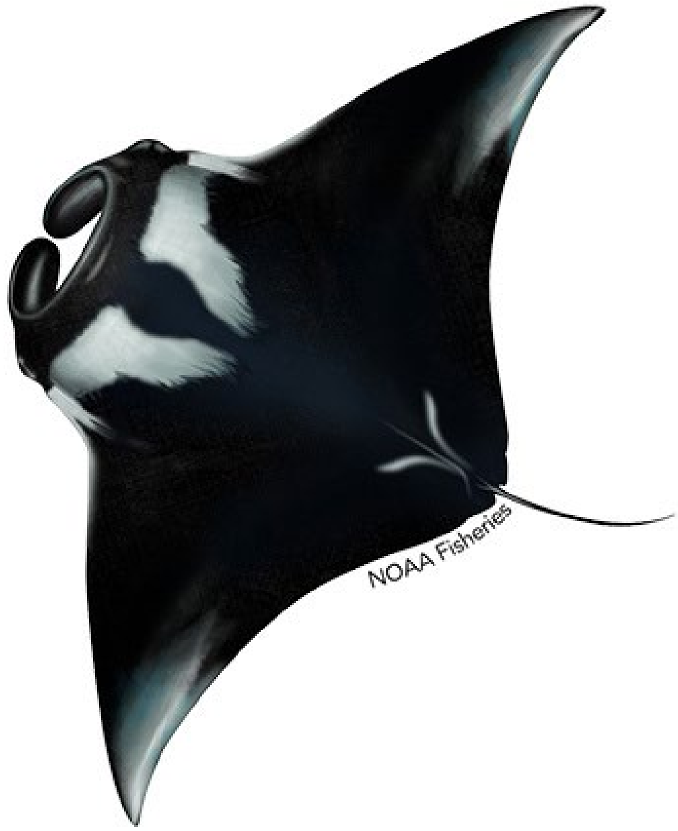
Draft Recovery Plan for the Giant Manta Ray (*Mobula birostris*)



Prepared by:
Office of Protected Resources
National Marine Fisheries Service

October 2024

PREFACE

We, NOAA Fisheries, have developed this Draft Recovery Plan for the giant manta ray (*Mobula birostris*) pursuant to the Endangered Species Act of 1973 (ESA), as amended (16 U.S.C. 1531 et seq.), and in accordance with our mission to recover and conserve protected species. Draft recovery plans are subject to public review, and comments received during the review period are considered during preparation of the final plan. Supplemental scientific assessments and supporting information for this Draft Recovery Plan are available on the NOAA Fisheries giant manta ray species profile page. The supplemental information (e.g., Recovery Status Review for the giant manta ray) is accessible for informational purposes but is not subject to formal public review.

The ESA establishes policies and procedures for identifying, listing, and protecting species of fish, wildlife, and plants that are endangered or threatened with extinction. The purposes of the ESA include, "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved, [and] to provide a program for the conservation of such endangered species and threatened species." 16 U.S.C. 1531(b). The definition of "conserve" and "conservation" under the ESA is "to use and the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary." 16 U.S.C. 1532(3). In other words, conservation of the species generally culminates in the endpoint of its recovery. The ESA definition of "species" includes "any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." The giant manta ray was listed as threatened on January 22, 2018 (83 FR 2916). A "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." 16 U.S.C. 1532(20). Therefore, a threatened species is one that is likely to become in danger of extinction within the foreseeable future throughout all or a significant portion of its range.

To help identify and guide recovery needs for listed species, section 4(f) of the ESA directs the Secretary to develop and implement recovery plans for listed species, unless a finding is made that a recovery plan would not promote the species' conservation. A recovery plan must incorporate, to the maximum extent practicable, the following: (1) a description of site-specific management actions necessary for the conservation and survival of the species; (2) objective, measurable criteria that, when met, will allow the species to be removed from the endangered and threatened species list; and (3) estimates of the time and cost required to achieve the plan's goals. See 16 U.S.C. 1533(f)(1)(B)(i)-(iii). This Draft Recovery Plan specifically addresses the recovery planning requirements of the ESA for the giant manta ray. It presents a recovery strategy based on the biological and ecological needs of the species, current threats, and existing conservation measures, all of which affect its long-term viability.

DISCLAIMER

Recovery plans delineate such reasonable actions as may be necessary, based upon the best scientific and commercial data available, for the conservation and survival of listed species. We publish these plans that we sometimes prepare with the assistance of recovery teams, contractors, state agencies, and others. Recovery plans represent the position of NOAA Fisheries, and do not necessarily represent the views, official positions, or approval of any individuals or other agencies involved in the plan formulation; they represent the official position of NOAA Fisheries only after the Assistant Administrator has signed the final plan. Recovery plans are guidance and planning documents only. Identification of an action to be implemented by any public or private party does not create a legal obligation beyond existing legal requirements. Nothing in this plan should be construed as a commitment or requirement that any federal agency obligate or pay funds in any single fiscal year in excess of appropriations made by Congress for that fiscal year in contravention of the Anti-Deficiency Act, 31 U.S.C. § 1341, or any other law or regulation. Approved recovery plans are subject to modification as dictated by new findings, changes in species status, and the completion of recovery actions.

Recommended Citation:

National Marine Fisheries Service. 2024. Draft Recovery Plan for the Giant Manta Ray (*Mobula birostris*). October 2024, Version 1. NOAA Fisheries, Office of Protected Resources, Silver Spring, MD. 20901. 59 pages.

Download a digital copy of this Draft Recovery Plan from the Conservation and Management tab of our NOAA Fisheries giant manta ray profile web site, specifically at https://www.fisheries.noaa.gov/species/giant-manta-ray/conservation-management.

Guide to the Plan

This Draft Recovery Plan is one part of a three-part format in which recovery planning components for the giant manta ray are divided into three separate documents. The first document, the Recovery Status Review (NMFS 2024a), provides detailed information on the giant manta ray's biology, ecology, status and threats, and conservation efforts to date, which has typically been included in the background section of a species' recovery plan. Highlights of the Recovery Status Review are summarized in the Introduction of this Draft Recovery Plan for the benefit of the reader, but readers can consult the Recovery Status Review if they seek additional information. The second document, this Draft Recovery Plan, focuses on the statutory components of a recovery plan, as required under the ESA to the maximum extent practicable: (1) a description of site-specific management actions necessary for the conservation and survival of the species (hereafter referred to as recovery actions); (2) objective, measurable criteria that, when met, will allow the species to be removed from the endangered and threatened species list (hereafter referred to as recovery criteria); and (3) estimates of the time and cost to achieve the plan's goals. Site-specific recovery actions in this Draft Recovery Plan are described at a high level and are strategic in nature. More in-depth, stepped-down activities that address the site-specific recovery actions for the giant manta ray can be found in a third stand-alone document, the Draft Recovery Implementation Strategy (NMFS 2024c). The Draft Recovery Implementation Strategy is a flexible, operational document separate from the Draft Recovery Plan that provides specific, prioritized activities necessary to fully implement recovery actions in the plan, while affording us the ability to modify these activities efficiently to reflect changes in the information available and progress towards recovery. All documents used to inform this Recovery Plan, including the Recovery Status Review and the Draft Recovery Implementation Strategy, are available on the NOAA Fisheries giant manta ray species profile page web site.

ACKNOWLEDGMENTS

NMFS gratefully acknowledges the contributions of the numerous individuals in developing the Draft Recovery Plan for the Giant Manta Ray.

The primary authors of this draft plan are:

Ms. Maggie Miller, NMFS Office of Protected Resources, Silver Spring, MD.
Ms. Calusa Horn, NMFS Southeast Regional Office, St. Petersburg, FL.
Ms. Chelsey Young, NMFS Pacific Islands Regional Office, Honolulu, HI.
Dr. John K. Carlson, NMFS Southeast Fisheries Science Center, Panama City, FL.

We also thank the following for their technical assistance, review, time, and contributions to the recovery planning process: Ms. Kristina Dauterman, Ms. Rini Ghosh, Dr. Nick Farmer, Ms. Angela Somma, and Ms. Melissa Snover. We also gratefully acknowledge the participants that were involved in our first giant manta ray recovery planning expert elicitation meeting: Dr. Melissa Cronin, Dr. Nick Farmer, Dr. Andrea Marshall, Ms. Jessica Pate, Dr. Guy Stevens, and Dr. Josh Stewart.

Table of Contents

1. Introduction

1.1 ESA Listing of the Giant Manta Ray and Species' Biology and Status

On January 22, 2018, after considering the best available scientific and commercial information, we listed the giant manta ray (*Manta birostris*) as a threatened species throughout its range (83 FR 2916). The final rule became effective on February 22, 2018. On November 22, 2023, we revised the scientific name of the listed species to *Mobula birostris* (50 CFR 223.102(e)) to reflect the scientifically accepted taxonomy and nomenclature of this species (88 FR 81351). The status review of the giant manta ray (Miller and Klimovich 2017) concluded that the species has a high probability of extinction in the foreseeable future (>50 years), primarily due to overutilization for commercial purposes. Although there is considerable uncertainty regarding the species' current abundance throughout its range, the best available information indicates that the species has experienced population declines of potentially significant magnitude due to fisheries-related mortality within the Indo-Pacific and eastern Pacific portion of its range, which we determined qualifies as a "significant portion its range" under the final Significant Portion of Its Range (SPR) policy (79 FR 37577; July 1, 2014).

Giant manta rays inhabit tropical, subtropical, and temperate bodies of water worldwide, and are commonly found offshore, in oceanic waters, and near productive coastlines. Within waters under U.S. jurisdiction, the giant manta ray can be found along the Atlantic east coast as far north as Long Island, New York, within the Gulf of Mexico, and within the waters of the U.S. Virgin Islands, Puerto Rico, Hawaiian Islands, and Jarvis Island (in the U.S. Pacific Remote Island Area). Manta rays have also been sighted off the coast of the Northern Mariana Islands, Guam, and American Samoa; however, it is likely that these are mainly reef manta rays (*Mobula alfredi*) based on photographs.

Although capable of long-distance movements of 100s to >1000 km (Andrzejaczek et al. 2021), and previously thought to be a migratory species, many giant manta ray populations appear to be philopatric (Stewart et al. 2016), with few examples of long-distance dispersal (Andrzejaczek et al. 2021; Knochel et al. 2022). Several authors have reported that giant manta rays likely occur in small regional subpopulations (Lewis et al. 2015; Stewart et al. 2016; Marshall et al. 2018; Beale et al. 2019) and may have distinct home ranges (Stewart et al. 2016). The degree to which subpopulations are connected by migration is unclear but is assumed to be low for certain populations (Stewart et al. 2016; Marshall et al. 2018) with regional or local populations unlikely to be connected through immigration and emigration (Marshall et al. 2018), making them effectively demographically independent. However, further research is needed to better understand life history traits and variability among populations throughout the species' range.

The global population size of the giant manta ray is also difficult to assess, but many abundance trajectories have been estimated based on long time series of sightings at diving sites. Generally, divers encounter the giant manta ray less frequently than the reef manta ray, and this is thought to be due to their oceanic habitat preference. Locally, abundance varies substantially and may be based on food availability and the degree that they were, or are currently, being fished. In most regions, giant manta ray population sizes are likely to be small (with recorded individuals <1000). Regional populations have been estimated in the Eastern Pacific and Indian Oceans. At 22,316 individuals, Ecuador is thought to be home to the largest identified population of *M. birostris* in the world, with large aggregation sites within the waters of the Machalilla National Park and the Galapagos Marine Reserve (Hearn et al. 2014; Harty et al. 2022). The next largest population has been noted in Raja Ampat, Indonesia, but is clearly a lot smaller, estimated at around 1,875 individuals (Beale et al. 2019). The other estimated populations are similar in size, with 1,172 in the Revillagigedo Archipelago, Mexico (Cabral et al. 2023), more than 400 individuals in Banderas Bay, Mexico (Domínguez-Sánchez et al. 2023), and 600 in Mozambique (Marshall 2008).

In terms of life history, the giant manta ray is a long-lived species, with the maximum age estimated at 45 years, based on the related reef manta ray (*M. alfredi*) longevity (Marshall et al. 2022). Manta rays, like all myliobatiformes, are viviparous (i.e., the species gives birth to live young) and supply nutrients to developing embryos through lipid-rich histotroph, sometimes called uterine milk (Wourms 1981, Hamlett et al. 2005). Although the precise duration of gestation is unknown, it is suspected that gestation would be similar to that observed in the reef manta ray, which is generally accepted to be 12 to 13 months (Yamaguchi 2007; Kitchen-Wheeler 2013). In addition, Rambahiniarison et al. (2018) provided evidence of a potential resting period between pregnancies, indicating that not all individuals reproduce every year. Investigations of pregnant females with intact embryos indicated the presence of a single embryo per pregnancy (Müller and Henle 1841; Beebe and Tee-Van 1941; Coles 1969; Rambahiniarison et al. 2018) with size at birth estimated to be approximately 200–210 cm disc width (DW) (Rambahiniarison et al. 2018). These life history characteristics, such as long gestation, the potential for up to 5 years between pregnancies, and low fecundity (one pup per litter), result in low overall productivity and limit the ability of giant manta rays to cope with threats and recover from significant decreases in abundance.

1.2 Threats to the Species' Viability and Other Stressors

The 2017 Status Review Report (Miller and Klimovich 2017) and the 2018 final listing rule (83 FR 2916) identified and assessed the factors contributing to the decline of the giant manta ray. The Recovery Status Review (NMFS 2024a) presents an updated threats assessment that incorporates new information that has become available since the 2018 listing about potential emerging stressors and the scope and severity of existing threats, as well as restructuring of some of the sections to better inform the recovery planning process. The purpose of the threats assessment is to identify, evaluate, and rank the stressors to the giant manta ray in order to understand which stressors are contributing to the species' decline and thus are considered threats to the species that should be addressed in the recovery plan.

Table 1 below presents a summary of the threats assessment from the Recovery Status Review. We assessed the stressors for each region within the species' range (Atlantic Ocean, Indian Ocean, Pacific Ocean) to identify the threats. We also identified subregions within the Atlantic and Pacific Ocean regions, based on the available data (see section 3.3.1 below for detailed explanation and rationale for identifying these subregions). We identified and prioritized threats that are most urgent and significant for the recovery of the species according to the following criteria: 1) the frequency with which the stressor occurs, 2) the severity of the stressor, 3) the trend of the stressor, 4) the certainty that the stressor is affecting the species, and 5) the relative concern regarding the effect of the stressor, relative to other stressors, on the subregional/regional population.

