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International concern is growing with regard to the sustainability of manta and devil ray (collectively mobulids) fisheries as demand for mobulid products has increased in international markets over the last decade. While Indonesia has been reported to be one of the worlds' top three catchers of mobulid rays, detailed information on these fisheries and the status of Indonesian mobulid populations are lacking. Through collection of historical and recent mobuild fisheries data from published and unpublished sources, this study aimed to identify trends in abundance of Indonesian manta and devil rays and explore socio-economic factors and incentives associated with mobulid fisheries. Comparison of catches from 2001-5 to the most recent data from 2013-14 revealed dramatic declines in mobulid landings over the study period of 64% at Cilacap, 75% at Lamakera, and 94% at Tanjung Luar. The largest declines were observed for *Manta* spp. and the two large devil rays, *Mobula tarapacana* and *Mobula japanica*. Anecdotal reports indicated that catches had declined substantially at three additional sites and local extirpations are strongly suspected to have occurred at three locations. A lack of data on the population ecology of Indonesia's mobulids makes it difficult to determine whether natural fluctuations may be playing a part in the declining catch rates. However, mobulid life history traits, including low reproductive rates and late age of sexual maturation, indicate that fishing pressure is likely the primary driver in these declines. Interviews in Lamakera, a community which depends on income from its targeted mobulid fishery, suggest that programs focused on education, training and infrastructure development to enable shifts to sustainable livelihood alternatives are likely to offer the most successful path to long-term conservation and management of manta and devil rays, while simultaneously yielding economic and social benefits to fishing communities.

Assessing Indonesian Manta and Devil Ray Populations Through Historical Landings and Fishing Community Interviews

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Abstract

International concern is growing with regard to the sustainability of manta and devil ray (collectively mobulids) fisheries as demand for mobulid products has increased in international markets over the last decade. While Indonesia has been reported to be one of the worlds' top three catchers of mobulid rays, detailed information on these fisheries and the status of Indonesian mobulid populations are lacking. Through collection of historical and recent mobuild fisheries data from published and unpublished sources, this study aimed to identify trends in abundance of Indonesian manta and devil rays and explore socio-economic factors and incentives associated with mobulid fisheries.

Comparison of catches from 2001-5 to the most recent data from 2013-14 revealed dramatic declines in mobulid landings over the study period of 64% at Cilacap, 75% at Lamakera, and 94% at Tanjung Luar. The largest declines were observed for Manta spp. and the two large devil rays, Mobula tarapacana and Mobula japanica. Anecdotal reports indicated that catches had declined substantially at three additional sites and local extirpations are strongly suspected to have occurred at three locations. A lack of data on the population ecology of Indonesia's mobulids makes it difficult to determine whether natural fluctuations may be playing a part in the declining catch rates. However, mobulid life history traits, including low reproductive rates and late age of sexual maturation, indicate that fishing pressure is likely the primary driver in these declines.

Interviews in Lamakera, a community which depends on income from its targeted mobulid fishery, suggest that programs focused on education, training and infrastructure development to enable shifts to sustainable livelihood alternatives are likely to offer the most successful path to long-term conservation and management of manta and devil rays, while simultaneously yielding economic and social benefits to fishing communities.

Introduction

There has been growing international concern in recent years regarding the sustainability of manta and devil ray (collectively mobulids) fisheries as demand for mobulid products has increased in international markets (Heinrichs *et al*., 2011; Couturier *et al*., 2012). Most large elasmobranchs are recognized for their conservative life history strategies; slow growth, late sexual maturation, long life spans, long gestation periods, low reproductive rates and low natural mortality, factors that make them highly vulnerable to overfishing (Dulvy *et al*., 2003; Musick and Ellis, 2005; Garcia *et al*., 2008). Rapidly declining regional population trends have been observed in many elasmobranch species as a result of fishing pressure (Baum *et al*., 2003; Shepherd and Myers, 2005) including the near extinction of two skate species (*Raja laevis* and *Raja batis*) (Brander, 1981; Casey and Myers, 1998). With fecundity among the lowest of all elasmobranch species, mobulid rays are exceptionally vulnerable to fishing pressure (Couturier *et al.*, 2012). Recent vulnerability analysis indicates that mobulid populations can only withstand very low levels of fishing mortality (Dulvy *et al*., 2014) and have limited capacity to recover once depleted (Couturier *et al*., 2012). These vulnerabilities coupled with increasing trade in mobulid products, has prompted efforts to intensify mobulid protective measures internationally, resulting in addition of both *Manta* species to Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 2013 and listing of *Manta birostris* (2011), *Manta alfredi* and all *Mobula* species (2014) on Appendix I and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS).

Indonesia has been reported to be one of the top three catchers of mobulid rays (Heinrichs *et al*., 2011), reporting landings in the FAO category *Mantas, devil rays, nei* of 5,647 tonnes in 2013 (Fishstat, 2015). Both *Manta* species (*M. birostris*, *M. alfredi*) and 5 of the 9 recognized *Mobula* (devil ray) species (*M. japanica, M. tarapacana, M. thurstoni, M. kuhlii, M. eregoodootenkee*) are found in Indonesian waters, with all but one of these species (*M. eregoodootenkee*) recorded in fishery landings (White *et al*., 2006a). Historically, artisanal fisheries have targeted manta and devil rays for local consumption (Barnes, 2005). However in the 1990's, the emergence of the international trade in mobulid prebranchial appendages (gill plates) for use as a Chinese health tonic, in addition to government subsidies enabling expansion and modernization of artisanal fishing fleets, resulted in new and expanded targeted commercial fisheries (Dewar, 2002; White *et al*., 2006a; Heinrichs *et al*., 2011). Dharmadi and Fahmi (2014) further report that demand for gill plates has continued to drive increased fishery pressure on *Manta* spp. over the past decade. Mobulid rays are also landed as valuable retained bycatch from gillnet fisheries for tuna and were observed in four of fourteen landing sites surveyed throughout Indonesia by White *et al*. (2006a) between April 2001 and October 2005.

Recognizing the biological vulnerability of these species (Dulvy *et al*., 2014) and the sustainable economic benefits of mobulid tourism (O'Malley *et al*., 2013), Indonesia passed legislation in January 2014 to protect both species of manta ray throughout Indonesian waters (Indonesian Ministry of Marine Affairs and Fisheries Ministerial Decree #4/2014 conferring full protected species status to species of the genus *Manta*). While the government has been proactive in cracking down on the now-illegal *Manta* spp. gill plate trade (Hilton, 2015), obtaining a better understanding of the status of Indonesia's mobulid populations and the socio-economics of mobulid fishing communities will be critical to ensuring the sustainable conservation and management of both manta and devil rays. Through collection of historical and recent mobuild fisheries data from published and unpublished sources, this study aimed to identify trends in abundance of Indonesian manta and devil rays and assess the effects of fisheries on populations. The second objective was to identify mobulid product market values and other socio-economic factors associated with mobulid fisheries in order to assess the potential for programs to assist fishing communities to shift effort to more sustainable fisheries and other economic alternatives.

Methodology

Data Collection

Historical and recent manta and devil ray landings were compiled through review of published literature and collection of previously unpublished data from anecdotal reports and field surveys conducted by Reef Check Foundation Indonesia (RCFI) and Coral Reef Alliance (CORAL), Indonesian Institute of Sciences (LIPI) and Ministry of Marine Affairs and Fisheries (KKP), Wildlife Conservation Society (WCS), Gili Ecotrust (GET), WWF-Indonesia (WWF), Indonesian Nature Foundation (LINI), and Misool Baseftin Foundation (MBF) from 2006 to 2015. Primary focus was placed on locations identified in published literature as the most important mobulid fishery sites in Indonesia; Lamakera (East Nusa Tenggara province) as the largest targeted *Manta* spp. fishery (Dewar, 2002), Tanjung Luar (West Nusa Tenggara province) as the largest targeted shark and ray fishery landing site, and Cilacap (Central Java province) as being representative of elasmobranch bycatch fisheries (White *et al*., 2006a; Fahmi and Dharmadi, 2015). Through casual and semi-structured interviews, and direct observations, qualitative data were also compiled from Lamakera, Tanjung Luar, and several other mobulid fishing communities, including trends in mobulid catch and fishing effort, fishery characteristics, and the socio-economics of the mobulid fishery.

Lamakera is the collective name given to two villages adjacent to each other, Motonwutun and Watobuku[1], located at the eastern tip of Solor Island, East Solor Regency, East Nusa Tenggara Province. Mobulid landings from Lamakera were compiled from Dewar (2002) (2002 and historical), unpublished data from community landings records (2003-13), and surveys conducted by WWF and RCFI/CORAL (2014). In addition data on fishery capacity, effort and cost were collected in 2011 (RCFI/CORAL), and from February 2013 to June 2015 (WWF/RCFI/CORAL). Data recorded included mobulid catch number by genus, per boat and in total, fishing gears used, fishing date, trip time, fishing grounds, vessel capacity, weight and price.

Tanjung Luar is a village located on the island of Lombok in East Lombok

[1] Any reference to Lamakera in this manuscript refers to both villages.

