Environ Biol Fish (2025) 108:611–638
https://doi.org/10.1007/s10641-024-01636-w

Global assessment of manta and devil ray gill plate and meat trade: conservation implications and opportunities

Marta D. Palacios · Laura Weiand · Betty J. L. Laglbauer · Melissa R. Cronin · Sarah Fowler · Rima W. Jabado · Thanda Ko Gyi · Daniel Fernando · Godefroy De Bruyne · Stanley K. H. Shea · Paul Hilton · Yi-Li Gao · Guy M. W. Stevens

Received: 31 July 2024 / Accepted: 7 November 2024 / Published online: 14 December 2024

Abstract Due to overexploitation in fisheries partly driven by international trade demand, mobulid rays are among the most threatened of elasmobranch families. We conducted a global assessment of the state of manta and devil ray trade employing expert elicitation through country-focused online surveys ($n = 109$) and interviews ($n = 21$), along with analysis of the FAO Total Production and CITES Trade Databases, and online trade and physical store surveys in China and Hong Kong SAR. Findings across 75 countries reveal significant mobulid landings in 43 countries. Globally, mobulid meat is consumed locally in at least 35 countries and exported from ten, with five major destination countries. Gill plates are extracted in 14 countries and exported from at least 14 across Asia and Africa, with five major destination countries in Asia. Meat and gill plate prices ranged between 0.24 – 10 and 4.8 – 1260 USD/kg respectively, depending on country and product form. Physical retailers of gill plates declined in Guangzhou and Hong Kong SAR in the past decade, while online retailers increased,

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10641-024-01636-w.

M. D. Palacios · L. Weiand · B. J. Laglbauer · D. Fernando · P. Hilton · G. M. W. Stevens (✉)
The Manta Trust, Catemwood House, Norwood Lane, Corscombe, Dorset DT2 0NT, UK
e-mail: guy@mantatrust.org

M. D. Palacios · M. R. Cronin
Mobula Conservation, La Paz, Mexico

M. R. Cronin
Duke University Nicholas School of the Environment, Durham, NC, USA

S. Fowler
Save Our Seas Foundation, Geneva, Switzerland

R. W. Jabado
Elasmo Project, PO Box 29588, Dubai, United Arab Emirates

R. W. Jabado
James Cook University, Townsville, Australia

T. Ko Gyi
Myanmar Ocean Project, 24 Myaing Hay Wun Housing, Yangon 11061, Myanmar

D. Fernando
Blue Resources Trust, Colombo, Sri Lanka

G. De Bruyne
Wildlife Conservation Society, BP 7847 Libreville, Gabon

S. K. H. Shea
ADM Capital Foundation, Suite 2405, 9 Queen's Road Central, Victoria, Hong Kong SAR

S. K. H. Shea
BLOOM Association, c/o, ADMCF, Suite 2405, 9 Queen's Road Central, Victoria, Hong Kong SAR

but overall, the total number of retailers rose from 41 to 135 between 2011 and 2023. By linking country-specific mobulid management data to their roles in the meat and gill plate trade, price ranges, consumption patterns, and landing data, we ranked 75 countries from highest to lowest impact upon mobulid populations, identifying 14 as high-priority. Findings highlight the need for improved capacity-building in fisheries management and stronger enforcement aimed collectively at reversing the current unsustainable consumption and trade of mobulids.

Keywords Mobulid · CITES · Policy · Fisheries · Mobula

Introduction

Mobulid vulnerability

Unsustainable fisheries are driving global population declines for elasmobranchs (sharks and rays) at alarming rates (Pauly et al. 1998; Queiroz et al. 2019). Of most concern are rays, which include five out of the seven most threatened elasmobranch families (Dulvy et al. 2021). Among these five families, manta and devil rays (genus *Mobula*, also referred to as mobulids) have a high extinction risk due to intrinsic vulnerability and unsustainable fishing pressure in both industrial and small-scale fleets (Ward-Paige et al. 2013; Lewis et al. 2015; Haque et al. 2022; Pacoureau et al. 2021; Fernando and Stewart 2021; Venables et al. 2024). This highly threatened genus currently comprises nine extant species found circumglobally in tropical, subtropical, and temperate waters (Notarbartolo-di-Sciara et al. 2017; White et al. 2018; Notarbartolo-di-Sciara et al. 2019; Hosegood et al. 2020), three of which are listed among the top 75 Evolutionarily Distinct and Globally Endangered (EDGE) elasmobranchs (https://www.edgeofexistence.org/). Mobulids are especially susceptible to anthropogenic threats (e.g., fisheries, boat collisions, habitat degradation from coastal development, and disturbances from unregulated tourism activities) (Stewart et al. 2018; Murray et al. 2020; Strike et al. 2022) because of their highly conservative life histories, namely low fecundity, slow growth, and late maturation (Notarbartolo-di-Sciara 1988; Marshall and Bennett 2010; Pardo et al. 2016).

The oceanic and coastal habitats used by mobulids expose them to capture in a range of fishing gear, particularly in gillnet and purse seine fisheries (Croll et al. 2016). They constitute a notable component of incidental catch worldwide, reported from at least 21 small-scale fisheries in 15 countries/territories (hereafter just "countries") (Croll et al. 2016; Alfaro-Cordova et al. 2017; Stewart et al. 2018; Fernando and Stewart 2021). Industrial fisheries also capture a considerable number of mobulids as bycatch, which has been estimated at ~ 13,000 individuals per year in the global tuna purse seine fleet (mostly discarded) (Croll et al. 2016; Lezama-Ochoa et al. 2019). Although stock assessments are lacking, mobulids are considered overfished in Sri Lanka, where mortality rates for the spinetail devil ray *M.* (Bonnaterre 1788) were estimated to be two to six times higher than what is considered the maximum healthy rate for the population to increase naturally over time (Pardo et al. 2016; Fernando and Stewart 2021).

Declining population trends and their life history vulnerabilities have resulted in seven mobulid species being listed as Endangered on the International Union for the Conservation of Nature's (IUCN) Red List of Threatened Species: the oceanic manta ray *M. birostris* (Walbaum 1792), the sicklefin devil ray *M. tarapacana* (Philippi 1892), the spinetail devil ray *M. mobular*, the bentfin devil ray *M. thurstoni (Lloyd 1908)*, the longhorned pygmy devil ray *M. eregoodoo* (Cantor 1849), the shorthorned pygmy devil ray *M. kuhlii* (Müller and Henle 1841), and the Atlantic pygmy devil ray *M. hypostoma* (Bancroft 1831) (IUCN 2024). The remaining two species, the reef manta ray *M. alfredi* (Krefft 1868) and Munk's pygmy devil ray *M. munkiana* (Notarbartolo-di-Sciara 1987), are assessed as vulnerable (IUCN 2024).

Mobulid trade

Mobulids were historically fished for domestic use, primarily for their meat, which was consumed either fresh or dried, and occasionally for other parts like cartilage and skin. Their meat is generally considered low quality in most regions, and not a primary target for consumption, and is often dried and labelled

Y.-L. Gao
Ningbo Key Laboratory of Agricultural Germplasm Resources Mining and Environmental Regulation, College of Science and Technology, Ningbo University, Cixi 315300, China

generically as "dry fish" (Ossiander et al. in press). In recent decades, a supply chain expansion driven by demand for the dried prebranchial appendages of mobulids (commonly called gill plates or gill rakers) led to a drastic increase of international trade into key hubs in Asia (Croll et al. 2016; O'Malley et al. 2017). For instance, the estimated annual increase in weight of gill plates sold in Guangzhou (China) between 2011 and 2013 was 9% for manta rays (oceanic manta ray and reef manta ray at 21,876 to 23,811 kg); 107% for sicklefin devil ray (20,324 to 42,165 kg), and 204% for spinetail devil ray and other mobulids (17,952 to 54,493 kg) (O'Malley et al. 2017).

Mobulid gill plates are sold in the Chinese medicinal market as treatment for a variety of ailments as having anti-inflammatory properties, clearing away heat and toxic material, and eliminating stasis to activate blood circulation (O'Malley et al. 2017). However, there is no scientific evidence to support their efficacy, and recent studies have shown that gill plates and meat of several species (i.e., spinetail devil ray, reef manta ray, and Munk's pygmy devil ray) contain harmful levels of heavy metals, such as arsenic, cadmium, lead, and mercury, exceeding international recommended limits for cadmium, lead, and arsenic (Ooi et al. 2015; Baro-Camarasa et al. 2021; Bordbar et al. 2023). Furthermore, a health risk assessment by Essumang (2009) in Ghana also identified potential cancer risks and other adverse health effects from consuming arsenic-contaminated oceanic manta ray meat. While some practitioners have asserted that mobulid gill plates are a part of traditional practices, the first reference in traditional Chinese medicine literature to mobulid gill plates dates back to only 1976 (O'Malley et al. 2017).

Some of the largest reported mobulid fisheries in the world include Sri Lanka, Indonesia, and Bangladesh, with virtually all the gill plates destined for markets in Hong Kong Special Administrative Region (SAR) and mainland China (O'Malley et al. 2017; Croll et al. 2016; Fernando and Stewart 2021). A comprehensive assessment of the gill plate trade showed that, from 2010 to 2013, Guangzhou (China) accounted for the majority of the trade (O'Malley et al. 2017). However, by 2015, the Guangzhou market had declined (reportedly due to conservation campaigns and government policies), while gill plate sales in Hong Kong SAR increased between 2011 and 2015 (O'Malley et al. 2017). A rapid assessment in 2016 found a higher proportion of dried seafood stores in Hong Kong SAR (30%) selling gill plates compared to Guangzhou (6%) (Hau et al. 2016).

International and national protections

In 2013, in response to population declines and the increasing threat of the gill plate trade, both species of manta ray (oceanic manta ray and reef manta ray) were added to Appendix II of the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES). The remaining mobulid ray species were added to CITES Appendix II in 2016. With these listings, all 184 CITES parties are required to ensure that commercial trade in mobulid species is legal, sustainable, and traceable. Therefore, exports of mobulids or parts thereof must be accompanied by a CITES permit from the exporting or re-exporting nation. However, the recent analysis of CITES trade data (2017 – 2021) prepared for the Review of Significant Trade (RST) process, highlighted the increase and high volume in trade of the gill plates and fins of these threatened species globally, notably in Sri Lanka, India, and Yemen (CITES Secretariat and UNEP-WCMC 2023).

Furthermore, mobulids were listed on Appendices I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) in 2011 (manta rays) and 2014 (devil rays). The CMS Appendix I listing means that the 63 CMS Range States are expected to prohibit their take; landings, domestic sale, and international export should therefore not occur in these countries. Two UNEP Regional Seas Conventions and Action Plans (RSCAP) include mobulid species in their annexes: the Mediterranean population of the spinetail devil ray is listed in Annex II (Endangered or Threatened Species) of the Barcelona Convention, and Annex III of the Cartagena Convention Protocol for Specially Protected Areas and Wildlife (SPAW) in the Wider Caribbean lists the oceanic manta ray (**Online Resource 1**).

Following these listings on international treaties, four Regional Fisheries Management Organizations (RFMOs) established conservation and management measures for mobulids (i.e., the Inter-American Tropical Tuna Commission, Indian Ocean Tuna Commission, Western and Central Pacific Fisheries Commission, and the International Commission for the Conservation of Atlantic Tunas) (Cronin et al. 2023a;

Okes and Sant 2022). Additionally, multiple national-level policies were implemented to protect mobulid rays between 2006 and 2023 recognising the critical conservation status of these species, although the level of enforcement varies widely. Currently, at least 40 countries have developed policies or legislation providing full or partial protection to the mobulid species occurring in their waters (Laglbauer et al. in press).

Study aims

Despite the first listings on Appendix II of CITES and Appendices I and II of CMS occurring over a decade ago and national protections enacted in dozens of countries (Laglbauer et al. in press), mobulid populations have continued to decline (Fernando and Stewart 2021; Venables 2020; Carpenter et al. 2023; Venables et al. 2024) and trade (including of their derivatives) persists (Heinrichs et al. 2011; Whitcraft et al. 2014; O'Malley et al. 2017; Ooi et al. 2015; Bordbar et al. 2023). Although information on fisheries, landings, consumption, and trade is scarce and inconsistent across countries, records of landings and international trade do exist (e.g., FAO Total Production and CITES Trade Databases) (Okes and Sant 2022). To evaluate the current state of the mobulid meat and gill plate trade, we conducted a comprehensive global assessment using a mixed methods approach. Our objectives were to (1) determine how many countries are involved in mobulid ray landings and local consumption, (2) identify which countries participate in international trade, including importation, exportation, or both, (3) ascertain the price range of mobulid-derived products, (4) assess the scale of the gill plate market in Guangzhou and Hong Kong SAR, and (5) establish a priority ranking of countries based on their impact on mobulid populations. By examining trends in consumption and trade, we aimed to highlight the existing gaps and challenges in protecting these species and to contribute to the development of informed conservation strategies.

Methods

Approach

The mixed-methods approach involved expert elicitation through country-focused online surveys and interviews, along with analysis of the FAO Total Production and CITES Trade Databases, online trade surveys, and physical store surveys conducted in Guangzhou and Hong Kong SAR. Subsequently, we assessed the level of impact to mobulid populations for each surveyed country, ranking them in priority order for conservation and management attention/action.

Between November 2023 and February 2024, we requested participation from stakeholders who have experience in the field of elasmobranch fisheries research worldwide (especially in mobulids). We reached out to the IUCN Species Survival Commission Shark Specialist Group members [Our Members—IUCN SSC Shark Specialist Group (iucnssg.org)], The Manta Trust research affiliate network [Manta Trust Research Portal (research.mantatrust.org)], and searched relevant peer-review literature for country contacts. Respondents participated in a country-focused online survey and interviews aimed at gathering and synthesising qualitative information on the trade of mobulid meat and gill plates. Participants included in this study had information on mobulid range states spanning America, Europe, Asia, Africa, and Oceania. Our study exclusively focused on nations where both industrial and artisanal fisheries operating within their exclusive economic zones (EEZs) could supply mobulid gill plates and meat for local consumption, export or import, while recognising that industrial fisheries operating in international waters may also be a source of mobulid products entering international trade.