To determine the overall risk presented by each stressor to the species, the factors described above were evaluated together to determine an overall "risk" score based on the following scale: low, low-to-moderate, moderate, moderate-to-high, and high. See **Box 1** below for definitions of the terms used in the threats assessment. More detailed methodology is presented in the Recovery Status Review (NMFS 2024a). It should be noted that this overall risk score is for the rangewide species level; it is not an overall score for the particular subregion/region wherein the threat is being assessed. Additionally, this is a qualitative assessment based on a structured decision-making exercise using best professional judgment and consideration of the best available scientific information presented in the Recovery Status Review to help organize and prioritize recovery actions and activities.

As used in this Recovery Plan, a threat is any stressor, natural or human-related, that impedes recovery or contributes to the giant manta ray's extinction risk. Stressors with an overall ranking of high, moderate-to-high, or moderate risk were considered to be important sources of risk to the species that must be addressed in order for the species to recover, and thus are considered to be threats for the purposes of this Recovery Plan. Stressors identified as low-to-moderate risk may also be considered an important source of risk to the species overall if the stressor, at the regional/subregional level, is contributing to a reduction in local populations that may impact long-term recruitment and survival at the subregional/regional scale. We examined the relative concern regarding the effect of the stressor, relative to other stressors, on the subregion/regional population, to account for how stressors may be operating in the identified significant portion of the species' range, and to inform the overall extinction risk each stressor poses at the rangewide species level. Stressors identified with an overall low risk in every subregion/region (where it occurs) or globally are not currently known to be impeding recovery, and thus are not considered to be threats. These stressors do not need to be minimized or eliminated to achieve recovery, but should be investigated further to better understand how they may be acting on the population and whether they may become threats in the future. If NOAA Fisheries determines that other stressors are impeding recovery, the Recovery Plan will be updated to address and mitigate newly identified threats.

Based on the assessment presented in the Recovery Status Review and summarized in **Table 1** below, the main threats to the giant manta ray are as follows:

- Targeted catch and bycatch in artisanal/small-scale fisheries.
- Inadequate regulatory mechanisms to address targeted fishing and/or bycatch and retention of the species.
- Illegal retention and enforcement issues.

These threats occur in a significant portion of the species' range, which comprises the Indian Ocean, Western Pacific Ocean Subregion and Eastern Pacific Ocean Subregion. It is important to note that the main *driver* of these threats is the international gill plate trade supported by the high demand for manta ray gill plates.

Additionally, we consider the stressors below to be "lesser" threats or those where we have a moderate level of concern regarding the effect of the stressor, relative to other stressors, on the subregional or regional populations, resulting in a low-to-moderate risk of impeding the overall recovery of the species throughout its range, or driving the giant manta ray's extinction risk.

- Bycatch in commercial fisheries, particularly purse seines, gill nets, longlines, and trawls.
- Inadequacy of fisheries regulations and enforcement.

Based on the assessment presented in the Recovery Status Review and summarized in **Table 1** below, the following stressors are not considered threats to the species currently, but should be monitored to determine whether they may become threats to the giant manta ray in the future:

- Climate change
- Environmental contaminants/pollutants
- Vessel strikes
- Entanglement
- Recreational fishery interactions
- Tourism
- Aquarium Trade

Box 1. Definitions of parameters used in **Table 1**: Assessment of Threats to the Giant Manta Ray

Major effect: the effect(s) of the stressor on a specific aspect of life history or behavior of the giant manta ray.

Frequency: the occurrence and regularity of the stressor over time

- High: very likely to occur (ex. will be fished or caught as bycatch) and occurs on a yearly basis
- Moderate: may occur (ex. possibly caught as bycatch) some years and not others.
- Low: infrequent

Severity: the effect the stressor has on individuals of the species

- High: causes high probability of direct mortality, including at-vessel or post-release mortality for fisheries threats.
- Moderate: causes moderate probability of direct mortality, including post-release mortality and/or sublethal impacts that result in decreased productivity and fitness.
- Low: does not cause direct mortality and has a negligible or unknown impact on productivity and fitness.

Trend: the change in frequency or extent of the stressor over time

- Increasing
- Stable
- Decreasing
- Unknown

Certainty: the amount of evidence regarding the effects of the stressor in a subregion or region

- High: direct evidence or multiple lines of indirect evidence
- Moderate: indirect, limited, or unclear evidence
- Low: little or no evidence

Relative concern within region: the amount of concern regarding the effect of the stressor, relative to other stressors, on the subregion/regional population

- Minimal: stressor is unlikely affecting local populations to a degree that would influence long-term recruitment and survival at a subregion/regional scale
- Moderate: stressor is contributing to a reduction in local populations that may impact long-term recruitment and survival at a subregion/regional scale
- Significant: stressor is contributing to reduction in local populations that is causing significant declines in populations at a subregion/regional scale

Overall extinction risk ranking: the factors described above were evaluated together qualitatively to determine an overall "risk" at the **species** level. The risk ranking level identifies which stressors are considered threats that impede the overall recovery of the species or drive the manta ray's extinction risk throughout its range.

- Low
- Low to moderate
- Moderate
- Moderate to high
- High

Table 1. Giant Manta Ray Stressor/Threats Assessment Summary Table

Atlantic Ocean Region							
Stressor (Cause)	**Major Effect**	**Frequency**	**Severity**	**Trend**	**Certainty**	**Relative Concern within Region**	**Overall Extinction Risk Ranking**
1A Western North Atlantic							
Commercial fisheries bycatch; trawl	Injury/ Mortality	High	Moderate - High	Unknown	High	Moderate	Low-Moderate
Commercial fisheries bycatch; longline	Injury/ Mortality	High	Low - Moderate	Unknown	High	Minimal	Low
Commercial fisheries bycatch; gillnet	Injury/ Mortality	Moderate	Moderate	Unknown	High	Minimal	Low
Commercial fisheries bycatch: purse seine	Injury/ Mortality	Low	Moderate	Unknown	Low	Minimal	Low
Recreational fisheries interactions	Injury/ Mortality	High	Low	Increasing	High	Minimal	Low
Inadequacy of fisheries regulations	Injury/ Mortality	n/a	Moderate	Stable	Moderate	Moderate	Low-Moderate
1B Eastern and Southern North Atlantic							
Commercial fisheries bycatch; longline	Injury/ Mortality	Moderate	Low - Moderate	Unknown	Low	Minimal	Low

Commercial fisheries bycatch; purse seine	Injury/ Mortality	Moderate	Moderate	Unknown	Low	Minimal	Low
Commercial fisheries bycatch;trawls	Injury/ Mortality	Moderate	Moderate - High	Unknown	Low	Minimal	Low
Artisanal/small- scale fisheries (for commercial or subsistence)	Injury/ Mortality	High	High	Unknown	Low	Moderate	Low-Moderate
Illegal retention/ enforcement issues	Mortality	High	Moderate - High	Unknown	Low	Moderate	Low-Moderate
Inadequacy of fisheries regulations	Injury/ Mortality	n/a	Moderate - High	Stable	Moderate	Moderate	Low-Moderate
Indian Ocean Region							
Stressor (Cause)	**Major Effect**	**Frequency**	**Severity**	**Trend**	**Certainty**	**Relative Concern within Region**	**Overall Risk Ranking**
Artisanal/small- scale fisheries (for commercial or subsistence)	Injury/ Mortality	High	High	Increasing	High	Significant	High
Commercial fisheries bycatch; purse seine	Injury/ Mortality	Moderate-High	Moderate	Unknown	Low	Moderate	Low-Moderate
Commercial fisheries bycatch; longline	Injury/ Mortality	Moderate	Low	Unknown	Low	Moderate	Low-Moderate

Commercial fisheries bycatch; gillnet	Injury/ Mortality	High	Moderate	Unknown	Low	Moderate	Low-Moderate
Inadequacy of fisheries regulations	Injury/ Mortality	n/a	Moderate - High	Stable	Moderate	Significant	Moderate
Illegal retention/ enforcement issues	Mortality	High	High	Stable	High	Significant	High
Pacific Ocean Region							
Stressor (Cause)	**Major Effect**	**Frequency**	**Severity**	**Trend**	**Certainty**	**Relative Concern within Region**	**Overall Risk Ranking**
3A Western Pacific Ocean							
Commercial fisheries bycatch; purse seine	Injury/ Mortality	Moderate	Moderate	Unknown	Moderate	Moderate	Low-Moderate
Commercial fisheries bycatch; gillnet	Injury/ Mortality	Moderate	Moderate	Unknown	Moderate	Moderate	Low-Moderate
Commercial fisheries bycatch; longline	Injury/ Mortality	Moderate	Low - Moderate	Unknown	Moderate	Moderate	Low-Moderate
Artisanal/small- scale fisheries (for commercial or subsistence)	Mortality	High	High	Unknown	Moderate	Significant	Moderate-High
Illegal retention/ enforcement issues	Mortality	High	High	Stable	High	Significant	Moderate-High

Inadequacy of fisheries regulations	Injury/ Mortality	n/a	Moderate - High	Stable	Moderate	Moderate	Low-Moderate
3B Central Pacific Ocean							
Commercial fisheries bycatch; longline	Injury/ Mortality	Moderate	Low - Moderate	Unknown	Moderate	Minimal	Low
Commercial fisheries bycatch; purse seine	Injury/ Mortality	Moderate	Moderate	Unknown	Moderate	Minimal	Low
Inadequacy of fisheries regulations	Injury/ Mortality	n/a	Low	Stable	Moderate	Minimal	Low
3C Eastern Pacific Ocean							
Stressor (Cause)	**Major Effect**	**Frequency**	**Severity**	**Trend**	**Certainty**	**Relative Concern within Region**	**Overall Risk Ranking**
Commercial fisheries bycatch; purse seine	Injury/ Mortality	High	Moderate	Unknown	Moderate	Moderate	Low-Moderate
Artisanal/small- scale fisheries (for commercial or subsistence)	Injury/ Mortality	High	High	Decreasing	High	Significant	Moderate-High
Illegal retention/ enforcement issues	Mortality	High	High	Unknown	High	Significant	Moderate-High
Inadequacy of fisheries regulations	Injury/ Mortality	n/a	Moderate - High	Stable	Moderate	Moderate	Low-Moderate

Globally / International						
Stressor (Cause)	**Major Effect**	**Frequency**	**Severity**	**Trend**	**Certainty**	**Overall Risk Ranking**
Climate change	Fitness, Productivity, Reproduction	n/a	Unknown	Increasing	Low	Low
Entanglement (e.g., ghost-fishing/ marine debris; mooring lines)	Injury/ Mortality	High	Moderate	Increasing	Moderate	Low
Tourism	Fitness, Productivity, Reproduction	High	Unknown	Increasing	Low	Low
Aquarium Trade	Fitness, Productivity, Reproduction	Low	Unknown	Unknown	Moderate	Low
Environmental contaminants/ pollutants	Fitness, Productivity, Reproduction	n/a	Unknown	Unknown	Low	Low
Vessel strikes	Injury/ Mortality	High	Moderate	Increasing	Moderate	Low

2. Recovery Strategy

Of the stressors evaluated for the giant manta ray, those we identified as being the main threats, as they appear in **Table 1**, are artisanal/small-scale fisheries, inadequacy of fisheries regulations, and illegal retention and enforcement issues. These threats are concentrated in the Indian, Western Pacific, and Eastern Pacific Oceans. Given the species' extremely low reproductive output and overall productivity, the giant manta ray is inherently vulnerable to these threats that are depleting its abundance, with a low likelihood of recovery. Although there is considerable uncertainty regarding the species' current abundance throughout its range, the best available information indicates that the species has experienced population declines of potentially significant magnitude due to fisheries-related mortality within this significant portion of its range, and, thus, is likely to become in danger of extinction in the foreseeable future.

Further contributing to this likelihood of extinction and impeding the recovery of the species are the inadequacy of fishery regulations and enforcement to minimize the bycatch of the species in commercial fisheries globally. Because giant manta rays are obligate ram ventilators (i.e., they need to swim constantly to move water over their gills and "breathe"), they likely have high at-vessel and post-release mortality rates when caught as bycatch, particularly in purse seines, gillnets, trawls, and longlines. Given their large population declines in the Indian Ocean and subregions of the Pacific, and demographic risks in other portions of their range (e.g., small populations, sparsely distributed), in conjunction with the species' inherent vulnerability to depletion, the levels of mortality from commercial bycatch in the significant portion of the species' range as well as other subregions can lead to drastic declines in overall abundance and prevent recovery.

There are also several other stressors that are of lesser concern given the paucity of information but should be monitored to determine whether they may become threats to the giant manta ray in the future, including: entanglement, vessel strikes, recreational fisheries interactions, environmental contaminants/pollutants, effects of climate change, tourism, and the aquarium trade.

Since listing, the implementation of a wide array of research and conservation efforts, including surveys and monitoring to evaluate residency, movement patterns, and survivorship, distribution modeling efforts, development of safe handling and release guidelines, training and materials to support federal fisheries observer programs, and protected species aerial surveys have created the foundation for recovery of the giant manta ray, particularly in U.S. waters. These efforts have been conducted with our partners, including non-governmental organizations, for profit institutions, state and federal partners.

However, due to the global distribution of the species, with the concentration of threats and notable declines of giant manta ray populations in foreign waters, we must take a multinational approach to this recovery strategy. One of the greatest hurdles for this effort may be correctly prioritizing actions and sites for implementation in order to prevent extirpation of extant populations and encourage reestablishment of populations. This

Recovery Plan, therefore, provides a strategy for ensuring that viable populations of giant manta rays exist that contribute to multiple, stable metapopulations of the species throughout its global range.

To achieve this, NOAA Fisheries must first and foremost continue to cooperate with both domestic and international partners to continue to establish protective regulations and enforce and increase awareness of existing laws, regulations, and policies that protect giant manta rays from fisheries-related mortality. Protection and management efforts are needed throughout the species' global range. This will require the cooperation of NOAA Fisheries, other Federal and State agencies, Regional Fisheries Management Organizations (RFMOs) and Cooperating Parties, artisanal, commercial, and recreational fishermen, conservation organizations, and other interested parties. Coordination on a multinational level will be required to:

- improve reporting and compliance with current conservation and regulatory measures;
- support investigations to identify aggregation sites and fisheries overlap to reduce bycatch;
- develop and implement regulatory measures to minimize fishery interactions and prevent fishery-related mortality;
- prioritize outreach and education campaigns; and
- eliminate the international gill plate trade.

In addition to actions designed to protect the species from further fisheries-related mortality, a number of information gaps related to demographic parameters, genetics, movement, habitat requirements, and threat sensitivity need to be addressed. These issues will need to be sufficiently understood so that threats can be abated to ensure long-term conservation of the giant manta ray to the point where the species no longer requires the protections of the ESA.

Ultimately, effective recovery action implementation for giant manta rays relies on successful collaboration with domestic and international partners, building upon existing management, research and conservation efforts.

