A Review of Fishery Interactions, Conservation and Management Tools, and the Necessity of Research for Further Conservation of Mobulid Species, with a Focus on Manta Rays

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Abstract

Manta rays and devil rays, known as mobulids, are classified in the Mobulidae family. There are two species of manta ray: *Mobula birostris*, the oceanic manta ray, and *Mobula alfredi*, the reef manta ray. They are found in pelagic, offshore marine habitats in tropical and subtropical waters. There is little research on these species, with the oceanic manta ray being less studied. Research has been improving due to concern about fishery interactions; bycatch, entanglement, and gill plate harvesting are the greatest threats to mobulid species (Stewart et al., 2018). Mobulids are highly susceptible to these threats since they are a K-selected species (low fecundity, matrotrophic reproduction, large size at birth, slow growth rates, late maturity, and longevity) (Fernando and Stewart, 2021). As a result, conservation efforts are needed. Oceanic manta rays were thought to be highly migratory but display a high degree of residency like reef manta rays. This allows conservationists to protect their range by establishing marine protected areas (MPAs) (Stewart et al., 2016a). Manta rays tend to feed at coastal, surface waters during the day and deeper, offshore waters at night. Oceanic manta rays are found at the surface in April and May and in deeper waters from June to September, which can allow for restrictions and limitations on fishing when manta rays are present (Stewart et al., 2016b). Enforcement and gill net limitations are necessary to prevent bycatch (Fernando and Stewart, 2021). Gill plate fisheries need to be managed and enforced as most places illegally purchase and export gill plates (O'Malley et al., 2017). To make conservation successful, more research needs to be done. Research on genetic diversity is key to understanding population dynamics. In addition, research focusing on the impacts on mobulids from bycatch is imperative as the survival rate of mobulids is low once they are captured. By researching these species and working with conservation agencies, management plans can be implemented to reduce the mortality of mobulid species (Stewart et al., 2018).

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Introduction

Manta rays and devil rays belong to the family Mobulidae and are known collectively as mobulids. They were previously thought to be separate families, but due to genetic similarities, are now considered one family (Stewart et al., 2018). There are currently two species of manta ray within this family: *Mobula birostris*, the oceanic manta ray, and *Mobula alfredi*, the reef manta ray. There is a debate about a third species: *Mobula. cf. birostris*, the Caribbean manta ray, which is currently a subspecies of the oceanic manta ray (Stewart et al., 2018). These filter-feeding species are found globally in subtropical and tropical waters, specifically inhabiting colder, pelagic, upwelled regions and are often found near seamounts and oceanic islands. These species are primarily understudied, with the oceanic manta ray being the least studied; not much is known about the oceanic manta ray such as its natural history, ecology, and behavior, making conservation difficult (Stewart et al., 2016b). Recent studies on manta rays have focused on movements, feeding ecology, courtship, and mating (Fernando and Stewart, 2021). Significant progress has been made in understanding the biology and ecology of mobulids. This data has determined that fishery interactions are the greatest threat to mobulids, specifically being caught as bycatch, becoming entangled, and being harvested for their gill plates (Fernando and Stewart, 2021; Stewart et al., 2018).

Fishery interactions

The greatest contributors to direct mortality of mobulids are targeted and bycatch fisheries. Many target species, such as tuna, aggregate in the tropics and subtropics, overlapping with mobulid habitats. This attracts many fisheries to these areas, increasing the chance of mobulid bycatch; they can get caught in almost every type of fishing gear including drift nets, gill nets, traps, trawls, longlines, and purse seines (Stewart et al., 2018). Gill nets are the most utilized gear type and are responsible for extremely large proportions of bycatch. This is because they are kept in the water for hours to days at a time (Fernando and Stewart, 2021). Even if mobulids are released after being caught, they are extremely vulnerable to being handled when out of the water. This is because they lack a rigid skeleton to protect vital organs and have a high metabolic rate. They can also get hooked and entangled in fishing gear, causing injuries and deformities of their fins (**Fig. 1**), and can get struck by boats due to their surface behavior (Stewart et al., 2018).