Regency, West Nusa Tenggara Province, and is the main shark and ray fishing port for East Lombok. Tanjung Luar catch data were compiled from unpublished surveys conducted by RCFI over 35 survey days from June 2007 through June 2012, and by GET/WCS over 347 survey days from March 2013 through December 2014. The White *et al.* (2006a) study observed landings in Tanjung Luar over 59 survey days from April 2001 to October 2005. All surveys recorded the number of mobulids observed landed by species or genus using species identification references by Compagno and Last (1999) or White *et al*. (2006b). Sex and disc width (DW) of individuals were also recorded in 2013. In January 2014, RCFI in collaboration with WCS and LINI conducted a rapid survey of shark and ray fishery characteristics throughout East and West Nusa Tenggara Provinces (USAID unpublished data, 2014).

Cilacap is a port city in southern Java in the Cilacap Regency, Central Java Province. Data on mobulid ray landings and fishery characteristics were compiled from White *et al*. (2006a) (2001-5) and unpublished data from LIPI/KKP. LIPI/KKP surveyors recorded mobulid catch in weight daily from 2006 to 2013 and catch by number of mobulids over 214 survey days from May to November 2014. Mobulids were identified to the species level based on the White *et al*. (2006b) reference. Cilacap surveyors were chosen from among local fisheries officers with the best knowledge of mobulids and were further trained in shark and ray identification.

Data Analysis

Annual Catch Estimates and Trends

For Tanjung Luar (2007 to 2014) and Cilacap (2014) estimated annual catches of total mobulids, *Manta* spp., and *Mobula* spp., and by species for the years in which species-specific data were available, were calculated using a modified version of the formula described in White *et al.* (2006a). The White *et al*. (2006a) formula divided the total number of mobulids observed landed over the survey period by the number of survey days to estimate mean daily landed catch (MDLC), and then multiplied this number by 365 to approximate average annual landings over the period. The current study substituted the reported typical number of fishing days per year rather than assuming 365 fishing days per year. For Lamakera, the number of mobulids landed was collected daily in 2014 by a local enumerator, providing accurate annual catch. For the 2003-13 period the mean estimated annual catch was calculated for each year from community records that provided annual mobulid catch as a high-low range. To assess catch trends, estimated landings from Tanjung Luar and Cilacap and recorded annual catches from Lamakera were then compared to earlier estimates from published studies and across survey periods using a simple formula (catch from period 2 minus catch from period 1 divided by catch from period 1). For comparison purposes, the White *et al*. (2006a) estimates from 2001-5 were adjusted using the revised number of fishing days. Cilacap catch data by weight (2006-13) were roughly converted to an estimated number of mobulids using the average mobulid weight from specimens measured during 2001-5 Cilacap surveys (White *et al.,* 2006a). To check for seasonal trends at Tanjung Luar, total *Manta* spp. and *Mobula* spp. landings in each month across the study period (2007-2014) were compiled. Estimated numbers of *Manta* spp. and *Mobula* spp. that would have been landed at Tanjung Luar in each month, assuming that rays were landed daily, were also calculated to account for the varied number of survey days in each month.

Lamakera mobulid trade revenue estimates

Mobulid product market prices for 2010 and 2014 were obtained through interviews with community members in 2011 and 2014/15 respectively, while 2002 prices were calculated from data in Dewar's (2002) study. Estimated dried gill plate and meat yields per *Manta* and *M. tarapacana* were obtained through community interviews, and estimated gill plate yield per *M. japanica* was obtained from recent gill plate trade research (O'Malley *et al*., in review). Meat yield from *M. japanica* was roughly estimated as 80% of *M. tarapacana* meat yield. Estimates of annual mobulid trade revenue were calculated by multiplying the market prices for gill plates and meat from an average size manta ray and an average size mobula ray by manta and mobula ray annual catches. Because *Mobula* spp. catches were not recorded to species level, the revenue estimates for 2002 and 2010 assumed *Mobula* species composition of 70% *M. tarapacana* and 30% *M. japanica* based on community interview responses. For 2014 the number of *M. tarapacana* reported landed by the local enumerator was used and the balance of *Mobula* spp. landings were assumed to be *M. japanica*.

Results

Mobulid fisheries: characteristics; catch data, trends and fishing effort; species composition

Including this study's three primary mobulid catch sites (Lamakera, Tanjung Luar, Cilacap), review of published literature and unpublished sources identified quantified catch reports from eight mobulid fishery sites and unquantified reports from thirteen sites (Fig. 1). The manta and devil ray fisheries identified spanned most of the Indonesian archipelago, with the largest concentration of landings at sites off the Indian Ocean coasts of East and West Nusa Tenggara and Java. From 2001-5, the period for which the most catch data were available, quantified mobuild catches from seven locations totalled approximately 4,800 manta and devil rays annually, with this study's focus sites accounting for approximately 68% of these landings (Fig. 2). Comparison of catches from 2001-5 to the most recent data from 2013-14 revealed fluctuating landings at all three primary locations from year to year and dramatic declines in mobulid landings over the study period. Anecdotal reports from the other mobulid fishery sites identified indicated that catches had declined substantially at three locations and local extirpations are strongly suspected to have occurred at three other locations.

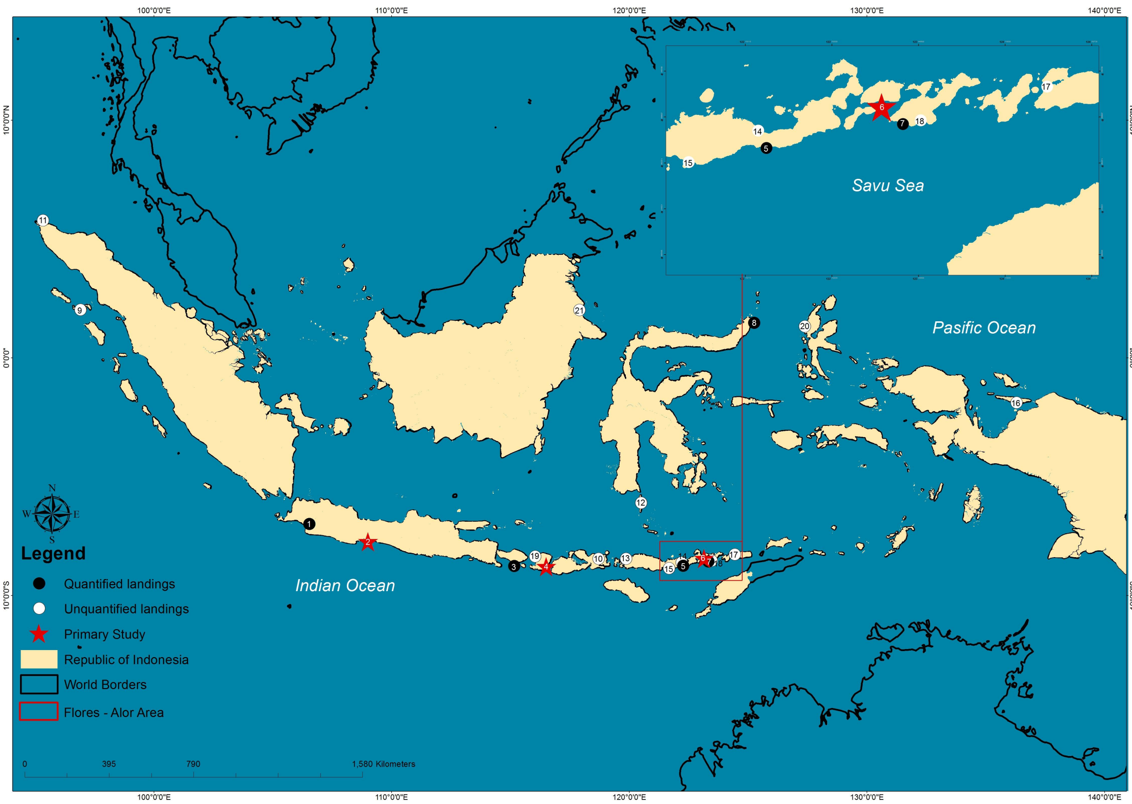

Figure 1. Map showing the location of identified mobulid landing sites:

Sites with quantified mobulid landings reported: 1. Pelabuhanratu (West Java) - White *et al*., 2006a; 2. Cilacap (Central Java) - White *et al*., 2006a, LIPI/KKP, unpublished data; 3. Kedonganan (Bali) - White *et al*., 2006a; 4. Tanjung Luar (Lombok) - White *et al*., 2006a, RCFI/GET/WCS, unpublished data; 5. Bola (Flores) - USAID unpublished data; 6. Lamakera (Solor) - Dewar, 2002, M. Songge, pers. comm., 2015, RCFI, unpublished data; 7. Lamalera (Lembata) - Barnes, 2005, Pet-Soede, 2002; 8. Lembeh Strait (N. Sulawesi) - Pet-Soede and Erdmann, 1998, Perrin *et al.,* 2002)

Sites with unquantified mobulid fisheries / landings reported: 9. Banyak Islands (Sumatra) – RCFI, unpublished data; 10. Bima (Sumbawa) – USAID, unpublished data; 11. Weh Island (Sumatra) - WCS unpublished data; 12. Selayar (S. Sulawesi) – J. Schultheis, pers. comm., 2015; 13. Labuan Bajo (Flores) – USAID, unpublished data; 14. Maumere (Flores) – USAID, unpublished data; 15. Ende (Flores) – USAID, unpublished data; 16. Yapen (Cenderawasih) – MBF, unpublished data; 17. Unspecified village near Lewalu

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(Alor) – RCFI, unpublished data; 18. Labala (Lembata) - Pet-Soede 2002; 19. Gili Islands – D. Robbe, pers. comm., 2013; 20. Guraici Islands (Halmahera) – M. Bode, pers. comm., 2012; 21. Mainland market near Sangalaki (E. Kalimantan) – E. Oberhauser, pers. comm., 2012.

