Untangling the Indonesian tangle net fishery: describing a data-poor fishery targeting large threatened rays (Order Batoidea)

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Abstract

Shark-like batoids (Order Rhinopristiformes) are normally taken as incidental catch in fisheries targeting other species, one exception is a poorly understood Indonesian tangle net fishery. Market surveys of Muara Angke landing port recorded landed catch for this fishery. Recent catch data from Indonesian Capture Fisheries (2017 – 2018) were also examined to provide contemporary information. During the market surveys, 1,559 elasmobranchs were recorded, comprised of 24 species of batoids and nine species of sharks. The most abundant were pink whipray *Pateobatis fai* and bottlenose wedgefish *Rhynchobatus australiae*, the latter being the main target species. Catch composition differed between individual tangle net boat landings, likely reflecting different fishing grounds, seasonal variation and potential localised declines in species over time. The fishery is highly selective for larger size classes, but smaller size classes of target species are also caught in high numbers in other Indonesian fisheries such as trawl, small mesh gillnet, and hand- and long- line fisheries. As of July 2018, the tangle net fishery was still operating, but few wedgefish were caught and the main landed catch was stingrays. Evidence of substantial and rapid declines in landings of wedgefish species, raises concerns about the status of shark-like batoids and stingrays in Indonesia.

Keywords: South-East Asia, wedgefish, giant guitarfish, stingrays, liongbun net, conservation, threatened species

Introduction

Over the past three decades the declines of many chondrichthyan (sharks, rays, and chimaeras) populations have become a significant environmental concern [1-3]. The declines are a consequence of the rapid expansion of chondrichthyan take in fisheries [4], and globalisation of trade [5, 6]. Chondrichthyans have intrinsically low biological productivity, as the result of their slow growth, late maturity, long generation times, and low fecundity, and therefore are slow to recovery from population declines [7]. Overfishing is the major threat to chondrichthyans, with one-quarter of shark and ray species threatened from target and non-target fisheries [8]. Population declines have been driven by the high prices of various shark and ray products on the global markets, particularly fins, but also demand for other products such as meat, gill plates, cartilage and skin for leather [6]. The magnitude of the declines and the subsequent conservation issues has become a key focus for major international management conventions and agencies, such as Convention on International Trade in Endangered Species (CITES), Convention on the Conservation of Migratory Species of Wild Animals (CMS), the United Nations Food and Agriculture Organisation (FAO), and Regional Fisheries Management Organisations (RFMOs). To date, most of the scientific studies and conservation efforts have focused on the decline of shark populations [9-11], and until recently, there has been little attention to the declines in ray populations despite them being among the most threatened groups of chondrichthyans [8].

The reported global chondrichthyan catch has been increasingly dominated by rays (Order Batoidea) [8]. Rays are mainly taken as bycatch in fishing gears such as trawls, pelagic and bottom long lines, purse seines, and gillnets, while there are few targeted fisheries [12]. The larger species of batoids have some of the lowest intrinsic rates of population increases [13-15], and like most chondrichthyans, cannot sustain high levels of fishing pressure before population collapse [16, 17]. Shark-like batoids (Rhinopristiformes) include five families: Pristidae (sawfishes, 5 species), Rhinidae (wedgefishes, 10 species), Rhinobatidae (guitarfishes, 32 species), Glaucostegidae (giant guitarfishes, 6 species) and Trygonorrhinidae (banjo rays, 8 species) [18, 19]. The vast majority of wedgefishes and giant guitarfishes are strongly associated with soft-bottom habitats in shallow (<100 m) tropical and temperate coastal waters, and play an important trophic role in soft sediment ecosystems [20-22]. This results in high exposure to intensive and expanding fisheries [23, 24]. These coastal habitats are under threat from anthropogenic influences, which is also a significant threat for these rays [25, 26]. Globally these species have become an important component of fisheries landings as result of their high valued fins, which are considered amongst the most lucrative shark and ray product [4, 23, 27, 28]. These batoids are extremely sensitive to overexploitation, with four of the families considered the most at risk of extinction of the chondrichthyans [8], and wedgefishes and giant guitarfishes have surpassed sawfishes being the most imperilled marine fish families globally[29] . The most recent International Union for Conservation of Nature's (IUCN) Red List of Threatened Species assessments for wedgefishes and giant guitarfishes have found that all but one of the 16 species have experienced an extremely high risk of extinction and are classified as Critically Endangered (CR) [29]. Only the eyebrow wedgefish, *Rhynchobatus palpebratus* was not assessed as CR, instead as Vulnerable (VU), due to it occurring primarily in Australia where there is low fishing pressure and some management measures in place [29]. Substantial declines and localised extinctions have already been reported for several batoid species [30] and there is limited information available on the species' interactions with fisheries and their life history, both of which limit development of effective management.

Indonesia is the world's largest contemporary elasmobranch fishing nation, accounting for ca. 13% of the global elasmobranch catch [31]. It is the third largest exporter of shark fins in regards to quantity, with an average of 1235 tonne and sixth largest in value, worth an average of US$10 million per year [32]. In Indonesia, wedgefishes and giant guitarfishes are caught as bycatch in a variety of fisheries, but in addition are specifically targeted in the tangle net fishery, also referred to as set bottom gillnets, shark/ray gillnets, and locally as "jaring liongbun" [=gillnet guitarfish] and "jaring cucut" [=gillnet shark]. This fishery uses hung, large diameter mesh (50 - 60cm) bottom-set gillnet, to specifically capture large rays. The high value fins of wedgefishes and giant guitarfishes is a particularly strong driver for this fishery, with the fins worth around 1.5 times more than those from other species [27], as well as leather products from stingrays, which have high market value and are increasing in demand [33, 34].

The Indonesian tangle net fishery began in the Aru Islands in the mid-1970s, and it rapidly expanded throughout the whole Indonesian archipelago [27]. In 1987, the Aru Island tangle net fishery peaked with 500 boats [35], and the rapid development of the fishery during this time was primarily driven by shark-fin exports [36, 37]. The trade of these fins was suspected to be the primary reason for the doubling of value of the Indonesian fin exports to Hong Kong in the 1980's [36]. However, apparent declines in catch and increases of fishing effort, the number of tangle net boats fishing around the Aru Islands dropped to approximately 100 boats in 1996 [27]. Yet despite the decline in the number of boats and catch of the target species, the fins from wedgefish had such high value in the fin trade, the fishery was still considered economically viable and continued to operate, albeit with fewer vessels. The tangle net fishery also began operating from other ports in Indonesia, including Cirebon (West Java) from 1994 [38, 39] and the larger port Muara Angke (Jakarta) with the earliest records from 1991 [40]. In 2000, 100 gillnet vessels based in Cirebon were active [38]. In 2015, a total of 14 gill nets boats that fish in the Arafura Sea were reported to be active in Bitung, North Sulawesi [41]. In Muara Angke in 2004, 13 vessels were recorded to be operational in the tangle net industry, in waters around Borneo, Sulawesi and as far as West Papua. The number of boats operating from Muara Angke declined to 7 in 2005 [42]. There is no catch and size composition data available for this fishery, and the fishery as a whole is poorly defined and little understood. National fisheries landings data, including landings data for the tangle net fishery, are recorded as a single categories, such as "sharks" or "rays" with no species-specific details. There is strong anecdotal evidence of declines of wedgefish and giant guitarfish in some areas Indonesia as a result of this fishery [27, 35]. This raises concerns about the sustainability of the fishery and the population status of many of ray species caught.

To achieve sustainable use of these species, managers and conservation practitioners need to understand their population status, risk exposure, and resilience to fishing pressure and other threats. This requires data on fisheries catch composition, changes in relative abundance, and their interactions with fisheries. This information can then be used to inform the basis for the development of local and international management plans and conservation action for these threatened rays [43, 44]. The main aims of this paper are to (1) examine species, size and sex composition of the landed catch of tangle net fishery and changes over time in abundance and species compositions, (2) and to discuss the results in terms of potential consequences for the fishery, conservation and management.

Materials and Methods

Muara Angke market surveys: 2001 – 2005

Elasmobranch catches from the tangle net fishery were recorded at the Muara Angke landing site (North Jakarta, Indonesia) and the adjacent village where post-landing processing of fish occurred between April 2001 and December 2005 (Fig. 1). Landing site surveys were conducted on 18 occasions, and for each visit the landing site was surveyed for 1–4 consecutive days, resulting in a total 53 sampling days (SI Table 1). Informal interviews were conducted with the local fishers to enquire about the fate of the catch, prices and products of the fishery, and destinations of the various products.

Figure 1. The location of the Muara Angke landing port and processing village in Jakarta (star), and the location of Cirebon (diamond) and Benoa Harbour (triangle), Java Indonesia.