3. Recovery Goals, Objectives, and Criteria

The following section describes the goal, objectives, and criteria of this Recovery Plan, which set standards for determining when sufficient recovery progress has been made such that the species no longer needs the protections of the ESA and can be delisted. These standards refer to the definitions of endangered and threatened under section 3 of the ESA:

"endangered" means a species is in danger of extinction throughout all or a significant portion of its range, whereas "threatened" means that a species is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

For the purposes of recovery planning, the recovery goal is to address and ameliorate threats responsible for the species' decline in order to ultimately achieve recovery and, therefore, delist the species (NMFS 2020). Recovery objectives describe the conditions necessary for achieving the recovery goal. They are identified in terms of demographic parameters, reduction or elimination of threats to the species (the five ESA section 4(a)(1) factors), and any other particular vulnerability or biological needs inherent to the species. Recovery criteria are established for each recovery objective (NMFS 2020). The recovery criteria are the targets, or values, used to measure progress toward achieving the recovery objectives. Recovery criteria are subject to revision based on new information and insights.

3.1 Goal

The ultimate goal of this Recovery Plan is to increase giant manta ray population viability across its range, such that the species can achieve recovery and be removed from the List of Endangered and Threatened Wildlife under the ESA (i.e., delist).

3.2 Objectives

We identified three recovery objectives for the giant manta ray that address demographic concerns and threats abatement. They are outlined below along with their associated recovery criteria.

The three objectives for the giant manta ray are to:

1) Ensure the giant manta ray maintains resiliency and geographic representation, and is a functional component of the ecosystem, by increasing overall abundance to achieve viable populations in all ocean basins;

2) Increase giant manta ray resiliency by managing or eliminating significant anthropogenic threats; and

3) Ensure the continued viability of the giant manta ray through development and effective implementation of regulatory mechanisms for the long-term protection of the species.

A prerequisite to achieving these objectives is obtaining sufficient data to determine whether they have been met. As a result, some of the recovery actions in section 4.1 below focus on research and data collection.

3.3 Criteria

To evaluate progress toward each of these recovery objectives and the overall goal, we developed the Recovery Criteria described below. There are two types of recovery criteria: 1) demographic criteria that reflect the population and life history parameters that indicate the species is no longer threatened or endangered, and 2) threats-based criteria that indicate the threats to the species are sufficiently minimized, managed, or eliminated. The demographic criteria is a specific target to support the objectives of species' viability (e.g., abundance, productivity, spatial distribution, and diversity). Threats-based criteria identify when threats have been minimized such that they are not contributing to the species being in danger of extinction within the foreseeable future throughout all or a significant portion of its range. Information we will assess to determine whether the threats-based criteria have been met will include how the species has responded to minimization measures, as measured by the demographic recovery criteria or reflected in the published literature, technical memoranda, population monitoring results, and other credible sources.

3.3.1 Geographic Regions

The giant manta ray was determined to likely become an endangered species within the foreseeable future throughout a significant portion of its range (83 FR 2916, January 22, 2018). In order to ensure that the delisting criteria and recovery actions cover the demographic issues and threats within the significant portion of the species' range, we divided the species' range into three geographic regions with two of these regions consisting of smaller subregions (**Figure 1**). These regions and subregions are not Recovery Units or Management Units (defined as special units that are essential to the recovery of the entire listed entity, or that reflect different management needs or authorities, respectively). Instead, we identified the regions to account for variation in the status of the giant manta ray along different segments of the species' range, and to allow for differences in how the Recovery Criteria are applied across regions. Because the species was listed based on its status in a significant portion of its range, the demographic recovery criterion or threats-based recovery criteria do not apply to all subregions as achieving those criteria in all subregions is not necessary for species recovery.

Regions and subregions are identified based on the status of and stressors and threats to giant manta ray populations within different geographic portions of the species' global range. Although the species was listed as threatened rangewide and is accorded the status of a threatened species throughout its range, the listing was based on the status of the population in a significant portion of its range. Therefore, considering the status of the population in different geographic portions was a key component of evaluating actions necessary for the species' recovery. The delineations take into consideration the information on population connectivity and movement and major biogeographical boundaries. The number of subregions varies by region based on the available data, including information on threats and status of the populations.

Below, we list and describe each region and its subregions:

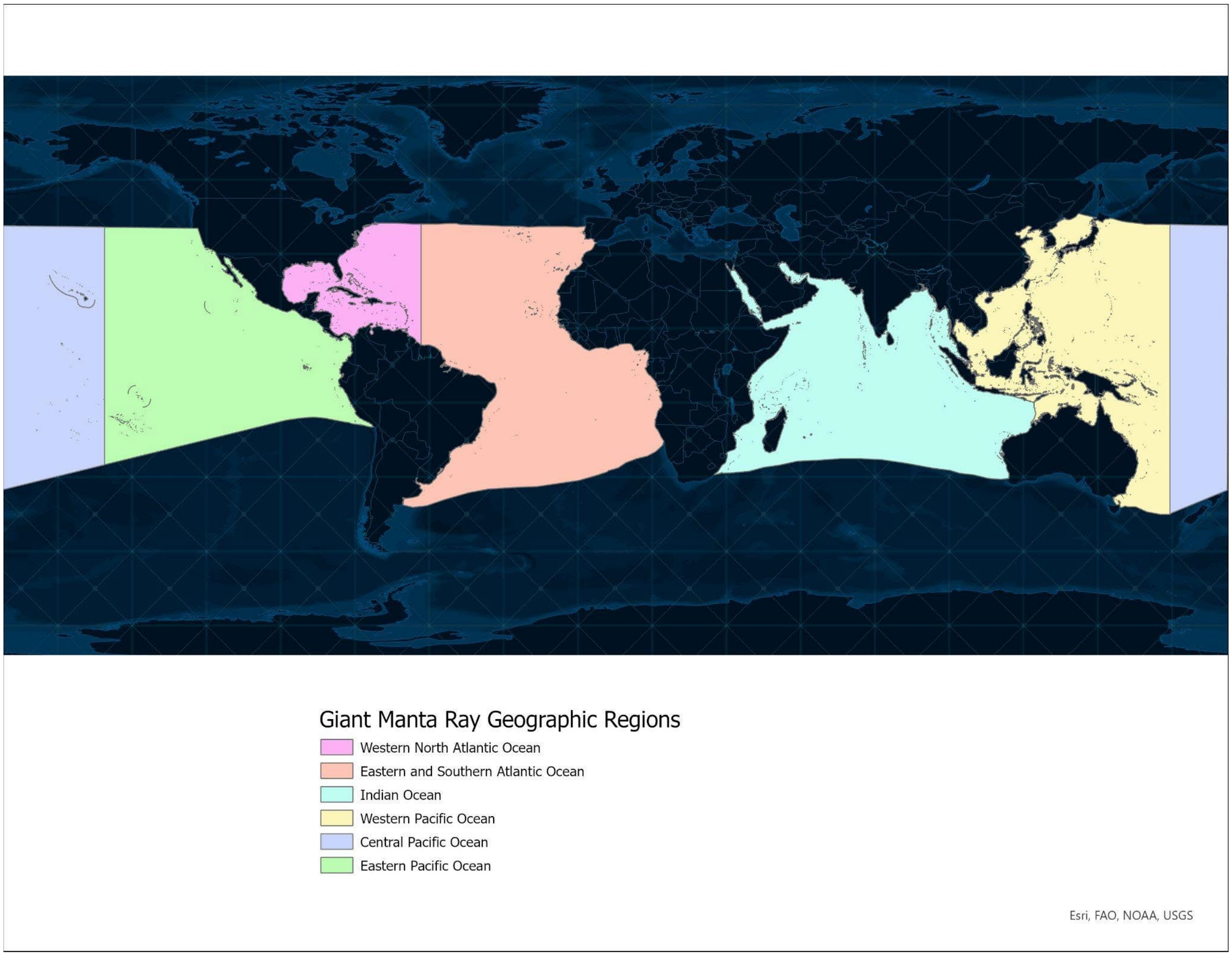


Figure 1. Map displaying the range of the giant manta ray divided into regions and subregions.

Region 1 – Atlantic Ocean

This region encompasses the range of the species within the Atlantic Ocean. This region includes giant manta ray populations that experience fisheries-related mortality but there is limited information available on the status and trends of these populations. We delineated the following subregions based on the best available data, taking into consideration the information on population connectivity and movement:

- 1A – Western North Atlantic (including Gulf of Mexico and Caribbean Sea): 57°W longitude & north of equator boundary line
- 1B – Eastern and Southern Atlantic; east of 57°W longitude & north of equator boundary line, and all waters south of the equator line

Giant manta ray populations within Subregion 1A are caught as bycatch in a number of commercial fisheries but are not known to be subject to targeted fisheries. There is limited data available to evaluate the status and trends of these populations to assess whether declines have occurred as a result of fisheries-related mortality and/or other stressors (e.g., vessel strike, entanglement). Giant manta ray populations within Subregion 1B are targeted by artisanal/small-scale fisheries and caught as bycatch by both artisanal/small-scale and commercial fisheries within this subregion. However, there is little to no information on the status of these giant manta ray populations. Within Subregion 1B there is evidence of illegal retention and enforcement issues, which may contribute to population declines, yet data is lacking.

Region 2 - Indian Ocean

This region encompasses the range of the species within the Indian Ocean. These giant manta ray populations are commonly targeted by artisanal/small-scale fisheries and caught as bycatch by both artisanal/small-scale and commercial fisheries. The subsequent level of fisheries-related mortality has caused significant declines in the populations. Contributing to this issue is a lack of adequate regulatory measures in certain countries to address fisheries-related mortality. There is also evidence of illegal retention and enforcement issues in areas of the region, which is contributing to significant declines of the giant manta ray populations.

Region 3 - Pacific Ocean

This region encompasses the range of the species within the Pacific Ocean. This region contains giant manta ray populations that are experiencing significant declines due to fisheries-related mortality and populations that are assumed to be fairly stable due to minimal fishing pressure. We delineated the following subregions based on the low likelihood of connectivity between large manta ray populations:

- 3A – Western Pacific Ocean; 163°E longitudinal boundary line; excludes New Caledonia

- 3B – Central Pacific Ocean; 163°E longitudinal boundary line; includes New Caledonia, extends to 150°W longitude - the IATTC boundary line
- 3C - Eastern Pacific Ocean; east of the 150°W longitudinal boundary line

Giant manta ray populations in Subregion 3A and Subregion 3C are or were commonly exposed to artisanal/small-scale fisheries and have experienced significant fisheries-related mortality, which has led to major declines in the populations. There is also evidence of illegal retention and enforcement issues in certain areas of these subregions contributing to population declines. Additionally, these giant manta ray populations are also observed caught as bycatch in a number of commercial fisheries; however, the artisanal/small-scale fisheries remain the greatest threat. In contrast, giant manta ray populations within Subregion 3B are not known to be subject to targeted fisheries and are thought to be only minimally caught as bycatch in commercial fisheries. There is limited data available to evaluate the status and trends of these populations to assess whether declines have occurred as a result of fisheries-related mortality and/or other stressors (e.g., vessel strike, entanglement).

3.3.2 Delisting Criteria

To delist the giant manta ray, the demographic-based recovery criterion and all of the threats-based recovery criteria discussed in sections 3.3.3 and 3.3.4 should be met. However, it is possible that delisting could occur without meeting all of the recovery criteria if the best available information indicates the giant manta ray no longer meets the definition of a threatened or endangered species.

3.3.3 Demographic Recovery Criterion

Objective 1: Ensure the giant manta ray maintains resiliency and geographic representation, and is a functional component of the ecosystem, by increasing overall abundance to achieve viable populations in all ocean basins;

1. The annual rate of population change is found to be increasing, on average, at a rate of a minimum of 2-4% in the Indian Ocean, Western Pacific Ocean Subregion and Eastern Pacific Subregion, and is stable or increasing at a rate of a minimum of 1-2% in at least one Atlantic Ocean Subregion, over 40 years (2 generations). These subregions and regions represent all ocean basins and include the significant portion of the giant manta ray's range that was the basis for the ESA listing. This criterion can be determined by using the rate of population growth from annual count data or an index of relative abundance.

Justification

There is currently little data available to measure the absolute abundance and/or relative abundance of the giant manta ray throughout its range. Monitoring exists in some areas, particularly popular scuba diving destinations, and when photographs are available these can provide relative population trends through mark-recapture statistical models (e.g. Marshall et al. 2011; Kitchen-Wheeler et al. 2012) or an index of sighting per unit effort over time (Bucair et al. 2021a). Given the long timeframes that are likely to be involved with giant manta ray recovery, standardized protocols that can be compared over the long-term will be essential. The most efficient way to implement these protocols would be to make them part of monitoring systems that already exist. When these data sets of abundance are available, there are several approaches that can be used to model and determine an abundance trend that take into account and correct for factors unrelated to abundance (e.g., changes in sea surface temperature). Relative abundance trends can be standardized using generalized linear mixed models (GLMM) (Maunder and Punt 2004). Generalized linear mixed models are extensions of generalized linear models (GLMs) and are commonly used to model fishery catch rates. If multiple indices of abundance are available in a given subregion, to determine recovery within that subregion, hierarchical analysis can also be used and provides an overall abundance trend for these multiple indices of abundance (e.g., Conn 2010). Multiple indices of abundance can also be further analyzed using dynamic factor analysis (DFA) to produce simplified, broad-scale common trends in relative abundance over the entire subregion (Peterson et al. 2017). In addition to these approaches, Bayesian state-space models offer a powerful and flexible framework to model variable population trends. Bayesian state-space models have properties that could help improve the objectivity of population assessments. One potential tool, JARA (https://github.com/henningwinker/; Winker and Sherley 2019), was used in the International Union for the Conservation of Nature (IUCN) red list assessment of 13 pelagic and coastal-pelagic sharks, including giant manta ray. JARA determined the global abundance of oceanic sharks and rays has declined by 71% since 1970 (Pacoureau et al. 2021). JARA determines the percentage change in the population from the calculated posteriors of the estimated population time series and estimates the overall observed and projected (± 95% confidence interval (CI)) population trajectory over a time threshold. Regardless of the approach, the annual rate of population change, on average, of 2-4% is based on the intrinsic rate of population increase (Rmax) estimated for giant manta ray (J. Carlson unpublished) calculated using 6 methods outlined in Cortés (2016). These six methods have been used to quantify extinction risk within a conservation framework for a variety of aquatic species, with the results for the giant manta ray showing a range of Rmax values, from 0.022 to 0.045, with an average of 0.033 and a standard deviation of 0.010. The assumption of Rmax, through the Euler–Lotka equation and its associated derivations, assumes no resource limitations and therefore density independence. This assumption would thus be valid for the giant manta ray given the assumed very low levels of abundance of the populations in the Indo-Pacific region. Furthermore, we find that the 2-4% increase in the annual rate of population change would need to be maintained, on average, over 40 years. The 40 years is based on the 2 generation lengths of giant manta. While there are multiple methods and definitions for generation time, we determined generation time to be the time it takes, on average, for a sexually mature female giant manta ray to be replaced by offspring with the same reproductive capacity, which follows within the methods used for Rmax in Cortés (2016). As such, we selected the 40 years as an appropriate timeframe over which the population biomass needs to maintain an increasing trend, on average, because it is biologically based (approximately two generations) and reasonably expected to encompass environmental and fisheries-based stochastic events that may affect the population over that extended timeframe. However, we note that life history information for giant manta rays has a high degree of uncertainty and, as such, the Rmax estimates may change in the future.