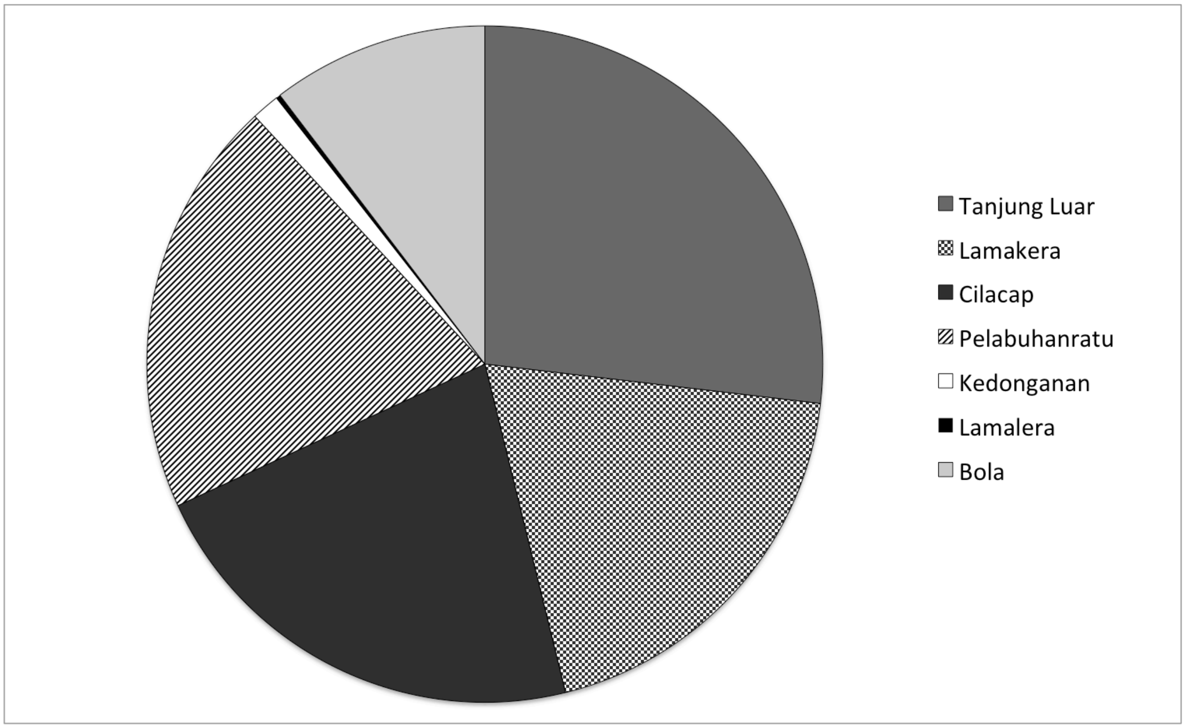

Figure 2. Mobulid landings 2001-5 from the seven landing sites for which quantified catch data were identified: Lamakera (Average 2002-6 landings, 2001 data were not available), Tanjung Luar, Cilacap, Pelabuhanratu, Kedonganan, Lamalera **(**Only 2001 landings available)**,** and Bola (Only 2003 landings available).

Lamakera

Lamakera fishermen target mobulids using a metal spear attached to a long bamboo pole (Fig. 3). When mobulids are seen at the surface a crew member will leap off the bow of the boat driving the spear and attached rope into the back of the animal (Fig. 4).

Figure 3. Lamakera fisherman holding a spear used to catch mobulid rays.

Figure 4. Lamakera fisherman demonstrating harpooning technique.

Manta birostris is the primary target, and *M. tarapacana* and *M. japanica* are also targeted using this method. In addition *M. japanica* (and possibly other *Mobula* spp.) are sometimes caught as bycatch in Lamakera's tuna gillnet fishery, though bycatch of *Manta* spp. and *M. tarapacana* is reported to be rare. In 2013-14 mobulids made up less than 1% of total net catches and over 90% of harpoon catches. Mobulid hunting season lasts for eight months starting in late March, peaking in July and ending in October, with occasional catches in November and December. From January to late March no mobulid hunting takes place, as the regular rainfall during this time (West monsoon) prevents adequate drying of the gill plates. During the hunting period, there are reportedly two to four days per month, around the beginning of the moon cycle (new moon), when mobulids (primarily *M. birostris*) aggregate on the surface and the fishermen target them intensively. The remainder of the month fishermen hunt them opportunistically. Fishing locations change throughout the hunting season, with mobulids occurring closer to the village in the Lamakera Strait from late March to June, and moving into the Savu Sea off Pulau Tiga (small islands of south Solor), Bola, Sikka, and Rusa Island, off Lembata Island from July to October. Some fishers also reported recently expanding the fishing area into southern Flores as mobulids have become more difficult to find in the traditional hunting grounds.

This targeted mobuild fishery landed an estimated 1,500 "manta" rays in 2002 (range 1,050 to 2,400) compared to historic levels of 200 to 300 annually (Dewar, 2002), though recent interviews indicate that these figures more likely represented all mobulids (M. Songge, pers. comm., 2015). Increased catches were attributed to substantially increased fishing effort in the late 1990's driven by the emerging international demand for manta and devil ray gill plates and enabled by government subsidies to finance a shift from traditional to motorized vessels and expansion of the fleet from 18 to 30 boats (Dewar, 2002; Cesar *et al.*, 2003, M. Songge pers. comm., 2011). Cesar (2003) reported that the motorized vessels dramatically shortened time to reach fishing grounds from four days to one day. During the 2011 survey, researchers observed a further increase in mobulid fishing effort with 40 fishing boats outfitted to target mobulids and other large marine species in the village. Interviews conducted in 2014/15 revealed that the number of fishing boats targeting mobulids had increased further to a current total of 57 boats and fishermen were traveling longer distances to target mobulids. Although 2014-15 interviews revealed that many Lamakera fishers had very recently begun to shift away from mobulid hunting as their primary fishery focus, these fishers still target mobulids opportunistically, and around peak days when mobulids are sighted in the area, indicating that directed mobulid fishing effort from these fishers is still more-or-less the same as reported in 2011.

Catch records disclosed by the village elder (2003-13) and from 2014 surveys revealed a steady decline in mobuild landings from the Dewar (2002) average estimate of 1,500 annually to an average estimate of 550 by 2007 and decreasing further to a total recorded catch of 213 by 2014. Landings from 2014 represented an 86% decline in annual mobulid catch compared with Dewar's (2002) assessment (Table 1A, Fig. 5A) despite substantially increased effort. Village interviews revealed further indications of declines in abundance of manta and devil rays. Lamakera fishermen interviewed by Dewar (2002) and the current study in 2011 reported they used to hunt manta rays year-round in the channel next to their island and manta rays were no longer found there, suggesting that a local population may have been extirpated, or less likely but possibly changed distribution as a result of fishing pressure. Most fishers interviewed in 2014/15 reported that the number of mobulid rays had declined in recent years and several stated that the average sizes had decreased. One interviewee noted that during the 1980s and 1990s they would frequently catch pregnant mobulid rays, but in recent years only approximately 10% of those landed were pregnant. In 2014 out of approximately 138 manta rays caught, only four were pregnant (less than 3%). Several fishermen also reported recently beginning to make longer mobulid-hunting trips to southern Flores as a result of manta and devil rays becoming harder to find in the traditional hunting grounds.

Lamakera's local language includes three words for mobulids – "*pari berlalang*" for *Manta* spp., "*pari bong*" for larger yellowish mobulids referring to *Mobula tarapacana,* and "*pari mokung*" for smaller bluish mobulids referring to *Mobula japanica*. The village does not record catches at the species level, though the village elder, who has been tracking mobulid catches since 2003, reported that mobulid catches comprise approximately 60-70% *Manta* spp. and 30-40% *Mobula* spp., and this ratio has remained fairly constant (M. Songge, pers. comm., 2015). *Manta birostris* was the most frequently caught mobulid at Lamakera throughout the study period. *Manta alfredi* was not observed, and none of the interview respondents reported ever catching this species when shown images of both species. *Mobula tarapacana* and *Mobula japanica* were the only devil rays observed during survey trips. It is possible that other species are also caught, however precise species identification was difficult to determine through interviews. Due to similar morphology of some devil ray species, it is possible that villagers may identify multiple species under one or both of the local words for devil rays. *M. tarapacana* was reported as the most abundant devil ray species landed historically, though catches of this species have declined sharply in recent years with only approximately 20 caught in 2014 (M. Songge, pers. comm., 2015).