The number of each species landed from a tangle net boat was recorded. Due to the large number of landings and time constraints on each day surveyed, the number of specimens, biological data and measurements could not be taken from all sharks and rays present. Only specimens that could be accessed were surveyed, as randomised selection for sex/size was not possible. At the Muara Angke fishing port, catch composition could only be recorded for a brief period while the boats were being unloaded (Fig. 2a, b). As catches were unloaded over an ~2 hr period, the sharks and rays were placed into large hand-wheeled carts and taken to the adjacent village processing area, located less than a kilometre from the fishing port itself. Within the village processing area, the large sharks and rays from the tangle net fishery were typically taken to one of about 4 processing 'houses' (Fig. 2 d). Species and size composition data was more readily collected during the unloading from the boat at the fishing port. Similar data could be obtained at the village processing area, often from the previous day's landings, but it was not possible to determine how many boats they originated from if more than one boat had landed in the previous two days. On days when catches were recorded in Muara Angke landing port, these catches were not examined again in the village processing area. Due to the relatively low number of landings observed per trip, this issue was rarely encountered (SI Table 1). In addition, landings from tangle net fishing boats operating in the

Banda and Arafura Seas which land at Benoa Harbour, Bali (Fig. 1), were also observed on one occasion. These catches arrived into the village processing area by freezer truck direct from Bali. Often individual tangle net boats would come into port once a month, and on three occasions it was possible to document the entire catch from these tangle net boats. These boats were recorded in Muara Angke landing port in July 2004, October 2004 and October 2005, and will be referred as Boat One, Boat Two and Boat Three, respectively. Boat Three included the catches of two boats which landed on the same day. However not all catch was examined for one of the boats, therefore the catches were combined and will be referred to as Boat Three.

Figure 2. Tangle net fishery catches at Muara Angke, Jakarta: (a) Large bottlenose wedgefish *Rhynchobatus australiae* unloaded from tangle net boats at the port; (b) Large stingrays being processed at the adjacent village processing area; (c) Drying ray skins which will be used to make stingray leather products such as wallets and belts; (d) Wedgefish landings from Arafura Sea at the village processing area – *Rhynchobatus australiae* in centre of image highlighting the line of three white spots (yellow circle) diagnostic in this species.

Catch composition of elasmobranchs from other fisheries were also recorded during the Muara Angke surveys to allow for a comparison of the size composition of species between the tangle net fishery and the other fisheries exploiting the same species. This included landings from small-mesh gillnet (<20 cm mesh size) fisheries, Java Sea and Arafura Sea trawl fisheries, southern Java trammel net fishery, and various hand- and long-line fisheries, which were operating out of the landing sites surveyed (see [12]). Similar to the tangle net fishery landings, only landed catch that could be accessed when a boat was unloading could be surveyed and randomised selection was not possible.

Biological data

When possible, the disc width (DW) for the Dasyatidae, Myliobatidae, Aetobatidae, Gymnuridae and Rhinopteridae, and total length (from the tip of the snout to the tip of the upper lobe of the caudal fin; TL) for the sharks and shark-like batoids (Pristidae, Glaucostegidae and Rhinidae) were measured to the nearest 1 mm, and sex recorded. As the shark-like batoids were typically landed without fins, an estimated TL was recorded when animals were landed without fins. Removal of fins from these rays occasionally occurred following the landing, and after the weighing of specimens. Total weight (TW) of whole individuals (fins attached and not gutted) was recorded to the nearest g or kg (depending on the size of the individual), however, the vast majority of batoids and sharks could not be weighed at the landing site. When large numbers of similar sized individuals were observed, measurements were taken from a sub-set of whole individuals that could be accessed, and used to estimate DW, TL and TW for the remaining individuals not measured. For the individuals where the lengths were measured but not weighed, the weight of each individual was calculated using the equation for the relationship between length and whole weight for the species (SI Table 2). For species where a length-weight equation was not available, the estimated weight was calculated using the equation from a morphologically similar species (SI Table 1). In instances when the size of individuals for a particular species were not recorded, the weight was estimated using the average weight of the individuals for that species. Total weight was then determined for each species landed in the fishery. Details on the reproductive biology of each species recorded were reported in [12]

Species identification

Species were identified using the keys in [45] and [46], with nomenclature updated using [47] and [48]. The identity of a subsample of *Rhynchobatus* species caught in the tangle net fishery was also further verified by genetic analysis (see [49]) and from images using recently determined colour pattern differences between species [47]. The key colour pattern difference used to differentiate *R. australiae* from its closest regional congeners was the pattern of white spots around the dark pectoral spot present in all but the largest individuals. In *R. australiae*, there is a line of 3 white spots located adjacent to the black pectoral spot, or its usual position if faded [47]. In two large pregnant females which possessed no white spots or black pectoral spots, due mainly to their poor condition, the typical *R. australiae* spot pattern was evident in late-term embryos allowing for confirmation of their identity. The stingrays, *Maculabatis gerrardi* and *Maculabatis macrura* have overlapping distributions and differ in mostly subtle morphological characteristics [47], thus without genetic identification, the two species cannot be readily differentiated. Furthermore, since *M. macrura* was only recently recognised as valid and distinct from *M. gerrardi* [47], our data could not be retrospectively confirmed as either or both species. Although these records could constitute either species, herein we refer to these species as the prevailing name used for the whitespotted species in Indonesia, *M. gerrardi*.

Data analysis

Species composition of the landings was expressed as percentage of the total number of individuals by the recorded number and mass for each species at the landing site and processing village. Minimum, maximum and mean ± standard error (S.E.) for DW, TL and TW are reported for each species. Size frequency histograms for the most abundant species were produced. Data for the three individual tangle nets was grouped to demonstrate overall landed species composition, and to the variation of species composition between individual boats, data from Boat One and Boat Two were displayed to examine differences in catches between vessels..

Contemporary tangle net fishery: 2005 – 2014 & 2017 - 2018

Total *Rhynchobatus* spp. landings in tonnes across all Indonesian fisheries between 2005 – 2014 was obtained from the Indonesian Capture Fisheries department (Dharmadi pers. data). Information on how the data was collected was not available. Muara Angke landing survey data was obtained (Dharmadi pers. data) from the Indonesian Capture Fisheries department, from 2nd January 2017 – 16th July 2018. The date of arrival into the landing port, vessel, owner, fishing gear, total number of animals caught, and the main three species and landed catch caught per species in kilograms (kg) was recorded for each boat.

Ethics Statement

All marine life examined in this study were landed from fisheries in Indonesia and were already dead upon inspection. Permission to undertake surveys in Indonesia was granted by the Research Centre for Fisheries Management and Conservation in Jakarta as part of collaborative projects funded by the Australian Centre for International Agricultural Research (project codes FIS/2000/062 and FIS/2003/037). No other authorisation or ethics board approval was required to conduct the study.

Results

Muara Angke market surveys: 2001-2005

Species and size composition of the fishery

Across 18 sampling trips, totalling 53 survey days, the tangle net boats were recorded in Muara Angke landing port 8 times, and 7 times within the village processing area. A total of 1,551 elasmobranchs were recorded from tangle net fishery landings at Muara Angke during port surveys between April 2001 and December 2005. This comprised 1,526 batoids (98.3% of the catch) comprising 24 species from seven families (Table 1). The most abundant family was the Dasyatidae, contributing 72.5% to the total number of elasmobranchs recorded, followed by the family Rhinidae, comprising 20.8% of total observed catch. Only 25 sharks were recorded, with nine shark species from four families (Table 1). As not all individuals could be counted when landed, and in many cases the numbers were estimated, the numbers presented thus represents an underestimation of the total number of individuals caught in this fishery during the survey period. Of the 33 shark and ray species recorded in this fishery during the surveys, 24 species (80%) are listed as threatened (Critically Endangered, Endangered, or Vulnerable) in the IUCN Red List of Threatened Species (Table 1).

Family Pristidae

Two largetooth sawfish *Pristis pristis* caught in the Arafura/Banda Sea region were recorded from the Benoa Harbour landings in August 2002 (Table 2; Fig. 1). Both individuals were adult males and both ca. 420 cm TL and estimated total landed weight of 220 kg (Table 2).

Family Glaucostegidae

Two species of giant guitarfish were recorded in Muara Angke landing port: the clubnose guitarfish *Glaucostegus thouin* and giant guitarfish *Glaucostegus typus.* The presence of *G. thouin* in the fishery was recorded once in April 2001 (Table 2). However due to the logistics of accessing these rays upon unloading from the boat and the rotten state of the specimens, the estimates of numbers or size was not possible for *G. thouin*. Yet, *G. thouin* individuals were present in a number of images taken during surveys, so it is likely to be a regular catch in this fishery. Fourteen *G. typus* were recorded on three occasions (Table 2), however only a subset of specimens were able to be measured. Seven were females, six males and one not sexed, with an estimated total landed weight of 386 kg (Table 1).