3.3.4 Threats-based Recovery Criteria

Objective 2: Increase giant manta ray resiliency by managing or eliminating significant anthropogenic threats.

The Threats-based Recovery Criteria describe what is needed to adequately reduce or mitigate the threats to support the long-term survival and recovery of the giant manta ray. In addition to meeting the demographic recovery criterion in section 3.3.3, the following threats-based recovery criteria must be met in order to delist the giant manta ray.

We organized the threats-based recovery criteria according to the five ESA listing factors that are considered when determining whether a species is endangered or threatened, and also when reclassifying or delisting any listed species:

(a) The present or threatened destruction, modification or curtailment of its habitat or range;
(b) Overutilization for commercial, recreational, scientific, or educational purposes;
(c) Disease or predation;
(d) Inadequacy of existing regulatory mechanisms; or
(e) Other natural or manmade factors affecting its continued existence.

Factor B: Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

2a. Fcurrent (i.e., the current level of total fishing mortality (at-vessel + post-release mortality)) < Flimit (i.e., the fishing mortality rate that corresponds to the maximum level of mortality that can occur that may drive the population to low levels in the long-term) over a period of 2 generations (~40 years) for each subregion/region in the Demographic Recovery Criterion (i.e., Indian Ocean, Western Pacific Ocean, Eastern Pacific Ocean, and any subregion in the Atlantic Ocean).

OR

2b. Based on population viability analysis (which focuses on the number of females), theoretical levels of annual fishing mortality will not exceed 1% of the current population size for each subregion/region in the Demographic Recovery Criterion.

Justification
The most significant threat to the giant manta ray is overutilization for commercial purposes. The species has experienced population declines of significant magnitude within a significant portion of its range due to fisheries-related mortality. Manta rays are both targeted and caught as bycatch in fisheries worldwide. The fisheries that target mobulids are artisanal, with mobulids traditionally targeted for their meat; however, since the 1990s, a market for mobulid gill plates has significantly expanded, increasing the demand for manta ray products, particularly in China. This demand ultimately caused a transition of the artisanal fisheries from subsistence fishing to commercial export fishing of manta rays. Due to their extremely low fecundity, this transition resulted in massive declines in manta ray populations and fishery collapse in many areas, including within the Eastern Pacific and Indian Ocean regions and the Western Pacific Ocean subregion. Targeted fishing, particularly for the commercial export of manta rays, is clearly unsustainable and must be eliminated in order to recover manta ray populations. Additionally, direct harvest for domestic consumption of the species must also be deterred until populations recover and subsistence harvest can be done sustainably.

In addition to targeted fishing, bycatch has a significant impact on giant manta rays. Given the global distribution of manta rays, they are frequently caught as bycatch in a number of commercial and artisanal fisheries worldwide. In fact, manta rays comprise the greatest proportion of ray bycatch in the purse-seine fisheries operating in the Indian Ocean and the Eastern Pacific Ocean (Oliver et al. 2015). They are also exceptionally vulnerable to bycatch in artisanal fisheries that use a variety of gear (e.g., gillnets, driftnets, trawls, and harpoons) and operate within the Indian Ocean and the Western and Eastern Pacific Ocean subregions.

To adequately reduce or mitigate the threat of fisheries-related overutilization to support the long-term survival and recovery of the giant manta ray, criteria related to fishing mortality rates or population viability is necessary.

Fishing mortality-based (F-based) reference points can be derived analytically using life history information. This approach assumes that reference points are a function of life history parameters, specifically that F-based reference points are related to the intrinsic rate of population increase (rmax) and natural mortality rate (M). Since the natural mortality rate is used in the computation of the intrinsic rate of population increase, only relationships between F and rmax would be used to define three reference points:

> Fmsy = rmax /2, where Fmsy is the fishing mortality rate that results in maximum sustainable yield (MSY), which corresponds to a population size that can be harvested sustainably and still grow.
>
> Flim = 0.75 rmax, where Flim is the fishing mortality rate that corresponds to the maximum level of mortality that can occur that may drive the population to low levels in the long term, but not necessarily extinction.
>
> Fcrash = rmax, where Fcrash is the minimum unsustainable fishing mortality rate that theoretically will lead to population extinction in the long-term.

Once the F-based reference points are derived, an estimate of the current level of fish mortality (Fcurrent) will be derived to compare them. In the absence of a formal stock assessment, Fcurrent can be obtained using area-based methods (as used in the Sustainability Assessment for Fishing Effects (SAFE) approach, e.g., Zhou and Griffiths 2008; Zhou et al. 2009), catch-based methods (catch curves), length-based methods, or other independent estimates of fishing mortality (e.g., from conventional or electronic tagging).

A level of risk can then be established based on the current level of total fishing mortality relative to the F-based reference points. For a subregion/region to be considered to have met this recovery criteria, the current level of total fishing mortality should be between the fishing mortality rate that results in maximum sustainable yield and the fishing mortality rate that results in the maximum level of mortality that could drive the population to low levels. This means that while fishing mortality is still occurring, the level of mortality and associated risk would be low enough that the population would still be able to grow over the long-term (and eventually meet the demographic criterion described in section **3.3.3 Demographic Recovery Criteria**). This level of fishing mortality would fall in between the low and medium "risk" categories as shown below in **Figure 2**. Uncertainty can be incorporated into the calculation of rmax (Cortés 2016) and comparing the independently derived estimate of the current level of fishing mortality to the F-based reference point at each iteration (**Figure 2**).

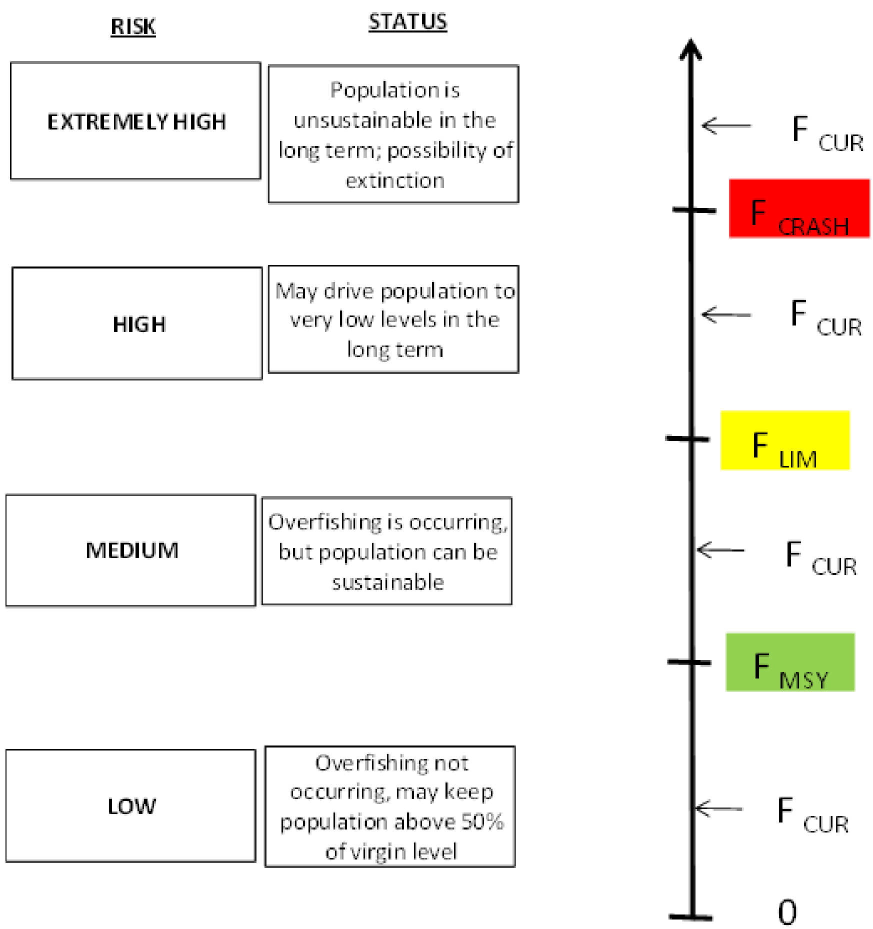


Figure 2. Graphical representation of F-based reference points and risk levels modified by Cortés (2019) from Table 1 in Zhou et al. (2011).

In determining an appropriate timeframe for this criterion to be met, we examined the life history of the giant manta ray. Generation time, which is defined as the time it takes, on average, for a sexually mature female giant manta ray to be replaced by offspring with the same spawning capacity, is estimated to be around 20-22 years (J. Carlson unpublished). As a long-lived species that matures relatively late, has relatively slow growth rates and low productivity, we selected 40 years as an appropriate timeframe for this criterion because it is biologically based (approximately 2 generations) and reasonably expected to encompass environmental and fisheries-based stochastic events that may affect the population in the future. For a long-lived species with relatively low productivity, this timeframe would ensure that the threats have been reduced to an adequate level that ensures the species as a whole to maintain stability at the recovered level and resilience to stochastic events.

Given that demographic studies indicate that giant manta rays have among the lowest productivity compared to other sharks and rays (Dulvy et al. 2014), this slow life history is likely a key reason why they have little capacity to withstand fishing pressure. To show an example of how to determine the level of fishing mortality manta rays can withstand and still allow their population to recover, Carlson et al. (2022) constructed an age-structured Leslie matrix population viability model for five subpopulations and the largest known metapopulation of giant manta ray in the Eastern Pacific Subregion. Various scenarios of theoretical fishing mortality as a proportion of the population were calculated. Results showed that the population only grew when annual mortality was less than or equal to 1% of the initial population size of 15,728 females. Any level of fishing mortality above this level would not allow the population to rebuild.

Objective 3. Ensure the continued viability of the giant manta ray through development and effective implementation of regulatory mechanisms for the long-term protection of the species.

Factor D: Inadequacy of Existing Regulatory Mechanisms

3. All nations identified by the respective RFMOs, their compliance committees, the Food and Agricultural Organization of the United Nations [FAO], and/or CITES as having significant catch, bycatch, and/or trade of giant manta rays have acceded to international and multilateral agreements and enacted national legislation or equivalent regulatory measures to implement management measures specified under the agreements.

4. Measures prohibiting retention and sale of any part or whole carcass of giant manta rays by both artisanal/small-scale and commercial fishing vessels are implemented and/or maintained by the Indian Ocean Tuna Commission (IOTC), Western and Central Pacific Fisheries Commission (WCPFC), and the Inter-American Tropical Tuna Commission (IATTC) RFMOs, and Parties are implementing these measures adequately as measured by landings data and country reports to RFMOs as well as at-sea compliance monitoring and observer programs. This can be verified by each of the compliance committees in the respective RFMOs.

5. Within an individual country's exclusive economic zone (EEZ) located within the Indian Ocean region and Eastern Pacific and Western Pacific Ocean subregions that are not subject to RFMO retention prohibitions and are known to have fisheries that catch giant manta rays, laws are developed and/or maintained, implemented, and enforced to prohibit direct targeting of the species as well as retention of any part of the species when caught as bycatch and to prohibit trade in manta ray gill plates.

Justification

Inadequate regulatory mechanisms to control overutilization of giant manta rays in artisanal/small-scale fisheries and commercial fisheries were identified as a significant threat to the species. Although various regulations and management measures have been implemented to limit harvest and trade of the species both internationally and nationally, these measures were deemed only partially effective due to lack of compliance, variable enforcement, and evidence of illegal fishing within the Indian Ocean, Western Pacific, and Eastern Pacific portions of the species' range (NMFS 2024a). Therefore, ensuring adequate implementation of and compliance with these mechanisms will help reduce fisheries mortality and support the long-term sustainability and recovery of the species.

International Trade

6. The number of giant manta ray gill plates in international trade is at or near zero, on average, over 20 years (one generation), demonstrating that the trade has been essentially eliminated.

Justification:
Since the 1990s, a market for mobulid gill plates has significantly expanded, increasing the demand for manta ray products, particularly in China. Although not historically a part of Traditional Chinese Medicine (TCM), the gill plates of mobulids are being pushed for acceptance as TCM, with marketers claiming to consumers that they have healing and immune boosting properties, and could also be used for childhood chicken pox and lactation aids (Heinrich et al. 2011). As a result, demand has significantly increased, with a high trade and market value for manta ray gill plates (~$130/kg local trade up to $860/kg market value; Rathnayake 2023; Hau et al. 2016), incentivizing fishermen who once avoided capture of manta rays to directly target these species or retain them as bycatch (Heinrichs et al. 2011; CITES 2013). Thus, this demand represents the main economic driver of mortality of this species throughout its global range. As such, giant manta rays are unlikely to recover until the international trade in their gill plates is eliminated. This could occur through an uplisting of the species in CITES to Appendix I, prohibiting the international trade of the species, or by eliminating the demand of gill plates for use in Asian medicine through strong consumer outreach and education. In order to evaluate the demand, the number of giant manta ray gill plates in the trade and their price trends locally, nationally, and internationally will be tracked and monitored. For international trade to be considered eliminated, the number of giant manta ray gill plates in the trade has to be near zero, on average, over 20 years, and the population needs to show a positive trend in line with the demographic criterion above. In order to decrease the demand (shown by declining trends in price), additional disincentive consumer campaigns, greater enforcement (to decrease the illegal, unreported, and unregulated (IUU) fishing of giant manta rays), or regulatory measures may be necessary to meet this criteria.

Below are the ESA listing factors for which we have not developed any threats-based recovery criteria.

Factor A: Present or Threatened Destruction, Modification, or Curtailment of Habitat or Range

As described in the status review (Miller and Klimovich 2017) and more recent Recovery Status Review (NMFS 2024a), due to their association with nearshore habitats, giant manta rays may be at elevated risk for exposure to a variety of contaminants and pollutants, including brevotoxins, heavy metals, polychlorinated biphenyls, oil spills and plastics. However, at this time, there is no information on the lethal concentration limits of these metals or other toxins in giant manta rays. Additionally, there is no evidence to suggest that current concentrations of these environmental pollutants are causing detrimental physiological effects to the point where the species may be at an increased risk of extinction. While the ingestion of plastics is likely to negatively impact the health of the species, the levels of microplastics in giant manta ray feeding grounds, frequency of ingestion, and biological impacts are not currently known.