Villagers reported additional landings of small devil ray species caught as bycatch by outside fishers targeting tuna using nets. While not recorded, Lamakera fishermen report that the number of small devil rays caught by fishers from Ende (Flores) and Gorong (village close to Lamakera) and landed in Lamakera is much higher than the number of large devil rays caught by Lamakera fishers, with Ende fishers reportedly landing 100 small devil rays in only two months between April and May 2015. The number of these outside fishers has been increasing every year and there are currently 12 Ende boats and 15 Gorong boats fishing in the waters surrounding Lamakera.

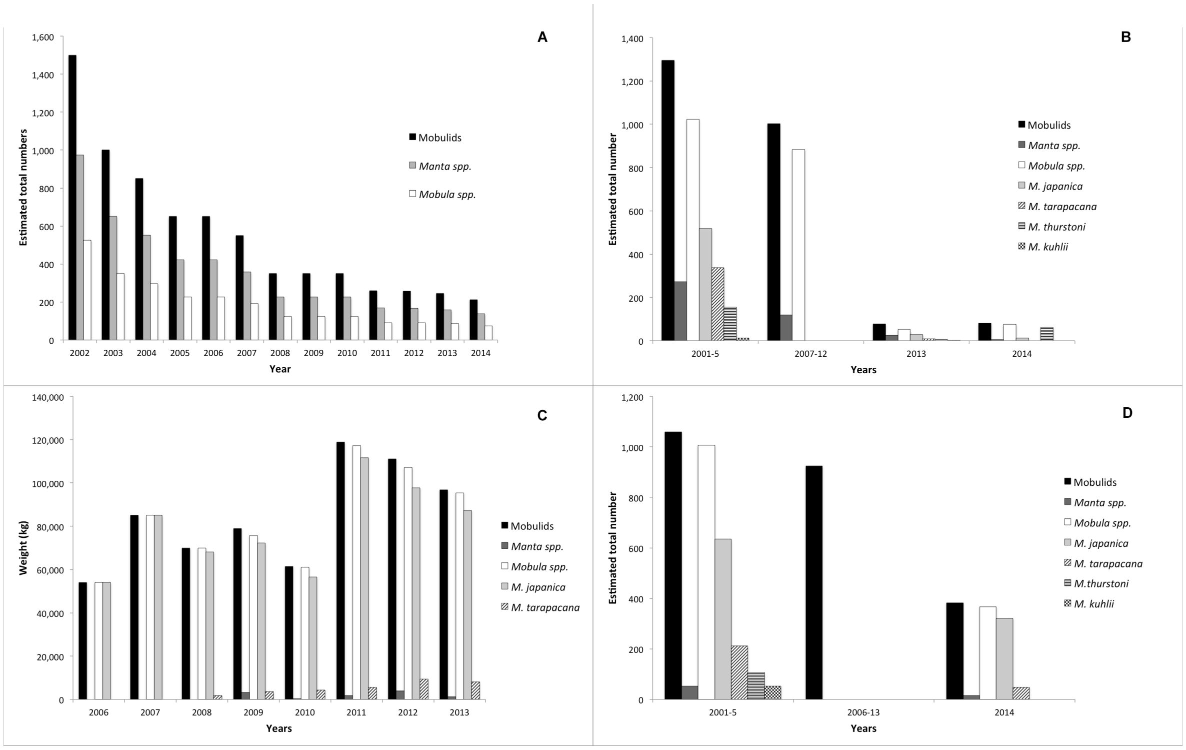

Figure 5. Estimated mobulid landing trends from the 3 primary sites:

A) **Lamakera –** 2002 estimated landings (Dewar, 2002); 2003-13 reported average annual landings by genus; 2014 actual recorded landings by genus.

B) **Tanjung Luar –** 2001-5 modified estimate of average annual landings by genus and species (White *et al*., 2006a); 2007-12 estimated average annual landings by genus; 2013 and 2014 estimated average landings by genus and species.

C) **Cilacap** – 2006-13 gillnet + longline – mobulids landed by weight (kg).

D) **Cilacap –** 2001-5 modified estimate of average annual landings by genus and species (White *et al*., 2006a); 2006-13 estimated number of mobulids landed in gillnet fishery using average weight per mobulid landed at Cilacap 2001-5 (White *et al*. 2006a); 2014 estimated annual landings by genus and species.

Table 1. Average Estimated Annual Mobulid Landings 2001-14:
A) Lamakera all gears

	2002-6	2007-12	2013-14	Change 2002-6 vs 2013-14
Mobulids	930	353	229	-75%
Manta spp.	605	229	149	-75%

Mobula spp.	326	123	80	-75%

B) Tanjung Luar all gears

	2001-5	**2007-12**	**2013-14**	**Change 2001-5 vs 2013-14**
Mobulid	1,295	1,003	80	-94%
Manta spp.	272	120	14	-95%
Mobula spp.	1,023	883	66	-94%
M. tarapacana	337		3	-99%
M. japanica	518		20	-96%
M. thurstoni	155		39	-75%
M. kuhlii	13		1	-93%

C) Cilacap gillnet fishery

	2001-5	**2006-13**	**2014**	**Change 2001-5 vs 2014**
Mobulids	1,059	924	383	-64%
Manta spp.	53		15	-71%
Mobula spp.	1,006		367	-63%
M. tarapacana	212		48	-77%
M. japanica	635		320	-50%
M. thurstoni	106		0	-100%
M. kuhlii	53		0	-100%

Tanjung Luar

Tanjung Luar fishermen reportedly target mobulids around Flores, Sumba, Timor Leste, northern Australian territorial waters, and a location between Indonesia and Australia that takes four days to reach. Mobulids are landed at Tanjung Luar throughout the year with a peak season from March to June, and low mobulid catches from September through December. Reported seasonality roughly coincided with observed catches, with highest estimated mobulid catch from 2007-14 surveys in June and lowest in September (Fig. 6A, B), and the White *et al*. (2006a) surveys in 2001-5 reporting the largest landings in March and lowest in November. *Manta* spp. were caught primarily with spears and gill nets, and *Mobula* spp. were caught in specific trawl nets about 100 meters long with a wide mouth funnelling down to a closed pocket at the end. Multiple fishing gear types are stored on a single boat and deployed based on which target species are encountered.

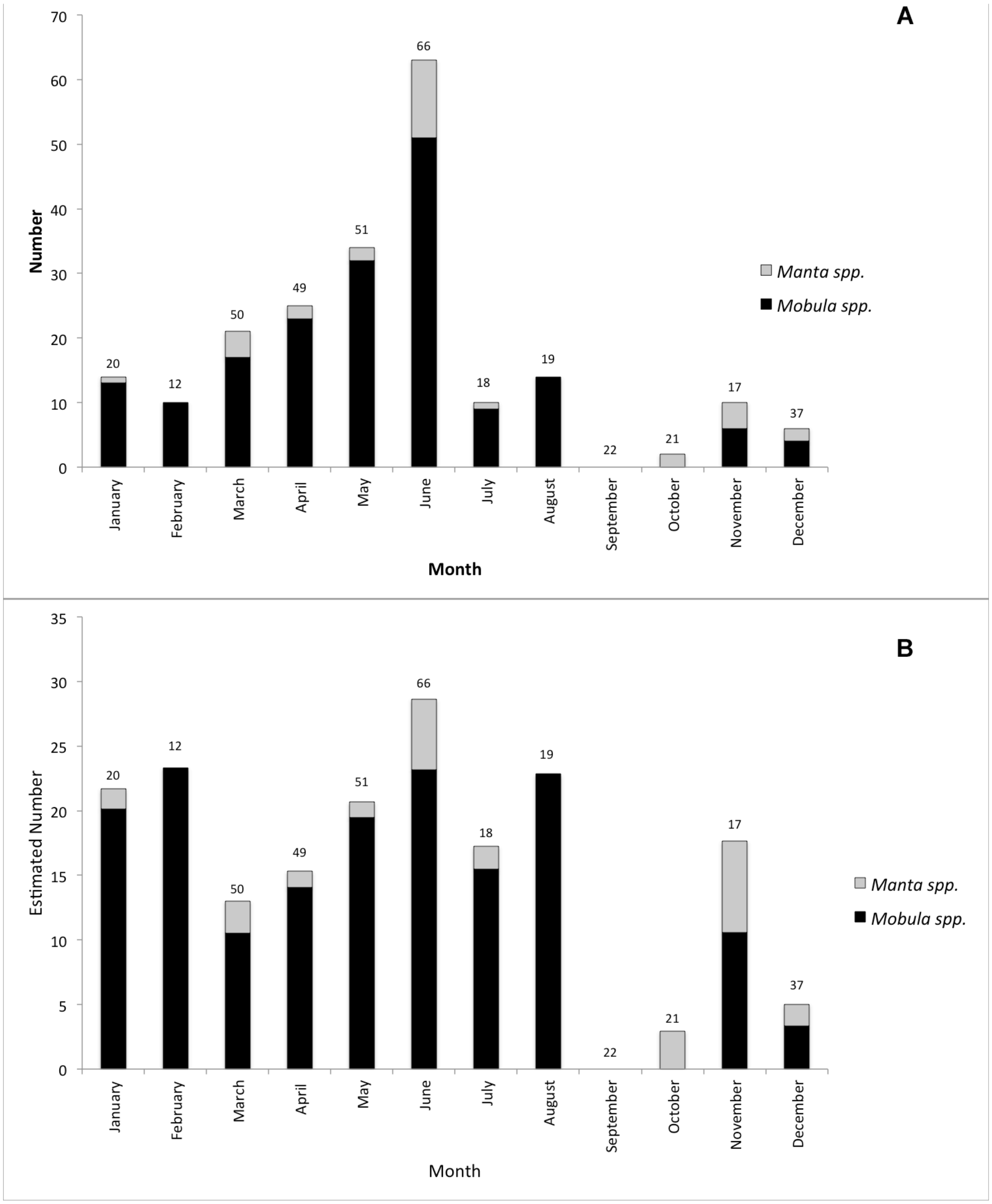

Figure 6. A) Numbers of *Manta* spp. and *Mobula* spp. recorded at Tanjung Luar in each month during the entire study period (2007 – 2012 and 2013-2014), and **B)** Estimated