Family Rhinidae

Three species of wedgefish were recorded from Muara Angke landing port: the bowmouth guitarfish *Rhina ancylostoma*, the bottlenose wedgefish *Rhynchobatus australiae*, and the eyebrow wedgefish *Rhynchobatus palpebratus. Rhina ancylostoma* was recorded on 7 occasions over the sampling period (Table 2). The landed catch of *R. ancylostoma* comprised 15 females, 10 males, and 32 specimens counted but not sexed, with an estimated total landed weight of 4.4 tonnes (Table 1). Females ranged from 139–250 cm TL and 22.9–133.6 kg, and males ranged from 130–260 cm TL and 18.7– 150.3 kg, and only one unsexed was measured at 270 cm TL and 168 kg. *Rhynchobatus australiae* comprised the largest component of wedgefishes in the Indonesia tangle net fishery and the second most abundant species recorded (Table 1). It was recorded on 8 occasions (Table 2) and a total of 238 individuals with an estimated total landed weight of 24 tonnes, comprising 99 females, 18 males and 121 unsexed individuals. A subset of 29 individuals were measured, the majority of which were females approximately 300 cm TL (Fig. 3a). On one occasion, approximately 7.1 tonnes

Table 1. Species composition, number of individuals of a species observed (no.) and overall percentage (% by no.) of the catch for the elasmobranchs caught by the tangle net fishery, and landed in Muara Angke landing port, Jakarta Indonesia in April 2001 – December 2005. The reported maximum size (Reported Max. size) and observed minimum (Min.), observed maximum size (Max.), and observed mean (± S.E.) size (DW/TL cm) and minimum estimated total weight (kg) are reported for each species, with the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species status (as of May 2019). IUCN categories are CR, Critically Endangered; EN, Endangered; VU, Vulnerable; LC, Least Concern; DD, Data Deficient. Dashed lines indicate species presence was recorded in landings, but data was not able to be documented.

Family	Scientific name	Common name	IUCN Listing	Year Assessed	Reported Max. size	No.	% by No.	Min. size	Max. size	Mean Size	± S.E.	Min. weight	Max. weight	Mean Weight	± S.E.
Pristidae	*Pristis pristis*	Largetooth sawfish	CR	2013	656.0	2	0.128	--	420.0	420.0	--	--	220.3	220.3	--
Glaucostegidae	*Glaucostegus thouin*	Clubnose guitarfish	CR*	2019	250.0	--	--	--	--	--	--	--	--	--	--
	Glaucostegus typus	Giant sholvenose ray	CR*	2019	270.0	14	0.898	170.0	260.0	206.0	13.15	14.86	51.36	27.57	5.543
Rhinidae	*Rhina ancylostoma*	Bowmouth guitarfish	CR*	2019	270.0	57	3.656	130.1	270.0	190.2	22.97	18.68	168.4	77.38	24.29
	Rhynchobatus australiae	Bottlenose wedgefish	CR*	2019	300.0	238	15.27	190.0	300.0	282.1	4.662	30.21	118.7	100.9	4.181
	Rhynchobatus palpebratus	Eyebrow wedgefish	VU*	2019	262.0	30	1.924	--	--	--	--	--	--	--	--
Dasyatidae	*Bathytoshia lata*	Brown stingray	LC	2007	260.0	1	0.064	--	202.0	202.0	--	--	--	300.0	--
	Himantura leoparda	Leopard whipray	VU	2015	140.0	31	1.988	83.20	120.0	98.72	3.016	14.37	39.45	23.61	2.061
	Himantura uarnak	Coach whipray	VU	2015	160.0	57	3.656	42.60	147.6	99.50	6.204	4.015	69.83	28.57	4.189
	Himantura undulata	Honeycomb whipray	VU	2011	130.0	1	0.064	--	112.8	112.8	--	33.27	--	33.27	--
	Maculabatis astra	Blackspotted whipray	LC	2015	80.0	4	0.257	--	79.00	79.00	--	13.26	--	13.26	--
	Maculabatis gerrardi	Whitespotted whipray	VU	2004	116.0	194	12.44	62.70	89.50	75.85	1.036	6.560	19.40	12.01	2.410
	Megatrygon microps	Smalleye stingray	DD	2015	222.0	1	0.064	--	174.8	174.8	--	111.3	--	111.3	--
	Pastinachus ater	Broad cowtail ray	LC	2015	200.0	199	12.76	86.00	149.0	114.3	2.618	15.74	71.67	37.98	2.332
	Pateobatis fai	Pink whipray	VU	2015	146.0	264	16.93	70.50	168.4	110.9	4.595	9.101	100.4	36.45	4.143
	Pateobatis jenkinsii	Jenkin's whipray	VU	2015	150.0	187	11.99	59.20	138.4	82.59	1.791	5.621	58.47	14.78	1.207
	Pateobatis uarnacoides	Whitenose whipray	VU	2004	119.0	125	8.018	51.70	118.8	91.23	4.206	3.869	38.38	20.42	2.390
	Taeniurops meyeni	Blotched stingray	VU	2015	180.0	51	3.271	62.80	164.0	116.8	5.332	6.615	93.37	40.25	4.713
	Urogymnus asperrimus	Porcupine ray	VU	2015	115.0	5	0.321	76.50	103.4	89.95	9.511	11.40	26.17	18.78	5.222
	Urogymnus granulatus	Mangrove whipray	VU	2015	141.0	10	0.641	97.20	141.0	118.8	6.300	22.07	61.55	39.72	5.728
Gymnuridae	*Gymnura zonura*	Zonetail butterfly ray	VU	2006	108.0	7	0.449	70.50	91.60	79.78	3.036	2.442	5.466	3.657	0.4433

Aetobatidae	*Aetobatus ocellatus*	Spotted eagle ray	VU	2015	330.0	45	2.886	108.9	214.4	138.6	3.994	19.37	135.4	41.43	4.151
Myliobatidae	*Aetomylaeus vespertilio*	Oranate eagle ray	EN	2015	300.0	11	0.706	146.2	240.0	187.5	17.157	45.11	187.1	100.6	26.66
Carcharhinidae	*Carcharhinus amboinensis*	Pigeye shark	DD	2005	248.0	--	--	--	--	--	--	--	--	--	--
	Carcharhinus obscurus	Dusky shark	VU	2007	360.0	2	0.128	--	--	--	--	--	--	--	--
	Carcharhinus leucas	Bull shark	NT	2005	340.0	2	0.128	--	--	--	--	--	--	--	--
	Carcharhinus limbatus	Common blacktip shark	NT	2005	193.0	6	0.385	--	--	--	--	--	--	--	--
	Galeocerdo cuvier	Tiger shark	NT	2005	550.0	4	0.257	--	--	--	--	--	--	--	--
Ginglymostomatidae	*Nebrius ferrugineus*	Tawny nurse shark	VU	2003	320.0	3	0.192	--	--	--	--	--	--	--	--
Hemigaleidae	*Hemipristis elongata*	Fossil shark	VU	2015	240.0	3	0.192	109.6	122.9	116.3	4.702	5.719	25.14	6.989	0.8984
Sphyrnidae	*Sphyrna lewini*	Scalloped hammerhead shark	EN	2007	346.0	3	0.192	--	175.4	175.4	--	--	--	25.14	--
	Sphyrna mokarran	Great hammerhead shark	EN	2007	610.0	2	0.128	--	--	--	--	--	--	--	--

* The newest IUCN Red List assessments of these rays have been accepted but have not been published on the IUCN Red List website. Status information is available from [29]

Table 2. Elasmobranch species presence and absence landed from tangle net boats in Muara Angke landing port, Jakarta in April 2001 – December 2005, over a total of 53 survey days, grouped by months.

		2001			**2002**				**2003**		**2004**						**2005**						
Family	**Species**	Apr	Aug	Jul	Mar	May	Aug	Oct	Jan	Feb	Apr	Jul	Aug	Sep	Oct	Dec	Jan	Mar	May	Jun	Jul	Oct	Dec
Pristidae	*Pristis pristis*	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Glaucostegidae	*Glaucostegus thouini*	Y	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Glaucostegus typus	Y	--	--	--	--	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	Y	--	--
Rhinidae	*Rhina ancylostoma*	Y	--	--	--	--	--	Y	--	--	--	Y	--	--	Y	--	--	--	--	--	Y	Y	Y
	Rhynchobatus australiae	Y	--	--	Y	--	Y	Y	--	--	--	Y	--	--	Y	--	--	--	--	--	Y	Y	--
	Rhynchobatus palpebratus	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Dasyatidae	*Bathytoshia lata*	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Himantura leoparda	Y	--	--	--	--	Y	--	--	Y	--	Y	--	--	Y	--	--	--	--	--	Y	Y	--
	Himantura uarnak	Y	--	--	Y	--	Y	--	--	Y	--	Y	--	--	Y	--	--	--	--	--	--	Y	--
	Himantura undulata	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Y	--
	Maculabatis astra	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Maculabatis gerrardi	Y	--	--	Y	--	--	Y	--	Y	--	Y	--	--	Y	--	--	--	--	--	Y	Y	--
	Megatrygon microps	--	--	--	--	--	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--
	Pastinachus ater	Y	--	--	Y	--	Y	Y	--	--	--	Y	--	--	Y	--	--	--	--	--	Y	Y	--
	Pateobatis fai	Y	--	--	Y	--	Y	Y	--	Y	--	Y	--	--	Y	--	--	--	--	--	--	Y	--
	Pateobatis jenkinsii	Y	--	--	Y	--	Y	Y	--	--	--	Y	--	--	Y	--	--	--	--	--	Y	Y	--
	Pateobatis uarnacoides	Y	--	--	--	--	Y	Y	--	Y	--	Y	--	--	Y	--	--	--	--	--	--	Y	--
	Taeniurops meyeni	Y	--	--	Y	--	Y	--	--	Y	--	Y	--	--	Y	--	--	--	--	--	--	Y	--
	Urogymnus asperrimus	Y	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Urogymnus granulatus	Y	--	--	Y	--	Y	--	--	Y	--	Y	--	--	Y	--	--	--	--	--	--	Y	--
Gymnuridae	*Gymnura zonura*	Y	--	--	--	--	--	Y	--	Y	--	Y	--	--	--	--	--	--	--	--	--	Y	--
Aetobatidae	*Aetobatus ocellatus*	Y	--	--	Y	--	Y	Y	--	--	--	Y	--	--	Y	--	--	--	--	--	Y	Y	--
Myliobatidae	*Aetomylaeus vespertilio*	Y	--	--	--	--	--	--	--	Y	--	Y	--	--	Y	--	--	--	--	--	--	--	--
Carcharhinidae	*Carcharhinus amboinensis*	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Carcharhinus obscurus	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Y	--
	Carcharhinus leucas	--	--	--	--	--	--	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	Y	--
	Carcharhinus limbatus	Y	--	--	--	--	Y	--	--	--	--	Y	--	--	Y	--	--	--	--	--	--	Y	--
	Galeocerdo cuvier	Y	--	--	--	--	Y	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Y	--
Ginglymostomatidae	*Nebrius ferrugineus*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Y	--