In terms of the climate change stressor, it is important to note that manta rays frequently rely on coral reef habitat for essential life history functions (e.g., feeding, cleaning) and depend on planktonic food resources for nourishment, both of which are highly sensitive to environmental changes (Brainard et al. 2011; Guinder and Molinero 2013). As such, climate change may have an impact on the prey availability, distribution, and behavior of *M. birostris*. As declines in coral cover have been shown to result in changes in coral reef fish communities (Jones et al. 2004; Graham et al. 2008), the projected increase in coral habitat degradation may potentially lead to a decrease in the abundance of manta ray cleaning fish. Biogeochemical models may also project a decline in zooplankton biomass in the future of about 10% globally (Chust et al. 2014; Stock et al. 2014; Woodworth-Jefcoats et al. 2017), but some regions, particularly those in the tropics, could experience >50% declines (Stock et al. 2014). While it is unknown how this broad-scale decline in zooplankton biomass in the tropics could impact local areas where giant manta rays feed, the most likely outcome is that there will be lower zooplankton biomass available for manta rays and other zooplanktivores. In addition, changes in climate and oceanographic conditions, such as acidification, are also known to affect zooplankton structure (size, composition, diversity), phenology, and distribution (Guinder and Molinero 2013). As such, the migration paths and locations of both resident and seasonal aggregations of giant manta rays, which depend on these animals for food, may similarly be altered (Australian Government 2012; Couturier et al. 2012). This altering of the species' distribution for foraging grounds from other important habitat areas, such as cleaning stations or nursery areas, could have profound impacts on the species' viability. However, at this time, there is not yet enough information available about the giant manta ray's sensitivity to climate factors and its capacity to adapt to changes in those factors, including changes in prey distribution and abundance, to conclude that climate change is limiting the recovery of the species.

Overall, no threats have been identified as impeding the overall recovery of the species or driving the giant manta ray's extinction risk under Factor A, and this Recovery Plan does not include recovery criteria under Factor A; however, as discussed in section 1.2, these stressors should be monitored. An action is included in the recovery program to better understand the effects other stressors may have on the giant manta ray.

Factor C: Disease or Predation

As described in the status review (Miller and Klimovich 2017) and more recent Recovery Status Review (NMFS 2024a), there is no information to indicate that disease or predation represents a threat or even a stressor to the giant manta ray. Neither of these factors were important in the decline of the species historically and they are not believed to limit recovery of populations at this time. Therefore, no stressors or threats have been identified under Factor C, and this Recovery Plan does not include recovery criteria under Factor C.

Factor E: Other Natural or Manmade Factors Affecting Its Continued Existence

As described in the status review (Miller and Klimovich 2017) and more recent Recovery Status Review (NMFS 2024a), other natural or manmade factors, such as tourism, aquarium trade, entanglement, and vessel strikes may represent a potential risk to the species; however very little information is available on their current impacts to the overall status of the giant manta ray.

In terms of tourism, swimming with manta rays is a significant tourist attraction throughout the range of the species. This increasing demand to see and dive with the animals has the potential to lead to other unintended consequences that could harm the species, including potential inadvertent habitat destruction by divers (Osada 2010) and manta ray behavioral and metabolic alterations (Venables 2013; Hernández-Navarro et al. 2023). Additionally, somewhat related to tourism, giant manta rays are also being traded internationally for display in public aquariums, with six identified aquariums that are known to house captive wild caught manta rays for the purpose of public display. However, at this time, the number of individuals harvested for exhibition/aquarium and the long-term effects of tourism interactions on giant manta ray populations remain unknown.

In terms of entanglement and vessel strikes, both may result in mortality or severe injury to individuals. As manta ray seasonal sites are sometimes in areas of high maritime traffic, manta rays are at potential risk of being struck and killed by vessels. Additionally, researchers have reported manta ray mortalities and injuries from entanglement in fishing gear lines and nets as well as mooring and buoy lines, hook and line, and vessel strikes (Bucair et al. 2021a; Bucair et al. 2021b; Pate and Marshall 2020), with such injuries potentially affecting manta ray fitness in a significant way (The Hawaii Association for Marine Education and Research Inc. 2005; Deakos et al. 2011; Heinrichs et al. 2011; Couturier et al. 2012; CMS 2014; Germanov and Marshall 2014; Braun et al. 2015). However, there is very little quantitative information on the frequency of these occurrences and no information on the impact of these injuries and mortalities on the overall health of the populations.

Overall, no threats have been identified as impeding the overall recovery of the species or driving the manta ray's extinction risk under Factor E, and this Recovery Plan does not include recovery criteria under Factor E; however, as discussed in section 1.2, these stressors (entanglements, vessel strikes, tourism and aquarium trade) should be monitored. An action is included in the recovery program to better understand the effects other stressors may have on the giant manta ray.

4. Recovery Actions

As previously mentioned, we have designed this Recovery Plan to provide the foundation for recovering the giant manta ray. It provides an overall road map for achieving the recovery goal, objectives, and criteria, and includes strategic, site-specific recovery actions and time and cost estimates for these recovery actions to the maximum extent practicable for this species. Section 4(f) of the ESA does not define a particular level of specificity as being required for describing site-specific actions in a recovery plan. The descriptions we have included in the plan meet the statutory requirements as they include as much detail, including as regards the sites where recovery actions can be planned, as is practicable for a document of this type. The Recovery Implementation Strategy (NMFS 2024c), on the other hand, is a more dynamic document that steps-down the recovery actions into more specifically defined activities that implement and support the recovery actions. Unlike the Recovery Plan itself, which sets out the overarching path and is updated through a process that includes public notice and comment, the Recovery Implementation Strategy can more nimbly adapt over time based on the progress of recovery and the availability of new information, either as research is analyzed, literature is published, or when the status of the giant manta ray is reviewed. We elect to provide the additional level of specificity in the Recovery Implementation Strategy, to help further conservation of the species by providing as much transparency and information as possible to the public. Further, we note it would not be practicable to include such detail in the Recovery Plan itself given the rapid pace with which circumstances on the ground can change as to a range of issues, such as availability of funding, identification of emerging appropriate locations for projects, willingness of partners to implement actions, etc. Should the progress on activities in the Recovery Implementation Strategy indicate the recovery actions in the Recovery Plan should be revised, we will revise the Recovery Plan as appropriate and seek public comment on those revisions.

4.1 Recovery Action Outline

The Recovery Action Outline lists all of the recommended recovery actions needed to alleviate the threats and support the long-term sustainability and recovery of the giant manta ray. The recovery actions in this outline are not in order of priority. Unless otherwise indicated, the relevant "site" for each recovery action is located throughout each of the subregions/regions, which cover the entire range of the giant manta ray as shown in **Figure 1**.

Recovery Actions

Population Dynamics

1. Improve knowledge and understanding of giant manta ray population status, abundance trends, and genetic structure.
2. Improve knowledge and understanding of giant manta ray distribution, movement, and habitat use.
3. Improve knowledge and understanding of the demographics and life history of giant manta rays.

Fisheries Interactions

4. Minimize and ultimately eliminate targeted fisheries for giant manta rays in foreign fisheries through enhanced coordination and collaboration with relevant organizations to support national and regional development of policies, management plans, and capacity to make giant manta ray fishing commercially unviable and domestically less favorable relative to sustainable species.
5. Minimize fisheries bycatch and mortality of giant manta rays by determining and addressing the frequency of capture and severity of fishing interactions in artisanal/small-scale and commercial fisheries globally.
6. Minimize fisheries bycatch and mortality of giant manta rays in international fisheries through enhanced international coordination and participation with relevant international organizations, such as RFMOs.

International Trade

7. Implement management actions to eliminate giant manta ray gill plates in international trade.

Monitoring and Reporting

8. Improve species-specific monitoring and reporting of giant manta rays in commercial and artisanal fisheries by RFMOs and individual countries to improve estimates of catch and discards, provide a better understanding of the effects of IUU fishing, and measure progress towards recovery.

Regulatory Mechanisms and Enforcement

9. Minimize fishing mortality of giant manta rays through effective development, implementation, and enforcement of international and domestic measures such as legislation and regulations.

Outreach and Education

10. Develop and implement outreach and education strategies and programs to increase public (including consumers) and stakeholder (including fishermen) awareness on the status and recovery needs of the giant manta ray and decrease the demand for gill plates.

Other Actions

Other Stressors

11. Identify, evaluate, and minimize any other stressors that may be impeding recovery of giant manta rays.

Post-delisting Monitoring Plan

12. Develop a post-delisting monitoring plan to ensure continued sustainable fisheries management of giant manta ray post-delisting.

4.2 Recovery Action Narrative

In this section, we provide a description for each recovery action identified above, including a rationale for why each action is necessary for the recovery of the giant manta ray as well as a general description of how these recovery actions will be implemented. We also describe the other actions pertaining to other stressors and the post-delisting monitoring plan, which are not recovery actions.

Table 2 below provides a summary of the recovery program, linking the recovery actions to the threats identified as factors contributing to the threatened status of the giant manta ray.

Population Dynamics

1. Improve knowledge and understanding of giant manta ray population status, abundance trends, and genetic structure.

Understanding the population status and abundance trends of the giant manta ray throughout its range is essential for assessing the conservation status of the species and measuring progress towards achieving recovery. Therefore, this recovery action is needed to monitor progress towards achieving the demographic recovery criterion (1). Information on population status, abundance trends, and genetic structure also provides a foundation for monitoring whether management interventions to mitigate threats are having the expected effect on the species. This recovery action is therefore also needed to monitor progress towards achieving the threats-based recovery criteria for targeted fisheries and bycatch (2a, 2b) under Factor B and international trade (6) under Factor D. Without accurate knowledge of the magnitude of total catches and discards, it is not possible to estimate absolute abundance levels for the population. Therefore, methods of determining population status (see objectives and demographic criterion for delisting giant manta ray) will need to be developed and/or updated as new information on fisheries, abundance, and biology of the species require regular assessments. As such, activities under this recovery action should include developing and/or using alternative modeling methods appropriate to these situations to evaluate the status of the giant manta ray and measure recovery progress. For example, satellite tagging to estimate depth-use of manta rays to calibrate abundance models for availability bias would provide parameters essential to the development of effective population viability analyses. Additionally, advocating for increased support of monitoring of artisanal and commercial fisheries using either electronic monitoring (EM) and/or at-sea fisheries observers to improve the quality and quantity of data collected (e.g., landings and discards) to inform such research will be necessary. Increasing observer coverage to help achieve this is covered under recovery actions 6 and 8 below.

2. Improve knowledge and understanding of giant manta ray distribution, movement, and habitat use.

Currently, the distribution and habitat use of giant manta rays are not well understood, with some exceptions (e.g., Garzon et al. 2021, Farmer et al. 2022). The species tends to be a seasonal visitor, observed along productive coastlines with regular upwelling, oceanic islands, and at offshore pinnacles and seamounts. They are known to aggregate in various locations around the world in groups usually ranging from 100-1,000. The timing of these visits varies by region and seems to correspond with the movement of zooplankton, current circulation, tidal patterns, seasonal upwelling, and seawater temperature, with these sites potentially functioning as feeding sites, cleaning stations, or sites where courtship interactions take place. They have also been observed in estuarine waters near oceanic inlets and shallow waters near the edge of the continental shelf and proximity to abundant pelagic food resources, with use of these waters as potential nursery grounds. However, the extent of purported nursery grounds remains unknown. Additionally, based on satellite tagging and aerial studies, it appears that both broad and small-scale migrations are important to this species, however, it has been difficult to determine the extent of their distribution or habitat use throughout their life.

More research is needed to rigorously and specifically define the environmental features that make an area important to giant manta rays so these areas can be protected and/or managed adequately. Therefore, this recovery action is needed to monitor progress toward achieving the demographic recovery criterion (1), and to inform management and mitigation measures that will lead to achieving the threats-based recovery criteria related to targeted fisheries and bycatch (2a, 2b). Physical, chemical, biological, fishery, and other relevant data should be collected or compiled to characterize features of important habitats. Habitat characterization also involves, among other things, descriptions of prey types, densities, and abundances, and of associated oceanographic and hydrographic features. As such, activities under this recovery action should include the development of a predictive framework for identifying giant manta ray habitat as a management tool for potentially reducing fishery interactions. Research and analysis to characterize giant manta ray habitat use may also inform evaluation of climate change effects. Additionally, advocating for increased monitoring of artisanal and commercial fisheries using either EM and/or at-sea fisheries observers, to improve the quality and quantity of data collected (e.g., catch, landings, and discards) to inform such research will be necessary. Increasing observer coverage to help achieve this is covered under recovery actions 6 and 8 below.

3. Improve knowledge and understanding of the demographics and life history of giant manta rays.

It is important to obtain current and accurate information on life history parameters for the giant manta ray (e.g., age, growth, reproduction), as this information is used in population models to predict the productivity of the species and ensure current levels of fishing mortality are allowing the population to recover. Thus, this recovery action is necessary to measure progress toward achieving the demographic recovery criterion (1), as well as the targeted fisheries and bycatch (2a, 2b) threats-based recovery criteria under Factor B. Current information suggests giant manta rays exhibit life history traits that result in extremely low overall productivity, such as long gestation, late maturity, the potential for four to five years between pregnancies, and low fecundity (one pup per litter). However, much of this information is assumed based on reef manta ray (*M. alfredi*) life history traits (e.g., longevity, reproductive periodicity), and may vary by geographical region. Therefore, updating current life history information and determining whether life history parameters differ among the Regions or Subregions will be critical in determining population status and measuring recovery progress. As such, activities under this recovery action should focus on improving data collection and biological sampling of giant manta rays throughout its range.

Fisheries Interactions

4. Minimize and ultimately eliminate targeted fisheries for giant manta rays in foreign fisheries through enhanced coordination and collaboration with relevant stakeholders to support national and regional development of policies, management plans, and capacity to make giant manta ray fishing commercially unviable and domestically less favorable relative to sustainable species.