Fernando and Stewart, 2021 looked at catch and landing composition as well as mortality and impacts of fisheries on mobulids. They focused on Sri Lankan, a small, developing island nation in the Indian Ocean with a large fishing economy. They have an Exclusive Economic Zone (EEZ) that covers an area >517,000 km^2 (**Fig. 2**). 56% of fishermen use gill nets to catch tuna and billfish and, as a result, unintentionally catch mobulids. Because of this, mobulid species are being overexploited at unsustainable levels. In 2010, the number of oceanic manta rays caught was 100,000, but was reduced to only 1,000 per year from 2011-2019 because the population had declined so substantially. In addition, they discovered that juvenile oceanic manta rays are the most common age class caught, reducing population growth since these individuals are not sexually mature. To further the problem, most mobulids caught as bycatch are sold for their gill plates instead of being released (Fernando and Stewart, 2021).

In China and Southeast Asia, there is a growing market for mobulid gill plates, also known as pengyusai. Gill plates are structures found on mobulids which are used to filter zooplankton (**Fig. 3**). These plates are highly sought after because they are said to treat various health issues from acne to cancer (**Table 1**). There are many reasons why these plates are believed to promote healing. Concerns about pharmaceutical drugs being toxic and dangerous creates a demand for a more natural product. It is claimed that since gill plates are harvested from the ocean, it is pure and can help with respiratory problems; this increases the demand for gill plates due to the heavy air pollution in China. This is not only false information, but unregulated animal products such as gill plates are known to be unsafe and can contain toxins, heavy metals, and zoonotic diseases. Gill plates have been found to contain arsenic, cadmium, and mercury; some plates have been found to contain 20x more arsenic than the recommended limit (O'Malley et al., 2017).

To obtain these plates mobulids are captured and killed. The gill plates are then harvested and dried (**Fig. 4**), and the rest of the ray is discarded as the meat is not consumed. Because mobulids engage in behaviors such as surface-feeding and aggregations in large numbers, they are easily accessible to fisheries (O'Malley et al., 2017). This makes them susceptible to being overfished in combination with the fact that they are considered a K-selected species due to low fecundity, matrotrophic reproduction, large size at birth, slow growth rates, late maturity, and longevity (Fernando and Stewart, 2021). As a result, manta rays are listed as globally vulnerable to extinction (O’Malley et al., 2017).

O’Malley et al., 2017 further investigated this by performing internet searches and asking local vendors about their products. They would ask questions including: ‘Do you carry pengyusai?,’ ‘Can we see it?,’ ‘How much supply do you have?,’ ‘How much does it cost?,’ ‘How much do you sell per year?,’ ‘Where do you source it?,’ ‘What do your customers purchase pengyusai for?,’ ‘What trends are you seeing in supply and demand?,’ and ‘Can we take a photo?.’ They found that the demand for gill plates increased, and that the volume of gill plates for *Mobula* spp. tripled from 2011-2013. This is an underestimate as most of these plates were found to be unreported and illegally transported. In addition, doctors don't prescribe remedies from endangered animals, and most doctors won't prescribe gill plates as medicine due to the declining mobulid population. However, gill plates are still available over the counter and are continuously claiming various medical benefits that are not documented or researched. There is no regulation of tracking or trade of mobulids which has already caused a significant decline in their populations (O'Malley et al., 2017).

Conservation methods

It was first thought that the oceanic manta ray was a highly migratory species based on behaviors exhibited by similar species such as devil rays and whale sharks. But a study done by Stewart et al., 2016a used satellite telemetry, stable isotopes, and genetic analyses to discover that oceanic manta rays exhibit a high degree of residency like reef manta rays. Although both species can exhibit long-distance migrations, it is rare. Rather, these species transition between coastal sites and nearby, offshore habitats. This travel pattern causes them to be more susceptible to fishery interactions and have a higher local extinction rate because they occupy a small geographic range. On the other hand, conservation methods can be focused on one area, making it easier to implement management practices. This study found that fisheries target local populations, which dramatically increases local extinction. The study suggests that local management efforts and reducing or eliminating local fisheries are essential for preventing manta ray decline. They propose implementing "mega-marine protected areas," which would protect an entire species' geographic range. The Raja Ampat Shark and Ray Sanctuary in Indonesia covers most of the geographic range of manta rays and is successful due to strong self-enforcement and community engagement. However, it is important to consider international management since the geographic range of some oceanic manta rays can span across international borders (Stewart et al., 2016a).