Hemigaleidae	*Hemipristis elongatus*	--	--	--	--	--	--	--	--	--	--	--	--	--	Y	--	--	--	--	--	--	--	Y
Sphyrnidae	*Sphyrna lewini*	Y	--	--	--	--	--	--	--	--	--	Y	--	--	Y	--	--	--	--	--	--	--	--
	Sphyrna mokarran	Y	--	--	--	--	--	--	--	--	--	Y	--	--	Y	--	--	--	--	--	--	--	--
	Number of ray species	18	0	0	10	0	14	9	0	9	0	16	0	0	13	0	0	0	0	0	8	14	1
	Number of shark species	5	0	0	0	0	3	0	0	0	0	4	0	0	4	0	0	0	0	0	0	5	1
Total number of species observed		23	0	0	10	0	17	9	0	9	0	20	0	0	17	0	0	0	0	0	8	19	2

of *R. australiae* was landed from a single tangle net boat on the 14th August 2002. A total of 16 *Rhynchobatus* landed in the tangle net fishery had their identifications confirmed by genetic analysis (see [49]). Of these 16, two were from landings at Muara Angke and the remaining 14 from the Benoa Harbour landings. The 14 Benoa Harbour individuals consisted of five *R. palpebratus* (reported as *R. palpebratus/R. cf laevis* in [49]) and nine *R. australiae*. The known distribution of *R. palpebratus* is northern Australia and New Guinea and thus was not surprising for it to be observe in landings from the Arafura Sea region. The ratio of *R. palpebratus* to *R. australiae* determined from the genetic analysis (45:6%) was used to estimate the species composition of the 100 *Rhynchobatus* individuals recorded in the Benoa Harbour landings on the 14th August 2002 (SI Table 1). *Rhynchobatus palpebratus* was recorded on one occasion, with a total of 30 individuals but not sexed, measured or weighed (Table 1).

Figure 3. Size-frequency histograms of the most abundant ray species (represented by 10 or more measured individuals) in the tangle net catches: (a) *Rhynchobatus australiae*; (b) *Himantura leoparda*; (c) *Himantura uarnak*; (d) *Maculabatis gerrardi*; (e) *Pastinachus ater*; (f) *Pateobatis fai*. In this Figure and Figure 4, the species are placed in phylogenetic order from wedgefish through to eagle rays; white bars denote females, grey bars males and black bars unsexed individuals; the total number (n) of individuals, known size at birth (red line) and known size at maturity (M, male; F, female) when known; the size scale bar (x-axis) extends to the maximum known size for each of the species.

Family Dasyatidae

Stingrays were present in every tangle net catch landed in Muara Angke (Table 2). A total of 1130 stingrays, with an estimated mass of 30.2 tonnes, were recorded comprising 13 species from 8 genera (Table 1). The most abundant stingray species were the pink whipray *Pateobatis fai* (9.6 tonnes; Fig. 3f), broad cowtail ray *Pastinachus ater* (7.5 tonnes; Fig. 3e), whitespotted whipray *Maculabatis gerrardi* (2.3 tonnes; Fig. 3d), Jenkin's whipray *Pateobatis jenkinsii* (2.7 tonnes; Fig. 4a), and the whitenose whipray *Pateobatis uarnacoides* (2.5 tonnes; Fig. 4b). Other species that were recorded were brown stingray *Bathytoshia lata,* leopard whipray *Himantura leoparda* (Fig. 3b), coach whipray *Himantura uarnak* (Fig. 3c), honeycomb whipray *Himantura undulata*, blackspotted whipray *Maculabatis astra*, smalleye stingray *Megatrygon microps*, blotched stingray *Taeniurops meyeni* (Fig. 4c) and porcupine ray *Urogymnus asperrimus*. *Maculabatis astra* was only recorded from the single Benoa Harbour landing, this species is only present in the far eastern portion of Indonesia off West Papua and is allopatric from *M. gerrardi* [47]. As a result, this species is a good indicator species if a particular tangle net fishing catch was suspected of coming from the Arafura Sea region. Specimens from *H. leoparda, H. uarnak, P. fai, P. uarnacoides* and *T. meyeni* specimens were close to the known maximum size (Fig. 3,4). The majority of the specimens caught for each species were near or at a larger size than their known size at maturity (Fig. 3,4; SI Table 3).

Figure 4. Size-frequency histograms of the most abundant ray species (represented by 10 or more measured individuals) in the tangle net catches: (a) *Pateobatis jenkinsii*; (b) *Pateobatis uarnacoides*; (c) *Taeniurops meyeni*; (d) *Aetobatus ocellatus*. In this Figure and Figure 4, the species are placed in phylogenetic order from wedgefish through to eagle rays; white bars denote females, grey bars males and black bars unsexed individuals; the total number (n) of individuals, known size at birth (red line) and known size at maturity (M, male; F, female) when known; the size scale bar (x-axis) extends to the maximum known size for each of the species.

Family Aetobatidae

One species of eagle ray, spotted eagle ray *Aetobatus ocellatus,* was recorded in the tangle net fishery on 8 occasions (Table 2). A total of 45 individuals were observed, with an estimated total landed weight of 1.8 tonnes (Table 1). This comprised of 21 females, 22 males, and 2 unsexed specimens (Fig. 4d). *Aetobatus ocellatus* specimens were mainly caught close to or at a greater size than the known size at maturity (Fig. 4d; SI Table 3).

Other families

Similarly, only one species of Myliobatidae was recorded, the ornate eagle ray *Aetomylaeus vespertilio*, with an estimated landed catch of 1.1 tonnes, of which 5 were females, 1 male, and 5 unsexed individuals (Table 1). The specimens of this species recorded were all large, including one 160 kg female. They were recorded occasionally and comprised a small proportion of the total landed catch during 2001–2005 (Table 2). A single Gymnuridae species was recorded, the zonetail butterfly ray *Gymnura zonura* (Table 1). Sharks were a minor part of the tangle net catch in the Muara Angke surveys and rarely observed (Table 2). All of the shark species represented less than 1% of the total catch (Table 1). Carcharhinid sharks that were present in the fishery in small numbers were the pigeye shark *Carcharhinus amboinensis,* dusky shark *Carcharhinus obscurus* (n = 2), bull shark *Carcharhinus leucas* (n = 2), common blacktip shark *Carcharhinus limbatus* (n = 6) and tiger shark *Galeocerdo cuvier* (n = 4). In addition, other sharks recorded from the fishery were the tawny nurse shark *Nebrius ferrugineus* (n = 3) on one occasion, fossil shark *Hemipristis elongata* (n = 4) on two occasions, scalloped hammerhead *Sphyrna lewini* (n = 3) on 3 occasions, and great hammerhead *Sphyrna mokarran* (n = 3) on 3 occasions (Table 1; Table 2).