numbers of *Manta* spp. and *Mobula* spp. that would have been landed at Tanjung Luar in each month, assuming that rays were landed daily. In both A) and B) the total number of survey days when Tanjung Luar was visitied in each month is noted above each monthly histogram.

At Tanjung Luar mean daily landings (MDLC) of mobulids and annual mobulid catch estimates over the 2007 to 2014 data collection period revealed a progressive decline in catch numbers and a notable decline relative to the White *et al*. (2006a) annual catch estimates from 2001 to 2005 (Table 1B, Fig. 5B). Comparisons between the adjusted White *et al.* (2006a) estimates and this study's estimates from 2007 to 2012 showed a 23%, 15% and 56% decrease in annual catch for all mobulids, *Mobula* spp. and *Manta* spp. respectively. MDLC for the 2007 to 2012 period was 3.3 (± 0.71 SE) mobulids, 2.9 (± 0.67 SE) *Mobula* spp., and 0.4 (± 0.14 SE) *Manta* spp,), representing a 33% decline in MDLC of mobulids compared to White *et al*.'s (2006a) estimate of 4.4 (±0.74 SE) mobulids in 2001 to 2005. An increase in mobulid fishing effort was also apparent over the period. While White *et al*.'s (2006a) survey reported mobulids were only caught as by-catch, more recent surveys observed targeted mobulid fishing as early as 2007 and several fishers interviewed reported they had started to focus on mobulids as a primary target in 2010. In addition, fishery participants interviewed in 2011 indicated that the average size of the manta rays being caught was smaller and that there were fewer landings per boat despite a more directed fishing effort. In 2013 the majority of mobulids observed landed were below size at maturity (70% *Manta* spp., 75% *M. tarapacana*, 79% *M. japanica*, 100% *M. thurstoni*) (White *et al*., 2006a; Marshall *et al.*, 2009; Notarbartolo di Sciara, 1988). Comparison of landings data from 2013-14 shows a further dramatic decline in annual and daily catch relative to the 2007-12 estimates (92%, 93% and 88% for mobulids, *Mobula* spp. and *Manta* spp. respectively). MDLC for the 2013-14 period was 0.27 (±.54 SE) mobulids, 0.22 (±.28 SE) *Mobula* spp., and 0.05 (±.47 SE) *Manta* spp. Targeted shark and ray fishing effort apparently fluctuated over the past ten years with anecdotal reports of roughly 70 boats targeting sharks and rays in 2005 relative to 44 counted in early 2014 and currently 58 in 2015 (S. Campbell, pers. comm., 2015; USAID, unpublished data, 2014). While there are a number of factors which could contribute to changes in fishing effort, interview data suggested that effort decreases might be a reflection of; 1) diminishing elasmobranch stocks reducing the success rate of fishing trips, 2) improved protection and law enforcement of *Manta* spp. in Indonesia, and 3) decreasing value and demand of mobulid products, coupled with an increase in fishing trip costs (due to fuel price increase) making fishing trips less profitable. Although effort changes might have accounted for a proportion of the reduced landings, evidence of significant catch decline throughout periods of both increased and decreased effort strongly suggests an overall decline in CPUE for these species. Some recent interviews suggested that *Manta* spp. landings had shifted away from the main auction site at Tanjung Luar in response to announcement of Indonesia's manta protection law in January 2014, though researchers were unable to verify these claims. Over the same period, landings of *Mobula* spp. increased slightly, indicating the manta law likely did not negatively affect fishing effort or public landings of devil rays.

Mobula thurstoni was the most frequently caught mobulid at Tanjung Luar over the 2013-14 survey period, contributing 49% to the total mobulid catch, followed by *Mobula japanica* (25%), *Manta birostris* (13%), *Manta alfredi* and *Mobula tarapacana* (4% each), and *Mobula kuhlii* (1%), with the remainder consisting of 1% unidentified *Manta* spp. and 3% unidentified *Mobula* spp. Tanjung Luar was the only site at which both *Manta* species were observed landed and these landings represent the first published record of *M. alfredi* landed in an Indonesian fishery. Comparing species composition across the 2001-5 (White *et al*., 2006a) and 2013-14 survey periods, the proportion of *Manta* spp. of total mobulid catch decreased slightly (21% to 17%) and the proportion of the two largest devil ray species of total *Mobula* spp. catch declined substantially (from 84% to 36%). Catch numbers of the two large *Mobula* spp. declined by 97% from 2001-5 relative to 2013-14 (96% *M. japanica*, 99% *M. tarapacana*), while the two smaller *Mobula* spp. declined by 76% across the two survey periods (75% *M. thurstoni*, 88% *M. kuhlii*).

Cilacap

At Cilacap mobulids are caught as bycatch in tuna gillnet and longline fisheries. In 2014, a total of 127 tuna gillnet boats were reported to be actively operating. There are between 120 and 150 operational fishing days per boat over the 8 to 9 month fishing season, with an average of 16±3.9 fishing days per trip. May to September is the prime fishing season due to favorable weather and sea conditions, while fishers do not go out as frequently from January to April (Dharmadi and Fahmi, 2014). Primary tuna gillnet fishing grounds for Cilacap fishermen are off the south coast of Java in the Indian Ocean from 8 to 11^{o} S and 107 to 110^{o} E. From April to June, they operate in offshore waters, and from July to October they move to more inshore areas (Widodo *et al.*, 2011).

From 2006 to 2013 a total of 665.4 t of mobulids were recorded landed in the Cilacap gillnet fishery, with an average annual catch of 83.2 t ± 23.6 t. Applying the average mobulid weight (90 kg) reported from 2001-5 Cilacap surveys in White *et al.* (2006a), the average annual landings over this period were roughly estimated at 924 mobulids. The species composition by weight was 93% *M. japanica*, 2% *Manta* spp., and 5% *M. tarapacana*. During this period an additional 11 t of *M. japanica* were recorded in the longline fishery (average 1.4 t annually). Total mobulids recorded landed by weight each year during the study period in the Cilacap gillnet and longline fisheries combined are shown in Fig. 5C. From 2006 to 2010, annual mobulid catches fluctuated, and then declined from 2011 to 2013. From May to November 2014, a total of 273 mobulids, comprising 11 *M. birostris,* 228 *M. japanica* and 34 *M. tarapacana* were observed landed. During the sampling period, mobulids were landed on 46 of the 214 sampling days, with mean daily landing rates of 1.22 (± 1.16 SE) *Mobula* spp. and .05 (± 0.05 SE) *Manta* spp. Annual catch, assuming 300 fishing days per year, provided landing estimates of 383 mobulids, comprising 15 *M. birostris,* 320 *M. japanica* and 48 *M. tarapacana*. Catch data were only collected during the peak season in 2014, thus these annual estimates are likely to be skewed to the high side. Nevertheless, estimated 2014 mobulid landings compared with the adjusted White *et al.* (2006a) 2001-5 annual estimates represented catch declines of 64% for all mobulids, 71% for *Manta* spp., 50% for *M. japanica*, and 77% for *M. tarapacana*.

(Table 1C, Fig. 5D). None of the two smaller *Mobula* spp. were observed in 2014 catches, while these species made up roughly 15% of the mobulid catch from 2001-5.