Understanding the feeding behavior of manta rays can also help create conservation methods. Stewart et al. 2016b used pop-off satellite tags to track the dive behavior of oceanic manta rays to understand their feeding behavior. They found that oceanic manta rays stayed closer to the surface in April and May and didn't perform vertical migrations, whereas, from June to September, they migrated to deeper waters at night. This suggests that oceanic manta rays are more susceptible to surface-set gill nets between April and June than in July to September. In addition, trawls between 50-150 m can put the oceanic manta rays that are accessing those depths at risk. There are also surface threats such as boat strikes and entanglement in surface buoys and down-lines. Oceanic manta rays are most susceptible to these threats from April to June and again in November due to their surface behavior, including feeding and basking (Stewart et al., 2016b). Reef manta rays exhibit surface feeding behavior during the day in coastal habitats and are found in deeper, offshore waters during the night (**Fig. 5**) (Braun et al., 2014). This data can help conservationists create restrictions on fishing gear or limitations on the time of day and year that fishing can occur; most fisheries deploy surface-set gill nets at night, which can prevent entanglement if mobulids are feeding in deeper waters (Fernando and Stewart, 2021; Stewart et al., 2016b). There can also be local management of boating activities to reduce boat strikes and entanglement at the surface (Stewart et al., 2016b).

Fernando and Stewart, 2021 describes management efforts being done to reduce bycatch of mobulid species. They mention how the Convention on International Trade in Endangered Species of Wild Fauna and Flora ensures that trading species across international borders is not permitted if it is detrimental to the survival of the species. The national Department of Fisheries and Aquatic Resources requires that gill nets be less than 2.5 km for vessels going to the high seas and plans to require the same protocols within the EEZ in 2022 (Fernando and Stewart, 2021; Ministry of Fisheries and Aquatic Resources Development, Sri Lanka, 2018). However, enforcement of these regulations is inadequate. For example, the Maldives and the Chagos Archipelago prohibit fishing of mobulids, but Sri Lankan fisheries illegal fish within these marine protected areas (MPAs) (**Fig. 2**). Without proper enforcement, mobulid species could become locally extinct (Fernando and Stewart, 2021).

To effectively monitor gill plates, O'Malley et al., 2021 proposes multiple propositions to manage this activity. Import and export codes for both gill plates and other mobulid products should be required and make sure that countries report landings to the species level. This was done in 2015 when the Inter-American Tropical Tuna Commission passed a resolution prohibiting the retention or sale of mobulids and requiring that live animals be immediately released following safe release protocols while also recording data on both live and dead releases. In addition, countries known for gill plate trading need to be investigated. For example, Vietnam was the third most cited source country, but the authors found no records of trade. To help with this, restricting and enforcing consequences for gill plates can be effective. The Indonesian government announced in 2014 that manta rays are fully protected and have arrested and prosecuted traders who illegally exported or purchased manta gills. However, mobulid fisheries are not managed in any country besides China. Sustainable management is a solution that can still allow for fisheries without depleting mobulid populations. Education is also a very potent tool. Most people are unaware of the negative impacts of buying gill plates. 91% of the consumers surveyed would be willing to stop consuming gill plates to protect wildlife, and 97%

would halt due to known toxins. As a result, creating a campaign to inform the public is a key resource in conserving endangered manta species (O'Malley et al., 2017).

Need for more data

Although threats are identified and conservation methods have been proposed, a lack of data still raises concern. Stewart et al., 2016a found that although there is some evidence of oceanic manta rays migrating long distances, this does not generate substantial gene flow or interpopulation exchange of individuals. Domingues et al., 2018 describe a lack of data focusing on the genetic diversity of shark and ray species, with ray species being the least studied. Data on critically endangered, endangered, and vulnerable species have some of the lowest data despite being of most concern (**Fig 6**). Stewart et al., 2018 states that more genetic studies are needed to help identify distinct populations of mobulids to effectively create management strategies (**Fig. 7**). In addition, there is a strong correlation between genetic diversity and a population's resilience to extinction; overexploited fishes have been shown to have low genetic diversity (Stewart et al., 2018). A manta ray fishery in Mexico caused the near disappearance of mantas in the 1980s and 1990s. The Mexican government protected the species for 12 years, but the species never recovered, possibly due to low genetic diversity (Stewart et al., 2016a). Overfishing could also lead to population bottlenecks, preventing recovery, so understanding the effects of overfishing and bycatch on mobulid species is imperative to conserve them (Stewart et al., 2018).