Variation in species composition between individual tangle net boats

For the three tangle net boats of which the entire landed catch was document, the most abundant species was *M. gerrardi*, followed by *R. australiae, P. ater, R. ancylostoma, A. ocellatus, H. uarnak,* and *P. jenkinsii* (Fig. 5). Eighteen other species of elasmobranchs, comprising 10 ray species and 8 shark species, were also recorded but in low numbers. All three boats fished in waters around Kalimantan, however the species composition varied considerably between the individual boats (Fig. 6). Boat One reported fishing in waters around West Sumatra, to Riau Islands and Kalimantan, and in less than 100 meters of water (Fig. 1). From Boat One, 138 large rays representing 13 species, with an estimated weight of 11 tonnes, and 4 large carcharhinids (2 species) were recorded. The most abundant species for this boat was *R. australiae* with 69 specimens recorded (45.6%) (Fig. 6). Boat Two was from Pontianak in West Kalimantan (Fig. 1). A total of 111 specimens were recorded from Boat Two, comprised of 106 medium-large rays from 13 species, with a total estimated weight of 4.8 tonnes, and 5 sharks (4 species). The most abundant species was *M. gerrardi* with 33 individuals (29.7% of total catch) (Fig. 6). The landed catch of *R. australiae* and *M. gerrardi* appeared to be an inverse relationship between the Boat One and Boat Two (Fig. 6). Boat Three (which comprised the catches of two boats landed on the same day) was from Kalimantan (Fig. 1), with a total of 219 specimens were examined, comprised of 211 rays, with and estimated catch weight of 10 tonnes, and 5 sharks. The most abundant species was *M. gerrardi* with 102 individuals (46.6%).

Figure 5. Overall species composition and percentage (%) of catch of the three Indonesian individual tangle net boats, of which the catch was fully documented from Muara Angke landing port, Jakarta. Boat One landed on 7th July 2004; Boat Two landed on 16th October 2004; Boat Three which landed the 5th October 2005

Figure 6. Variation in the elasmobranch species composition for individual tangle net boat landings for Boat One (red) landed on 7th July 2004, and Boat Two (blue) landed on 16th October 2004 from the Indonesian tangle net fishery from Muara Angke, Jakarta.

Products from the tangle net fishery

From the informal interviews with the local fishers conducted in the 2001 – 2005 market surveys, the main products from the tangle net fishery were documented to be fins from shark-like batoids, leather from ray skins, salted meat, and vertebrae. The most important product from the tangle net fishery are the fins from wedgefishes and giant guitarfishes. During the surveys in 2005, the quoted price for fins from sawfish, wedgefish and guitarfish were approximately Indonesian rupiah (Rp) 3 million kg^{-1} (wet weight, ~US$202 in 2019 terms). Any fins frozen on board the tangle net boats did not come through the Muara Angke port, but were subsequently exported internationally to Hong Kong and Singapore, according to the local fishers.

Skins of stingrays, used to produce leather products, comprised the second most important product in the tangle net fishery (Fig. 2c). The species primarily used were from the genera *Himantura, Maculabatis*, *Pastinachus*, *Pateobatis* and *Urogymnus,* which together comprise a large component of the landed catch during the market surveys. *Pateobatis jenkinsii* was the most sought after stingray skin due to the row of enlarged thorns which extend down the midline of the body and tail. In 2005, the reported value by the local fishers of a 13 cm and 18 cm piece of stingray leather was Rp 25,000 and 35,000 (US $1.68 and $2.36 in 2019 terms), respectively, and approximately 3000–4000 skins were estimated to be exported per month to the Philippines and Japan. Ray meat, wedgefish in particular, was considered to be superior quality. In 2004, in the Muara Angke processing village the buying price for wedgefish and guitarfish meat was Rp 4,000–5,000 (US $0.27–0.34 in 2019) kg^{-1}. For stingrays, meat from the fishers was valued between Rp 2,000–3,500 (US $0.13–$0.24 in 2018) kg^{-1}. As the catch was landed in a deteriorated condition, meat from the rays and sharks is salted and dried. Salted meat was reported to be transported to West Java (Bandung, Bogor, Garut, Cianjur) and Central Java. Meat from wedgefish was stated to be sold for Rp 10,000–12,000 (US $0.67–$0.81 in 2019 terms) kg^{-1} for and for stingray meat Rp 6,000–8,000 (US $0.40–$0.54 in 2019 terms) kg^{-1}. The cartilage, such as vertebrae, comprised a small part of the products from this fishery. In 2004, the fishers received approximately Rp 20,000 (US $1.35 in 2018) kg^{-1} of dry vertebrae, which were then processed in Jakarta and exported to Korea and Japan.

Size selectivity of the tangle net fishery compared to other fisheries

The tangle net fishery is highly selective for wedgefish and guitarfish over 130 cm TL and stingrays over 50 cm DW (Fig. 3) as a result of the mesh size used. The smallest recorded individual caught in this fishery was a *P. uarnacoides* of 51.7 cm DW and the largest recorded individual was a male sawfish, estimated to be 420 cm TL. The smaller size classes for many of the species encountered in the tangle net fishery are also caught as bycatch in numerous other fisheries operating in Indonesian waters, including the trawls, hand- and long-lines, smaller mesh gillnets, and trammel nets (Fig. 7). All size classes of *R. australiae* are being caught by Indonesian fisheries; the neonates (~45 cm TL) are caught as bycatch in small mesh gillnets; sub-adults (~90–130 cm TL) were recorded in the Java

Sea trawl fishery; the larger and mature individuals (>170 cm TL) were recorded in hand- and long-line fisheries (Fig. 7a). Similar trends were seen for a number of dasyatid rays, with other life stages from neonates to sub-adults are also being caught in other fisheries (Fig. 7b). Catch of *Maculabatis gerrardi* was recorded from small mesh gillnet fishery (~20–70 cm DW), the Java Sea trawl fishery (~20–100 cm DW), and the trammel net fishery off southern Java (~30–70 cm DW) (Fig. 7b). *Pastinachus ater* was recorded in the hand- and long-line fisheries (~70–110 cm DW), compared to typically larger individuals in the tangle net fishery (~80–150 cm DW) (Fig. 7b). *Pateobatis fai* was recorded in the Java Sea trawl fishery (~60–70 cm DW), in the Arafura Sea trawl fishery (~139–160 cm DW) and hand- and long-line fisheries (~65–160 cm DW) (Fig. 7b). *Pateobatis jenkinsii* also exposed to fishing throughout all life stages, from small mesh gillnets (~25 – 75cm DW), hand- and long-line fisheries (~40–100cm DW), as well as the tangle net fishery (~60–140 cm DW) (Fig. 7b). Catch of *Pateobatis uarnacoides* was recorded in the Java Sea trawl fishery (~30–60 cm DW), and in the southern Java trammel net fishery (~25–55 cm DW) (Fig. 7b).

Figure 7. Comparison of the size ranges for the (a) *Rhynchobatus australiae* and (b) *Maculabatis gerrardi, Pateobatis ater, Pateobatis fai, Pateobatis jenkinsii,* and *Pateobatis uarnacoides* caught in the small mesh gillnet (blue), Java Sea trawl fishery (dark green), Arafura Sea trawl fishery (light green), trammel net (purple), hand- and long-line (yellow) and tangle net (red) in Indonesia.

Contemporary tangle net fishery: 2005–2014 & 2017–2018

From 2nd January 2017 to 16th July 2018, a total of 198 boat landings were recorded in the Muara Angke landing port. Of these landings, there were 14 were from tangle net boat landings and from 7 individual tangle net boats (Table 3). The species are only recorded under single labels in Indonesia Bahasa of "yong bung/cucut liong bung" [=wedgefish/shark ray], "pari" [=rays], "cucut" [=sharks], "manyung" [=local catfish species, *Netuma* spp.] and 'mix/mixed species'. Unknown wedgefish species comprised a small component of the total landings for these tangle net boats, with an estimated landed catch of 6 tonnes (Table 3). The majority of catch was recorded as rays with estimated landed catch of 43.9 tonnes, and unknown shark species were recorded once with 200 kg (Table 3). The local catfish species (*Netuma spp*.) was recorded from the tangle net landings, with an estimated catch of 5 tonnes, while unknown 'mixed species' accounted for 8 tonnes (Table 3). No

Table 3. Indonesian Capture Fisheries data on seven vessel landings from the tangle net fishery recorded at Muara Angke port in June 2017 - July 2018. The date of landing, vessel name, owner, and fishing gear, with main catch species, and landed catch weight (kilograms, kg) are reported. Dashed lines indicated no data was recorded. The species were recorded in Indonesia Bahasa, here they are reported in English with translation from Dharmadi. Source: [50]

Date of landing	Vessel name	Owner	Species 1	Catch (kg)	Species 2	Catch (kg)	Species 3	Catch (kg)	Total
4/06/2017	Surya Cemeralang II	Darman	Rays	12,000	--	--	--	--	12,000
28/07/2017	Hasanudin Jaya - 8	Ong Gikawati	--	--	--	--	--	--	--
13/09/2017	Hasanudin Jaya	Ong Gikawati	Rays	6,000	Mixed species	2,500	--	--	8,500
3/11/2017	Bahari Nusantara - XI	Darman	Rays	6,500	Mixed species	3,000	--	--	9,500
24/11/2017	Kerisi	Ong Gikawati	Rays	3,500	*Netuma spp.*	1,000	Mixed species	2,000	6,500
7/12/2017	Kerisi	Ong Gikawati	--	--	--	--	--	--	--
11/01/2018	Kerisi	Ong Gikawati	--	--	--	--	--	--	--
29/01/2018	Hasanudin Jaya	Ong Gikawati	Rays	4,500	Wedgefish spp 1	1,000	*Netuma spp.*	1,000	6,500
13/03/2018	Bahari Nusantara - XI	Darman	Rays	20,000	--	--			20,000
20/03/2018	Kerisi	Ong Gikawati	Sharks	200	*Netuma spp.*	1,000	Rays	3,000	4,200
29/03/2018	Tri Sanjaya	Hadi Suriadi	--	--	--	--	--	--	--
6/06/2018	Surya Cemeralang II	Darman	--	--	--	--	--	--	--
26/06/2018	Kerisi	Ong Gikawati	Rays	5,900	*Netuma spp.*	2,000	--	--	7,900
7/07/2018	Tri Sanjaya	Hadi Suriadi	Rays	2,503	Wedgefish spp 2	5,000	--	--	7,503

other data on species composition was recorded. The total landings data for wedgefish across all Indonesian fisheries (including the tangle net fishery, small-mesh gillnet (<20 cm mesh size) fisheries, Java Sea and Arafura Sea trawl fisheries, southern Java trammel net fishery, and various hand- and long-line fisheries), declined from 28,492 tonnes in 2005 to 7,483 tonnes in 2014, demonstrating a 73.7% reduced in landed catch (Fig. 8). Wedgefish landings declined by 87.2% between 2005 and 2008 (3,645 tonnes), with landings slightly increased in 2009 and then declined in 2010 (Fig. 8).