Four additional countries were assessed where surveys were not answered/conducted from published literature (i.e., Palestine; Abudaya et al. 2018), photographic evidence (i.e., Vietnam; Shark Guardian pers. comm.), and country seizure data (i.e., Hong Kong SAR and Somalia; Hau and Shea 2023) and CITES Trade Database (e.g., Sri Lanka).

Country-focused online survey

We utilised the online platform Qualtrics to administer a comprehensive country-focused online survey consisting of 26 questions, encompassing open-ended, and single-or multiple-choice format questions (**Online Resource 2**).

The questionnaire was structured into six sections and included questions featuring species and distribution maps to confirm the identification of

species, as well as photographs depicting mobulid meat and gill plate processing techniques. The first section gathered details on the respondents and their country or countries of expertise. The second section addressed the existence of fisheries targeting or incidentally catching mobulids that were either retained or discarded along with existing pertinent national regulatory measures. It also explored the types of fishing gear in which mobulids were most commonly captured, and the seasonality of these fisheries. The third section focused on investigating whether mobulids were processed prior to landing (i.e., at sea), or whether they were landed and processed onshore. Emphasis was placed on identifying specific landing sites, as well as documenting the frequency and quantity of mobulids landed per species. The fourth section centred on the meat trade, to determine if mobulid meat could be found in local markets and whether it was locally consumed or traded internationally. Additionally, it sought to identify in which forms the meat (frozen, fresh, or dried) was found in markets and sale prices (in USD per kilogramme). The fifth section focused on the trade in gill plates, and whether they were removed from the animal's body prior to sale, and processed (i.e., dried) within the country. Prices for gill plates were combined for fresh and dried presentations unless otherwise specified in the text.

Finally, participants were given the opportunity to share additional relevant information, as well as indicate their willingness to be contacted for an in-person interview.

For questions concerning expert knowledge on these topics, respondents were asked to clarify the level of evidence they possessed to support positive answers: affirming awareness (having heard of it), confirming personal observation (having seen it), or by having evidence such as photographs or videos (have evidence). Results presented in this study only include information that was either confirmed by personal observations or by evidence, such as photographs and videos. Any unverified information is explicitly noted as unconfirmed.

Interviews

After assessing country-focused online surveys, we carried out in-depth interviews via video call with select experts in countries where mobulid trade was directly observed. A structured questionnaire guided these interviews and focused on fisheries, policy, and trade. Questions focused on whether mobulids were traded domestically, including descriptions of associated value (**Online Resource 3**). Additionally, we collected information on trade routes, airports, or ports facilitating the export of mobulid-derived products, and final destinations. The regular consumption and sale of other ray species in the country was also explored, considering cultural or traditional practices. We investigated common names used to label products, discerning whether they were specific to each species or grouped under overarching terms. Finally, we asked experts' opinion on major gaps in domestic trade regulation and whether existing national protections had improved mobulid trade and traceability. With regards to CITES compliance, we inquired about the impact on trade of listing mobulids in Appendix II and identified the primary obstacles to enforcing international trade regulations for these species within the country.

FAO total production database

While acknowledging persistent and long-standing issues with the collection and reporting of shark and ray species data in the Food and Agriculture Organization of the United Nations (FAO) statistical reports (i.e., accurate classification or catch levels and extent of (un)reporting by each country) (Cashion et al. 2019; Fowler et al. 2021), we extracted data on mobulid catches using FishStatJ for the period of 2000 – 2021 from the FAO Total Production Database (FAO 2023). The FAO database records the volume of fish catches as capture production, intended to represent the live weight of catches by country, categorised by species or higher taxonomic levels (Okes and Sant 2022). This encompasses all retained catches as live weight (Garibaldi 2012), but it does not account for catches discarded at sea (Okes and Sant 2022).

Although mobulid catches could fall under multiple categories, or higher levels of species aggregation within FAO categorisation (i.e., rays, stingrays, mantas nei, or other broader categories), we used data on nominal mantas, devil rays, and nei (not elsewhere included) classification captures to elucidate the official global records of mobulid fishing and reporting countries.

CITES trade database

Trading mobulids or their parts internationally requires a CITES permit by signatory nations. Permits are issued only after CITES authorities prepare a legal acquisition finding (LAF) and a non-detriment finding (NDF), intended to confirm specimens are legally acquired and that trade is not detrimental to their survival (i.e., fisheries are sustainable). The CITES provisions also apply to specimens taken in areas beyond national jurisdiction (i.e., international waters). Parties are required to report their trade shipments (exports, imports, re-exports) in CITES species and products, although original documents do not have to be shared with other parties or the CITES Secretariat. CITES trade data (exports, imports, and re-exports), are published in the CITES Trade Database.

We downloaded data for the period 2017 – 2021 following the time frames of other analyses for mobulids (CITES Secretariat and UNEP-WCMC 2023) for the RST. All non-commercial trade records under the "Purpose" category were removed from the analysis, and only specimens taken from the wild (W) or introduction from the sea (X) (i.e., the marine environment not under the jurisdiction of any state) in the "Source" category were considered. Traded products could fall under several categories, such as meat, gill plates, fins, and specimens. In cases, where both export and import weights (kg) were reported for the same shipment, the import weight was used. The imports included in the analysis were all to Hong Kong.

To compare mobulid trade data (which are reported by weight of the dried parts) to fisheries landings and market source data, we calculated the proportion of the carcass utilised for human consumption (Rojas et al. in press), the conversions in weight loss from wet (fresh) to dry for meat and gill plates (Rojas et al. in press; Le Floch et al. in prep), and compared these values to each of the traded species based on the mean size (disc width) and weight of landed specimens (Rambahiniarison et al. 2018; Fernando and Stewart 2021; D'Costa and Stevens in prep).

Online gill plate trade surveys

Online trade surveys were conducted on five web-based platforms based on their widespread used, including Taobao, Jingdong, Pinduoduo, Douyin, and Kuaishou. The search term "Peng Yu Sai" was queried, which is used to describe mobulid gill plates in Mandarin and Cantonese. The presence of gill plates, price, maximum order quantity, online shop name, online shop physical location provided in the portal, and mobulid species (based on available photo identification, Stevens et al. 2018) were all recorded.

Store gill plate trade surveys

Physical stores selling "Peng Yu Sai" were surveyed in April 2023 in Guangzhou, by two native Cantonese and Mandarin speakers through a rapid assessment over a week. Trade surveys covered the main traditional Chinese medicine (TCM) commerce areas identified in previous surveys (O'Malley et al. 2017; Hau and Shea 2023), namely the Qingping Market in the north of Shamian Island, Liwan District and Yide Dry Seafood Market in the Yuexiu District. The Qingping Market survey comprised approximately 1000 stores in five main areas: Qingping TCM Center, Qingping East Market, Qingping Road TCM Section G, Qingping Road TCM Section H, and Li Ming market. Additionally, the survey extended to surrounding areas in Guangzhou Zheng Tian Dried Nuts Wholesale Market and Ti Yun East Street front stores on Qingping Road. The Yide Market survey comprised approximately 1000 stores in nine wholesale markets that specialise in dried seafood and related products.

Physical stores selling "Peng Yu Sai" were also surveyed in late 2015 and 2022 in Sheung Wan and Sai Ying Pun (Hong Kong SAR), by two native Cantonese speakers through a rapid assessment (Hau et al. 2016). These areas are the districts most densely populated with dried seafood stores in Hong Kong SAR. The area is concentrated around Des Voeux Road West (coined "Dried Seafood Street" by locals), with multiple streets dispersing from its centre. More than 350 stores were recorded and visited in this survey covering Bonham Strand, Bonham Strand West, Centre Street, Cleverly Street, Connaught Road West, Des Voeux Road Central, Eastern Street, Ko Shing Street, Kom U Street, Sutherland Street, and Wilmer Street.

Surveys were conducted by visually identifying the presence of dried gill plates on display at store fronts and asking storekeepers if stocks were kept in storage (and not displayed), and further inquiring about their

price, available stock, and reported origin to store owners. Gill plates were photographed where possible to further identify species or species groups they belonged to ("Manta", "*Mobula tarapacana* (Philippi 1892)", or "*M. mobular*/other *Mobula* spp."), based on morphological characters (O'Malley et al. 2017; Stevens et al. 2018). The prevalence of gill plates was also recorded to determine whether the store specialises in selling gill plates, or whether these are sold in smaller quantities alongside other seafood or TCM products.

Priority countries

Countries included in the country-focused online survey, interviews, and four additional countries (i.e., Palestine, Somalia, Vietnam, Hong Kong SAR) were examined further to assess their level of impact towards mobulid conservation. Subsequently, a list of priority countries was compiled ($n = 75$), ranked from highest to lowest level of impact and hence urgency of attention required. To do this, a total of 17 threat factors to mobulids were derived from the survey and interview data. The analysis also included whether the country is Party to international multilateral environmental agreements that have some form of mobulid management or protections in place, such as CITES, CMS, the Cartagena Convention SPAW Protocol, and the Barcelona Convention, the country's role in mobulid meat and gill plate trade, price range, and consumption patterns. Additionally, a quantification of national mobulid landings data was integrated from Laglbauer et al. in press, in which data was derived from expert interviews and a literature review. A scale from 0 to 1 was applied (0 = none; 0.5 = few mobulid landings; 0.75 = moderate landings; 1 = high amount of landings). To account for geographic differences and varying levels of impact on mobulid conservation, Mexico was divided into two regions: Pacific Mexico and Caribbean Mexico.

Each factor received a score on a continuous scale, e.g., for the factor "meat trade with various countries", a scale from 3 – 0 was applied (3 = yes, with multiple countries; 2 = yes, with one country; 1 = possible trade; 0 = none). To ensure that each factor contributes proportionally to the final ranking, each score was normalised to a common scale between 0.0 (lowest contribution to mobulid threats) and 1.0 (highest contribution to mobulid threats). A min–max scaling (Chakrabartty 2017) was applied to transform the data linearly to fit within a specified range. The sum and mean of scores were subsequently calculated for each country across the normalised factors. Considering the high correlation coefficient ($r = 0.761$) between the mean and sum of these values, a sum score was used to rank the countries against each other, resulting in a relative ranking in order of highest to lowest contribution to mobulid threats. Following this ranking, we assigned countries to prioritisation categories, "high", "moderate", and "low", which were determined both quantitatively and qualitatively. The countries categorised as "high" had a sum score of > 6.4 and were engaged in gill plate trade, "moderate" had a sum score of 3.6 – 6.3 and were participants in trade or consumption and landing mobulids through targeted fisheries or bycatch retention, and "low" had a sum score of < 3.6, with less contributions to mobulid threats.

Results

Country-focused online survey and interviews

A total of 178 experts comprising elasmobranch researchers and fisheries specialists across 112 countries (mobulid range states) were contacted via email. We obtained 109 country-focused online surveys with information from 71 countries (Fig. 1) (**Online Resource 4**), with an average of 1.4 ± 0.99 (mean ± SD) number of surveys answered per country, with a maximum of four surveys for one country (e.g., Indonesia).

In-depth interviews were made to researchers and fisheries experts in 19 countries, during which a total of 21 in-person questionnaires were conducted (**Online Resource 3**).

Information on the trade and fisheries of mobulids in countries where surveys were not answered/conducted was also gathered or complemented from published literature, photographic evidence, or country seizure data (Hau and Shea 2023) and CITES Trade Database (i.e., Palestine, Somalia, Vietnam, Hong Kong SAR). Therefore, data from 75 countries are presented here.

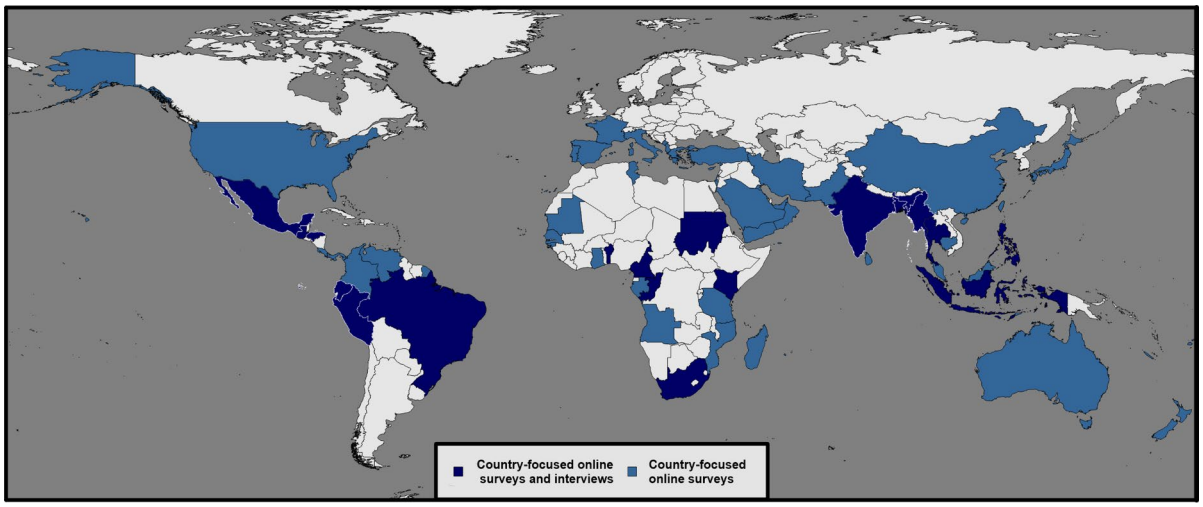


Fig. 1 Mobulid range states surveyed: country-focused online surveys (light blue) and interviews (dark blue)

FAO total production database

Within the FAO total production database for family Mobulidae (mobulids), nine countries reported captures between 2000 and 2021: Indonesia, Kenya, Liberia, Mauritania, Pakistan, Spain, Sri Lanka, Ecuador, and Peru (**Online Resource 5**). However, the findings of the country-focused online surveys and interviews reveal that mobulids are caught and landed in at least 43 countries (answer "evidence" $n=35$ and "seen it" $n=8$), of which 36 do not appear in the FAO Total Production Database. These are Angola, Bangladesh, Benin, Brazil, Cameroon, China, Cyprus (de facto Northern Cyprus), France, Gabon, Ghana, Greece, Guatemala, India, Iran, Italy, Madagascar, Malaysia, Mexico, Mozambique, Myanmar, Oman, Palestine, Philippines, Republic of Congo, São Tomé and Príncipe, Saudi Arabia, Senegal, Seychelles, Sudan, Taiwan, Tanzania, Tunisia, United Arab Emirates, Venezuela, Vietnam, and Yemen. Furthermore, our findings show they appear as discarded bycatch in 13 countries, including European Union countries, Thailand, USA, Australia, New Zealand, Costa Rica, French Polynesia, Maldives, Turkey, and South Africa. The spinetail devil ray ($n=37$ countries) and oceanic manta ray ($n=22$ countries) emerged as the most widely recorded species in landings.