O'Malley et al., 2017 discussed how immediate release of live mobulids is essential, but further research is needed. Evaluating survival rates is necessary to determine whether stricter protocols are required to avoid bycatch altogether. It was found that *Mobula mobular*, the giant devil ray, had mortality rates of 50-60% after being released from purse seines. The mortality rate for gill nets is likely higher as they are in the water longer. Pop-off satellite or acoustic tags could be used to evaluate survivorship rates. If mortality rates are high, methods to reduce bycatch should be studied. For example, studies suggest that using ultraviolet light-emitting diodes could deter mobulids from gill nets. This is important to study to ensure that these devices are effective. In addition, understanding species distribution is key to avoiding high bycatch rates. Observers on boats can help to ensure fisheries are reporting the correct amount of bycatch. Training courses to help identify mobulid species can assist with helping to understand which species are the most at risk. Satellite tracking and studies involving regions of high bycatch can be useful to implement regulations for MPAs (Stewart et al., 2018).

Conclusion

Fishery interactions provide the greatest threat to mobulid species which caused researchers to start studying them (Stewart et al., 2018). Although research has been done on the biology and ecology of mobulid species, information on the biology and life history is still extremely scarce (Fernando and Stewart, 2021). This lack of data hinders effective conservation action from protecting these species. It is imperative to understand *if M. cf. birostris* is a distinct species or a subspecies of *M. birostris* to employ effective management strategies as this species could require different conservation methods than the oceanic manta ray. Stewart et al., 2018 proposes research designs to effectively study these species. One way to do this is to use similar methods from previous studies. This can allow communication among research groups and would allow for collaboration with other researchers with similar research. Long-term data sets are also important to help address mobulid ecology and biology questions. Another key point is to include conservation agencies and resource managers in research efforts to create management plans in the future based on research findings. If progress is made on research efforts to mobulid species, significant management and conservation plans can be created over the next decade to help conserve these threatened species (Stewart et al., 2018).

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Figures

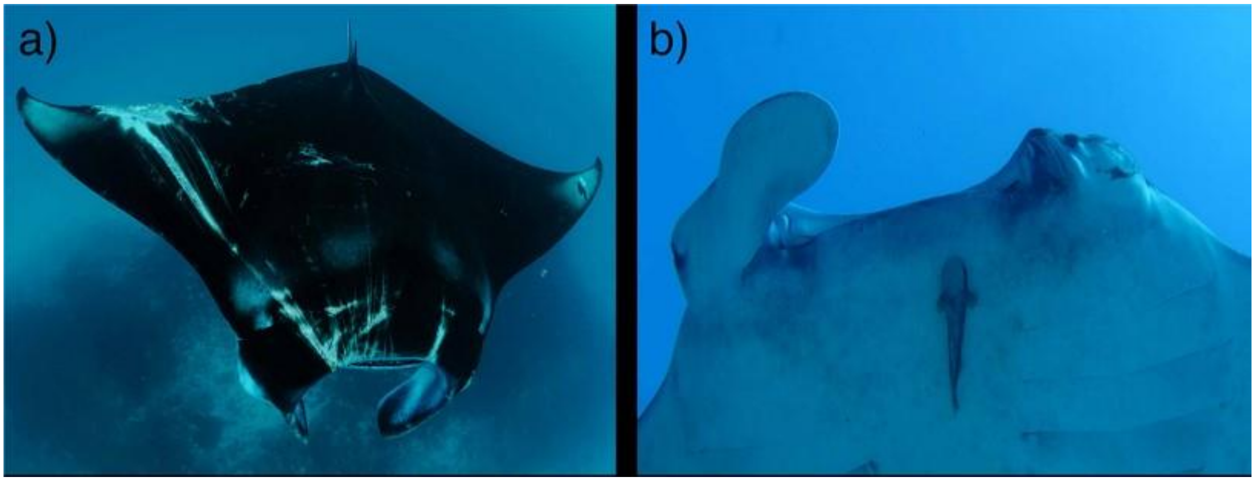

Figure 1. Entanglement in fishing gear can cause substantial damage and scarring (**a**), including amputations of cephalic fins and damage to eyes (**b**) (Stewart et al., 2018).