Other Indonesian mobulid fisheries identified

From March 1996 to February 1997, 1,424 manta rays were caught in large trap nets set in a migratory channel entering the mouth of the Lembeh Strait in northeast Sulawesi (Pet-Soede and Erdmann, 1998). The mantas and other marine life caught in these nets were processed locally for export mostly as pet food (Perrin *et al*., 2002). The Indonesian government subsequently banned the use of such nets (WCS). Prior to installation of the nets dive operators in the area reported the presence of manta rays was common in the channel, yet sightings since that time have been rare (Perrin *et al*., 2002; M. Erdmann, pers. comm., 2014), suggesting possible extirpation of a local aggregation. In South Sulawesi between 1992 and 1996, the owner of a dive resort in Selayar Island frequently observed up to 50 manta heads at a time discarded on the beaches and main harbour. Local fishers reported targeting the mantas as an easy source of cheap meat to sell to people in the mountains who could not afford skipjack tuna. By 1996, after only 4 years, the fishery had collapsed. Manta rays, previously sighted frequently on dives, were no longer seen (J. Schultheis, pers. comm., 2015), and still are not seen today (S. Wormold, pers. comm., 2015). A similar local extirpation may have occurred in the northwest Alor area over a period of approximately five years (MBF, unpublished data, 2013). The fishing cooperative representative at Lewalu village reported that approximately ten years earlier, off the west coast of Alor Island in the channel between Alor and Pantar Islands, one of the neighboring villages had started installing drift gillnets in the middle of the channel in order to target mackerel. These nets were reportedly 50m wide, set at a depth of 18-20m, and left overnight. Lewalu fishermen frequently observed manta rays caught as bycatch in the nets and within five years mantas were no longer seen in the area. The interviewee reported that manta sightings had been common prior to the installation of the nets, usually at the surface in groups of two but sometimes in larger groups of 10 to 15. After being shown photos of *Mobula* spp. and *Manta* spp., he was confident that the rays caught were *Manta* spp.

Though no photographic evidence was available, the interviewee reported that the mantas were approximately 3 to 4m from wing-tip to wing-tip, indicating that this was likely a *M. alfredi* population. When asked if Lewalu or any of the neighboring villages currently targeted *Manta* or *Mobula* spp. or caught these rays as bycatch, he replied that no one in the area catches mobulids anymore because they are never seen.

White *et al*. (2006a) estimated annual bycatch from drift gillnet fisheries targeting skipjack tuna of 1,170 *Mobula* spp. in Pelabuhanratu (West Java) and 78 mobulids, comprising predominantly *Mobula* spp., at Kedonganan (Bali). Adjusting the Pelabuhanratu and Kedonganan estimates to assume the same number of landing days per year as reported for Tanjung Luar (300) produced revised annual estimates of 962 and 64 mobulids respectively. More recent catch data were not identified for either of these sites. At the whaling village of Lamalera (Lembata), which has historically hunted manta rays for local consumption and barter, Barnes (2005) published community records referred to as "manta" catches from 1959 to 1992. Catches over this period fluctuated widely from the highest catch of 360 in 1969 to 40 in 1992, followed by catches referred to as "good" in 1994-5 and "very low" in subsequent years through 2001, a year in which Pet-Soede (2002) reported less than 10 mantas were landed (Fig. 7). A targeted mobulid fishery for local consumption and barter was observed in 2004 (Mustika, 2006), and in 2014 villagers reported that a gill plate trader from Bali comes one to two times per month to purchase dried gill mobulid gill plates for export, while meat is still consumed locally or bartered for corn (USAID, unpublished data, 2014).

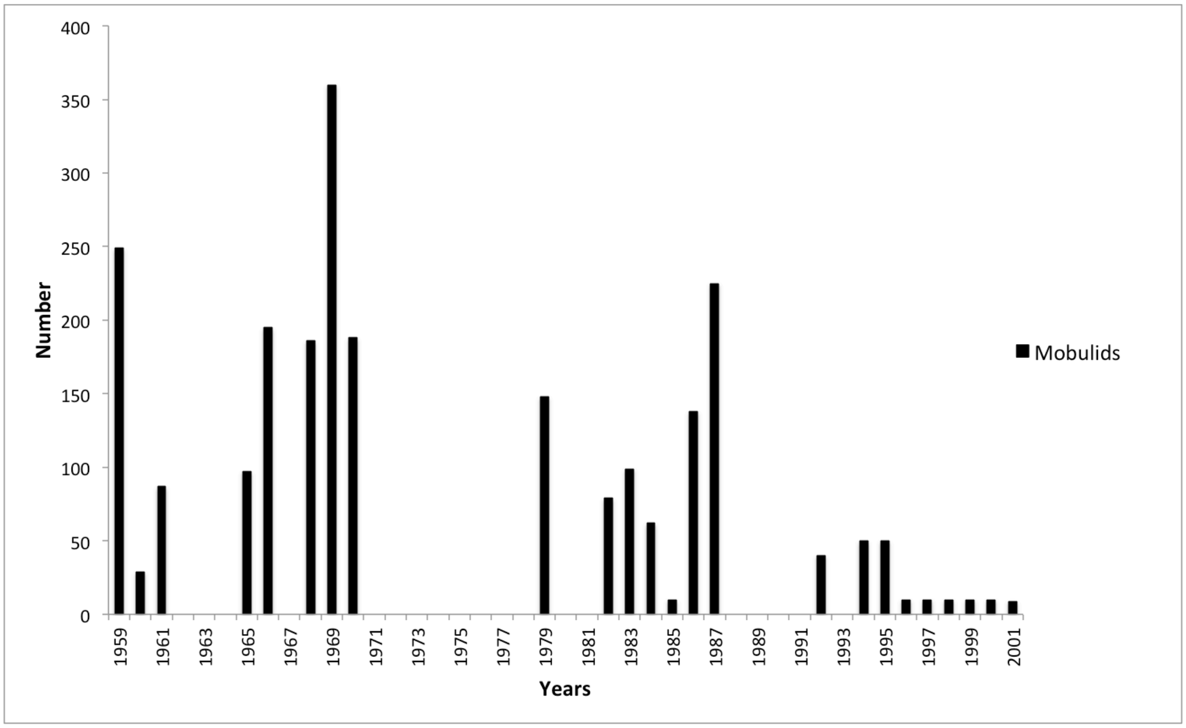

Figure 7. Lamalera historical mobulid landings 1950-2001 (Barnes, 2005; Pet-Soede, 2002).

Rapid field surveys conducted in January 2014 at important chondrichthyan landing sites and markets throughout East Nusa Tenggara, identified directed mobulid fisheries in Flores (Bola, Ende) and Sumbawa (Bima), and occasional mobulid bycatch from purse seine fisheries at Ende (Flores), Labuan Bajo (Flores) and unspecified sites in Alor (USAID, unpublished data, 2014). At Bola, a village located 30 km from Maumere on the Savu Sea coast, fishermen reported that catching devil and manta rays had become increasingly difficult and landings were now rare, while in 2003 they reported landings of approximately 500 *Mobula* spp. annually (N. Setiasih, pers. comm., 2015). During a rapid field survey conducted in 2013 at the Banyak islands (Sumatra) (RCFI, unpublished data), patrol staff at Yayasan Pulau Banyak reported that local fishermen caught “manta” rays as bycatch in gillnets, though it’s not clear whether “manta” referred to *Manta* spp. or all mobulids. They reported that sightings had become much less frequent, suggesting a population decline may have occurred as a result of bycatch fishing pressure. On Weh Island (Sumatra), manta rays (*M. birostris*) are landed as bycatch and sold in markets (WCS, unpublished data). Interviews conducted in June 2013 identified a small, directed mobulid fishery in the Papua Province (MBF, unpublished data). The village of Serui on Yapen Island in Cenderawasih Bay, targets a seasonal *Manta* spp. aggregation, landing 10 to 15 annually (B. Fritz, pers. comm., 2014). In addition, the Gili Eco Trust has documented occasional opportunistic targeting of manta rays in the Gili Islands (D. Robbe, pers. comm., 2013), and there have been unconfirmed reports of a directed mobulid fishery in the Guraici Islands, Halmahera (M. Bode, pers. Comm., 2012) and of *Manta* spp. found in a market in eastern Kalimantan, near Sangalaki Island (E. Oberhauser, pers. comm., 2012).

Market Value and Trade

Interviewees at Tanjung Luar and Lamakera reported gill plates as the most valuable mobulid part with *Manta* spp. gills more valuable than *Mobula* spp. gills. At Tanjung Luar mobulids are landed and sold whole to dealers for processing. The gill plates are dried at a nearby facility and sold to Chinese traders in Jakarta and Surabaya for export to markets in China and southeast Asia. The meat is sold locally for human consumption or elsewhere in Indonesia for use in animal feed, but is of nominal value. In Lamakera mobulids are landed and processed on the beach. Gill plates are removed first, washed and taken to the local gill plate buyer to be weighed and dried. The meat is cut into rings and dried for sale in the village and nearby fish markets for human consumption, animal feed and shark bait. An average (5m DW) *M. birostris* is reported to yield approximately 5kg of dried gill plates and 2 bundles of meat (20 rings per bundle weighing ~ 25kg), while an average (2 to 3m DW) *M. tarapacana* yields roughly 2 to 3 kg of dried gill plates and 1 bundle of meat. Two middleman companies purchase wet gill plates from the fishermen, and after drying sell the gills to Chinese traders in Jakarta and Surabaya for export to China. In 2011 a fishing crew in Lamakera received ~ US$234 (Rp 2 million) for an average (5m DW) manta ray, while the middleman would receive ~ $US621 (Rp 5.3 million) for the dried gill plates and meat from the same manta. In contrast, a middleman in Tanjung Luar paid twice as much for a similar sized manta in 2010 (US$453; Rp 4.1

million), and resold the dried gill plates and meat at a minimal profit margin, receiving ~ US$486 (Rp 4.4 million) (White *et al*., 2006a). Gill plates prices climbed steadily from 2005 to a peak in 2014 and have since declined, while meat prices increased from 2005 to 2010 and remained fairly level over the past five years. See Tables 2A & B for market prices reported from surveys in Tanjung Luar and Lamakera over different survey years.