CITES trade database

Of the 184 countries that are Party to CITES, five were identified as having reported trade of one or more mobulid species for commercial purposes from the wild between 2017 and 2021, whether as an exporter or origin country (CITES Trade Database, accessed May 2024). None of these reports identified the original source of the specimens traded as taken in the marine environment not under the jurisdiction of any state (i.e., international waters). During this period, trade reports in the CITES Database included seven for fins and 32 for gill plates. No mobulid meat was reported in the CITES Database. All trade in gill plates and fins were destined for Hong Kong. Sri Lanka accounted for 64% of all traded gill plates and fins (Table 1), which is why this country was selected for a RST on mobulids in 2023. Three mobulid species were listed on the 39 requested (Unique Identifier Code) exports and/or documented imports of gill plates and fins during this period, although almost a third ($n=12$) of the requests simply stated *Mobula* spp. (Table 1). The most frequently listed species, in both number of requested exports/recorded imports and by weight (kg), were, in descending order, the spinetail devil ray (39%), sicklefin devil ray (22%), and the oceanic manta ray (5%) (Table 1). Although trade in some species was reported to sharply increase over the period assessed in the CITES Secretariat and UNEP-WCMC report (2017 – 2021), in the case of *M.*

Table 1 CITES Trade Database: mobulids gill plate and fin data (2017 – 2021)

CITES Trade Database: mobulid ray data (2017–2021)						
	Gill plates		Fins		Total	
	kg	%	kg	%	kg	%
Exporter						
Sri Lanka	12,761.7	68%	880	37%	13,641.65	64%
India	6054.7	32%	0	0%	6054.7	29%
Yemen	0	0%	1418	59%	1418	7%
Oman	0	0%	88	4%	88	0%
Species						
Mobula spp.	5716.65	30%	1418	59%	7134.65	34%
Mobula birostris	1165.5	6%	0	0%	1165.5	5%
*Mobula mobular**	7486.15	40%	718	30%	8204.15	39%
Mobula tarapacana	4448.05	24%	250	10%	4698	22%
Year						
2017	0	0%	0	0%	0	0%
2018	4718.65	25%	0	0%	4718.7	22%
2019	5609.25	30%	880	37%	6489.25	31%
2020	4432.2	24%	500	21%	4932	23%
2021	4056.25	22%	1006	42%	5062	24%
Total	**18,816.4**	**100%**	**2386**	**100%**	**21,202.35**	**100%**

**Mobula mobular* records were combined with *M. japanica*

mobular, this was likely, in part, a result of taxonomic changes within the family (in 2019, *Mobula japanica* (Müller and Henle 1841) merged with *M. mobular* leading to high records for a "new" species previously reported as *M. japanica*). However, when all mobulid records are combined, the annual quantities reported remain similar from 2018 onward (Table 1).

Based on our conversion rates (Table 2), 80% of the whole mobulid carcass is utilised for human consumption, virtually all of which is meat from the pectoral fins. Once dried, the weight of the meat is reduced by 60% and the gill plates by 80% through water evaporation. When wet (fresh), the gill plates comprise approximately 1% of the total carcass

Table 2 Conversion values (wet to dry) for the body parts of the four most traded mobulid species. Percentage (%) given = proportion remaining by weight of the whole fresh (wet) carcass

Mobula spp.	[i]Disc Width (cm)	[ii]Whole Carcass (kg)	[iii]Meat (kg)		[iv]Gill plates (kg)	
			Fresh (80%)	Dried (32%)	Fresh (~1%)	Dried (~0.2%)
M. birostris	449.4	533.2	426.56	170.62	7.70	1.54
M. tarapacana	238.3	143.7	114.96	45.98	1.24	0.25
M. mobular	206.9	88.7	70.96	28.38	0.88	0.18
M. thurstoni	162.3	45.2	36.16	14.46	0.42	0.08

[i]Disc widths are based on the mean size of all individuals ($n = 1337$, excl.foetuses) landed in the Philippines (Rambahiniarison et al. 2018)

[ii]Weights of whole carcass based on Rambahiniarison et al. (2018) and D'Costa and Stevens (in prep); proportion of whole carcass used (20% discard) for human consumption is based on Rojas et al. (in press)

[iii]Wet (fresh)/dry meat conversions (60% reduction) based on Rojas et al. (in press)

[iv]Wet (fresh)/dry gill plate conversions (80% reduction) based on Le Floch et al. (in prep)

weight, reducing to just ~ 0.2% of the total carcass weight once dried. Using these ratios, and the data provided in the CITES Database, approximately 757 oceanic manta rays, 41,590 spinetail devil rays, 17,792 sicklefin devil rays, and a further 31,759 *Mobula* spp. (using the *M. mobular* conversion rate as the most traded mobulid) have reportedly been traded in the form of gill plates from 2017 to 2021. Each year (excluding 2017, when zero mobulid trade was reported), the average number of mobulid traded in the form of gill plates was 26,134. During this same period, Sri Lanka exported 12,761.65 kg of gill plates, equating to approximately 70,898 mobulid when using the *M. mobular* conversion rates. Given that Sri Lanka represents 68% of the total gill plate trade in the CITES Database, this equates to approximately 16,725 mobulids exported annually for this country, in the form of gill plates. When these estimates are compared to specific annual catch reconstructions of mobulid in Sri Lanka during 2018 – 2019 (Fernando and Stewart 2021), the total numbers are comparable (Table 3), although there is significant disparity between the species, likely a result of the high number of plates being traded under the genus only.

Four countries have voluntarily shared their NDFs for *Mobula* species: the USA, New Zealand, Bangladesh, and India (**Online Resource 6**). The USA has published three positive NDFs (two in 2018 and one in 2019; both for wild-caught live animals destined for large public aquaria). India has a positive NDF with conditions (the latter including research and improved data collection) for the smaller mobulid species during 2022 – 2024 inclusive. In contrast, New Zealand, Bangladesh, and India (for manta rays only) have published negative NDFs, meaning that they would not be able to issue export permits for these species. It should be assumed that LAFs and NDFs exist for all exports listed in the CITES Trade Database, even if unpublished, since they are a prerequisite for authorising trade. However, it is also possible that some do not exist.

Table 3 Mean number of mobulids landed and internationally traded annually in Sri Lanka, derived tough catch reconstruction and gill plate trade to body weight ratios, respectively (2018 – 2019)

Mobula spp.	CITES Trade Database	Fernando & Stewart (2021)
M. birostris	81	2001
M. tarapacana	4776	5080
M. mobular	5683	11,680
M. thurstoni	0	527
Mobula spp.	3378	0
Total	**13,918**	**19,288**

Scale of global mobulid meat trade and consumption

According to the country-focused online surveys and interviews, mobulid meat is consumed locally in 35 of the 75 countries surveyed (answer with "Yes, evidence available" $n = 23$; and "Yes, seen it" $n = 11$, and data from Abudaya et al. (2018) for Palestine) (Ghana, Oman, Republic of Congo, Yemen, Fiji, French Polynesia, Bangladesh, Brazil, Cameroon, Gabon, Greece, Guatemala, India, Indonesia, Iran, Madagascar, Malaysia, China, Mauritania, Mexico (Pacific), Mozambique, Myanmar, Palestine, Pakistan, Peru, Philippines, Tunisia, São Tomé and Príncipe, Senegal, Seychelles, Sri Lanka, Sudan, Venezuela, Vietnam, and United Arab Emirates), while the drivers of local consumption were variable across countries (Fig. 2a). With the inclusion of respondents that answered "Yes, heard of it", the number of countries where mobulid meat is locally consumed increases to 45 (**Online Resource 7**).

For local consumption, results show that most commonly the meat of the pectoral fins is eaten fresh. The meat is cut and prepared in different styles depending on the country (Fig. 3). In Mexico, meat is prepared as a fillet, with the muscles sliced along the pectoral fin, perpendicular to the central axis (Fig. 3k). In South America, West Africa and Southeast Asia, the meat is prepared by cutting the pectoral fin of the animal parallel to the central axis, slicing the fins into strips (Fig. 3l). If not consumed fresh, the meat is stored, usually through salting and sun-drying (Fig. 3d **– j**). For export, the meat is most commonly traded in dried form, with the exception of Oman and Ecuador where the meat can be exported in various forms, including fresh, frozen, or dried. In certain countries, like Senegal or Benin, mobulids are landed but not consumed locally, while in others, like Pakistan and Iran, mobulid meat is not intended for human consumption, but rather processed into fish meal. In Sri Lanka, the pectoral fins of sicklefin, spinetail, bentfin, and shorthorned pygmy devil rays are

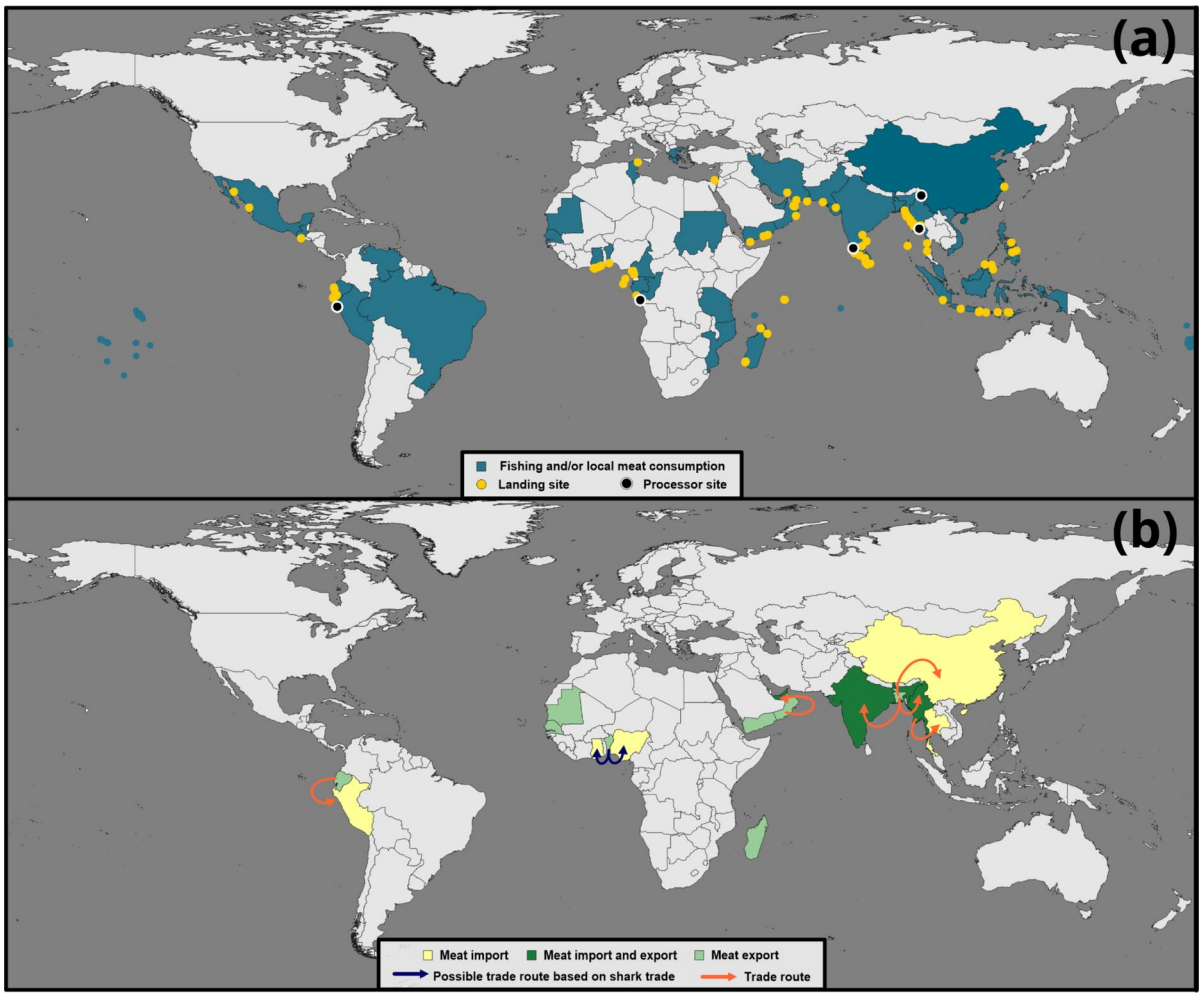


Fig. 2 Mobulid meat global trade map. **a** The map indicates countries where mobulids are landed and meat is locally consumed. Specific landing sites are highlighted in yellow, although landing can occur along the entire coast range. Reported processing sites for mobulid meat are highlighted in black. **b** Export and import routes of mobulid meat

sold as fresh meat in a few towns, but the meat of all mobulids (including any excess after selling fresh) is dried and sold as lower quality dried fish.

Exporting countries are highlighted in light green, importer countries in yellow, and exporters and importers countries in dark green. Confirmed trade routes are indicated by orange arrows while possible trade routes based on shark trade are indicated in blue.

The findings indicate that where meat consumption persists as a cultural tradition, such as in Guatemala, its consumption is notably concentrated during Easter holidays and the preceding weeks of fasting, serving as an affordable substitute for bony fishes during this time. The interviews elaborated on the use of mobulid meat in various traditional dishes, such as in Peru, where "Tortilla de Raya" uses dry meat (Fig. 3m), while Mexico typically uses both fresh and dry meat in traditional dishes, such as "Machaca de mantarraya". One interviewee mentioned that in Peru, historical Inca records have documented the utilisation of mobulids. In Bangladesh, dried meat is utilised to create talismans for fertility purposes, and it is also believed to possess curative properties against cancer. Additionally, in the Philippines, fishers and sellers use dried mobulid intestines and liver for consumption, whereas in Bangladesh, the intestines, cephalic lobes, and tails are sold in bulk.