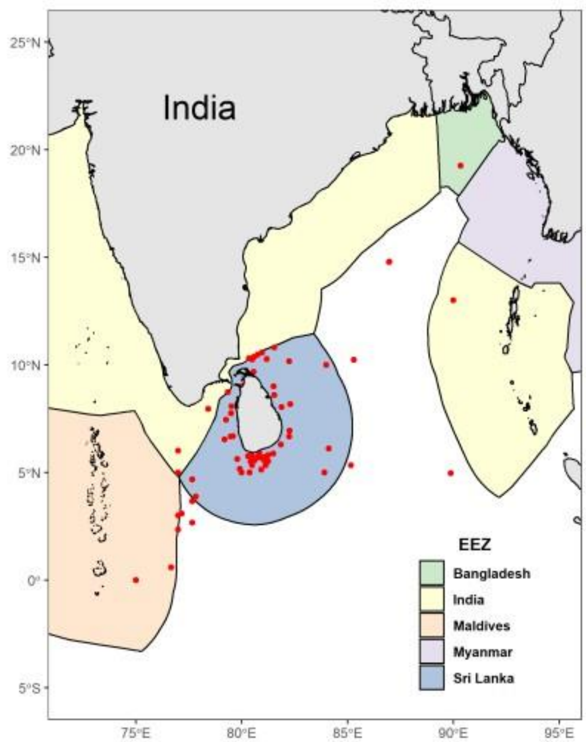

Figure 2. Map showing the Exclusive Economic Zones (EEZs) with points (in red) displaying locations of Sri Lankan's mobulid fishing grounds within their own and neighboring territories EEZs (Fernando and Stewart, 2021).

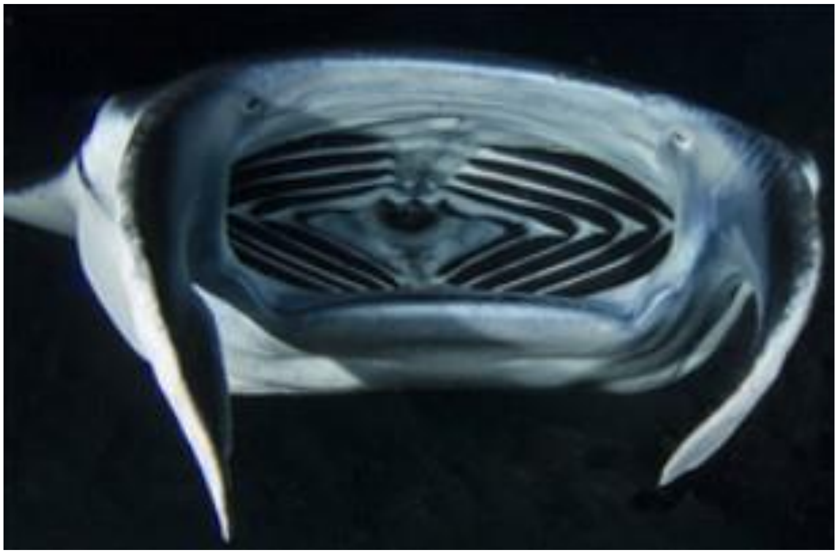

Figure 3. *Manta* spp. gill plate structure shown in live feeding manta (O'Malley et al., 2017).

Figure 4. A fisherman removes the gill plates of an oceanic manta ray (Stewart et al., 2018).