The most significant threat to the giant manta ray is overutilization for commercial purposes primarily by artisanal fisheries operating in areas outside of U.S. jurisdiction. Traditionally, foreign artisanal/small-scale fisheries would target mobulids for their meat; however, since the 1990s, a market for mobulid gill plates has significantly expanded, increasing the demand for manta ray products, particularly in China. This demand ultimately caused a transition of the artisanal fisheries from subsistence fishing to commercial export fishing of manta rays, resulting in massive declines in manta ray populations and fishery collapse in many areas, including within the Indian Ocean region and the Western Pacific and Eastern Pacific Ocean subregions. Targeted fishing for the commercial export of manta rays is unsustainable and must be prohibited in order to help recover manta ray populations. Additionally, direct harvest for domestic consumption of the species must also be eliminated until populations recover and the subsistence harvest can be done sustainably. Thus, this recovery action is aimed at eliminating the targeted fishing of the species, and is necessary to achieve the demographic recovery criterion (1) and the threats-based recovery criteria for fisheries-related mortality (2a, 2b) under Factor B. However, decreasing the demand for manta rays is complex and may vary by geographic location. For example, some communities are dependent on manta ray fisheries and the gill plate trade to support their livelihoods and thus would require a sufficient alternative for their income. Therefore, in order to successfully reduce targeted manta ray fisheries in foreign countries, significant coordination and collaboration with relevant organizations, fishing communities, foreign government officials, and other stakeholders is required to support local, national, and regional strategies to make mobulid fishing commercially unviable and domestically less favorable relative to sustainable species. This may include development of policies and management plans to prohibit targeted fishing, development of alternative livelihoods and food sources, implementation of incentives and increased enforcement capacity to assure compliance, and education and outreach events to motivate consumers, fishing communities, and the public to conserve giant manta rays. Thus, this recovery action is aimed at directly mitigating giant manta ray interactions with fishing activities, and is necessary to achieve the demographic recovery criterion and all of the threats-based recovery criteria.

5. Minimize fisheries bycatch and mortality of giant manta rays by determining and addressing the frequency of capture and severity of fishing interactions in artisanal/small-scale and commercial fisheries.

The species has experienced population declines of great magnitude within a significant portion of its range due to fisheries-related mortality. In addition to targeted fisheries, the combined at-vessel and post-release bycatch-related mortality in commercial and artisanal fisheries across the species' range contributes to the significant threat of overutilization of the species. The giant manta ray frequently interacts with purse seines and gillnets, and to a lesser degree, trawls, longlines, and harpoons, and has experienced large population declines in a significant portion of its range as a result. Thus, this recovery action is aimed at directly mitigating giant manta ray interactions with fishing activities, and is necessary to achieve the demographic recovery criterion (1) and the threats-based recovery criteria for fisheries-related mortality (2a, 2b) under Factor B. However, more information is needed to better understand factors that may affect the frequency with which giant manta rays interact with these fisheries in order to implement measures that have the potential to reduce these interactions. This recovery action will also provide information needed to develop effective regulatory measures to address fisheries interactions, and is therefore needed to achieve recovery criteria 4 and 5. Increasing the likelihood that manta rays will survive interactions that do occur, both at the vessel and after the manta rays are released, is also key to reducing the overall threat of fishing on the species and eventually improving overall population numbers. Factors that affect levels of at-vessel and post-release mortality vary by gear type and may include the following: how (and for how long) the animals are handled, methods of release, soak time, and the quantity of trailing gear left on the animal after being released. Therefore, activities under this recovery action will be aimed at determining and implementing methods to minimize overall interaction rates of giant manta rays in commercial and artisanal/small-scale fisheries, as well as minimizing mortality associated with capture, handling, and release of giant manta rays in various fishing gear. This could include, for example, the potential use of time-area closures during the seasonal migrations of giant manta rays, research on best methods to increase at-vessel and post-release survivorship (e.g., gear configurations), and development and implementation of species and gear-specific safe handling and release guidelines and/or regulations if necessary.

6. Minimize fisheries bycatch and mortality of giant manta rays in international fisheries through enhanced international coordination and collaboration with relevant international organizations, such as RFMOs.

Improved coordination through relevant tuna-RFMOs is needed to enhance the implementation of, compliance with, and effectiveness of existing conservation and management measures for giant manta rays, and to identify any new management measures needed to reduce the threat of fishing activities on the species. This recovery action is needed to achieve the demographic recovery criterion (1), as well as threats-based recovery criteria for fisheries-related mortality (2a, 2b) and inadequate regulatory mechanisms to address bycatch and international trade (4, 5 and 6). While several activities under this recovery action will be specific to a Region or Subregion, some activities will apply across all. Activities include proposing and negotiating specific measures within RFMOs, or working with members to sponsor these proposals, to prohibit the retention of giant manta rays in both commercial/industrial and artisanal/small-scale fisheries, encouraging Parties to implement domestic regulations to comply with RFMO measures (especially retention prohibitions and handling and release guidance), increasing observer coverage to at least minimum requirements but encouraging even greater coverage, and increasing data collection on giant manta rays to better understand the impact of fishing on the species.

In addition to improving coordination through the relevant tuna-RFMOs, there are many other international organizations and mechanisms that focus on conservation and management of species, including manta rays. Enhanced coordination between these organizations, specifically for giant manta rays, will be beneficial for promoting and supporting recovery across international and regional jurisdictions. These include international agreements such as CITES, the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and its Sharks Memorandum of Understanding (CMS Sharks-MOU), as well as other mechanisms and projects (e.g., United Nations Environment Programme [UNEP] Protocol for Specially Protected Areas and Wildlife [SPAW], IUCN Shark Specialist Group, International Seafood Sustainability Foundation [ISSF], and others as appropriate). Activities under this recovery action should focus on continued engagement, enhanced coordination, and implementation of various management and research activities aimed at conserving giant manta rays by reducing threats of overfishing and international trade of the species.

Because countries outside U.S. jurisdiction are the largest sources of giant manta ray mortality, effective implementation of management actions to reduce the threat of overfishing to the giant manta ray throughout its range will require the participation of the international fishing community, as well as foreign government officials and other stakeholders. However, some countries whose fishing fleets interact with giant manta rays may not have adequate institutional capacity and resources to properly implement fisheries regulations and/or monitoring and enforcement measures. They may also lack the resources to train fishermen in safe handling and release methods, species identification, and data collection protocols. Therefore, this recovery action includes investing in capacity building programs in these key countries particularly within the Indian Ocean Region, Western Pacific Subregion, and Eastern Pacific Subregion, which will be critical for reducing the main threat of overfishing on the giant manta ray.

7. Implement management actions to eliminate giant manta ray gill plates in international trade.

The international gill plate trade was identified as the main economic driver for commercially targeted, retained bycatch, and illegal retention of giant manta rays. Their large, distinctive gill plates are heavily sought after by China and obtain high market prices, from $130/kg up to $860/kg (depending on the location or shop) (Hau et al. 2016; Earth.org 2020, Rathnayake 2023). As such, fishermen that avoided manta rays historically now target or retain them as bycatch for the international gill plate trade. In fact, the estimated annual global landings of giant manta rays documented in fisheries is ~3,400 individuals; however, this number is likely highly underestimated as it does not include unreported or subsistence catches (Heinrichs et al. 2011). It is this demand and consequential level of take for the international trade that has clearly led to significant declines in giant manta ray populations and resulted in their listing under CITES Appendix II in order to ensure the trade is sustainable for the species. However, while this was a good first step to control international trade in the species, based on the species' extremely low productivity and small and declining populations, it is unlikely that any amount of trade by countries, particularly in the Indian Ocean Region and Western and Eastern Pacific subregions, will be sustainable for the giant manta ray. Therefore, activities under this recovery action should focus on engaging with CITES Parties on management actions to eliminate trade of giant manta rays, including exploring the amount of evidence that would support an uplisting proposal of the species to CITES Appendix I. Due to the complexity involved in a potential uplisting of the species and time required for completion, advocating for conducting a significant trade review of the species and strengthening non-detriment findings consistent with the species' existing CITES Appendix II listing are prudent actions to reduce this threat in the meantime. Additionally, activities, such as providing support to customs agencies to accurately identify giant manta rays and their products, will help enforce CITES international trade regulations and provide information on where most giant manta rays are being taken and the magnitude of illegal trade. Identifying the origin of giant manta ray products in the trade will help us better understand which RFMOs need to take further management action to address IUU fishing of the species based on their region of operation. This recovery action is needed to achieve the demographic recovery criterion (1) as well as all of the threats-based recovery criteria.

Monitoring and Reporting

8. Improve species-specific monitoring and reporting of giant manta rays in commercial and artisanal fisheries by RFMOs and individual countries to improve estimates of catch and discards, provide a better understanding of the effects of IUU fishing, and measure progress towards recovery.

Adequate monitoring and reporting is crucial for determining reliable estimates of catch, discards, and disposition (i.e., whether an animal is released alive or dead, and if released alive at-vessel, whether the animal survived), and provides vital data needed in population assessments. In addition, monitoring and reporting is important for determining the efficacy of existing national, international, and RFMO measures, so this recovery action is needed to measure progress toward achieving the demographic recovery criterion (1) and all of the threats-based recovery criteria. Currently, most of the tuna-RFMOs (i.e., IATTC, IOTC, and WCPFC) have prohibited retention of the giant manta ray by commercial/industrial fishing vessels. While this may appear to help reduce the amount of manta ray gill plates in the international trade (from commercial bycatch), the disposition of the manta ray remains highly uncertain. Additionally, within the IOTC, IATTC, and ICCAT, small-scale/artisanal fishing vessels are still allowed to target or catch the species if categorizing it as subsistence fishing, and, with the exception of the IOTC, appear to be allowed to sell or offer for sale any part of the ray (such as to local gill plate traders). Despite (or as a result of) these RFMO requirements, monitoring and reporting of catches and discards is highly variable across the species' range, with some countries not reporting and others with fisheries engaging in the illegal catch and unsustainable trade of the species. As a result, accurately determining the efficacy of these measures may not be possible, which makes future management decisions and their outcomes uncertain without improved reporting. Moreover, a lack of data regarding the disposition (i.e., discarded dead, released alive and/or injured) of giant manta rays in commercial and small-scale/artisanal fisheries will preclude the effective enforcement of RFMO conservation and management measures, particularly whether countries are adhering to retention prohibition measures.

Regulatory Mechanisms and Enforcement

9. Minimize fishing mortality of giant manta rays through effective development, implementation, and enforcement of international and domestic measures, such as legislation and regulations.

As described previously, management measures prohibiting retention of giant manta rays may eliminate targeted fishing and decrease overall mortality but require additional measures for best handling and release practices to maximize efficacy. Despite the adoption of no-retention measures by the RFMOs in the significant portion of the species' range, illegal retention of giant manta rays taken as bycatch or targeted for commercial purposes continues to occur, mainly driven by demand from the international gill plate trade. Therefore, activities under this recovery action should focus on tracking retention of the species over time and identifying areas where further regulation and/or enforcement are needed to reduce retention. In addition, based on results of research activities in recovery action 5, regulatory measures other than retention bans, including measures to avoid interactions in the first place (such as time/area closures) or measures that increase the survival of released manta rays such as modifications to fishing gear and best practices for handling and release, could be implemented.

While giant manta rays are not targeted (or retained) by U.S. commercial or recreational fisheries, they are known to be incidentally caught, albeit at much smaller levels compared to other foreign fisheries. Based on recent data (as described in NMFS 2024a), giant manta rays tend to have a high probability of being caught by the trawl fisheries (and to a lesser extent in other U.S. fisheries) during specific seasons and in specific locations. As such, implementing regulatory measures to minimize the bycatch and post-release mortality in these fisheries, through measures such as modifications in gear and/or spatial and temporal efforts, would further facilitate the recovery of the species, and show that we are taking all steps possible to further conserve the giant manta ray in domestic waters.

As mentioned above, the international gill plate trade is the main driver for the significant pressure on the global giant manta ray population, with evidence of gill plates from over 4,500 individuals being sold annually in the dried seafood and/or traditional Chinese medicine markets in China and Hong Kong (O'Malley et al. 2017). As such, the United States should continue working through RFMOs and other international mechanisms, such as CITES, to encourage countries engaged in the gill plate trade to adopt, implement, and enforce regulatory measures to minimize the number of giant manta rays killed for the gill plate trade (and eventually eliminate the trade altogether). This recovery action is needed to achieve the demographic recovery criterion and all of the threats-based recovery criteria.

Outreach and Education

10. Develop and implement outreach and education strategies and programs to increase public (including consumers) and stakeholder (including fishermen) awareness on the status and recovery needs of the giant manta ray.

Effective implementation of recovery actions to minimize fisheries-related mortality of giant manta rays in artisanal and commercial fisheries and ensure the long-term recovery of the species will require global cooperation and collaboration with fishermen and the public. A comprehensive outreach and education strategy that encourages consumers to find alternatives to TCM involving gill plates and promotes the conservation and value of living manta rays to both fishermen and the public could help reduce the demand for gill plates, eliminate international trade in the species, and facilitate the recovery of the species.

Because public and stakeholder support is needed for implementation of mitigation measures as well as the development and implementation of regulatory mechanisms, this recovery action will support progress toward achieving all of the threats-based recovery criteria. When aimed at consumers of TCM gill plates, the strategy will raise awareness of the unverified TCM health claims for gill plates, health dangers from consumption (i.e., heavy metals), and the importance of giant manta rays in the ecosystem in order to reduce demand. For fishermen, the strategy should address the impact of commercial, recreational, and subsistence fishing on the status of the species, and provide specific ways to reduce mortality associated with fisheries interactions. For those communities that rely on subsistence fishing of the species for revenue, developing sustainable alternative strategies, such as the creation and management of tourism sites, is essential for the conservation of the species. When aimed at building and maintaining public support for the conservation of giant manta rays, the strategy may include community science efforts and general outreach and education on the status and importance of the species. Increased public interest in conserving giant manta rays can help build partnerships and funding for the implementation of recovery actions. Because the giant manta ray is globally distributed and occurs in numerous countries representing diverse communities, cultures, and customs, an effective outreach and education strategy should draw on respective cultural insights and take advantage of communication avenues already being used by relevant communities, including social media and other online resources. While NOAA should lead the development and dissemination of outreach, education and communication strategies and materials as outlined above, other countries, international organizations, and RFMOs should also engage in these efforts in collaboration with NGOs, academia, and the private sector.

Other Stressors

11. Identify, evaluate, and minimize any other stressors that may be impeding recovery of giant manta rays.

There is no information at this time to indicate that the other stressors (i.e., climate change, environmental contaminants/pollutants, vessel strikes, entanglement, recreational fishery interactions, tourism, and aquarium trade) are threats that impede the overall recovery of the giant manta ray or drive its extinction risk. The data on these stressors are limited and there is a high degree of uncertainty around the potential effects these stressors may have on the giant manta ray. As such, these stressors currently pose an overall low risk to the species but should be monitored to ensure that they are not hindering the recovery of the species.