Figure 8. Total wedgefish (*Rhynchobatus spp.*) landings (tonnes) from all Indonesian marine fisheries, including the tangle net fishery, small-mesh gillnet (<20 cm mesh size) fisheries, Java Sea and Arafura Sea trawl fisheries, southern Java trammel net fishery, and various hand- and long-line fisheries, from 2005 – 2014. Source: [51]

Discussion

This study provides an major increase in our understanding of the data poor tangle net fishery in Indonesia, providing details on the species and size composition, size selectively of gear used as well as the other fisheries in the same area, and the consequent declines of shark-like batoids population in Indonesia. Substantial population declines can be inferred from the declining catch rates of the target species, *R. australiae,* and the decline in the number of vessels operating in the tangle net fishery from 500 in 1980's to 7 in 2017/2018, despite continuing high prices for fins and stingray leather. The reductions in vessels operating in the fishery suggests that populations of the target species have declined and were unable to economically sustain the level of catches made. Total wedgefish landings across all Indonesian fisheries drastically declined by almost 90% between 2005 and 2008 and has never recovered to 2005 levels. It must be noted that this data is from the multiple fisheries from the Indonesian National Fisheries Statistics. It has limited taxonomic detail and the trends cannot be verified with our tangle net survey results. In November 2015, [52] recorded 35 specimens without length data of *R. australiae*, 20 *G. thouin* and five *G. typus* from an unknown fishery, in the Muara Angke port. Despite the drastic declines in wedgefish populations, at least in part as a result of this targeting fishery, the Muara Angke tangle net fishery was still operational in July 2018. Wedgefish comprise a small component of the total landings for these tangle net boats, with the majority of catch beings rays. However, the current information is limited in taxonomic detail, as the catch is grouped under single labels such as 'rays', 'sharks', 'wedgefish' and 'mixed'. Thus the species, number caught and size composition information is limited. Regardless, this demonstrates that wedgefish and giant guitarfish, appear to comprise a small component of the fisheries catch today in Indonesia, compared to the extensive pre-1980's catches

[27]. Increasing fishing pressure on the stingrays may also be resulting in population declines, however there are insufficient data for stingrays in Indonesia to infer the extent of the declines. The loss of large, benthic, soft bottom elasmobranchs may have significant ecological consequences, altering important ecological processes. These rapid declines in wedgefish landings are consistent with known declines globally [30, 44, 53, 54], and supports the conclusion of ongoing population depletion for wedgefish species in Indonesia. Despite 80% of the species caught in the fishery being listed as threatened (Critically Endangered, Endangered, or Vulnerable) on the IUCN Red List of Threatened Species, the current status of populations and the extent of declines for these rays are uncertain, as there is no recent species-specific information for this fishery after 2005, requiring further investigation. Thus it appears that these groups may be facing a widespread conservation crisis [30].

With the declines in wedgefish and giant guitarfish catch, the tangle net fishery now appears to be reliant largely on the catch of rays for its viability as value for stingray leather has increased over the past decade. The catch of *R. australiae* appears to have an inverse relationship with *M. gerrardi*, where in cases when *R. australiae* catch is high, the catch of *M. gerrardi* is low. This difference in abundance is a probable indication of the declining abundance of *R. australiae* in some areas, in which case stingrays become the main catch. Both species are common demersal species in the Indo–West Pacific, and occupy similar habitats and areas of inshore continental shelves waters to at least 60 m [55, 56]. The time of year may also influence the catch, but more information is required both on catch composition of this fishery throughout the year. The low number of sharks in the tangle net fishery was also found in other tangle net fishery surveys [35, 38]. On one occasion, a smooth hammerhead *Sphyrna zygaena* was recorded from the tangle net fishery in Cirebon [38]. Whale sharks were recorded in 1988 and 2002 [35, 38], but there have been no contemporary records of *R. typus* caught in tangle net fishery. Non-elasmobranchs have been reported to be caught in the fishery in low numbers as bycatch or by-products, including green turtle, *Chelonia mydas,* and bony fish such as tuna recorded by the local name "tongkol" (Tribe *Thunnini*) [38] and sea catfish under the local name "manyung" [=*Netuma* spp]. There is limited information on species distribution, life history, habitat utilisation, and movement of shark-like batoid and stingrays worldwide [44]. Research on spatial ecology for wedgefish, guitarfish and stingrays is urgently required to identify critical areas (nursery or mating areas), seasonality of their habitat use, and vulnerability of the habitats to anthropogenic impacts [43, 44, 59, 60].

Misidentification of species can seriously compromise fisheries and conservation related research and management initiatives. *Rhynchobatus australiae* is the most commonly caught wedgefish species in South East Asia [49], yet it commonly confused with other large species, in particular with

Rhynchobatus djiddensis, Rhynchobatus laevis [49] *and R. palpebratus* [28]. *Rhynchobatus palpebratus* does not occur in the Java Sea and other western fishing areas in Indonesia and all images examined from landings during the market surveys in this study refer to *R. australiae* only. Misidentification is further compounded by the ambiguity over the ranges of these species and their occurrence in South East Asian fisheries [49]. For example, the broadnose wedgefish *R. springeri* overlaps in distribution with *R. australiae* off Java and Sumatra and catches could possibly have included this species. A single specimen of *R. springeri* was confirmed from the trawl fishery operating out of Muara Angke [49]. However, the majority of wedgefish recorded from the tangle net fishery were large females close to 300 cm TL, far larger than the maximum known size of 213 cm TL for *R. springeri* [47]. The other species are rarer in landings and possibly have more of a restricted and even fragmented spatial distributions [49]. Taxonomic confusion is also apparent with the giant guitarfish and stingray species in Indonesia and the tangle net fishery. Records of the sharp-nose guitarfish *Glaucostegus granulatus* from the tangle net fishery operating in the Arafura Sea in 1987, where it constituted 4.6% of the total landed catch [35], is likely to be a misidentification of *G. typus*. Prior to 2016, the range for *Glaucostegus granulatus* was poorly described with no records to suggest that this species occurred in Indonesia, and is now known to only occur in the northern Indian Ocean between Myanmar and the Persian Gulf [47]. *Aetobatus ocellatus* was previously considered to be conspecific with *A. narinari* and certain colour variations were previously considered to be a separate species, *A. guttatus*. However, [61] found that *A. narinari* is restricted to the Atlantic Ocean and *A. guttatus* is a junior synonym of *A. ocellatus*. Thus, only a single species is presently considered to occur in Indonesian waters. As the catch records may comprise both *M. gerrardi* and *M. macrura,* the numbers presented may be an overestimation of *M. gerrardi* catch. However, our data could not be retrospectively confirmed as either or both species. Future research on this fishery should aim to investigate whether both species are present in catches and, if so, in what proportions.

Elasmobranch populations can be sustainably fished [62], but this is dependent on the species biology and fishing pressure, and requires tailored management approaches [63]. In some fisheries where only adults or juveniles are caught, higher levels of fishing can be sustained [64, 65]. One approach for sustainable elasmobranch fishing is gauntlet fishing, where the fishery only targets neonates, juveniles and sub adult classes, and the large adults remain unfished [64, 65]. This could only be a possible strategy for Indonesia if all fisheries only take juvenile wedgefishes and stingrays. Yet, all life stages of wedgefish, giant guitarfish, and stingrays from the tangle net fishery are exposed to overlapping fishing pressure from multiple fisheries in Indonesia. The wedgefish, giant guitarfish and stingray populations in Indonesia have no respite from fishing pressure to allow for population recovery. The selectivity of large rays and their high economic value has been used as justification for the continuation of the tangle net fishery [35], without taking into consideration the impact of other fisheries and the biology of the species. At the time of the landing site surveys a number of the abundant species, e.g. *R. australiae*, individuals close to the known maximum sizes were still being observed in the catches (Fig. 3; Fig 4). It therefore can be inferred, that the populations of wedgefishes, giant guitarfishes, and stingrays are experiencing length selective fishing mortality. It is expected that the individuals from contemporary populations would be reaching a smaller maximum size and younger maximum age, than previous generations [66]. The majority of the *R. australiae, M. gerrardi, and P. uarnacoides* specimens were large females, with 16 individuals of *R. australiae* examined internally being pregnant [12]. Female *R. australiae* attain a larger size than males, and therefore are more likely to be captured in the large-meshed tangle nets [12]. The removal of large, breeding individuals from the population, causes a reduction in the reproductive potential of chondrichthyan populations, resulting in rapid declines in the fished populations [64]. Large bodied elasmobranchs typically have low reproductive rates and can only withstand modest to low levels of fishing mortality [13, 67-69]. Combined with life history information, the magnitude of Indonesia chondrichthyan catches, and the knowledge of the effects of fisheries on large species that mainly takes adults [64, 70, 71], it is likely that these populations of rays are experience unsustainable levels of exploitation and have little potential for recovery without significant reductions in fishing mortality.