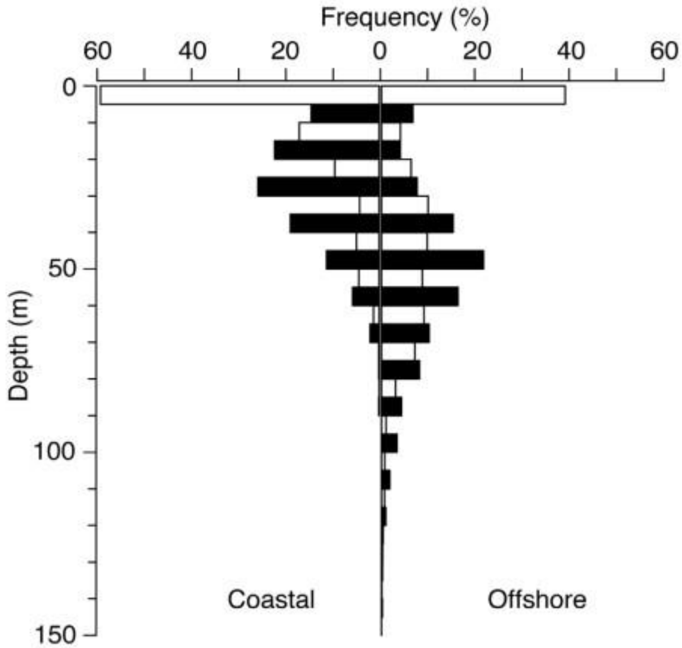

Figure 5. Coastal and offshore depth occupation. Frequency histogram comparing coastal (left) and offshore (right). White and black bars indicate day and night (Braun et al., 2014).

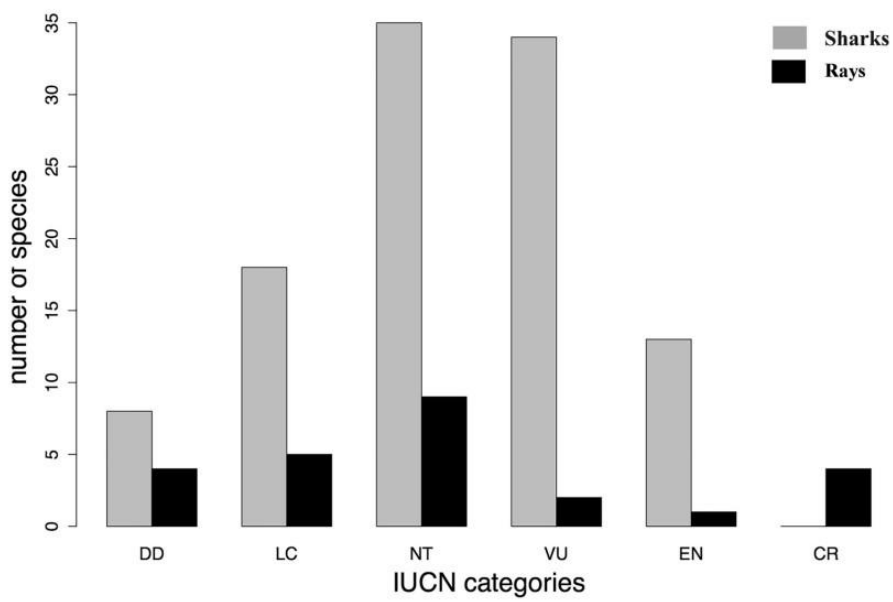

Figure 6. Numbers of articles published that describe the genetic diversity of shark and ray species for each IUCN category. *DD* data deficient, *LC* least concern, *NT* near threatened, *VU* vulnerable, *EN* endangered, *CR* critically endangered (Domingues et al., 2018).

