zebra Sharks Stegostoma fasciatum. *Marine Ecology Progress Series*, *368*, 269–281. https://doi.org/10.3354/meps07581

Dulvy, N. K. (2013). Super-sized mpas and the marginalization of species conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *23*(3), 357–362. https://doi.org/10.1002/aqc.2358

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., Carlson, J. K., Davidson, L. N. K., Fordham, S. V., Francis, M. P., Pollock, C. M., Simpfendorfer, C. A., Burgess, G. H., Carpenter, K. E., Compagno, L. J. V., Ebert, D. A., Gibson, C., Heupel, M. R., Livingstone, S. R., … White, W. T. (2014). Extinction risk and conservation of the world's sharks and Rays. *ELife*, *3*. https://doi.org/10.7554/elife.00590

Dulvy, N. K., Pacoureau, N., Rigby, C. L., Pollom, R. A., Jabado, R. W., Ebert, D. A., Finucci, B., Pollock, C. M., Cheok, J., Derrick, D. H., Herman, K. B., Sherman, C. S., VanderWright, W. J., Lawson, J. M., Walls, R. H. L., Carlson, J. K., Charvet, P., Bineesh, K. K., Fernando, D., … Simpfendorfer, C. A. (2021). Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. *Current Biology*, *31*(21). https://doi.org/10.1016/j.cub.2021.08.062

Dulvy, N. K., Sadovy, Y., & Reynolds, J. D. (2003). Extinction vulnerability in marine populations. *Fish and Fisheries*, *4*(1), 25–64. https://doi.org/10.1046/j.1467-2979.2003.00105.x

Ebert, D. A., Dando, M., & Fowler, S. L. (2021). *Sharks of the world a complete guide*. Princeton University Press.

Edgar, G. J., Stuart-Smith, R. D., Willis, T. J., Kininmonth, S., Baker, S. C., Banks, S., Barrett, N. S., Becerro, M. A., Bernard, A. T., Berkhout, J., Buxton, C. D., Campbell, S. J., Cooper, A. T., Davey, M., Edgar, S. C., Försterra, G., Galván, D. E., Irigoyen, A. J., Kushner, D. J., … Thomson, R. J. (2014). Global conservation outcomes depend on marine protected areas with five key features. *Nature*, *506*(7487), 216–220. https://doi.org/10.1038/nature13022

Ewell, C., Hocevar, J., Mitchell, E., Snowden, S., & Jacquet, J. (2020). An evaluation of regional fisheries management organization AT-sea compliance monitoring and observer programs. *Marine Policy*, *115*, 103842. https://doi.org/10.1016/j.marpol.2020.103842

Friedlander, A. M., Wagner, D., Gaymer, C. F., Wilhelm, T. 'A., Lewis, N. A., Brooke, S., Kikiloi, K., & Varmer, O. (2016). Co-operation between large-scale mpas: Successful experiences from the Pacific Ocean. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *26*, 126–141. https://doi.org/10.1002/aqc.2645

Gallagher, A. J., Amon, D. J., Bervoets, T., Shipley, O. N., Hammerschlag, N., & Sims, D. W. (2020). The caribbean needs big marine protected areas. *Science*, *367*(6479), 749–749. https://doi.org/10.1126/science.abb0650

Game, E. T., Grantham, H. S., Hobday, A. J., Pressey, R. L., Lombard, A. T., Beckley, L. E., Gjerde, K., Bustamante, R., Possingham, H. P., & Richardson, A. J. (2009). Pelagic protected areas: The missing dimension in ocean conservation. *Trends in Ecology & Evolution*, *24*(7), 360–369. https://doi.org/10.1016/j.tree.2009.01.011

Grip, K. (2016). International Marine Environmental Governance: A Review. *Ambio*, *46*(4), 413–427. https://doi.org/10.1007/s13280-016-0847-9