Fig. 3 Mobulid meat trade process. Mobulid rays (**a** spinetail devil ray, *Mobula mobular*, and **b** oceanic manta ray, *M. birostris,* Sri Lanka) are processed at fish markets, at landings sites, or at sea. The most desirable meat of the pectoral fins is separated from the gill plates and the rest of the carcass (**c** spinetail devil ray, *M. mobular,* and unidentified species Sri Lanka). This pectoral fin meat is further processed into smaller strips before often being washed (**d** Sri Lanka), salted (**e** Sri Lanka), and hung (**f** Myanmar, **g** Peru) or laid in the sun (**h** Peru, **i** Sri Lanka) to dry for several days to weeks before sale (**j** Myanmar). Fresh meat is also sold for direct consumption (or frozen), and in some locations the fresh meat from the pectoral fins is filleted (**k** Mexico) instead of being processed into fish steaks (**l** Sri Lanka). The meat is consumed in several traditional dishes, such as Machaca de Mantarraya (Mexico) and Tortilla de Raya (**m** Peru), but also used more generally as unspecified dried fish in dishes

The country-focused online surveys and interviews show that mobulid meat is exported internationally over land or sea by ten countries: Bangladesh (export to mainland China, India and Myanmar), Ecuador (to Peru), India, Madagascar, Mauritania, Myanmar (to Thailand), Oman (to United Arab Emirates), Senegal, United Arab Emirates, and Yemen (Fig. 2b). The meat is imported by five major destination countries (mainland China, Myanmar, Thailand, Peru, and United Arab Emirates), and transportation is most commonly by land across borders to adjacent countries, e.g., from Ecuador to Peru, or Myanmar to Thailand.

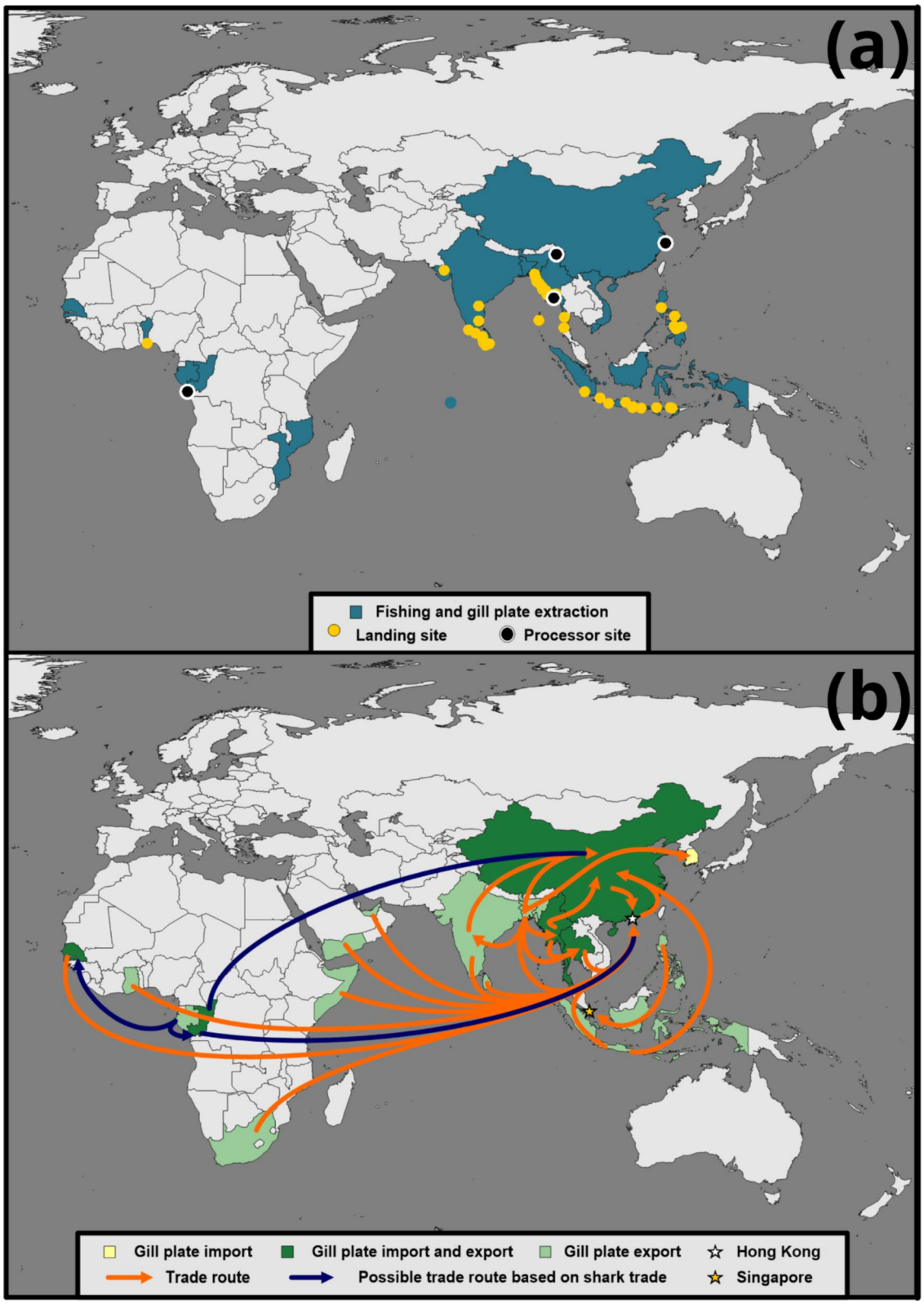
Scale of global mobulid gill plate trade and consumption

According to country-focused online surveys and interviews, gill plates are extracted and/or consumed locally in 14 of the 75 countries surveyed (answer with "Yes, evidence available" $n=9$; and "Yes, seen it" $n=5$) (Republic of Congo, Chagos Archipelago, China, Bangladesh, Benin, Gabon, India, Indonesia, Mozambique, Myanmar, Philippines, Senegal, Sri Lanka, and Vietnam) (Fig. 4a). Regarding the Chagos Archipelago, it is important to note that fishing in the territory is being conducted illegally by fishers from other regions. With the inclusion of respondents that answered "Yes, heard of it", the number of countries where gill plates are extracted and/or consumed locally increases to 17 (**Online Resource 7**).

Gill plate extraction methods vary between species, by the size of the ray, and locally preferred practices (Fig. 5). In most locations, the head is usually removed from the rest of the carcass once the ray has been landed (Fig. 5a), although gill plate removal from the head does also occur at sea in some locations (e.g., in Myanmar). Smaller rays (e.g., the four pygmy devil ray species) are usually processed only for their meat as the gill plates are small and time consuming to remove, making the process financially unviable. However, local consumption of gill plates has been recorded in Myanmar where small dry gill plates are sold at very low prices as scraps to make salads. In most locations in Southeast Asia, specialist workers remove the delicate gill plates from the branchial arches of the ray, resulting in a "set" of 20 gill plates per ray, which are either U-shaped with filaments projecting from just one edge, or l-shaped with filaments projecting from either side of the edge, depending on how the plates are cut from the branchial arches (Fig. 5d **– g**). The gill plates are then sun dried for up to a week before they are ready for sale (Fig. 5h – i). The plates are usually destined for international export where they are sold to consumers primarily in Southeast Asia through TCM retail shops, or online. The plates are usually consumed in a broth and are traded under the name Peng Yu Sai (Fig. 5l).

Country-focused online surveys, interviews results, CITES Trade data, and seizure data from Hong Kong SAR (Hau and Shea 2023) show countries exporting gill plates across Asia include mainland China (export to Hong Kong SAR), Hong Kong SAR (to mainland China), Indonesia (to mainland China and Hong Kong SAR), Myanmar (to mainland China and Thailand), Bangladesh (to India, Myanmar, mainland China, Hong Kong SAR, South Korea, and Thailand), Sri Lanka (to Hong Kong SAR), India (to mainland China and Hong Kong SAR), Philippines (to Singapore), Yemen (to Hong Kong SAR), and Thailand (to Hong Kong SAR). African countries exporting gill plates include South Africa (to Hong Kong SAR), Senegal (to Hong Kong SAR), Somalia (to Hong Kong SAR), and Ghana (to Hong Kong SAR). Given the existing routes for the international trade of shark fins, interviewees noted that Gabon and Republic of Congo are potential trade countries (to Senegal, Republic of Congo, Hong Kong SAR, and mainland China); however, this has not been substantiated with evidence. In the Middle East, the United Arab Emirates is an exporter to Hong Kong SAR.

Gill plates are imported by five major destinations: mainland China, Hong Kong SAR, Singapore, South Korea, and Thailand (Fig. 4b). In comparison to the meat trade, gill plates are typically exported via boat, land, or plane and are traded at the regional (e.g., Myanmar to Thailand), and interregional level (e.g., Ghana to Hong Kong SAR). As with the meat trade, the country-focused online surveys and interviews results indicate that Myanmar is an entrepôt for gill plate trading, importing from Bangladesh and re-exporting to mainland China via Yangon. Bangladesh also exports directly to other countries, such as mainland China, Myanmar, India, South Korea, Hong Kong SAR, and Thailand. Furthermore, mainland China, Hong Kong SAR, and Thailand may act as re-export hubs, channelling gill plates to Hong Kong


(a)
Fishing and gill plate extraction
Landing site
Processor site
(b)
Gill plate import
Gill plate import and export
Gill plate export
Hong Kong
Trade route
Possible trade route based on shark trade
Singapore

◂**Fig. 4** Mobulid gill plate global trade map. **a** The map indicates countries where mobulids are fished and gill plates are extracted. Specific landing sites are highlighted in yellow although landing can occur along the entire coast range. Processor sites for mobulid gill plates are highlighted in black. **b** Export and import routes of gill plates. Exporting countries are highlighted in green, importer countries in yellow, and exporters and importers countries in dark green. Trade routes are indicated by arrows. Confirmed trades are in orange, while possible routes based on shark products are in blue

SAR or mainland China, according to data from seizures (Hau and Shea 2023).

Processing sites

Our findings highlight the great diversity of processing methods employed globally, focused on some regions at commercial processing centres, while others rely on small-scale traditional or household-based processing techniques at fishing camps and landing beaches. The country-focused online surveys and interviews provided information on dedicated processing sites for gill plates and meat (Figs. 2 and 4, black dots) in the Republic of Congo, Peru, India, Sri Lanka, China, and Myanmar. In Peru, dried meat processing is centralised at a single location in Lambayeque State. Myanmar has several drying facilities in the south and west of the country where mobulid products are processed with shark-derived products. In Bangladesh, gill plates have been reported from at least two processing centres, although there are up to 20 shark and ray processing centres for other derived products exist in the country. In Sri Lanka, gill plates and meat are either extracted at the landing site itself or at shark and ray processing centres, while drying occurs at processing sites or at more basic operations run out of traders' houses (e.g., backyards or rooftops). In Indonesia, there are many landing sites (e.g., Muntjar, Java) where up to 40 individuals act as processors, cutting the meat and extracting the gill plates. In the Republic of Congo, the landing and initial processing of sharks and rays primarily take place in Songolo, within a designated fishing centre. However, the drying process occurs in homes. In contrast, in Sudan, Cameroon, and Kenya, mobulids are processed at beaches or in fishing camps. There is also evidence of mobulids being processed at sea by 12 countries, including Oman, Colombia, India, Myanmar, Senegal, Ecuador, Brazil, Sri Lanka, Cyprus (de facto Northern Cyprus), Mexico, Peru, and Philippines. Normally meat is dried at fishing camps or at the beaches where mobulids are landed; however, in places like Peru, Myanmar, and Sri Lanka, dedicated processing sites for mobulid-derived products also exist.

Mobulid meat global price ranges

The results show high variation in mobulid meat prices between countries (Fig. 6). Dried meat often procured higher prices than fresh meat, most likely due to processing and preservation methods required as well as market demand in those countries. The highest prices of dried meat (8 – 10 USD/kg) were found in Bangladesh and Myanmar. For fresh meat, the highest prices (6 – 8 USD/kg) were found in Benin, Mexico, Brazil, and Republic of Congo. Countries where dried meat was more expensive than fresh meat included Bangladesh (dry = 2 – 10 USD/kg; fresh = 1 – 6 USD/kg), Guatemala (dry = 3 – 6 USD/kg; fresh = 0.3 – 0.4 USD/kg), Indonesia (dry = 0.45 – 6 USD/kg; fresh = 1 – 2 USD/kg), Peru (dry = 6 USD/kg; fresh = 0.4 – 1.6 USD/kg), and Sri Lanka (dry = 4 USD/kg; fresh = 1.17 – 1.51 USD/kg). While fresh meat prices were higher than dry meat prices in Benin (dry = 2.5 – 5 USD/kg; fresh = 0.24 – 8 USD/kg), and Mexico (dry = 5.25 USD/kg; fresh = 7.26 USD/kg). Mobulid meat was also processed into fishmeal in Pakistan and sold at 0.35 USD/kg.