The major impact of climate change on giant manta rays is likely the projected decline in zooplankton biomass in tropical waters (Stewart et al. 2018). Biogeochemical models project a decline in zooplankton biomass in the future of about 10% globally (Chust et al. 2014; Stock et al. 2014; Woodworth-Jefcoats et al. 2017; Heneghan et al. 2023), but some regions, particularly those in the tropics, could experience >50% declines (Stock et al. 2014). Additionally, changes in climate and oceanographic conditions, such as acidification, are also known to affect zooplankton structure (size, composition, diversity), phenology, and distribution (Guinder and Molinero 2013). As such, the migration paths and locations of both resident and seasonal aggregations of manta rays, which depend on these animals for food, may similarly be altered (Australian Government 2012; Couturier et al. 2012). However, how that may affect *M. birostris* behavior and distribution, or impact its extinction risk, is still highly uncertain. Therefore, activities under this action could include research, vulnerability and risk assessments, and scenario planning, and should be focused initially on factors that have been identified as the most likely to affect the species, such as changes in prey abundance and distribution.

Giant manta rays may also be susceptible to environmental contaminants and pollutants through ingestion of heavy metals and microplastics during filter feeding. Microplastics are now present in every marine environment, easily permeate food webs, and are vectors for toxins (Germanov et al. 2019). The giant manta ray habitat and range overlaps with microplastic pollution hotspots in the Gulf of Mexico, North Atlantic Gyre, Bay of Bengal (Northeastern Indian Ocean), Coral Triangle (Western Pacific Ocean), North Pacific Gyre, South Pacific Gyre, and Indian Ocean Gyre (See Table 1 in Germanov et al., 2018). However, the rates of microplastic ingestion for giant manta rays, bioaccumulation of pollutants, and the impacts of plastic pollution on mobulid biology, ecology, and population viability have yet to be studied (Stewart et al. 2018). Therefore, activities under this action could include research to determine the implications of exposure to pollution and contaminants for the giant manta ray, especially at the level of individual fitness and population viability.

Vessel strikes and entanglement are also thought to injure and potentially kill giant manta rays. In terms of vessel strikes, documenting these on manta rays is extremely challenging because lethal impacts will likely cause the animal to sink (and, thus, the number being killed is unknown) and non-lethal impacts may not be recognizable (e.g., may look like predation bites or fishing-related injuries as opposed to a vessel strike). Rapid wound healing documented in manta rays as well as blunt force trauma with only internal injuries also indicates that vessel strikes are likely underestimated (McGregor et al. 2019; Pate and Marshall 2020). Yet, vessel strikes are evident in every monitored population across the globe (Stewart et al. 2018).

In addition to vessel strikes, foul hooking and entanglement in fishing gear and vertical lines are known to cause anthropogenic injuries in giant manta ray and have been evident in every monitored mobulid population across the globe. Entanglement of giant manta rays can also include severe injuries such as amputation or deformity of cephalic and pectoral fins, and damage to the eyes (Deakos et al. 2011; Heinrichs et al. 2011; Stewart et al. 2018; Pate et al. 2020; Braun et al. 2024). Fishermen interviews and internet photographs and videos reveal mantas with injuries consistent with hooks and fishing line entanglements, and manta researchers report that such injuries may affect manta fitness in a significant way (Deakos et al. 2011; Heinrichs et al. 2011; Couturier et al. 2012; CMS 2014; Germanov and Marshall 2014; Braun et al. 2015, Braun et al. 2024). However, there is very little quantitative information on the frequency of these occurrences and no information on the impact of these injuries on the overall health of the population. While these threats are known, the extent to which these impacts may affect individual health and overall population fitness is unclear (Couturier et al. 2012; Croll et al. 2016). Therefore, activities under this action could include monitoring of giant manta rays in areas where aggregations and important habitats overlap with high vessel traffic areas and/or fishing areas, public education and outreach campaigns to control vessel speeds when encountering manta rays and report injured/entangled manta rays, increased monitoring of entangled manta rays, and research to determine the implications of various injuries for the giant manta ray, especially at the level of individual fitness and population viability.

In terms of the aquarium trade, the number of manta rays being removed from the wild for aquarium and exhibit purposes is currently unknown at this time. There appears to be a relatively small number of aquariums globally that display giant manta rays, but the number of required "Special Activity Licenses" requested by various aquariums from around the globe suggests that interest may be increasing. Perhaps contributing to this interest may be the increase in manta ray tourism that has occurred over the last decade. However, while manta ray tourism is far less damaging to the species than, for example, the impact of fisheries, this increasing demand to see and dive with the animals has the potential to lead to other unintended consequences that could harm the species. For example, Osada (2010) found that a popular manta dive spot in Kona, Hawaii, had fewer emergent zooplankton and less diversity compared to a less used dive spot, and attributed the difference to potential inadvertent habitat destruction by divers. Tour groups may also be engaging in inappropriate behavior, such as touching the mantas. Given the increasing demand for manta ray tourism, with instances of more than 10 tourism boats present at popular dive sites with over 100 divers in the water at once (Anderson et al. 2011; Venables 2013), without proper tourism protocols, these activities could have serious consequences for manta ray populations. Therefore, activities under this action should include monitoring and evaluating effects related to these non-fishing activities, the aquarium trade and tourism, and implementing mitigation measures if necessary.

Post-delisting Monitoring Plan

12. Develop a post-delisting monitoring plan to ensure management of giant manta rays continues to be sustainable post-delisting.

A post-delisting monitoring plan should be developed to ensure that the giant manta ray population status is appropriately monitored for at least five years post-delisting to ensure that removal of the protections of the ESA does not result in a return to threatened status.

Table 2. Summary of recovery program, linking threats to recovery criteria and actions for the giant manta ray (*Mobula birostris*).

Listing Factor	Threat	Recovery Criteria	Recovery Action Numbers
B **Overutilization of the species for commercial, recreational, scientific, or educational purposes**	Targeted fisheries and bycatch	1, 2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
D **Inadequacy of Existing Regulatory Mechanisms**	Inadequacy of fisheries regulations and enforcement	1, 2, 3, 4, 5, 6, 7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
	International gill plate trade	1, 2, 3, 4, 5, 6, 7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10

4. Time and Cost Estimates

Achieving the recovery criteria for the giant manta ray is expected to require a minimum of 80 years from the publication of the final Recovery Plan. This takes into account 40 years as a timeframe to increase the average annual population trend (as described above in section **3.3.3 Demographic Recovery Criteria**) plus another 40 years (approximately two generations) to maintain this level demonstrating recovery, with this timeframe being biologically based and reasonably expected to encompass environmental and fisheries-based stochastic events that may affect the species. As we learn more about this species, and its threats and recovery actions are implemented and funded with close cooperation with partners, we will carefully monitor and assess progress toward recovery to ensure recovery is on track.

Presented below is a table of site-specific recovery actions, their priority number, and their estimated cost of implementation, projected to the estimated date of delisting (**Table 3**). Estimated costs include only project specific contract, staff, or operations costs in excess of base budgets. They do not include budgeted amounts that support ongoing agency staff responsibilities. This Recovery Plan does not commit NOAA or any partners to carry out a particular recovery action or expend the estimated funds.

Estimated costs incorporate planning, design, implementation, and research, monitoring, and evaluation associated with specific actions. Adaptive management actions evaluate the implementation of those actions to ensure that management/conservation tools are appropriately and effectively addressing impacts to the species and meeting the objective of this Recovery Plan. If the tools are not effective, changes in management should be made and additional planning and scientific research may be necessary. As such, the total cost of recovery stated in this plan is a rough estimate and may change substantially as efforts to recover the species continue.

Additionally, the assignment of priority numbers (**Box 2**) in the table does not imply that some recovery actions are of low importance, but instead suggests that lower-priority items (e.g., Priority #3) may be deferred while higher-priority actions (e.g., Priority #1) are implemented.

Other actions not required for recovery (actions 11 and 12) are not included in the estimated costs.

Box 2. Priority Assignments for Actions
Priority 1 Recovery Actions: These are recovery actions that must be taken to remove, reduce, or mitigate major threats and prevent extinction and often require urgent implementation. **Priority 2 Recovery Actions**: These are recovery actions to remove, reduce, or mitigate major threats and prevent continued population decline, or that require research needed to fill knowledge gaps to prevent continued population decline, but their implementation is less urgent than Priority 1 actions. **Priority 3 Recovery Actions**: These are recovery actions that should be taken to remove, reduce, or mitigate any remaining, non-major threats and ensure the species can maintain an increasing or stable population to achieve delisting criteria, including research needed to fill knowledge gaps and monitoring to demonstrate achievement of demographic criteria. **Priority 4 Post-Delisting Actions**: These are actions that are not linked to recovery criteria and are not needed for ESA recovery, but are needed to facilitate post-delisting monitoring under ESA Section 4(g), such as the development of a post-delisting monitoring plan that provides monitoring design (e.g., sampling error estimates). **Priority 0 Other Actions:** These are actions and activities that are not needed for ESA recovery or post-delisting monitoring but that would advance broader goals beyond delisting. Other actions include, for example, other legislative mandates or social, economic, and ecological values. These actions are given a zero priority number because they do not fall within the priorities for delisting the species, yet the numeric value allows tracking these types of actions in the NMFS Recovery Action Database.

Table 3. Recovery and other actions, priority number, and estimated costs. Each action likely includes costs that could not be reasonably estimated at this time.

Recovery Action	Priority #	Estimated Cost
1. Improve knowledge and understanding of giant manta ray population status, abundance trends, and genetic structure.	2	$43,035,000

2. Improve knowledge and understanding of giant manta ray distribution, movement, and habitat use.	2	$4,795,000
3. Improve knowledge and understanding of the demographics and life history of giant manta rays.	2	$2,200,000
4. Eliminate targeted fisheries for giant manta rays in foreign fisheries through enhanced coordination and collaboration with relevant organizations to support national and regional development of policies, management plans, and capacity to make giant manta ray fishing commercially unviable.	2	$4,150,000
5. Minimize fisheries bycatch and mortality of giant manta rays by determining and addressing the frequency of capture and severity of fishing interactions in artisanal/small-scale and commercial fisheries globally.	2	$13,020,000
6. Minimize fisheries bycatch and mortality of giant manta rays in international fisheries through enhanced international coordination and collaboration with relevant international organizations, such as RFMOs.	2	$18,520,000
7. Implement management actions to eliminate giant manta ray gill plates in international trade.	2	$4,550,000
8. Improve species-specific monitoring and reporting of giant manta rays in commercial and artisanal fisheries by RFMOs and individual countries to improve estimates of catch and discards, provide a better understanding of the effects of IUU fishing, and measure progress towards recovery.	3	$575,000
9. Minimize fishing mortality of giant manta rays through effective development, implementation, and enforcement of international and domestic measures such as legislation and regulations.	2	$4,000,000
10. Develop and implement outreach and education strategies and programs to increase public (including consumers) and stakeholder (including fishermen)	3	$5,440,000

awareness on the status and recovery needs of the giant manta ray and decrease the demand for gill plates.		
Other Actions		
11. Identify, evaluate, and minimize any other stressors that may be impeding recovery of giant manta rays.	0	-
12. Develop a post-delisting monitoring plan to ensure management of giant manta rays continues to be sustainable post-delisting.	4	-
Total Estimated Cost:		$100,285,000

Date of Recovery: If all actions are fully funded and implemented as outlined, including full cooperation of all partners needed to achieve recovery, then we estimate the earliest that the delisting criteria could be met would be 80 years.

Estimated Cost to Recovery: The cost to recover and ultimately delist the giant manta ray is estimated to be $100,285,000. Some costs are not determinable at this time; therefore, the total cost of recovery may be greater than this estimate.

5. References

Anderson RC, Adam MS, Kitchen-Wheeler A-M, Stevens G (2011) Extent and economic value of manta ray watching in Maldives. *Tourism in Marine Environments* 7: 15-27

Andrzejaczek S, Schallert RJ, Forsberg K, Arnoldi NS, Cabanillas-Torpoco M, Purizaca W, Block BA (2021) Reverse diel vertical movements of oceanic manta rays off the northern coast of Peru and implications for conservation. *Ecol Solut Evidence*. 2:e12051. https://doi.org/10.1002/2688-8319.12051

Australian Government (2012) Threatened Species Nomination Form - Manta alfredi, Department of the Environment. https://www.dcceew.gov.au/sites/default/files/env/pages/a7465fc2-2fa1-4de4-b562-4eb56012296d/files/nomination-manta-alfredi.pdf

Banks D (2008) “A soaring new citizen for the world’s biggest aquarium” CNN.com. https://www.cnn.com/2008/TRAVEL/08/25/manta.ray/index.html

Beale CS, Stewart JD, Setyawan E, Sianipar AB, Erdmann MV (2019) Population dynamics of oceanic manta rays (Mobula birostris) in the Raja Ampat Archipelago, West Papua, Indonesia, and the impacts of the El Niño-Southern Oscillation on their movement ecology. *Divers Distrib* 25:1472–1487. https://doi.org/10.1111/ddi.12962

Beebe W, Tee-Van J (1941) “Eastern Pacific Expeditions of the New York Zoological Society. XXVIII. Fishes from the Tropical Eastern Pacific. From Cedros Island, Lower California, South to the Galapagos Islands and Northern Peru.] Part 3. Rays, Mantas and Chimaeras.” *Zoologica; scientific contributions of the New York Zoological Society* 26: 245-280.

Brainard RE, Birkeland C, Eakin CM, McElhany P, Miller MW, Patterson M, Piniak GA (2011) Status review report of 82 candidate coral species petitioned under the U.S. Endangered Species Act. NOAA Tech Memo. U.S. Dep. Commer., NOAA-TM-NMFS-PIFSC-27

Braun CD, Skomal GB, Thorrold SR, Berumen ML (2015) Movements of the reef manta ray (Manta alfredi) in the Red Sea using satellite and acoustic telemetry. *Marine biology*: 2351 doi 10.1007/s00227-015-2760-3

Bucair N, Venables SK, Balboni AP, Marshall AD (2021a) Sightings trends and behaviour of manta rays in Fernando de Noronha Archipelago, Brazil *Mar. Biodivers. Rec.*, 14, p. 10, https://doi.org/10.1186/s41200-021-00204-w

Bucair N, Francini-Filho RB, Almerón-Souza F, Luiz OJ (2021b) Underestimated threats to manta rays in Brazil: primacies to support conservation strategies. *Global Ecol Conserv*. https://doi.org/10.1016/j.gecco.2021.e01753

Cabral MMP, Stewart JD, Marques TA, Ketchum JT, Ayala-Bocos A, Hoyos-Padilla EM, Reyes-Bonilla H (2023) The influence of El Niño Southern oscillation on the population dynamics of oceanic manta rays in the Mexican Pacific. *Hydrobiologia* 850:257–267

Carlson JK, Miller MHM, Young C (2022) "They can't take it anymore! At what levels of fishing mortality can the giant manta ray recover?" PowerPoint Presentation. Sharks International 2022 Conference, Valencia, Spain. October 20-22.