Table 2. Mobulid market prices in A) Tanjung Luar and B) Lamakera.

A) Tanjung Luar

	2005 (Aug)	2010 (Jul)	2014 (Jan)	2015 (Jun)
Whole *Manta**	1.67 mill. Rp	4.1 mill. Rp		3-6 mill. Rp*
	$169	$453		$225 - $450
Whole *Mobula*		1.67 mill. Rp		500K-3 mill. Rp
		$184		$38 - $225
Dried gills / kg - *Manta* (~ 3-6kg per manta)	275K Rp	800K Rp	2 mill. Rp	1.2 mill. Rp
	$28	$88	$169	$90
Dried gills /kg - *Mobula* (~ .5-3kg per mobula)	137.5K Rp			500,000Rp
	$14			$38
Mobulid meat / kg (~ 10-50kg per mobuild)	3K Rp	8K Rp	8K Rp	10K Rp
	$0.30	$0.88	$0.68	$0.75
Skin / cartilage - per *Manta*	330K Rp			
	$33			

B) Lamakera

	2002 (May)	2011 (Jul)	2014 (Jan)	2015 (Jun)
Whole *Manta**		2 mill. Rp	1 mill. Rp	
		$234	$84	
Dried gills / kg - *Manta*	280K Rp	1 mill. Rp	1.5 mill. Rp	1 mill. Rp
	$30	$117	$127	$75
Dried gills /kg - *Mobula*		250K Rp		400K Rp
		$29		$30
Mobulid meat / kg	1.5K Rp	6K Rp	6K Rp	6K Rp
	$0.16	$0.70	$0.51	$0.45
Skin / cartilage - per *Manta*	60K Rp			
	$6			

* Refers to ~ 5m DW manta. Tanjung Luar 2015 prices per whole manta refer to the range of prices depending on the size of the manta.

Socioeconomics of Lamakera's mobulid fishery

Fishing (and whaling) along with trading the products derived from these activities have traditionally been the sole sources of income in Lamakera (Barnes, 1995). While Lamakerans target a number of other species, including whale sharks, other shark species, whales, tuna, mackerel, billfish and reef fish, the mobulid fishery is reported to be the village's primary source of income. In 2013-14, 94.5% of 212 mobulid fishing trips were profitable, with 76% earning over Rp 1 million (~ US$85). Gross revenues from the mobulid trade, based on landing numbers and market prices for dried gill plates and meat, were estimated at US$158,000 (Rp 1.46 billion) in 2002. While the increase in gill plate prices somewhat offset the declining catches from 2002 to 2014, overall gross revenues from the mobulid trade fell to less than US$93,000 (Rp 1.1 billion) by 2014. With the recent reduction in gill plate prices, these revenues can be expected to decline sharply in 2015 (Table 3).

Table 3. Lamakera Mobulid Trade Revenue estimates

	Manta	*M. tarapcana**	*M. japanica**	**Total Mobulid**
2002 Mobulid Catch	975	368	158	1,500
Avg Yield Meat (kg)	50	25	20	
Price/kg Meat	1.5K Rp	1.5K Rp	1.5K Rp	
	$0.16	$0.16	$0.16	
Avg Yield Gills (kg)	5	2.5	0.5	
Price/kg Dried Gills	280K Rp	280K Rp	280K Rp	
	$30	$30	$30	
2002 Total Revenue	1.44 bill. Rp	14.48 mill. Rp	4.87 mill. Rp	1.46 bill. Rp
	$155,568	$1,566	$526	**$157,661**
2010 Mobulid Catch	228	86	37	351
Avg Yield Meat (kg)	50	25	20	
Price/kg Meat	6K Rp	6K Rp	6K Rp	
	$0.66	$0.66	$0.66	
Avg Yield Gills (kg)	5	2.5	0.5	
Price/kg Dried Gills	1 mill. Rp	250K Rp	250K Rp	
	$110	$28	$28	

2010 Total Revenue	1.21 bill. Rp	66.65 mill. Rp	21.1 mill. Rp	1.275 bill. Rp
	$133,451	$7,361	$2,327	**$140,812**
2014 Mobulid Catch	138	20	55	213
Avg Yield Meat (kg)	50	25	20	
Price/kg Meat	6K Rp	6K Rp	6K Rp	
	$0.51	$0.51	$0.51	
Avg Yield Gills (kg)	5	2.5	0.5	
Price/kg Dried Gills	1.5 mill. Rp	325K Rp	0Rp	
	$127	$27	$0	
2014 Total Revenue	1.1 bill. Rp	19.25 mill. Rp	6.6 mill. Rp	1.11 bill. Rp
	$91,194	$1,626	$557	**$93,377**

* *Mobula* spp. landings were not recorded to species level. For estimation purposes *M. tarapacana* was assumed to make up ~ 70% of *Mobula* spp. landings in 2002 and 2010 based on reports that *Mobula* spp. landed were predominantly *M. tarapacana* during this period. *M. tarapacana* landings were reported as 20 in 2014. *M. tarapacana* dried gill plate for 2014 was estimated assuming the same 50% price increase as for *Manta* spp. gills.

Discussion

Effects of fisheries on Indonesian mobuild populations

Catch and effort trends observed at the three largest known Indonesian mobulid fishery sites identified in this study suggest that large declines in abundance of manta and devil rays have occurred over the past ten to fifteen years. Anecdotal evidence of extirpation of local manta populations in Alor, Lembeh Strait, South Sulawesi, and Lamakera further highlights these species' extreme vulnerability to fishery pressure. The highly migratory nature of these species (Rubin *et al*., 2008; Croll *et al*., 2012; Couturier *et al*., 2012) and lack of data on the population ecology of manta and devil rays in Indonesia and throughout their range makes it difficult to determine whether natural fluctuations may be playing a part in the declining CPUE and to what extent the current level of exploitation is affecting regional populations. However, given the highly conservative life history traits of manta and devil rays, it is very likely that fishing pressure is the primary driver of these declines. In addition, reports of decreased size of mobulids caught in Lamakera and Tanjung Luar indicates "growth overfishing" at these sites. Growth overfishing occurs when large individuals are over-proportionately removed from the population and increases the risk of stock collapse (Diekert, 2012). Reports from Lamakera fishers of making longer trips as mobuilds have become harder to find in traditional fishing grounds may also suggest serial depletion. Catch declines for *Mobula* spp. were comparable to those for *Manta* spp., with declines most evident for the two larger species, *M. tarapacana* and *M. japanica,* which are also highly valued in the gill plate trade. Additionally, gill plate retailers and wholesalers interviewed in Guangzhou, China in 2011 and 2013, where over 99% of mobulid gill plate consumption is centred, reported Indonesia as one of the primary sources for manta and devil ray gill plates and reported increasing difficulty in sourcing gill plates (Heinrichs *et al*., 2011; O'Malley *et al*., in review), suggesting that the declines are significant enough to be evident in the broader gill plate market.

The Lesser Sunda Region, where several of the largest mobulid fisheries (Tanjung Luar, Lamakera, Lamalera) are located, is described as a transition zone where the Indian and Pacific Ocean fauna mix (DeVantier *et al*., 2008). Complex currents with high-energy upwellings and temperature variation characterize the region, promoting a high diversity of habitats and species. The region is known as an important corridor for cetaceans and other marine megafauna, including mobulids (Kahn & Pet, 2003; DeVantier *et al*., 2008), and population declines in this region could potentially impact populations of these highly migratory species across a broad geographic area. Manta and devil ray fisheries in this region could also threaten economically important tourism operations (O'Malley *et al.,* 2013). Tanjung Luar lies between two of Indonesia's most economically important manta ray tourism destinations; Nusa Penida, Bali, and Komodo National Park. Connectivity between these *Manta alfredi* aggregation sites has been discovered through mark-recapture photographic identification techniques, with a few individuals being photographed in both localities (Germanov and Marshall, 2014).

Also of great concern are the widespread anecdotal reports of undocumented directed, opportunistic and incidental catch of mobulids from artisanal fisheries and the large and increasing mobulid landings Indonesia has reported to the FAO since 2005. Indonesia's 2013 reported landings in the category *Mantas, devil rays, nei* of 5,647 t (Fishstat, 2015) can be roughly estimated to represent over 40,000 mobulids, based on the average mobulid weight of ~ 132 kg reported by White *et al*. (2006a), compared with this study's 2014 mobulid catch estimate of less than 700 from the three largest known Indonesian mobulid landing sites. In addition this study did not identify any recent quantified mobulid catch data from sites in the Western Central Pacific, while over 76% of Indonesia's reported landings were attributed to this region. Indonesia has made substantial progress in improving fishery landings collection, as evidenced by this country's switch from reporting chondrichthyan landings in two aggregate categories to 11 family categories in 2005 (Davidson *et al.,* 2015). However, it is likely that over-reporting and double-counting of elasmobranch catches have affected the accuracy of the data reported to FAO (Blaber *et al*., 2009; Fahmi and Dharmadi, 2015). Fahmi and Dharmadi (2015) explain that double counting occurs because landings are counted once on initial landing and again at major processing and distribution centres (usually Jakarta and/or Surabaya). In addition Dharmadi *et al*. (2015) cite the challenge of monitoring and accurate data collection from more than 1,000 landing sites across Indonesia's 81,000 km coastline and the urgent need for species identification training for Indonesian fisheries officers. While Indonesia should be commended as the only country to consistently report landings in the Mobulidae family category, it appears that there is still an opportunity for improvement in mobulid data collection to genus and species level, as is the case in most all of the world's fisheries.