Gill plate price ranges

Gill plate (fresh and dried combined) price ranges were found to be highly variable between source countries and destination countries (Fig. 7). Among the source countries, Bangladesh had the lowest starting price at 4.8 USD/kg, followed by the Philippines, Brazil, and Sri Lanka. Meanwhile, Myanmar, India, and Indonesia had the highest prices, reaching up to 200 USD/kg. In consumer countries like mainland China and Hong Kong SAR, mobulid gill plates command significantly higher prices compared to source countries, with prices ranging from 191 to 1260 USD/kg. A 2022 field survey in Guangzhou found Chinese retailers selling these plates for 283 to 456 USD/kg. Additionally, recent online research in 2024 identified five Chinese platforms selling dried mobulid gill plates, with prices starting at 249 USD/kg

Fig. 5 Mobulid gill plate trade process. In medium to large sized mobulid rays (≥ 1.3-m disc width), the head is usually removed from the rest of the carcass once the ray has been landed (**a** oceanic manta ray, *Mobula birostris*, Sri Lanka), although gill plate removal from the head (**b** *M. birostris,* India) does also occur at sea. (**c** Smaller rays (< 1.3-m disc width) are usually processed only for their meat as the gill plates are small). Specialist workers remove the delicate gill plates from the branchial arches of the ray (**d**), resulting in a "set" of 20 gill plates per ray (**e**), which are either U-shaped with filaments projecting from just one edge (**d** *M. birostris*), or l-shaped with filaments projecting from either side of the edge (**f** spinetail devil ray, *M. mobular*, **g** sicklefin devil ray, *M. tarapacana*), depending on how the plates are cut from the branchial arches. The gill plates are then sun dried (**h – i**, Puqi, China and Negombo, Sri Lanka, respectively) before they are ready for sale. The plates are usually destined for international export, sometimes illegally (**j – k** customs seizure of *M. birostris*, Indonesia), where they are sold to consumers primarily in Southeast Asia through TCM retail shops (**k**) or online. The plates, traded under the name Peng Yu Sai, are usually consumed in a broth (**l**)

and reaching up to 1260 USD/kg. The average price across 94 online retailers was 511.81 USD/kg. These findings point to substantial variations in price and demand for mobulid gill plates from landing to consumer markets.

Gill plate market

The quantity of known physical retailers in Guangzhou and online retailers across five platforms in the country were examined (Fig. 8). While numbers

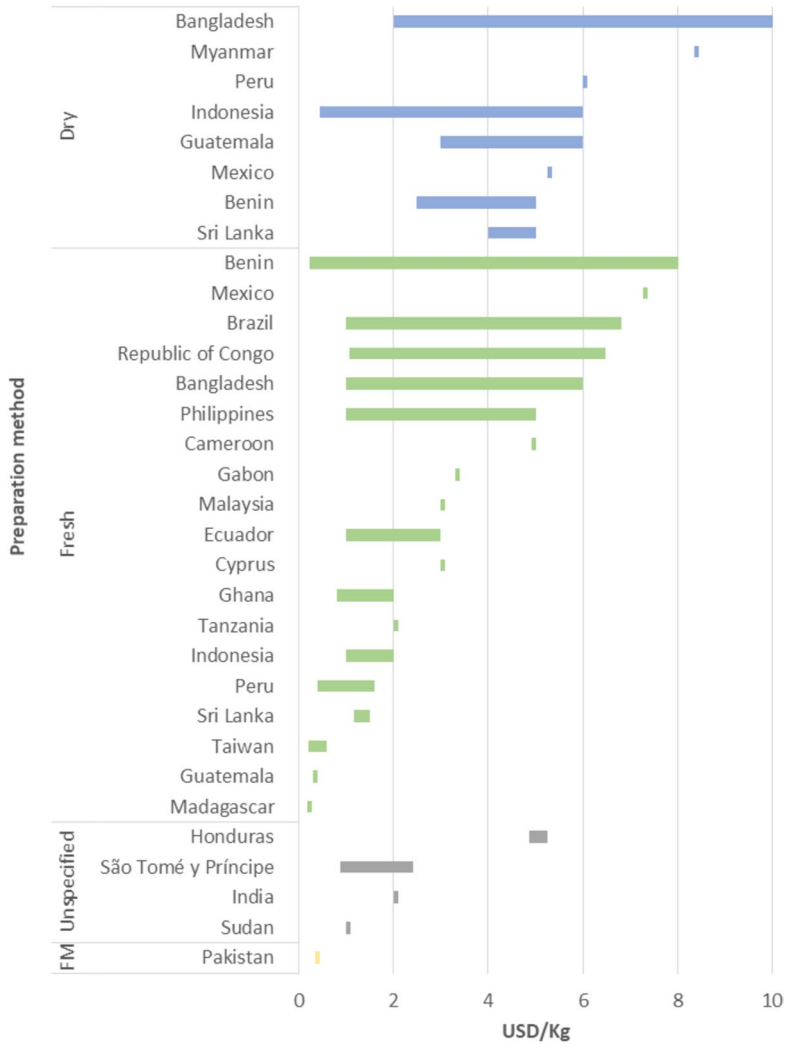


Fig. 6 Meat price range (USD per kilogramme) by country and preparation method. Price ranges are provided for dry meat (blue bars), fresh meat (green bars), and fishmeal (FM) (yellow bar). Unspecified meat (grey bars) denotes dry or fresh mobulid meat. Where price ranges were not provided by respondents, singular prices are used

of physical retailers offering gill plates ("Peng Yu Sai") declined from 2013 to 2023 in Guangzhou (60 – 41) and Hong Kong SAR (110 – 95), the number of online retailers increased significantly over the same timeframe (2014 – 2023), from 56 to 94 online retailers. In combination, the number of shops increased threefold from 41 (physical retailers) to 135 (physical and online retailers) between 2011 and 2023, during which time all mobulids were listed in CITES Appendix II.

Further analysis was conducted to compare prices across physical retailers of mobulid gill plates according to available species groups (manta ray, sicklefin devil ray, spinetail devil ray/other). As shown in Table 4, gill plates identified as manta rays sold at higher prices on average than sicklefin devil rays and spinetail devil rays/other. Accounting for inflation and adjusting prices relative to the base year, it was observed that mobulid gill plate prices increased over time (2011 – 2023) across all species groups, with averages rising from 204 to 267.20 USD/kg in the Guangzhou market.

Priority countries for mobulid conservation

Countries were examined to assess their level of impact upon mobulid populations and distinguish their level of priority for conservation, management, and research efforts. The analysis resulted in a list of "high", "moderate", and "low" priority levels according to activities negatively impacting mobulid populations (Fig. 9**; Online Resource 8 and 9**). Out

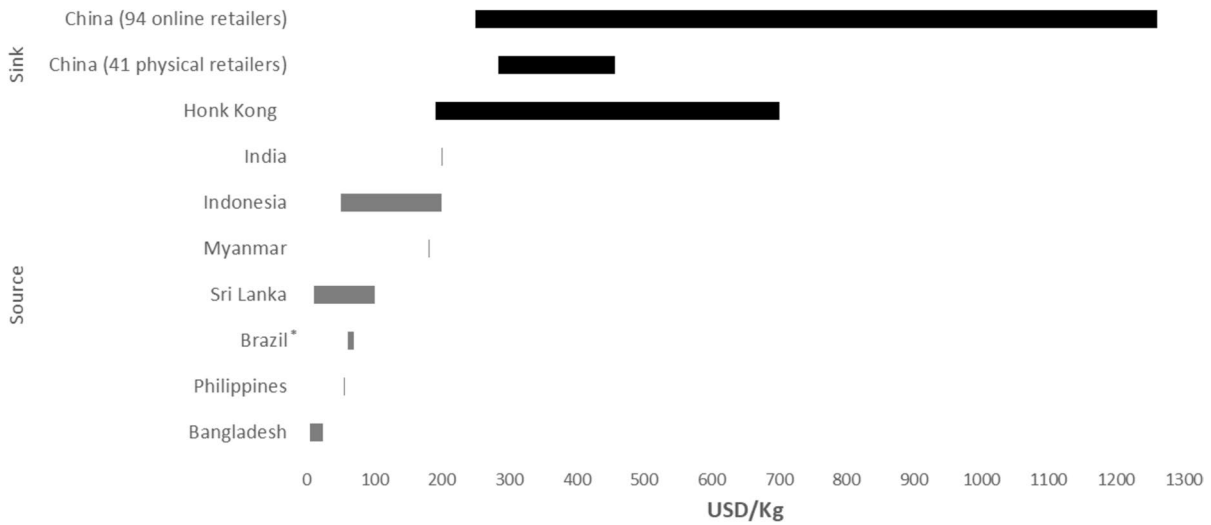


Fig. 7 Gill plate price range (fresh and dried combined) (USD/kg) for source (grey bars) and destination/consumer countries (black bars). Data sources for Hong Kong SAR retailers are from a 2016 – 2022 field survey, mainland China physical retailers (2022 field survey), and mainland China online retailers (2024 survey). *Brazil gill plate price range information from "have heard of it" source. Where price ranges were not provided by respondents, singular prices are used

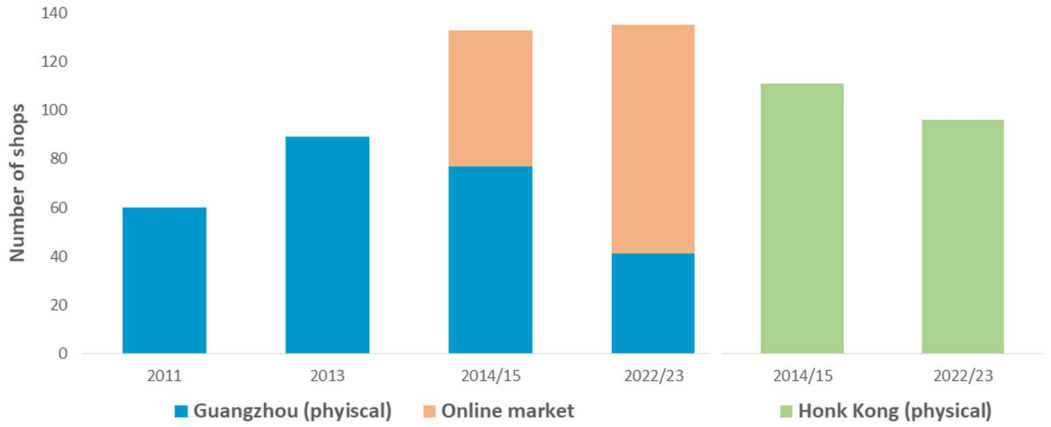


Fig. 8 Gill plate retailers. Blue bars indicate survey results from the Guangzhou market based on field survey and O'Malley et al. (2017). Orange indicates the number of online retailers on five major Chinese platforms. Green bars based on Hong Kong SAR physical retailer surveys

of the 75 countries analyzed (with Mexico divided into two regions, Pacific and Caribbean coast, totalling 76), 14 were identified as high-priority (sum score > 6.4 across rescaled factors) and ranked in descending order, included Myanmar, Sri Lanka, Bangladesh, India, Indonesia, Senegal, Republic of Congo, United Arab Emirates, Peru, China, Philippines, Ghana, Thailand, and Gabon. The high-priority group exhibited the following characteristics: moderate to high level of mobulid landings (Laglbauer et al. in press) as targeted or retained bycatch (excluding United Arab Emirates and Thailand), involvement in the gill plate trade (excluding Peru), and involvement in meat consumption and/or meat trade. Except for the United Arab Emirates, Thailand, Philippines, and Gabon, national protection in these countries do not

Table 4 Gill plate price per species group (USD/kg) for Hong Kong SAR, Guangzhou (*based on O'Malley et al. 2017) and Chinese online retailers. Accumulative inflation was used to adjust prices from the base year (source: International Monetary Fund, International Financial Statistics and data files)

	Physical retailers					Online retailers
	Hong Kong SAR	Guangzhou market				China
	2016 – 2021	2011*	2013*	2015*	2023	2023
Manta ray	$404.93	$277.00	$325.00	$329.00	$456.00	
Sicklefin devil ray	$313.67	$194.00	$256.00	$286.00	$379.00	
Spinetail devil ray/other	$251.44	$141.00	$193.00	$189.00	$283.00	
Average	$323.35	$204.00	$258.00	$268.00	$372.67	$511.81
Acc. inflation (%)		0	10.80%	14%	28.30%	28.30%
Adjusted price		$204.00	$230.14	$230.48	$267.20	$366.97

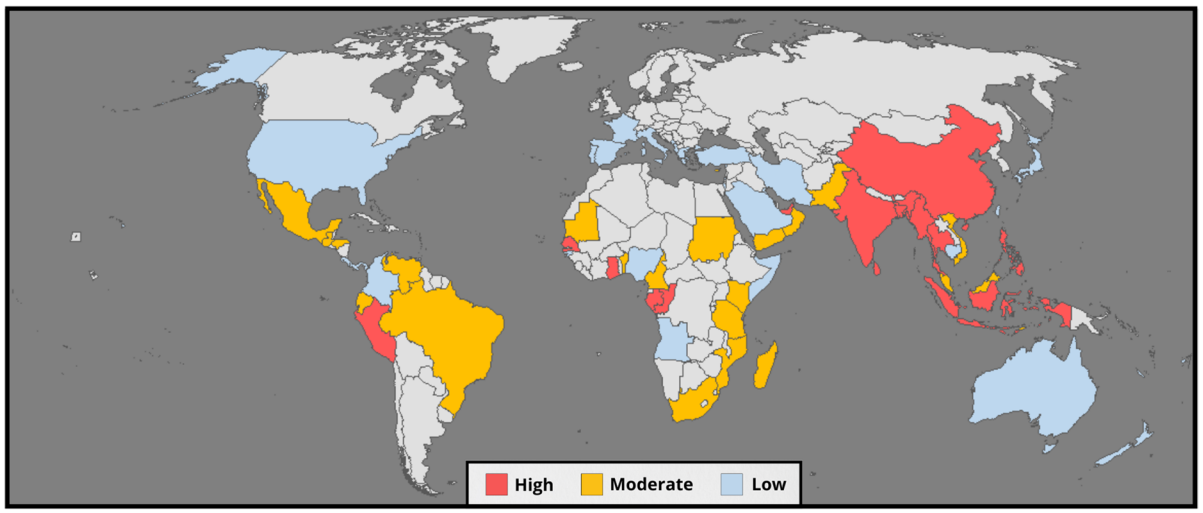


Fig. 9 Priority country map. Survey countries categorised into high, moderate, and low priority based on their known relative contribution to mobulid population threats. Scores are based on a composite quantitative and qualitative assessment of involvement in mobulid fisheries, consumption, or trade

cover all species of mobulids. Myanmar, Indonesia, Thailand, and China are not Party to CMS; however, all countries in this category are Party to CITES.