Grorud-Colvert, K., Sullivan-Stack, J., Roberts, C., Constant, V., Horta e Costa, B., Pike, E. P., Kingston, N., Laffoley, D., Sala, E., Claudet, J., Friedlander, A. M., Gill, D. A., Lester, S. E., Day, J. C., Gonçalves, E. J., Ahmadia, G. N., Rand, M., Villagomez, A., Ban, N. C., … Lubchenco, J. (2021). The MPA Guide: A framework to achieve global goals for the Ocean. *Science*, *373*(6560). https://doi.org/10.1126/science.abf0861

Heidrich, K. N., Juan-Jordá, M. J., Murua, H., Thompson, C. D., Meeuwig, J. J., & Zeller, D. (2022). Assessing progress in data reporting by Tuna Regional Fisheries Management Organizations. *Fish and Fisheries*, *23*(6), 1264–1281. https://doi.org/10.1111/faf.12687

Hilborn, R., Amoroso, R. O., Anderson, C. M., Baum, J. K., Branch, T. A., Costello, C., de Moor, C. L., Faraj, A., Hively, D., Jensen, O. P., Kurota, H., Little, L. R., Mace, P., McClanahan, T., Melnychuk, M. C., Minto, C., Osio, G. C., Parma, A. M., Pons, M., … Ye, Y. (2020). Effective fisheries management instrumental in improving fish stock status. *Proceedings of the National Academy of Sciences*, *117*(4), 2218–2224. https://doi.org/10.1073/pnas.1909726116

Hilborn, R., Stokes, K., Maguire, J.-J., Smith, T., Botsford, L. W., Mangel, M., Orensanz, J., Parma, A., Rice, J., Bell, J., Cochrane, K. L., Garcia, S., Hall, S. J., Kirkwood, G. P., Sainsbury, K., Stefansson, G., & Walters, C. (2004). When can marine reserves improve fisheries management? *Ocean & Coastal Management*, *47*(3-4), 197–205. https://doi.org/10.1016/j.ocecoaman.2004.04.001

Hutchings, J. A., & Reynolds, J. D. (2004). Marine fish population collapses: Consequences for recovery and extinction risk. *BioScience*, *54*(4), 297. https://doi.org/10.1641/0006-3568(2004)054[0297:mfpccf]2.0.co;2

IUCN. (2017, December 13). *Large-scale Marine Protected Areas: Guidelines for Design and Management*. IUCN. Retrieved from https://www.iucn.org/news/protected-areas/201712/large-scale-marine-protected-areas-guidelines-design-and-management

IUCN red list of threatened species. IUCN. (2022, November 1). Retrieved from https://www.iucn.org/resources/conservation-tool/iucn-red-list-threatened-species

IUCN The World Conservation Union. (2001). *Iucn red list categories and criteria: Version 3.1: As approved by the 51st meeting of the Iucn Council Gland, Switzerland: 9 February 2000*.

Juan-Jordá, M. J., Murua, H., Arrizabalaga, H., Merino, G., Pacoureau, N., & Dulvy, N. K. (2022). Seventy years of Tunas, billfishes, and sharks as sentinels of global ocean health. *Science*, *378*(6620). https://doi.org/10.1126/science.abj0211

Jutan, Y., Retraubun, A. S. W., Khouw, A. S., Nikijuluw, V. P. H., & Pattikawa, J. A. (2018). Study on the population of Halmahera walking shark (Hemiscyllium halmahera) in kao bay, north maluku, Indonesia. *International Journal of Fisheries and Aquatic Studies*, *6*(4), 36–41.

Kaiser, M. J. (2005). Are marine protected areas a red herring or fisheries panacea? *Canadian Journal of Fisheries and Aquatic Sciences*, *62*(5), 1194–1199. https://doi.org/10.1139/f05-056

Kaplan, D. M., Chassot, E., Gruss, A., & Fonteneau, A. (2010). Pelagic mpas: The devil is in the details. *Trends in Ecology & Evolution*, *25*(2), 62–63. https://doi.org/10.1016/j.tree.2009.09.003