Socioeconomics of Indonesian mobulid fisheries

There appear to have been only minimal efforts to record catch data or manage mobulid fisheries at the two largest directed fishery sites, Tanjung Luar and Lamakera. Additionally, fishery participants interviewed did not report any traditional management measures for marine megafauna, such as area or seasonal closures. Findings in this study with regard to Lamakera were consistent with those of Barnes (2005), who reported that local people in Lamakera and Lamalera had no control over stocks of fish and cetaceans. Over the past ten to twenty years, Lamakera's mobulid fishery has been a significant contributor to the community's gross domestic product (GDP), with the bulk of revenue generated from the sale of *Manta* spp. gill plates for export. However, this revenue has dwindled over the past ten years as mobuild catches, and more recently gill plate prices, have declined. In addition, recent global measures to prevent collapse of *Manta* populations, including restrictions on international trade (CITES, 2013) and Indonesia's prohibition of all *Manta* fisheries and trade and subsequent prosecution of manta traders, leave few prospects for future income from Lamakera's mobulid fishery. Cesar *et al.* (2003) described Lamakera's predicament as "the poverty trap" in a 2003 case study featuring Lamakera, which points to poverty as a root cause for biodiversity loss and unsustainable resource use, while correspondingly the unsustainable use of resources leads to more severe poverty as the natural resources are depleted.

As economics are the primary driver of marine megafauna fisheries in Lamakera, development of alternative sources of income is critical to addressing the economic threat posed to Lamakera and other communities that are largely dependent on unsustainable use of declining resources. Programs are currently underway to assist the village with three alternatives to which the community is receptive: 1) transition to more sustainable fisheries and practices, such as catching tuna using handlines, mini purse seines, and artisanal fish aggregating devices (FADs); 2) development of ecotourism focused on marine megafauna; and 3) production and trade of finely woven cloth. As the development of such alternatives can take time, a community-based research initiative, which trains and employs fishermen as manta ray and whale shark research staff, is underway to provide fishermen with an immediate alternative livelihood source. This initiative allows fishers to utilize their local knowledge and skills in the water, and as a result has been well received by the community. Tourism, with manta rays as the main attraction, has provided significant economic value to the local people in other parts of Indonesia and other regions of the world (Anderson *et al.*, 2010; O'Malley *et al.*, 2013), while providing a strong incentive to communities to protect these species. Tourist expenditures on manta ray dives in Indonesia are estimated at over US$15 million annually (O'Malley *et al*., 2013), and devil rays are also highly valued in the dive tourism industry both internationally (Sobral, 2013) and in Indonesia (M. Miners, pers. comm., 2015). Similarly tourism focused on whale watching and shark diving have been growing rapidly over the past decade and represent estimated global annual tourist expenditures of US$2.1 billion and US$314 million respectively (O'Connor *et al*., 2009; Cisneros-Montemayor *et al.*, 2012). The abundance and variety of marine megafauna in the waters surrounding Lamakera present significant opportunities for marine based nature-watching tourism. However, such opportunities may not be present in other areas of Indonesia such as Tanjung Luar and Cilacap. Therefore it is highly recommended that alternative livelihood options are explored and developed on a site-specific basis.

Limitations and Potential Biases of Data

While it is largely accepted that fisheries data are often subject to inaccuracies and inconsistencies (Vieira and Tull, 2008), this study posed additional challenges since it was necessary to collate data from a variety of sources, which were collected over a number of years by different groups of researchers with varying data collection protocols and levels of training. In addition seasonal and day-to-day mobulid catch rates proved to be highly variable, and the low number of survey days in some data collection periods could have skewed some annual estimates. While qualitative interview data and changes in number of boats targeting mobulids provided sufficient data to conclude general increase or decrease in effort, the availability of data on detailed fishery activity and environmental factors potentially affecting mobuild distribution would have enabled calculation of CPUE across survey years to more effectively track changes in mobulid abundance. Finally, accurate identification of species and even genus in the Mobulidae family is notoriously difficult due to close similarities in morphology. Without photographic documentation of all mobulids observed landed, it is not possible to verify species identification with certainty and some misidentifications may have occurred. Despite these limitations, the findings from this study present important insights into the current and historic state of mobulid fisheries in

Indonesia, where very little data exist on mobulid catch and species composition and even less information has been published on the socio-economics of these fisheries.

Conclusion and Recommendations

As fishing pressure has increased in the last decade, the sustainability of both bycatch and targeted mobulid fisheries must be evaluated. The Indonesian government should be commended for its efforts to conserve *Manta* spp. by prohibiting all take of these species and aggressively prosecuting illegal trade in *Manta* gill plates. However, apart from a few no-take marine protected areas and prohibition of take of all mobulids in the Raja Ampat Regency, there are currently no protective measures in place for *Mobula* spp., which share similar biological vulnerabilities and are subject to the same threats as *Manta* spp. Management and conservation measures for *Mobula* spp. in Indonesian waters should be considered to prevent further population declines and collapse. Continued pressure on the illegal international trade of *Manta* spp. gill plates and local trade in meat along with demand reduction campaigns in China and other countries that consume mobulid gill plates are needed to remove the strong financial incentives to target mobulids. Bycatch also poses a significant threat to manta and devil rays (Croll *et al*., 2012; Couturier *et al*., 2012; Croll *et al*., in review), and cannot be addressed with species protection laws and enforcement alone. While mobulid catches declined most dramatically in the targeted mobuild fisheries in Lamakera and Tanjung Luar, a decline of 64% over approximately 10 years at Cilacap, reported substantial catch decline at the Banyak Islands, and possible local extirpation at Alor from these non-target fisheries highlight the need to address bycatch as a significant threat to Indonesian manta and devil rays. Adoption by Regional Fishery Management Organizations (RFMOs) of no-retention policies for incidentally caught mobulids in order to discourage "intentional bycatch", implementation of mandatory bycatch mitigation measures (i.e. gear modifications; change of location when mobulids are visible at the surface), and training on safe-release techniques to maximize survival of released rays should be encouraged to minimize mobulid bycatch mortality. In addition, spatial and time-based fishing closures (or bans on certain types of gear) could protect mobulids when they aggregate for cleaning, mating or feeding.

Despite Indonesia's significant improvements in fisheries data collection over the past decade (Davidson *et al*., 2015), collation of mobulid fisheries data for this study has highlighted the scarcity of accurate baseline data on Indonesia's manta and devil ray populations. Identification of all mobulid landing sites as well as fisheries with substantial discarded mobulid bycatch, collection of detailed information on the numbers and species captured, and further research into Indonesian mobulid population ecology are needed to inform conservation and management efforts. Implementation of workshops for all relevant stakeholders to provide training and materials on mobulid identification and consistent data collection protocols is also strongly recommended.

While important, ecological knowledge alone is not always sufficient for conservation goals to be achieved successfully. It is also vital to understand how social factors affect human interactions with the environment, especially in poorer regions where communities often depend on natural resources as their primary source of livelihood. Many conservationists recognize the importance of the social aspects of conservation problems (Walpole and Goodwin, 2001; Vieira and Tull, 2008; Simpfendorfer *et al*., 2011), however a gap between the biological and social sciences is often apparent and may limit the effectiveness of conservation management (Fox *et al*., 2006). Community-based conservation (CBC), where local communities participate in and benefit from conservation management programmes, is the most likely path to success for biodiversity conservation (Mehta and Kellert, 1998). Accordingly it is important to understand the socio-economics of mobulid fisheries in Indonesia and ensure that stakeholder communities' attitudes and opinions are considered. Development and socialization of alternative sources of income and educational facilities for villages that target mobulids as well as those that use fishing methods that result in high rates of mobulid bycatch or habitat destruction, will be critical to ensure community acceptance of and compliance with conservation measures. Interviews from Lamakera suggest that mobulid fishing community members are open to shifting to alternative target fisheries and learning new ways to fish more sustainably. In addition most children and young adults were not interested in becoming fishermen despite much of Lamakera's revenue, traditions and culture stemming from fishing (Barnes, 1995). Greater educational and employment opportunities for Lamakera residents, if used to foster alternative income opportunities, could help decrease fishing pressure on mobulids and other megafauna while building a more sustainable economic future for the community. Investment in community programs to provide conservation education as well as specific training and infrastructure to assist communities with making these shifts could greatly reduce unsustainable mobulid fisheries while simultaneously providing economic and social benefits to these communities.

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