The countries categorised as "moderate" priority (sum score rescaled = 3.7 – 6.3) included 26 countries (Fig. 9**, Online Resource 8 and 9**). The top fiftieth percentile of the category in descending order included Yemen, Oman, Madagascar, Hong Kong SAR, Vietnam, Mauritania, Guatemala, Benin, Mexico (Pacific), Tanzania, Ecuador, Cameroon, Malaysia, and Pakistan. These countries exhibit the following characteristics: involved in either targeting and/or retaining and discarding mobulids as bycatch, with varying levels of mobulid landings categorised as high, medium, or low (Laglbauer et al. in press). Singapore and Hong Kong SAR, however, do not land mobulids. Chagos Archipelago, Hong Kong SAR, and South Africa are participants in the gill plate trade, while Ecuador, Madagascar, Mauritania, Yemen, Oman, and Benin trade mobulid meat.

In the categorisation of countries as "low" priority ($n = 36$) (with a sum score rescaled of < 3.7). The top fiftieth percentile of the category in descending order included Greece, Mexico (Caribbean), Taiwan, Saudi Arabia, Angola, Cyprus (de facto Northen Cyprus), Kenia, Iran, Turkey, French Polynesia, USA, Cyprus,

Colombia, Comoros and Mayotte, Palau, Panama, Fiji, and New Zealand. These countries were characterised by medium–low quantity of mobulid landings, with the exception of Mexico (Caribbean) and USA which were found to have high mobulid bycatch, either retained and landed or discarded. Seven countries from the low-priority group had national protection measures covering all mobulid species (Mexico Caribbean, Iran, Costa Rica, Australia, Fiji, Maldives, and Israel). None of the countries in this group participated in gill plate consumption, while countries consumed mobulid meat: Iran, Fiji, Cyprus, Greece, and French Polynesia. Although mobulid meat is consumed along the Pacific coast of Mexico, this practice is not confirmed on the Caribbean coast. Furthermore, none of these countries engaged in the trade of mobulid meat or gill plates, with the exception of Somalia and Nigeria, which were involved in trading gill plates and mobulid meat, respectively.

Discussion

Despite some regulatory progress since mobulids were listed on CITES, our results show that the trade in both mobulid meat and gill plates continues at a global scale, albeit better-documented. The findings of the study underscore persistent challenges in managing fisheries that capture and/or land mobulids, gathering species-specific data on catches and trade volumes, reducing local and international consumption of mobulid derivative products, and regulating the trade, at national and international scales.

Mobulids are being fished, consumed, and/or traded in countries where they are protected under national regulations (21 countries), as well as through the Barcelona (five countries) and Cartagena (one country) UNEP Regional Seas Conventions and Action Plans (**Online Resource 7**). Additionally, mobulids are listed under Appendix I and II of the CMS and Appendix II of the CITES (**Online Resource 1**). Despite these designations, all the countries landing mobulids are Party to CITES (43), and most also to CMS (33). Regarding fisheries conservation and management measures, four RFMOs have prohibited the retention of mobulids (Cronin et al. 2023a; Okes and Sant 2022). However, mobulas are still being landed in 28 of these RFMOs member states.

To contextualise the ongoing challenges of mobulid conservation, we (1) examine extent and variations in trade of mobulid meat and gill plates globally, (2) report on the apparent gap in FAO Total Production and CITES Trade Databases, and (3) provide recommendations on priority countries with urgent mobulid conservation needs and other policy actions.

Global mobulid meat and gill plate consumption and trade

Findings highlight that both gill plate and meat consumption drive fisheries and trade, with fisheries in Latin American countries primarily driven by meat consumption, while African and Asian countries are motivated by a combination of meat and gill plate demand. Relative to gill plate volume data (Heinrichs et al. 2011; O'Malley et al. 2017; Hau and Shea 2023, CITES Trade Database), accurate volume data for meat consumption and trade is scarce due to lack of reporting and/or mislabelling. However, our findings indicate that supply for the domestic meat market and international trade significantly contribute to fishing mortality. This assessment is based on the number of countries landing mobulids ($n = 43$), consuming their meat ($n = 35$), and participating in the international meat market ($n = 12$), compared to the countries extracting or using gill plates ($n = 14$) and engaging in international gill plate trade ($n = 15$) (**Online Resource 7**). Furthermore, population declines have been reported in areas where mobulid fisheries or bycatch retention are driven solely by meat consumption (i.e., Eastern Tropical Pacific, White et al. 2015; Griffiths and Lezama-Ochoa 2021). Our results indicate that mobulid meat consumption is not merely a by-product of captures for gill plates, but a distinct product with long-established markets. This market is driven by both domestic and international demand, albeit with local consumption likely constituting a substantial proportion of the demand. On the other hand, the supply of gill plates for international trade remains a key driver for mobulid fisheries in Asian countries, with evidence of expansion into some African and Middle Eastern countries. While some countries (e.g., Peru, Ecuador, Madagascar, Mauritania, Yemen, Oman, Benin, and Nigeria) are not trading gill plate trade, they are actively involved in international meat trade, which is also a significant driver of mobulid population depletions. Considering the scale

of mobulid meat consumption, the landings sites and trade routes are likely far more extensive than reported here.

Fisheries, consumption, and trade of mobulids in countries with national protections continue due to inadequate surveillance by governmental agencies at landing ports and the decentralisation of landing sites across beaches, islands, and at unofficial locations. This makes it extremely challenging to monitor and control landings along extensive coastlines, (e.g., Brazil, Bucair et al. 2024). Additionally, the mislabelling or use of umbrella terms to sell mobulid meat, especially in the dried form, complicates the traceability of these products in domestic and international markets (e.g., Mexico, Ossiander et al. in press). In fisheries governed by RFMOs, the absence of observers, or the presence of observers with limited taxonomic knowledge, combined with inadequate enforcement of bycatch mitigation measures and significant data collection and transparency gaps (Cronin et al. 2023a), prevents rigorous external science for these species and facilitates the capture and underreporting of mobulids (e.g., Western Indian Ocean, Croll et al. 2016). Even illegal mobulid fisheries operating inside Marine Protected Areas (MPAs) can be overlooked due to limited taxonomic knowledge among enforcement personnel, hindering accurate reporting of illegal catches (e.g., Chagos, Harris and Stevens 2024). Dedicated processing sites identified in this study for mobulid products can provide a focused-based approach for monitoring and enforcement. However, the findings also emphasise the diversity of processing methods for mobulid products, ranging from dedicated factories to traditional or household-based techniques. This diversity, as found in small-scale fisheries methods more generally (Tahiluddin and Kadak 2022; Abiodun and John 2017), may complicate efforts to record and regulate mobulid landings and trade, ultimately reflecting the complexities of enforcing national and international agreements within diverse socio-economic contexts.

While further research could confirm the extent of the domestic and international trade in each country, there is clearly widespread inadequate enforcement or awareness of domestic and international regulations. Indeed, it seems likely that mobulid meat and gill plates are being transported and concealed (intentionally or unwittingly) with other products, such as rays, sharks, or other dried fish, likely taking the same routes as shark fin (as reported in western Africa, i.e., Benin and Ghana). The limitations in monitoring local consumption highlights the need for more robust traceability mechanisms at the national level to ensure compliance with regulations.

Key gill plate source countries are primarily concentrated in Africa, the Middle East, and South-, Southeast-, and East-Asia, with Myanmar and Thailand participating as important entrepôts for gill plate trading. Focusing CITES enforcement in entrepôt countries can prevent network (exporters, traders, and importers) unification (Niedermüller et al. 2021). Of particular note are the African and Middle Eastern nations, such as UAE, Somalia, Ghana, South Africa, and Senegal, which have emerged as traders that were previously overlooked. Historically, the gill plate trade has been concentrated, or primarily documented in the Indian Ocean (O'Malley et al. 2017; Fernando and Stewart 2021), where populations are closest to the primary market demand. This has led to significant declines in mobulid populations in countries like South Africa, Mozambique, Sri Lanka, and Indonesia (Rhoner et al. 2013; Lewis et al. 2015; Venables 2020; Fernando and Stewart 2021; Carpenter et al. 2023). The expansion of the gill plate trade to new geographical regions, specifically western Africa, may reflect mobulid populations becoming increasingly overexploited, driving traders to seek out more distant sources. International trade continues due to inadequate surveillance by customs at major ports, airports, and terrestrial border controls, which overlook much of the illegal trade, particularly for gill plates, due to lack of personnel or expertise to identify these products (e.g., in 2020, a large shipment of mobulid gill plates without CITES documentation, valued at an estimated USD $116,000, was seized in Hong Kong SAR, The Manta Trust 2020).

Shortfall in FAO and CITES reporting

Mobulids have historically been caught in a wide range of fisheries and countries (Croll et al. 2016; Laglbauer et al. in press), with domestic and international trade previously recorded (Heinrichs et al. 2011; O'Malley et al. 2017; Rojas et al. in press). However, this study highlights the extent of underreporting, or complete lack of reporting, of mobulids at the species-level (under the category nominal mantas, devil rays, and nei) to the FAO, with only nine out

of 43 fishing countries providing data on captures. Among these countries, over half are regularly targeting or retaining mobulids, yet the majority of these catches are not reported to the FAO. For instance, Myanmar emerged during this study as the top priority country with urgent mobulid conservation needs due to its significant role in the meat and gill plate trade, price ranges, consumption patterns, and landing data. Despite this, Myanmar has not reported any chondrichthyan species captures to the FAO. This discrepancy underscores the pervasive issue of national underreporting in FAO Total Production Data (Cashion et al. 2019; Fowler et al. 2021; Okes and Sant 2022), raising concerns on the accuracy and transparency of official national fisheries data. Furthermore, this has implications for assessing the effectiveness of CMS and CITES because the global declines in landings reported by the FAO, which coincide with the implementation of protective measures for mobulids (CITES 2016; CMS 2015) (**Online Resource 5**), are most likely a result of a cessation in reporting by these countries rather than actual compliance (Okes and Sant 2022).

Although CITES has a high potential for compliance compared to other multilateral environmental agreements, this study revealed that international trade for mobulid meat and gill plates involves at least 20 countries, yet only five of these countries reported mobulid trade to CITES (CITES Trade dataset 2017 – 2021). Furthermore, CITES trade data presented records of mobulid fins traded by Sri Lanka, Yemen, and Oman; however, fins were not mentioned during any of the country-focused online surveys ($n = 109$) and interviews ($n = 21$) conducted to experts during this study. In the past, it has been highlighted that the CITES Database does not accurately reflect the trade in species and their derivatives, especially elasmobranchs (Okes and Sant 2022). Our findings support this, as we identified significantly more international trade routes, mobulid product quantities, and countries than those detailed in the CITES database.

Additionally, during the study period, no commercial trade reports to CITES indicated that specimens were taken from the marine environment outside the jurisdiction of any state (i.e., international waters). However, mobulid fisheries beyond national jurisdiction waters have been described in CITES reporting countries, such as Sri Lanka (Fernando and Stewart 2021). This country ranked second as the top priority for urgent mobulid conservation needs and is the only country that has entered the CITES Review of Significant Trade (RST) process for mobulids. The RST process can lead to wildlife trade suspensions from Parties found not to be complying (Articles IV 2(a) and IV 3, Resolution Conf. 12.8 (Rev. CoP18); CITES 2019). However, only a very small number of species-case studies from countries can be reviewed under this process, and no elasmobranchs were included until 2023, when *Mobula* species from Sri Lanka were identified as endangered, traded in high volumes, with sharp increases in reported trade, and selected as an RST case study (CITES Secretariat and UNEP-WCMC 2023).

Overall, these discrepancies indicate that the current reporting mechanisms may not reflect the full extent of mobulid captures and trade, underscoring the need for improved monitoring and reporting practices to ensure transparency and accountability in fisheries management, especially for CMS or CITES enforcement, and strengthening evidence-based decision-making.

Stronger international regulations, such as a CITES Appendix I listing, could significantly curb the export of mobulid products to high-demand markets, if bolstered by the implementation of CMS Appendices in signatory countries and stricter national protection enforcement. This may be the case for several high priority countries that are signatories of CMS and with national mobulid protections already in place (e.g., Bangladesh exporting meat and gill plates to five countries, or United Arab Emirates importing meat from Oman and exporting gill plates to Hong Kong SAR).

Mobulid meat and gill plate market

Although mobulid meat is consumed in more countries than gill plates, the economic value of individual gill plates is much higher per kilogramme. This is driven by a high demand in key consumer markets including mainland China, Hong Kong SAR, and Singapore (Heinrichs et al. 2011; O'Malley et al. 2017; Zhou et al. 2024). Along the gill plate trade value chain, the price per kilogramme increases significantly from source to consumer markets. For example, across source countries, gill plates on average sell for $99 USD/kg, while consumer countries sell gill plates on average at $523 USD/kg, showing a percentage increase of over 400%

on average across the value chain. The meat trade value chain is more fragmented, and there is a lack of data on destination countries, which is required for a similarly detailed comparison to be made. However, we have identified prices of fresh meat at landing sites ranging from 0.24 to 8 USD/kg for fresh and 0.45 to 10 USD/kg for dried meat (Fig. 6).

Across different countries that sell mobulid ray meat, there are large variations in price ranges (Fig. 6). Typically, dried meat fetches a higher selling price because processing improves transportability and preservation. Additionally, fresh meat from developing countries in tropical regions may be unable to enter international trade due to a lack of refrigeration transportation, further increasing the value of dried meat. Bangladesh, Myanmar, and Peru stand out for their comparatively high prices in dried mobulid meat, as well as their prominent participation in the meat trade. This suggests a potential link between countries participating in trade activities and meat prices, indicating that international demand for mobulid meat may drive an increase in prices, even in regions where local economic conditions might not typically support such high price levels for domestic consumption. This can further incentivise countries to get involved or remain in the meat trade. Another driver of trade includes local traditions and beliefs that rely on mobulid meat, as seen in Bangladesh for fertility purposes and cancer cures, or in Peru, where local cuisine drives the use in particular dishes. Furthermore, mobulid meat can enter domestic or international markets under generic names (e.g., manta raya meat in Mexico) due to the difficulty of identifying the meat at the genus level (Ossiander et al. in press).

Our findings show that since the listing of mobulids under CITES Appendix II, trade has not reduced; indeed, trade appears to now exceed levels prior to the CITES listings. As species become rarer and increasingly protected, demand and price for the products derived from them tend to increase (Harrison et al. 2016; Kuo et al. 2018; Siriwat and Nijman 2020). Gill plate prices have also been increasing over time, across all mobulid species groups sampled, based on values corrected for inflation. Kuo et al. (2018) found similar price trends with dried seahorse trade in Thailand. Although official data indicated a decline in export volume of dried seahorses following the implementation of the CITES listing in 2005, they found that seahorse prices had risen, estimating the dried seahorse market at 26.5 million USD, versus the declared 5.5 million USD.