Wedgefish and giant guitarfish have a higher than average population productivity compared to other chondrichthyans, and therefore can potentially recover from population declines more rapidly than other threatened species [15]. However, this will require significant reductions in fishing mortality, and in cases where all age/size classes are fished, as in Indonesia, there are considerably many management and conservation challenges to achieving sustainable outcomes. Wedgefishes and giant guitarfishes are not managed in Indonesia [72], or through international trade or fishing restrictions. Given global concerns for this group of species, and the importance of trade in high value fins and leather, use of international trade regulations such as CITES listing may help to achieve positive conservation outcomes [3]. *Rhynchobatus australiae* and the common guitarfish, *Rhinobatos rhinobatos* are listed on the CMS under Appendix II, and *R. australiae, Rhynchobatus djiddensis, Rhynchobatus laevis,* and *R. rhinobatos* were listed on Annex 1 of the CMS Memorandum of Understanding (MOU) on the Conservation of Migratory Sharks in 2018 [73]. These listings cover migratory species that have an unfavourable conservation status, requiring only international cooperation on their conservation and management, though CMS listing are non-binding, and Indonesia is not a signatory to the agreement [74]. The families Rhinidae and Glaucostegidae have been proposed for listing on CITES Appendix II [75]. International Agreements such as CITES and CMS are only one step of many needed to conserve these species. Regional and national fisheries management strategies are required to address the overfishing of stocks, which will require reductions in fishing effort. Such measures should be concerned primarily with limiting take, licencing, gear restrictions, and catch or effort limits. These direct methods can be combined with indirect methods, such as trade restrictions and developing capacity for species-specific data collection [3]. In addition, there is a need to include appropriate and economically viable incentives for livelihood alternatives for fishers, as failure to do so may result in low compliance and illegal fishing throughout much of their range [31, 76]. However, we also acknowledge that these fisheries are complex social-ecological systems, and that successful management will require significant improvements in governance across local, global and regional scales [77]. For tropical and developing countries, such as Indonesia, species identification is a chronic problem for industrial and artisanal fisheries [78]. The lack of resources and capacity to collect, analyse and interpret fisheries data in developing countries such as Indonesia often hinders the development of effective management strategies and needs to be addressed [79-81]. Lastly, information and research on the biology, life history and movements of these species are required for assessments of exploited stocks and of species' vulnerability to fishing pressure. Evidence of substantial and rapid declines in landings of the target species raises concerns about the status of shark-like batoids in Indonesia. Management across multiple fisheries and life stages, instead of single fishery management, is required to ensure the sustainability and conservation of rays, in particular *R. australiae*, which is caught across a wide range of fisheries at all life stages. The result of this study emphasise the urgency for effective management for the conservation of these rays.

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Supporting Information

SI Table 1. Dates of the market surveys conducted in the Muara Angke landing port and the associated village processing area in Jakarta April 2001 – December 2005. The total number of species and specimens for rays and sharks per survey day are reported.

SI Table 1. Length-weight relationship for the elasmobranch species caught in the Indonesian tangle net fishery and landed in Muara Angke, Jakarta April 2001 – December 2005.

SI Table 2. Size at maturity (DW/TL cm) for species with length frequency data in the Indonesian tangle net fishery and landed in Muara Angke, Jakarta April 2001 – December 2005.