Katsanevakis, S., Coll, M., Fraschetti, S., Giakoumi, S., Goldsborough, D., Mačić, V., Mackelworth, P., Rilov, G., Stelzenmüller, V., Albano, P. G., Bates, A. E., Bevilacqua, S., Gissi, E., Hermoso, V., Mazaris, A. D., Pita, C., Rossi, V., Teff-Seker, Y., & Yates, K. (2020). Twelve recommendations for Advancing Marine Conservation in European and Contiguous Seas. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.565968

Magris, R. A., & Pressey, R. L. (2018). Marine Protected Areas: Just for show? *Science*, *360*(6390), 723–724. https://doi.org/10.1126/science.aat6215

Maxwell, S. M., Hazen, E. L., Lewison, R. L., Dunn, D. C., Bailey, H., Bograd, S. J., Briscoe, D. K., Fossette, S., Hobday, A. J., Bennett, M., Benson, S., Caldwell, M. R., Costa, D. P., Dewar, H., Eguchi, T., Hazen, L., Kohin, S., Sippel, T., & Crowder, L. B. (2015). Dynamic Ocean Management: Defining and conceptualizing real-time management of the Ocean. *Marine Policy*, *58*, 42–50. https://doi.org/10.1016/j.marpol.2015.03.014

McClenachan, L., Cooper, A. B., Carpenter, K. E., & Dulvy, N. K. (2012). Extinction risk and bottlenecks in the conservation of Charismatic Marine Species. *Conservation Letters*, *5*(1), 73–80. https://doi.org/10.1111/j.1755-263x.2011.00206.x

Miranda, R., Miqueleiz, I., Darwall, W., Sayer, C., Dulvy, N. K., Carpenter, K. E., Polidoro, B., Dewhurst-Richman, N., Pollock, C., Hilton-Taylor, C., Freeman, R., Collen, B., & Böhm, M. (2022). Monitoring extinction risk and threats of the world's fishes based on the sampled Red List Index. *Reviews in Fish Biology and Fisheries*, *32*(3), 975–991. https://doi.org/10.1007/s11160-022-09710-1

Murawski, S. A., Wigley, S. E., Fogarty, M. J., Rago, P. J., & Mountain, D. G. (2005). Effort distribution and catch patterns adjacent to temperate mpas. *ICES Journal of Marine Science*, *62*(6), 1150–1167. https://doi.org/10.1016/j.icesjms.2005.04.005

Musick, J. A., Berkeley, S. A., Cailliet, G. M., Camhi, M., Huntsman, G., Nammack, M., & Warren, M. L. (2011). Protection of marine fish stocks at risk of extinction. *Fisheries*, *25*(3), 6–8. https://doi.org/10.1577/1548-8446(2000)025<0006:pomfsa>2.0.co;2

Musick, J. A., Harbin, M. M., Berkeley, S. A., Burgess, G. H., Eklund, A. M., Findley, L., Gilmore, R. G., Golden, J. T., Ha, D. S., Huntsman, G. R., McGovern, J. C., Sedberry, G. R., Parker, S. J., Poss, S. G., Sala, E., Schmidt, T. W., Weeks, H., & Wright, S. G. (2000). Marine, estuarine, and diadromous fish stocks at risk of extinction in North America (exclusive of Pacific Salmonids). *Fisheries*, *25*(11), 6–30. https://doi.org/10.1577/1548-8446(2000)025<0006:meadfs>2.0.co;2

Novaczek, E., Howse, V., Pretty, C., Devillers, R., Edinger, E., & Copeland, A. (2017). Limited contribution of small marine protected areas to regional biodiversity: The example of a small Canadian no-take MPA. *Frontiers in Marine Science*, *4*. https://doi.org/10.3389/fmars.2017.00174

Oberle, D. B. (2022). *Home Page*. IUCN. Retrieved from https://www.iucn.org/

Pacoureau, N., Rigby, C. L., Kyne, P. M., Sherley, R. B., Winker, H., Carlson, J. K., Fordham, S. V., Barreto, R., Fernando, D., Francis, M. P., Jabado, R. W., Herman, K. B., Liu, K.-M., Marshall, A. D., Pollom, R. A., Romanov, E. V., Simpfendorfer, C. A., Yin, J. S., Kindsvater, H. K., & Dulvy, N. K. (2021). Half a century of global decline in oceanic sharks and Rays. *Nature*, *589*(7843), 567–571. https://doi.org/10.1038/s41586-020-03173-9