Recent studies have shown population declines of over 80% and up to 99% in Indian Ocean mobulid populations (Rhoner et al. 2013; Lewis et al. 2015; Venables 2020; Fernando and Stewart 2021; Carpenter et al. 2023; Venables et al. 2024). It would therefore seem evident that as mobulid populations decline closest to the market demand centre, and protections are heightened, access to and availability of the product incur additional costs, further increasing the retail price for gill plates. Moreover, enhanced protection measures often push the trade of these species to underground smuggling routes (e.g., the Myanmar and India mobulid trade, as documented in the 2020 film "Peng Yu Sai"). Once openly available in retail shops, these products are now increasingly sold online, where it becomes more challenging for authorities to trace and apprehend illegal traders. There is plenty of evidence of threatened species being sold on social media websites and e-commerce platforms (Soriano-Redondo et al. 2023). Indeed, the gill plate trade has increasingly moved from physical markets (e.g., Guangzhou, China) to online selling platforms in recent years.

To address concerns in the demand driven gill plate trade, focus should be placed on consumer characteristics behaviour, which may have a preference for protected and large species, such as oceanic manta rays (Zhou et al. 2024); education; traceability; and strengthened law enforcement. Regulating and enforcing online trade is crucial for effective compliance and may require a suite of cybercrime tools, such as implementing digital monitoring and surveillance systems for threatened species, genetic traceability toolkits, collaborating with and tracking online selling platforms (such as *Taobao, Jingdong, Pinduoduo, Douyin,* and *Kuaishou*), and launch targeted awareness campaigns for online consumers.

Priority countries with urgent mobulid conservation needs

In this study, we quantitatively and qualitatively categorised countries (involved in mobulid fisheries, consumption, or trade) into high, moderate, or low priority countries based on their relative contribution to mobulid population impact (Fig. 9**, Online Resource 8 and 9**). This categorisation aims to

facilitate decision-making on prioritising conservation, management, and research efforts, ensuring that resources are directed towards the regions where they are most needed and can have the greatest impact on preserving and recovering mobulid populations. The high-priority countries significantly impact mobulid populations through targeted fishing, bycatch retention, and/or acting as major exporters of gill plates. While Peru is the one country from the high-priority list that may not currently be involved in the gill plate trade, its high mobulid landings, and involvement in the meat trade, and the existing trade routes for shark-derived products with Asia (Shea and Slee 2024), suggest a high potential risk for entering the gill plate trade, which warrants monitoring. Additionally, countries where mobulids are landed at low rates (i.e., the United Arab Emirates and Thailand) were identified as high-priority due to their roles as transit hubs in the trade, connecting source and destination countries. In these cases, strengthening enforcement of existing regulations—particularly as mobulids are protected under national legislation in both countries—should be prioritised. Addressing the challenges of reducing mobulid trade and consumption requires a multifaceted approach, including stronger measures for domestic implementation of CMS and RFMO recommendations, and encouraging countries to adopt and enforce conservation measures already established by these regulatory bodies. This could include implementing a zero quota for fisheries, helping in the recovery of some overexploited populations (e.g., Sri Lanka, Fernando and Stewart 2021), or enacting and enforcing bycatch mitigation strategies such as spatial–temporal closures of bycatch hotspots, deploying helicopters or drones to avoid setting nets when mobulids are spotted, and using modified brailers to safely release these animals (Cronin et al. 2023b). Other conservation measures could involve extending RFMO resolutions to new regions to ensure broader protection and encouraging priority countries with urgent mobulid conservation needs to become CMS signatories (e.g., Myanmar or Indonesia).

Among the high-priority countries, Thailand appears to play a crucial role in the trade as a major re-export hub, channelling gill plates to Hong Kong SAR according to seizure data (Hau and Shea 2023), although it apparently does not target or retain bycatch of mobulids (i.e., they are discarded). As highlighted in the literature, mainland China and Hong Kong SAR are key importers of gill plates driven by demand for local consumption (O'Malley et al. 2017; Hau and Shea 2023; Zhou et al. 2024). Other countries importing included Singapore, Thailand, Myanmar, and potentially Republic of Congo and Senegal through shark fin routes. Myanmar, which ranked as the highest priority country, has a land border with mainland China offering an accessible corridor for overland trade of gill plates, with additional transportation occurring by air, while the Myanmar meat trade to Thailand takes place in the southern region, predominantly by boat. This indicates a direct route for movement of mobulid products, facilitating continuation or participation in trade, and increasing pressure on mobulid populations. The apparent lack of border control and enforcement underscores the urgent need to strengthen measures to combat trafficking of mobulid products across borders, such as improving surveillance and enforcement at customs, major ports, airports, and terrestrial borders to prevent illegal trade. This may include capacity building, training and cooperative interventions with police officials, customs, CITES and national authorities to identify products of mobulids species, and implement existing regulations such as CITES or national bans. This includes addressing the mislabelling of mobulid products with the creation and implementation of methods for fast and on-site detection of CITES-listed mobulid species with mobulid products (But et al. 2020). Additionally, collaborating with key industries—such as airlines, shipping companies, and financial institutions—will further reinforce these efforts by monitoring and preventing the illegal transportation of wildlife products.

Although the low-priority countries ranked lower, this could be the result of the lack of data for these countries. For example, Somalia is involved in the gill plate trade as an exporter to multiple destinations, and Nigeria (one of the world's ten largest fishing nations) is a possible exporter and importer of mobulid meat based on shark fin trade routes. However, the lack of comprehensive data on the low-priority countries might pose a greater impact to mobulid populations than currently recognised in this study. With more detailed data to inform the analysis, countries such as Somalia and Nigeria could potentially move into higher threat categories, highlighting the need for

better data collection, monitoring, and research in these countries to accurately assess the impact on mobulid ray populations.

Limitations of the study

The nature of uncovering illegal or unregulated activities, from fisheries data to trade route assessments, is compounded by a lack of transparency and a reliance on sometimes anecdotal information, making it difficult to obtain a comprehensive understanding of the threats to these species that is not under representative. In this study, we utilised expert elicitation through online surveys and interviews. While this approach yields valuable insights, it has limitations, particularly the potential bias that may result in disproportionate data capture from regions with stronger research infrastructure or be limited in their information on trends and seasonality. Additionally, the lack of responses from certain countries could lead to an underrepresentation of threats to mobulid populations, particularly in regions with limited research infrastructure (i.e., Western Africa region). This may result in the underreporting of areas that are significantly involved in the global trade of mobulids (e.g., Singapore and Malaysia). Without comprehensive case studies, some countries' roles in the mobulid trade may be underrepresented or overlooked. Future research should prioritise in-depth studies in these areas to gain a more accurate understanding of global mobulid trade dynamics.

Centralised datasets like FAO and CITES offer valuable insights; however, they often fail to capture the full scope of wildlife trafficking. These datasets tend to disproportionately represent certain species, regions, and sectors, influenced by the resources and enforcement capabilities available in specific countries (Keskin et al. 2023). As a result, they often overlook areas where trade remains unreported or where surveillance is limited.

However, by using a mixed-method approach, combining expert elicitation along with analysis of the FAO Total Production and CITES Trade Databases, and online trade and physical store surveys in China and Hong Kong SAR, we aimed to fill existing data gaps and address potential biases inherent in each data source. This integrated methodology enhances the robustness of our findings and provides a clearer picture of the dynamics surrounding mobulid ray trafficking.

Conclusions

Research has demonstrated that current mobulid fisheries mortality rates, encompassing both targeted catch and bycatch, are unsustainable, and have led to widespread population declines. Despite CITES Appendix II and CMS Appendix I listings and other protective measures for mobulids, including through RFMOs and RSCAPs, these regulations, some of which have been in place for over a decade, are often inadequately implemented and insufficient to reduce mortality, likely due to continued demand for meat and gill plates.

It is evident that both gill plate and meat consumption drive fisheries and trade. The consumption of mobulid meat is widespread at local and international scale, while gill plate demand has not reduced at major Asian trade hubs. Indeed, the trade in gill plates appears to be growing and migrating to online platforms, incentivised by the high economic value for demand-country traders. Monitoring and reporting of catch, landings and trade data, and enforcement of regulations remain weak, due to inadequate capacity, further contributing to the ongoing decline of mobulid species. Since 2017, when international trade in all mobulid species was regulated, each of the nine manta and devil rays species have either moved up the threat status level on the IUCN Red List of Threatened Species, or remained in a threatened category (IUCN 2024). Although improved capacity-building for fisheries management, enforcement, and the filling of data gaps are crucial actions that should be taken, especially in high-priority countries, these efforts alone will not be enough to halt continued population declines. Priority measures include the protection of mobulids in all high priority countries and the implementation of bycatch mitigation measures to reduce fisheries mortality. Furthermore, stronger regulations and enforcement measures, including a prohibition on commercial trade of mobulid products through a CITES Appendix I listing would be beneficial. Supported by the implementation of CMS Appendix I listings and prohibitions in RFMOs, there might still be a chance to conserve mobulid species.

Acknowledgements The authors thank all the experts who participated in the online surveys and in-depth interviews. Without their valuable knowledge, this research would not have been possible. The authors also thank Roy Yang and Yiyi Liang for conducting the retail gill plate surveys.

Author contribution Conceptualization: Marta D. Palacios, Laura Weiand, Betty Laglbauer, Melissa R. Cronin, Guy M. W. Stevens; methodology: Marta D. Palacios, Laura Weiand, Betty Laglbauer, Melissa R. Cronin, Guy M. W. Stevens; formal analysis and investigation: Marta D. Palacios, Laura Weiand, Betty Laglbauer, Godefroy De Bruyne, Stanley K. H. Shea, Daniel Fernando, Paul Hilton, Rima W. Jabado, Thanda Ko Gyi, Yi-Li Gao, Sarah Fowler, Melissa R. Cronin, Guy M. W. Stevens; writing—original draft preparation: Marta D. Palacios, Laura Weiand, Betty Laglbauer; writing—review and editing: Marta D. Palacios, Laura Weiand, Betty Laglbauer, Godefroy De Bruyne, Stanley K. H. Shea, Daniel Fernando, Paul Hilton, Rima W. Jabado, Thanda Ko Gyi, Yi-Li Gao, Sarah Fowler, Melissa R. Cronin, Guy M. W. Stevens; funding acquisition: Betty Laglbauer, Guy M. W. Stevens; supervision: Guy M. W. Stevens.

Funding The Shark Conservation Fund, the Wildlife Conservation Society, The Waterloo Foundation, the Berman Foundation, and The Manta Trust funded the research and publication of this paper.

Data availability Data is available upon request from fisheriespolicy@mantatrust.org.

Declarations

Ethical approval IRB number (HS-FY2023-179) by the UC Santa Cruz Office of Research Compliance Administration (ORCA).

Conflict of interest Dr. Guy Stevens is a Guest Editor on this special issue but was not involved in the peer review of this article and had no access to information regarding its peer review.

References

Abiodun JA, John PP (2017) Biodiversity and abundance of fish and some processing methods in Lower Niger River Idah, Kogi State, Nigeria. Niger J Fish Aquac 5:20–25. https://www.nijfaq.com.ng/index.php/ojs-nijfaq/article/view/86

Abudaya M, Ulman A, Salah J et al (2018) Speak of the devil ray (*Mobula mobular)* fishery in Gaza. Rev Fish Biol Fisheries 28:229–239. https://doi.org/10.1007/s11160-017-9491-0

Alfaro-Cordova E, Del Solar A, Alfaro-Shigueto J et al (2017) Captures of manta and devil rays by small-scale gillnet fisheries in northern Peru. Fish Res 195:28–36. https://doi.org/10.1016/J.FISHRES.2017.06.012

Bancroft EN (1831) On several fishes of Jamaica. Proc Zool Soc Lond 1831:134

Baró-Camarasa I, Marmolejo-Rodríguez AJ, Cobelo-García A, Palacios MD et al (2021) Essential and non-essential trace element concentrations in muscle and liver of a pregnant Munk's pygmy devil ray (*Mobula munkiana*) and its embryo. Environ Sci Pollut Res 29:61623–61629. https://doi.org/10.1007/s11356-021-17390-w

Bonnaterre PJ (1788) Tableau encyclopédique et méthodique des trois règnes de la nature, ichtyologie. Panckoucke

Bordbar L, Strogyloudi E, Hatzianestis I et al (2023) First evidence of trace metals and persistent organic contaminants from an endangered marine species, *Mobula mobular* (Bonattere, 1788) caught in Hellenic waters (Saronikos Gulf). Mar Biol Res 19:399–406. https://doi.org/10.1080/17451000.2023.2256343

Bucair N, Mendonça S, Santos PRS et al (2024) Occurrence, distribution and threats to mobulid rays in Brazil: a review and updated database. Aquat Conserv 34:6. https://doi.org/10.1002/aqc.4203

But GWC, Wu HY, Shao KT et al (2020) Rapid detection of CITES-listed shark fin species by loop-mediated isothermal amplification assay with potential for field use. Sci Rep 10:4455. https://doi.org/10.1038/s41598-020-61150-8

Cantor TE (1849) Catalogue of Malayan fishes. J Asiat Soc Bengal 18:983–1443.

Carpenter M, Parker D, Dicken ML, Griffiths CL (2023) Multi-decade catches of manta rays (*Mobula alfredi, M. birostris*) from South Africa reveal significant decline. Front Mar Sci 10:1128819. https://doi.org/10.3389/FMARS.2023.1128819

Cashion MS, Bailly N, Pauly D (2019) Official catch data underrepresent shark and ray taxa caught in Mediterranean and Black Sea fisheries. Mar Policy 105:1–9

Chakrabartty SN (2017) Composite index: methods and properties. J Appl Quant Methods 12(2):25–33

CITES Secretariat and UNEP-WCMC (2023) Selection of species for inclusion in the Review of Significant Trade following CoP19. Summary output: Fauna. UNEP-WCMC, Cambridge.