Chust W, Allen JI, Bopp L et al. (2014) Biomass changes and trophic amplification of plankton in a warmer ocean. Global Change Biology, 20, 2124–2139.

CITES (2013) Consideration of proposals for amendment of Appendices I and II: Manta Rays. Sixteenth meeting of the Conference of the Parties. Bangkok, Thailand, March 3-14

CMS (2014) Proposal for the inclusion of the reef manta ray (Manta alfredi) in CMS Appendix I and II. 18th Meeting of the Scientific Council, UNEP/CMS/ScC18/Doc.7.2.9

Coles RJ (1916) Natural history notes on the devil-fish, Manta birostris (Walbaum) and Mobula olfersi (Müller). *Bulletin of the American Museum of Natural History* 35: 649-657.

Conn, PB (2010) Hierarchical analysis of multiple noisy abundance indices. *Canadian Journal of Fisheries and Aquatic Sciences* 67 (2010): 108-120.

Cortés E (2016) Perspectives on the intrinsic rate of population growth. Methods in Ecology and Evolution, 7(10), pp.1136-1145.

Couturier LI, Marshall AD, Jaine FR, Kashiwagi T, Pierce SJ, Townsend KA, Weeks SJ, Bennett MB, Richardson AJ (2012) Biology, ecology and conservation of the Mobulidae. *Journal of fish biology* 80: 1075-1119 doi 10.1111/j.1095-8649.2012.03264.x

Croll DA, Dewar H, Dulvy NK, Fernando D, Francis MP, Galván-Magaña F, Hall M, Heinrichs S, Marshall A, McCauley D, Newton KM, Notarbartolo-Di-Sciara G, O'Malley M, O'Sullivan J, Poortvliet M, Roman M, Stevens G, Tershy BR, White WT (2015) Vulnerabilities and fisheries impacts: the uncertain future of manta and devil rays. *Aquatic Conservation: Marine and Freshwater Ecosystems*: n/a-n/a doi 10.1002/aqc.2591

Deakos MH, Baker JD, Bejder L (2011) Characteristics of a manta ray Manta alfredi population off Maui, Hawaii, and implications for management. *Mar Ecol Prog Ser* 429: 245-260 doi 10.3354/meps09085

Dulvy NK, Pardo SA, Simpfendorfer CA, Carlson JK (2014) Diagnosing the dangerous demography of manta rays using life history theory. *PeerJ* 2 doi ARTN e400; 10.7717/peerj.400

Earth.org (2020) "300kg Haul of Manta Ray Gill Plates Seized in Hong Kong Highlights Sri Lanka's Unsustainable Fisheries" Earth.org Ltd, November 9, 2020. Web: https://earth.org/manta-ray-gill-plates-seized-in-hong-kong-highlights-sri-lankas-unsustainable-fisheries/

Farmer, N.A., Garrison, L.P., Horn, C. et al. (2022) The distribution of manta rays in the western North Atlantic Ocean off the eastern United States. Sci Rep 12, 6544.

Garzon, F., Graham, R., Witt, M. & Hawkes, L. (2021) Ecological niche modeling reveals manta ray distribution and conservation priority areas in the Western Central Atlantic. Anim. Conserv. 24, 322–334.

Germanov ES, Marshall AD (2014) Running the gauntlet: regional movement patterns of Manta alfredi through a complex of parks and fisheries. *PLoS One* 9: e110071 doi 10.1371/journal.pone.0110071

Germanov ES, Marshall AD, Hendrawan IG, Admiraal R, Rohner CA, Argeswara J, Wulandari R, Himawan MR and Loneragan NR (2019) Microplastics on the Menu: Plastics Pollute Indonesian Manta Ray and Whale Shark Feeding Grounds. *Front. Mar. Sci.* 6:679. doi: 10.3389/fmars.2019.00679

Graham RT, Witt MJ, Castellanos DW, Remolina F, Maxwell S, Godley BJ, Hawkes LA (2012) Satellite Tracking of Manta Rays Highlights Challenges to Their Conservation. *Plos One* 7 doi ARTN e36834 10.1371/journal.pone.0036834

Guinder V, Molinero JC (2013) Climate Change Effects on Marine Phytoplankton. In A.H. Arias & M.C. Menendez (Eds.), *Marine Ecology in a Changing World*. CRC Press. 10.1201/b16334-4.

Hamlett WC, Kormarik CG, Storrie M, Serevy B, Walker TI (2005) Chondrichthyan parity, lecithotrophy and matrotrophy. In Reproductive Biology and Phylogeny of Chondrichthyes (ed. Hamlett W. C.), pp. 395-434.

Harty K, Guerrero M, Knochel AM, Stevens GMW, Marshall A, Burgess K, Stewart JD (2022) Demographics and dynamics of the world's largest known population of oceanic manta rays *Mobula birostris* in coastal Ecuador. Mar Ecol Prog Ser 700:145-159. https://doi.org/10.3354/meps14189

Hau L, Ho K, Shea S (2016) Rapid survey of mobulid gill plate trade and retail patterns in Hong Kong and Guangzhou markets, BLOOM Association Hong Kong

Hawaii Association for Marine Education and Research Inc. (2014) Manta Rays. http://hamerinhawaii.org/education/manta-rays/

Hearn AR, Acuña D, Ketchum JT, Peñaherrera C, Green J, Marshall A, Guerrero M, Shillinger G (2014) Elasmobranchs of the Galapagos Marine Reserve. In: Denkinger, J., Vinueza, L. (eds) The Galapagos Marine Reserve. Social and Ecological Interactions in the Galapagos Islands. Springer, Cham. https://doi.org/10.1007/978-3-319-02769-2_2

Heinrichs S, O'Malley M, Medd H, Hilton P (2011) Manta Ray of Hope: The Global Threat to Manta and Mobula Rays. Manta Ray of Hope Project.

Heneghan, R.F., Everett, J.D., Blanchard, J.L. *et al.* Climate-driven zooplankton shifts cause large-scale declines in food quality for fish. *Nat. Clim. Chang.* 13, 470–477 (2023). https://doi.org/10.1038/s41558-023-01630-7

Hernández-Navarro C, Elorriaga-Verplancken FR, Galván-Magaña F, Valdivia-Anda G, Peña R, Ketchum JT, Hoyos-Padilla EM (2023) Stress Biomarkers in the Giant Manta Mobula birostris Associated to Tourism in the Revillagigedo National Park, Mexico. *Open Journal of Veterinary Medicine* 13, 136-146. https://doi.org/10.4236/ojvm.2023.137012

Kitchen-Wheeler AM, Ari C, Edwards AJ (2012) Population estimates of Alfred mantas (Manta alfredi) in central Maldives atolls: North Male, Ari and Baa. *Environmental Biology of Fishes* 93: 557-575 doi 10.1007/s10641-011-9950-8

Kitchen-Wheeler A-M (2013) The behaviour and ecology of Alfred mantas (Manta alfredi) in the Maldives. Newcastle upon Tyne, England: Newcastle University.

Knochel AM, Cochran JEM, Kattan A, Stevens GMW, Bojanowksi E, Berumen ML (2022) Crowdsourced data reveal multinational connectivity, population demographics, and possible nursery ground of endangered oceanic manta rays in the Red Sea. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 32(11), 1774–1786. https://doi.org/10.1002/aqc.3883

Lewis SA, Setiasih N, O'Malley MP, Campbell SJ, Yusuf M, Sianipar AB (2015) Assessing Indonesian manta and devil ray populations through historical landings and fishing community interviews. *PeerJ PrePrints*, 2167-9843

Marshall AD (2008). Biology and Population Ecology of Manta birostris in Southern Mozambique. Brisbane, QLD: University of Queensland.

Marshall AD, Dudgeon CL, Bennett MB (2011) Size and structure of a photographically identified population of manta rays Manta alfredi in southern Mozambique. *Marine Biology*, 158, pp.1111-1124.

Marshall A, Barreto R, Carlson J, Fernando D, Fordham S, Francis MP, Derrick D, Herman K, Jabado RW, Liu KM, Rigby CL, Romanov E (2022) *Mobula birostris* (amended version of 2020 assessment). *The IUCN Red List of Threatened Species* 2022: e.T198921A214397182. https://dx.doi.org/10.2305/IUCN.UK.2022-1.RLTS.T198921A214397182.en. Accessed on 26 September 2023.

Maunder MN, Punt AE (2004) Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* Volume 70, Issues 2–3, Pages 141-159, ISSN 0165-7836. https://doi.org/10.1016/j.fishres.2004.08.002.

McGregor F, Richardson AJ, Armstrong AJ, Armstrong AO, Dudgeon CL (2019) Rapid wound healing in a reef manta ray masks the extent of vessel strike. PLOS ONE 14(12): e0225681. https://doi.org/10.1371/journal.pone.0225681

Müller J, Henle FGJ (1841) Systematische Beschreibung der Plagiostomen. Berlin, Veit, pp. 1–200.

NMFS (2020) Recovery Planning Handbook. Version 1.0. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Protected Resources. https://www.fisheries.noaa.gov/resource/document/nmfs-recovery-planning-handbook-version-10

Oliver S, Braccini M, Newman SJ, Harvey ES (2015) Global patterns in the bycatch of sharks and rays. *Marine Policy* 54: 86-97

O'Malley MP, Townsend KA, Hilton P, Heinrichs S, Stewart JD (2017) Characterization of the trade in manta and devil ray gill plates in China and South-east Asia through trader surveys. *Aquatic Conservation: Marine and Freshwater Ecosystems* 27: 394-413 doi 10.1002/aqc.2670

Osada K (2010) Relationship of zooplankton emergence, manta ray abundance and SCUBA diver usage Kona Hawaii. Hawai'i, USA: University of Hawai'i at Hilo.

Pacoureau N, Rigby CL, Kyne PM, Sherley RB, Winker H, Carlson JK, Fordham SV, Barreto R, Fernando D, Francis MP, Jabado RW, Herman KB, Liu K-M, Marshall AD, Pollom RA, Romanov EV, Simpfendorfer CA, Yin JS, Kindsvater HK, Dulvy NK (2021) Half a century of global decline in oceanic sharks and rays. *Nature* 589, 567–571. https://doi.org/10.1038/s41586-020-03173-9

Pate JH, Marshall AD (2020) Urban manta rays: potential manta ray nursery habitat along a highly developed Florida coastline. *Endang Species Res* 43:51-64. https://doi.org/10.3354/esr01054

Peterson CD, Belcher CN, Bethea DM, Driggers WB, Frazier BS, Latour RJ (2017) Preliminary recovery of coastal sharks in the south-east United States. *Fish Fish*; 18: 845–859. https://doi.org/10.1111/faf.12210

Rambahiniarison JM, Lamoste MJ, Rohner CA, Murray R, Snow S, Labaja J, Araujo G and Ponzo A (2018) Life History, Growth, and Reproductive Biology of Four Mobulid Species in the Bohol Sea, Philippines. *Front. Mar. Sci*. 5:269. doi: 10.3389/fmars.2018.00269

Rathnayake Z (2023) "'It's not like chicken farming': why manta rays are being chopped up in Sri Lanka." Seascape: the stats of our oceans. The Guardian.org, May 4, 2023. https://www.theguardian.com/environment/2023/may/04/its-not-like-chicken-farming-why-manta-rays-are-chopped-up-in-sri-lanka

Stewart JD, Beale CS, Fernando D, Sianipar AB, Burton RS, Semmens BX, Aburto-Oropeza O (2016) Spatial ecology and conservation of Manta birostris in the Indo-Pacific. *Biological Conservation* 200: 178-183 doi 10.1016/j.biocon.2016.05.016

Stewart JD, Jaine FRA, Armstrong AJ, Armstrong AO, Bennett MB, Burgess KB, Couturier LIE, Croll DA, Cronin MR, Deakos MH, Dudgeon CL, Fernando D, Froman N, Germanov ES, Hall MA, Hinojosa-Alvarez S, Hosegood JE, Kashiwagi T, Laglbauer BJL, Lezama-Ochoa N, Marshall AD, McGregor F, Notarbartolo di Sciara G, Palacios MD, Peel LR, Richardson AJ, Rubin RD, Townsend KA, Venables SK and Stevens GMW (2018) Research Priorities to Support Effective Manta and Devil Ray Conservation. *Front. Mar. Sci*. 5:314. doi: 10.3389/fmars.2018.00314

Stock CA, Dunne JP, John JG (2014) Drivers of trophic amplification of ocean productivity trends in a changing climate. Biogeosciences, 11, 7125–7135.

Venables S (2013) Short term behavioural responses of manta rays, Manta alfredi, to tourism interactions in Coral Bay, Western Australia. Perth, Australia: Murdoch University.

Venables S, McGregor F, Brain L, van Keulen M (2016) Manta ray tourism management, precautionary strategies for a growing industry: a case study from the Ningaloo Marine Park, Western Australia. *Pacific Conservation Biology* doi 10.1071/pc16003

Winker H, Sherley RB (2019). JARA: Just another red-list assessment. bioRxiv, https://doi.org/10.1101/672899

Woodworth-Jefcoats, P. A., Polovina, J. J., & Drazen, J. C. (2016). Climate change is projected to reduce carrying capacity and redistribute species richness in north pacific pelagic marine ecosystems. Global Change Biology, 23(3), 1000-1008. https://doi.org/10.1111/gcb.13471

Wourms JP (1981) Viviparity: The Maternal-Fetal Relationship in Fishes, *American Zoologist*, 21(2): 473–515. https://doi.org/10.1093/icb/21.2.473

Yamaguchi M (2007) "Manta ray birth in Japan touted as first in captivity." Seattle Post-Intelligencer. Hearst Newspapers, LLC., June 17, 2007. https://www.seattlepi.com/national/article/manta-ray-birth-in-japan-touted-as-first-in-1240974.php

Zhou S, Griffiths SP (2008) Sustainability Assessment for Fishing Effects (SAFE): an application to elasmobranch bycatch in an Australian trawl fishery. *Fisheries Research* **91**, 56–68.

Zhou S, Griffiths SP, Miller M (2009) Sustainability assessment for fishing effects (SAFE) on highly diverse and data-limited fish bycatch in a tropical prawn trawl fishery. *Marine and Freshwater Research* **60**, 563-570.

Zhou S, Smith AD, Fuller M (2011) Quantitative ecological risk assessment for fishing effects on diverse data-poor non-target species in a multi-sector and multi-gear fishery. *Fisheries Research*, 112(3), pp.168-178