Pendoley, K. L., Schofield, G., Whittock, P. A., Ierodiaconou, D., & Hays, G. C. (2014). Protected species use of a coastal marine migratory corridor connecting Marine Protected Areas. *Marine Biology*, *161*(6), 1455–1466. https://doi.org/10.1007/s00227-014-2433-7

Pita, C., Horta e Costa, B., Franco, G., Coelho, R., Sousa, I., Gonçalves, E. J., Gonçalves, J. M. S., & Erzini, K. (2020). Fisher's perceptions about a marine protected area over time. *Aquaculture and Fisheries*, *5*(5), 273–281. https://doi.org/10.1016/j.aaf.2020.01.005

Pressey, B. (2013). Australia’s new marine protected areas: why they won't work [web log].

Pytka, J., & Pauly, A. (n.d.). *The Convention on Migratory Species and Sharks*. IUCN SSC Shark Specialist Group. Retrieved from https://www.iucnssg.org/cms.html

Reynolds, J. D., Dulvy, N. K., Goodwin, N. B., & Hutchings, J. A. (2005). Biology of Extinction Risk in marine fishes. *Proceedings of the Royal Society B: Biological Sciences*, *272*(1579), 2337–2344. https://doi.org/10.1098/rspb.2005.3281

Schoeman, R. P., Patterson-Abrolat, C., & Plön, S. (2020). A global review of vessel collisions with Marine Animals. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00292

Selig, E. R., Turner, W. R., Troëng, S., Wallace, B. P., Halpern, B. S., Kaschner, K., Lascelles, B. G., Carpenter, K. E., & Mittermeier, R. A. (2014). Global priorities for marine biodiversity conservation. *PLoS ONE*, *9*(1). https://doi.org/10.1371/journal.pone.0082898

Sequeira, A. M., Mellin, C., Meekan, M. G., Sims, D. W., & Bradshaw, C. J. (2013). Inferred global connectivity of whale shark *rhincodon typus* populations. *Journal of Fish Biology*, *82*(2), 367–389. https://doi.org/10.1111/jfb.12017

Shiffman, D. S., Macdonald, C. C., Wester, J. N., Walsh, M. B., Chevalier, A., Kachelriess, D., & Friedman, K. J. (2021). Marine Species Conservation at CITES: How does media coverage inform or misinform? *Marine Policy*, *134*, 104813. https://doi.org/10.1016/j.marpol.2021.104813

Simpfendorfer, C. A., & Dulvy, N. K. (2017). Bright spots of sustainable shark fishing. *Current Biology*, *27*(3). https://doi.org/10.1016/j.cub.2016.12.017

Toonen, R. J., Wilhelm, T. ‘A., Maxwell, S. M., Wagner, D., Bowen, B. W., Sheppard, C. R. C., Taei, S. M., Teroroko, T., Moffitt, R., Gaymer, C. F., Morgan, L., Lewis, N., Sheppard, A. L. S., Parks, J., & Friedlander, A. M. (2013). One size does not fit all: The emerging frontier in large-scale marine conservation. *Marine Pollution Bulletin*, *77*(1-2), 7–10. https://doi.org/10.1016/j.marpolbul.2013.10.039

Vincent, A. C., Sadovy de Mitcheson, Y. J., Fowler, S. L., & Lieberman, S. (2013). The role of CITES in the conservation of marine fishes subject to international trade. *Fish and Fisheries*, *15*(4), 563–592. https://doi.org/10.1111/faf.12035

Vitousek, P. M., Mooney, H. A., Lubchenco, J., & Melillo, J. M. (1997). Human domination of Earth’s ecosystems. *Urban Ecology*, 3–13. https://doi.org/10.1007/978-0-387-73412-5_1

Ward, T. J., Heinemann, D., & Evans, N. (2001). *The role of Marine Reserves as Fisheries Management Tools: A review of concepts, evidence and international experience*. Bureau of Rural Sciences.