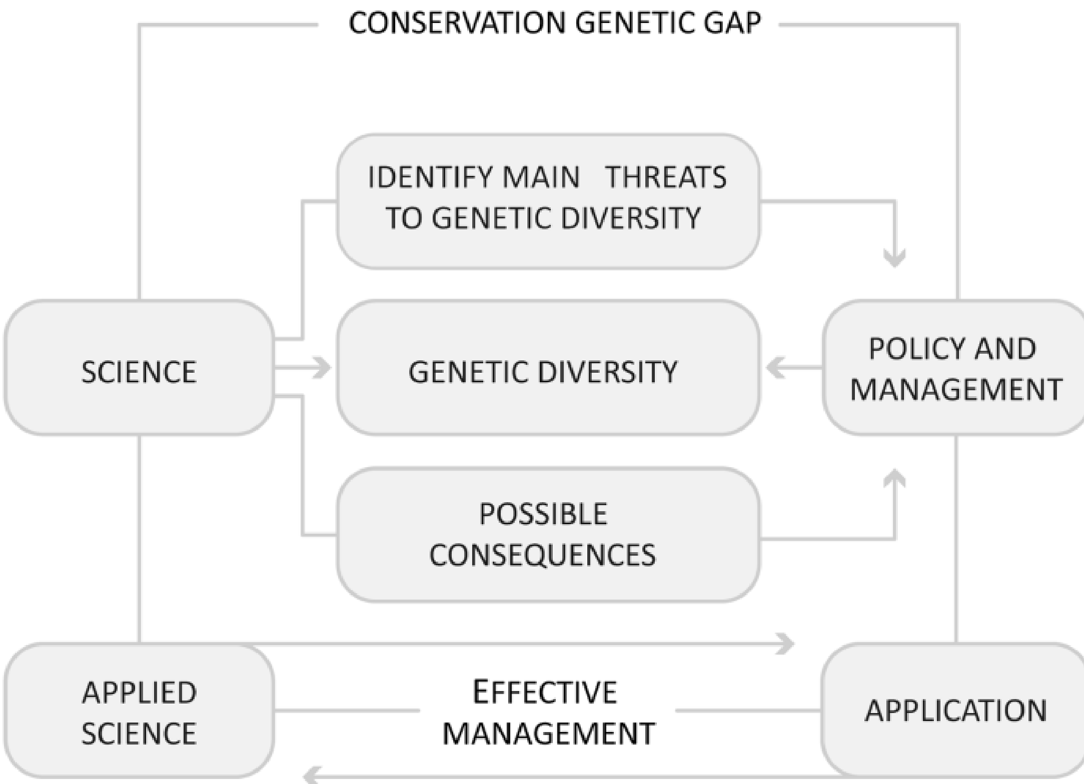

Figure 7. The link between scientific knowledge and conservation policies aimed at preserving the genetic diversity of shark and ray species. Scientists must generate knowledge that identifies the main threats to genetic diversity and their deleterious effects on shark and ray populations, whereas policymakers must consider the information provided by scientists and apply this information to their conservation policies in order to effectively manage species populations (Domingues et al., 2018).

Tables

Table 1. Vendor-recommended uses of gill plates (O'Malley et al., 2017).

	2015 surveys		2013–2014 surveys		2011 surveys	
	Number of vendors	Percentage of vendors reporting	Number of vendors	Percentage of vendors reporting	Number of vendors	Percentage of vendors reporting
Recommended use	13		71		31	
General health*	0	0%	41	58%	11	35%
Removes toxins	1	8%	41	58%	2	6%
Chicken Pox/Small Pox/Measles	2	15%	35	49%	4	13%
Lactation aid	5	38%	33	46%	0	0%
Cough /Sore Throat /Phlegm/Tonsil inflammation (Children)	0	0%	29	41%	6	19%
Reduce internal heat	0	0%	27	38%	7	23%
Lung support	0	0%	17	24%	0	0%
Liver support	1	8%	14	20%	0	0%
Eyesight support	5	38%	13	18%	0	0%
Skin Complaints/Acne/Boils	0	0%	13	18%	5	16%
Cancer	0	0%	9	13%	1	3%
Fever	1	8%	9	13%	6	19%
Reduce inflammation	6	46%	8	11%	0	0%
Aids digestion /good for stomach	1	8%	8	11%	1	3%
Overuse of alcohol-tobacco-stay up all night	5	38%	7	10%	0	0%
Aids blood circulation	1	8%	7	10%	1	3%
Kidney support	4	31%	4	6%	5	16%
Irritability	3	23%	3	4%	0	0%
Not TCM	1	8%	3	4%	1	3%
Mumps	0	0%	1	1%	2	6%
Fertility aid	1	8%	1	1%	1	3%
Hyperactivity (babies)	1	8%	1	1%	0	0%
Thyroid gland support	3	23%	0	0%	1	3%

*'General Health' also includes: Nourish Yin, Adjust Qi, Enhance physical fitness, Avoid hospital/medical injections, Boosts immunity