CITES (2016) Convention on International Trade in Endangered Species of Wild Fauna and Flora. Consideration of proposal for amendment of appendices I and II. https://cites.org/eng/cop/17/prop/index.php. Accessed May 2024

CITES (2019) Review of significant trade in specimens of Appendix II species. https://cites.org/sites/default/files/document/E-Res-12-08-R18.pdf. Accessed May 2024.

CMS (2015) Convention on the conservation of appendix I migratory species of wild animals (CMS) effective appendices I and II of the convention on the conservation of migratory species of wild animals (CMS). https://www.cms.int/en/species/appendix-i-ii-cms. Accessed May 2024

Croll DA, Dewar H, Dulvy NK et al (2016) Vulnerabilities and fisheries impacts: the uncertain future of manta and devil rays. Aquat Conserv 26:562–575. https://doi.org/10.1002/AQC.2591

Cronin MR, Amaral JE, Jackson AM et al (2023a) Policy and transparency gaps for oceanic shark and rays in high seas tuna fisheries. Fish Fish 24:56–70. https://doi.org/10.1111/FAF.12710

Cronin MR, Croll DA, Hall MA et al (2023b) Harnessing stakeholder knowledge for the collaborative development of Mobulid bycatch mitigation strategies in tuna fisheries. ICES J Mar Sci 80:620–634

D'Costa NG, Nicholson-Jack A, Stevens Guy MW (in prep) A review on the size-weight ratio of mobulids globally.

Dulvy NK, Pacoureau N, Rigby CL et al (2021) Overfishing drives over one-third of all sharks and rays toward a global extinction crisis. Curr Biol 31:4773-4787.e8. https://doi.org/10.1016/J.CUB.2021.08.062

Essumang DK (2009) Analysis and human health risk assessment of arsenic, cadmium, and Mercury in *Manta birostris* (Manta Ray) caught along the Ghanaian coastline. Hum Ecol Risk Assess 15:985–998. https://doi.org/10.1080/10807030903153451

FAO. (2023) Fishery and aquaculture statistics. global capture production 1950–2021 (FishStatJ). In: FAO Fisheries and Aquaculture Division [online]. Rome. Updated 2023. www.fao.org/fishery/en/statistics/software/fishstatj. Accessed May 2024

Fernando D, Stewart JD (2021) High bycatch rates of manta and devil rays in the "small-scale" artisanal fisheries of Sri Lanka. PeerJ 9:e11994. https://doi.org/10.7717/PEERJ.11994

Fowler S, Bräutigam A, Okes N, Sant G (2021) Conservation, fisheries, trade and management status of CITES-listed sharks. Federal Agency for Nature Conservation (BfN), Germany. BfN-Skripten 607. https://bfn.bsz-bw.de/frontdoor/deliver/index/docId/7/file/Skript607.pdf

Garibaldi L (2012) The FAO global capture production database: a six-decade effort to catch the trend. Mar Policy 36(3):760–768

Griffiths SP, Lezama-Ochoa N (2021) A 40-year chronology of the vulnerability of spinetail devil ray (*Mobula mobular*) to eastern Pacific tuna fisheries and options for future conservation and management. Aquat Conserv 31:2910–2925. https://doi.org/10.1002/aqc.3667

Haque AB, Cavanagh RD, Spaet JLY (2022) Fishers' tales—impact of artisanal fisheries on threatened sharks and rays in the Bay of Bengal. Bangladesh Conserv Sci Pract 4:e12704. https://doi.org/10.1111/CSP2.12704

Harris JL, Stevens GM (2024) The illegal exploitation of threatened manta and devil rays in the Chagos Archipelago, one of the world's largest no-take MPAs. Mar Policy 163:106110

Harrison JR, Roberts DL, Hernandez-Castro J (2016) Assessing the extent and nature of wildlife trade on the dark web. Conserv Biol 30:900–904. https://doi.org/10.1111/COBI.12707

Hau L, Shea S (2023) Re-visit of mobula gill plates in the Hong Kong dried seafood market after CITES Appendix II listing. Bloom Association Hong Kong. https://www.bloomassociation.org/en/wp-content/uploads/2024/05/Re-visit-of-Mobula-gill-plates-in-the-Hong-Kong-dried-seafood-market-after-CITES-Appendix-II-listing_onlinerevised.pdf

Hau L, Ho K, Shea S (2016) Rapid survey of mobulid gill plate trade and retail patterns in Hong Kong and Guangzhou Market. https://bloomassociation.org/en/wp-content/uploads/2016/04/Rapid-survey-of-Mobulid-gill-plate-trade-and-retail-patterns-in-Hong-Kong-and-Guangzhou_Revised.pdf. Accessed May 2024

Heinrichs S, O'Malley M, Meds H, Hilton P (2011) The global threat to manta and *Mobula* rays. Shark Savers. https://wildaid.org/wp-content/uploads/2017/09/The-Global-Threat-to-Manta-and-Mobula-Rays-WEB.pdf

Hosegood J, Humble E, Ogden R et al (2020) Phylogenomics and species delimitation for effective conservation of manta and devil rays. Mol Ecol 29:4783–4796. https://doi.org/10.1111/MEC.15683

IUCN. (2024). IUCN Red List of Threatened Species. https://www.iucnredlist.org/. Accessed May 2024

Keskin BB, Griffin EC, Prell JO, Dilkina B, Ferber A, MacDonald J et al (2023) Quantitative investigation of wildlife trafficking supply chains: a review. Omega 115:102780. https://doi.org/10.1016/j.omega.2022.102780

Krefft G (1868) Deratoptera alfredi (Prince Alfred's ray). Illus Sydney News 5:1–16.

Kuo T-C, Laksanawimol P, Aylesworth L et al (2018) Changes in the trade of bycatch species corresponding to CITES regulations: the case of dried seahorse trade in Thailand. Biodivers Conserv 27. https://doi.org/10.1007/s10531-018-1610-2

Laglbauer et al. (in press) Global mobulid ray fisheries and policy review to inform conservation gaps.

Le Floch M, Roberts H, Tanna A, Fernando D (in prep) From a gill plate to a mobula ray: conversion ratios for monitoring and regulation.

Lewis SA, Setiasih N, Fahmi, Dharmadi D, O'Malley, MP, Campbell SJ, Yusuf M, Sianipar A B (2015) Assessing Indonesian manta and devil ray populations through historical landings and fishing community interviews. https://doi.org/10.7287/PEERJ.PREPRINTS.1334V1

Lezama-Ochoa N, Hall M, Román M, Vogel N (2019) Spatial and temporal distribution of mobulid ray species in the eastern Pacific Ocean ascertained from observer data from the tropical tuna purse-seine fishery. Environ Biol Fish 102:1–17. https://doi.org/10.1007/S10641-018-0832-1

Marshall AD, Bennett MB (2010) Reproductive ecology of the reef manta ray *Manta alfredi* in southern Mozambique. J Fish Biol 77:169–190. https://doi.org/10.1111/J.1095-8649.2010.02669.X

Müller J, Henle J (1841) Systematische Beschreibung der Plagiostomen. Verlag von Veit und Comp

Murray A, Garrud E, Ender I, Lee-Brooks K, Atkins R, Lynam R et al (2020) Protecting the million-dollar mantas; creating an evidence-based code of conduct for manta ray tourism interactions. J Ecot 19:132–147. https://doi.org/10.1080/14724049.2019.1659802

Niedermüller S, Ainsworth G, de Juan S, Garcia R, Ospina-Alvarez A, Pita P, Villasante S (2021) The shark and ray meat network: a deep dive into a global affair. WWF, Rome

Notarbartolo di Sciara G (1988) Natural history of the rays of the genus *Mobula* in the Gulf of California. Fish Bull 86:45–66

Notarbartolo di Sciara G, Fernando D, Adnet S et al (2017) Devil rays (Chondrichthyes: Mobula) of the Arabian Seas, with a redescription of *Mobula kuhlii* (Valenciennes in Müller and Henle, 1841). Aquat Conserv 27:197–218. https://doi.org/10.1002/AQC.2635

Notarbartolo di Sciara G, Adnet S, Bennett M et al (2019) Taxonomic status, biological notes, and conservation of the longhorned pygmy devil ray *Mobula eregoodoo* (Cantor, 1849). Aquat Conserv 30:104–122. https://doi.org/10.1002/AQC.3230

Okes N, Sant G (2022) Missing sharks: a country review of catch, trade and management recommendations for CITES-listed shark species. UK, TRAFFIC International, Cambridge

O'Malley MP, Townsend KA, Hilton P et al (2017) Characterization of the trade in manta and devil ray gill plates in China and South-east Asia through trader surveys. Aquat Conserv 27:394–413. https://doi.org/10.1002/AQC.2670

Ooi MSM, Townsend KA, Bennett MB et al (2015) Levels of arsenic, cadmium, lead and mercury in the branchial plate and muscle tissue of mobulid rays. Mar Pollut Bull 94:251–259. https://doi.org/10.1016/J.MARPOLBUL.2015.02.005

Ossiander I, Bernardi G, Palacios M, Croll D, Newton K, et al (in press) Composition and conservation status of rays sold in Baja California Sur, Mexico.

Pacoureau N, Rigby CL, Kyne PM et al (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

Pardo SA, Kindsvater HK, Cuevas-Zimbrón E et al (2016) Growth, productivity, and relative extinction risk of a data-sparse devil ray. Sci Rep 6:33745. https://doi.org/10.1038/SREP33745

Pauly D, Christensen V, Dalsgaard J et al (1998) Fishing down marine food webs. Science 279:860–863

Peng Yu Sai documentary (2020). Peng Yu Sai (TV Movie 2020)

Philippi RA (1892) Algunos peces de Chile. An Mus Nac Chile Seccion 1 Zool 3:1–17.

Queiroz N, Humphries NE, Couto A et al (2019) Global spatial risk assessment of sharks under the footprint of fisheries. Nature 572:461–466. https://doi.org/10.1038/S41586-019-1444-4

Rambahiniarison JM, Lamoste MJ, Rohner CA, Murray R, Snow S, Labaja J, Araujo G, Ponzo A (2018) Life history, growth, and reproductive biology of four mobulid species in the Bohol Sea. Philippines Front Mar Sci 5:269. https://doi.org/10.3389/fmars.2018.00269

Rohner CA, Pierce SJ, Marshall AD et al (2013) Trends in sightings and environmental influences on a coastal aggregation of manta rays and whale sharks. Mar Ecol Prog Ser 482:153–168. https://doi.org/10.3354/meps10290

Rojas et al. (in press) Fisheries, trade, and conservation of manta and devil rays in Peru.

Shea S, Slee B (2024) Meat on the menu and fins for export: Latin America's shark trade with Asia. Stichting IFAW (International Fund for Animal Welfare), The Hague, The Netherlands. 44pp

Siriwat P, Nijman V (2020) Wildlife trade shifts from brick-and-mortar markets to virtual marketplaces: a case study of birds of prey trade in Thailand. J Asia-Pac Biodivers 13(3):454–461. https://doi.org/10.1016/J.JAPB.2020.03.012

Soriano-Redondo A, Alwasiti H, Kulkarni R, Correia RA, Bryukhova S, Lita NM, Rigor LA, Tejerero DR, Tenazas TM, Di Minin E (2023) Online wildlife trade in species of conservation concern. Conserv Lett 16(6):e12985. https://doi.org/10.1111/CONL.12985

Stevens GMW, Fernando D, Dando M, Notarbartolo di Sciara G (2018) Guide to the manta and devil rays of the world. Wild Nature Press, Plymouth

Stewart JD, Jaine FRA, Armstrong AJ et al (2018) Research priorities to support effective manta and devil ray conservation. Front Mar Sci 5:314. https://doi.org/10.3389/fmars.2018.00314

Strike EM, Harris JL, Ballard KL, Hawkins JP, Crockett J, Stevens GMW (2022) Sublethal injuries and physical abnormalities in Maldives manta rays, *Mobula alfredi* and *Mobula birostris*. Front Mar Sci 9:773897. https://doi.org/10.3389/fmars.2022.773897

Tahiluddin AB, Kadak AE (2022) Traditional fish processing techniques applied in the Philippines and Turkey. Menba Kastamonu University Faculty of Fisheries Journal 8(1):50–58

The Manta Trust (2020) Mega haul of manta ray gill plates seized in Hong Kong highlights Sri Lanka's unsustainable fisheries. Press release. https://www.mantatrust.org/gill-plate-seizure

Venables SK, Rohner CA, Flam AL, Pierce SJ, Marshall AD (2024) Persistent declines in sightings of manta and devil rays (Mobulidae) at a global hotspot in southern Mozambique. Environ Biol Fish 1-7(12). https://doi.org/10.1007/s10641-024-01576-5

Venables SK (2020) Ecology and conservation of a threatened reef manta ray (*Mobula alfredi*) population in southern Mozambique. Dissertation, The University of Western Australia. https://doi.org/10.26182/C5NG-SF57

Walbaum JJ (1792) Petri Artedi sueci genera piscium. In: Ichthyologiae pars III, vol 3. Ant Ferdin Rose, Greifswald, pp 1–723.

Ward-Paige CA, Davis B, Worm B (2013) Global population trends and human use patterns of Manta and Mobula rays. PLoS ONE 8:e74835. https://doi.org/10.1371/journal.pone.0074835

Whitcraft S, O'Malley M, Hilton P (2014) The continuing threat to manta and mobula rays: 2013–14 market surveys, Guangzhou, China. WildAid, San Francisco

White ER, Myers MC, Flemming JM, Baum JK (2015) Shifting elasmobranch community assemblage at Cocos Island-an isolated marine protected area. Conserv Biol 29(4):1186–1197. https://doi.org/10.1111/cobi.12478

White WT, Corrigan S, Yang L et al (2018) Phylogeny of the manta and devil rays (Chondrichthyes: mobulidae), with an updated taxonomic arrangement for the family. Zool J Linn Soc 182:50–75. https://doi.org/10.1093/zoolinnean/zlx018

Zhou X, Yang A, Miao Z, Zhang W, Wang Q, MacMillan DC (2024) Consumer characteristics and preferences for mobulid gill plates in China. Conserv Biol 38:e14244. https://doi.org/10.1111/cobi.14244