Wilhelm, T. 'A., Sheppard, C. R., Sheppard, A. L., Gaymer, C. F., Parks, J., Wagner, D., & Lewis, N. (2014). Large marine protected areas - advantages and challenges of going big. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *24*(S2), 24–30. https://doi.org/10.1002/aqc.2499

Womersley, F. C., Humphries, N. E., Queiroz, N., Vedor, M., da Costa, I., Furtado, M., Tyminski, J. P., Abrantes, K., Araujo, G., Bach, S. S., Barnett, A., Berumen, M. L., Bessudo Lion, S., Braun, C. D., Clingham, E., Cochran, J. E. M., de la Parra, R., Diamant, S., Dove, A. D. M., . . . Sims, D. W. (2022). Global collision-risk hotspots of marine traffic and the world’s largest fish, the whale shark. *Proceedings of the National Academy of Sciences*, *119*(20). https://doi.org/10.1073/pnas.2117440119

Worm, B., Davis, B., Kettemer, L., Ward-Paige, C. A., Chapman, D., Heithaus, M. R., Kessel, S. T., & Gruber, S. H. (2013). Global catches, exploitation rates, and rebuilding options for Sharks. *Marine Policy*, *40*, 194–204. https://doi.org/10.1016/j.marpol.2012.12.034 '

Appendix I

Table 1. Key and secondary species-specific attributes used for classification of the threatened carpet shark into the four conservation categories.

Key Attributes	Definition/Additional Information
Geographic Range	The geographic area that incorporates the entirety of the range of the species. Data obtained using IUCN Red List's calculations from the species' range maps. Measurements are in sq/km. (IUCN, 2022)
Area of Occupancy (AOO)	IUCN defines AOO as: "the area within a species' extent of occurrence, which is occupied by a taxon, excluding cases of vagrancy" (IUCN, 2022). Measurements are in sq/km. The AOO of the species is the smallest area of its geographic range that is required at any stage for the survival of its extant population (IUCN, 2001)
Number of Locations	IUCN defines 'location' as a geographically or ecologically distinct area in which a single threatening event can rapidly affect all individuals of the taxon present (IUCN, 2022). Species' populations and habitats are either spread into multiple locations or not.
Habitat Type	The area or environment that the organism resides in naturally. Habitats of carpet sharks were categorized into three main types: (1) coastal (e.g., coral reefs, mangroves, seagrass beds, shallow rocky outcrops, etc.), (2) oceanic/pelagic, and (3) deep water (mostly soft sediments)
Aggregatory Behaviour	IUCN defines aggregation as "A geographically restricted clustering of individuals that typically occurs during a specific life history stage or process such as breeding, feeding or migration. This clustering is indicated by highly localized relative abundance, two or more orders of magnitude larger than the species' average recorded numbers or densities at other stages during its life-cycle." (IUCN, 2022). Species either have aggregations or no aggregation.
Migratory Behaviour	"The entire population or any geographically separate part of the population of any species or lower taxon of wild animals, a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries" (Pytka & Pauly). Species are either migratory or not migratory.
Threat Type	IUCN defines direct threats as "the proximate human activities or processes that have impacted, are impacting, or may impact the status of the taxon". "Direct threats are synonymous with sources of stress and proximate pressures." "Threats can be past (historical, unlikely to return or historical, likely to return), ongoing, and/or likely to occur in the future." (IUCN, 2022). Threats to carpet sharks were categorized into three main types: (1) site-scale, (2) broad-scale, and (3) both site-scale and broad-scale.

Secondary Attributes	Definition/Additional Information
Existing Conservation Measures	This includes any species-specific conservation measures implemented for carpet shark species as well as those implemented for other purposes that the shark can also benefit from. This includes any site-scale protection (e.g., MPAs and MPA networks) and Broad-Scale Measures (e.g., Fisheries regulations)