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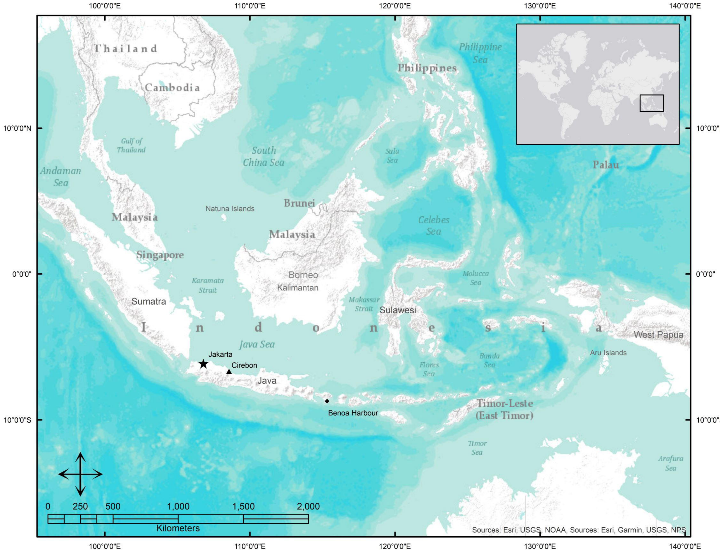
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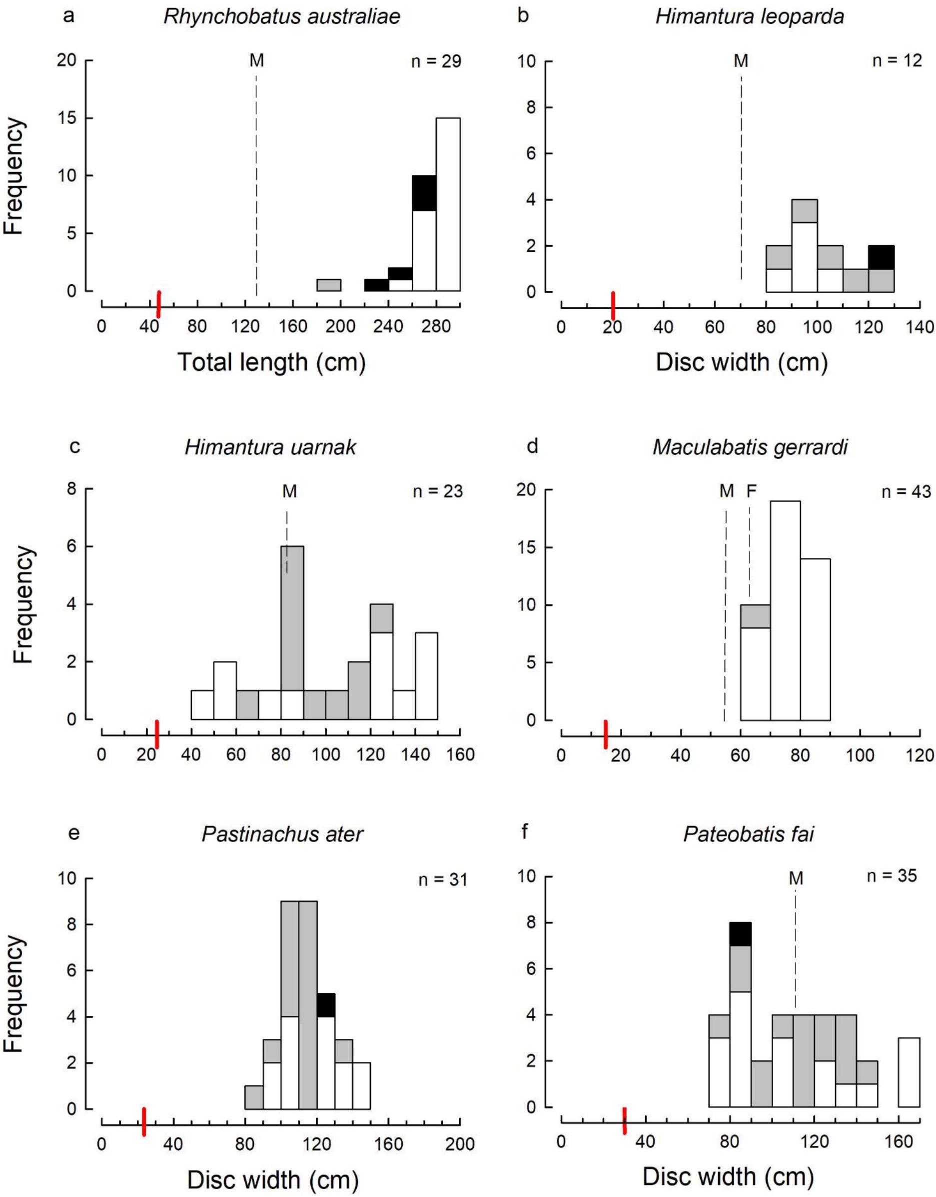
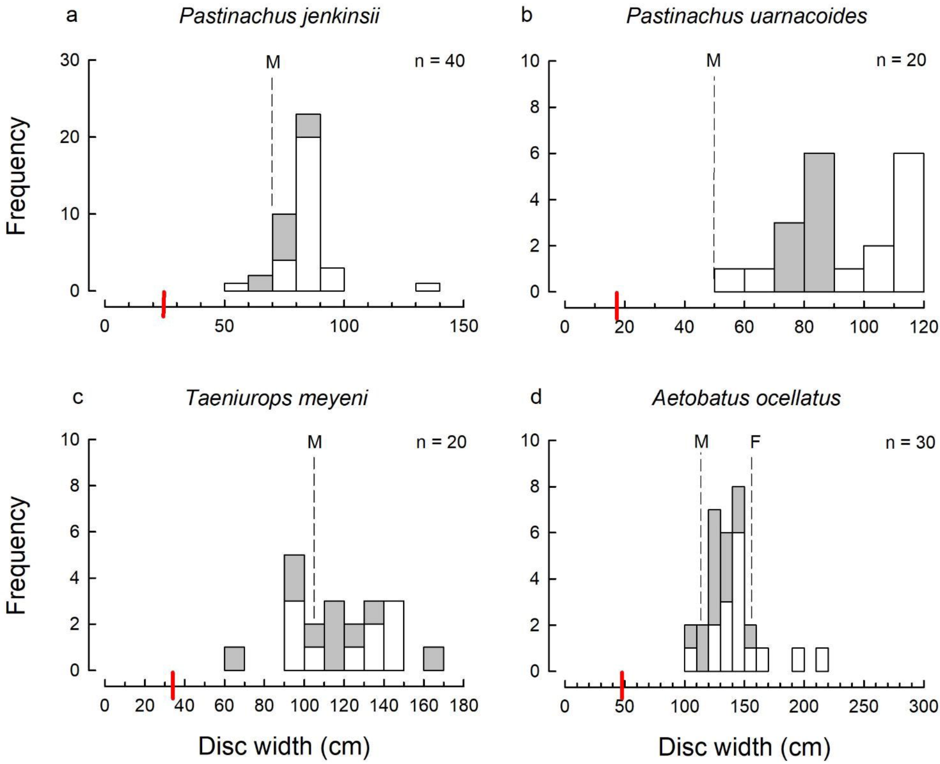
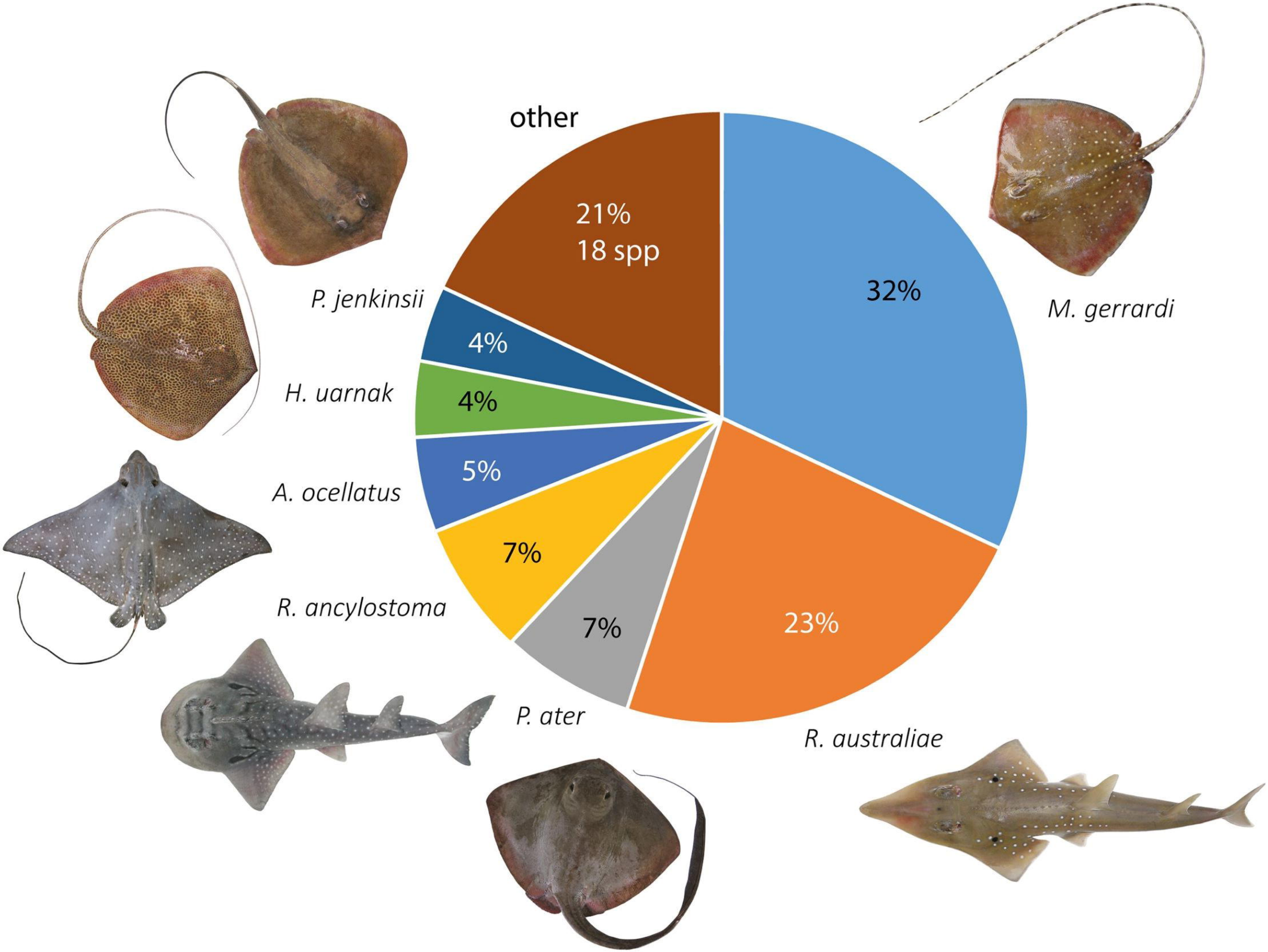
Philippine Sea
Gulf of Thailand
South China Sea
Sulu Sea
Andaman Sea
Palau
Natuna Islands
Brunei
Malaysia
Malaysia
Celebes Sea
Singapore
Borneo
Kalimantan
Karamata Strait
Molucca Sea
Sumatra
Makassar Strait
Sulawesi
Indonesia
West Papua
Java Sea
Jakarta
Cirebon
Aru Islands
Java
Flores Sea
Banda Sea
Benoa Harbour
Timor-Leste (East Timor)
Timor Sea
Arafura Sea
0
250
500
1,000
1,500
2,000
Kilometers
Sources: Esri, USGS, NOAA, Sources: Esri, Garmin, USGS, NPS


a
b
c
d

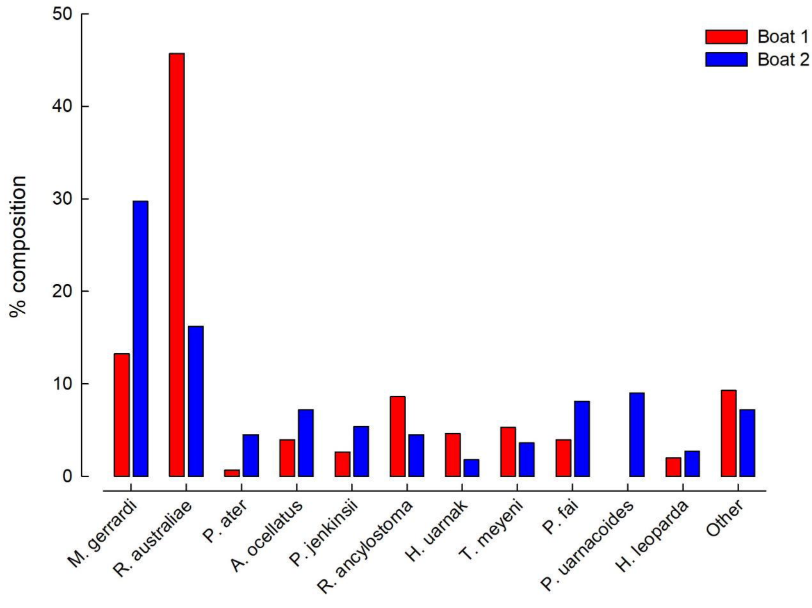

a
Rhynchobatus australiae
n = 29
M
Frequency
Total length (cm)
b
Himantura leoparda
n = 12
M
Disc width (cm)
c
Himantura uarnak
n = 23
M
Frequency
d
Maculabatis gerrardi
n = 43
M F
e
Pastinachus ater
n = 31
Frequency
Disc width (cm)
f
Pateobatis fai
n = 35
M
Disc width (cm)



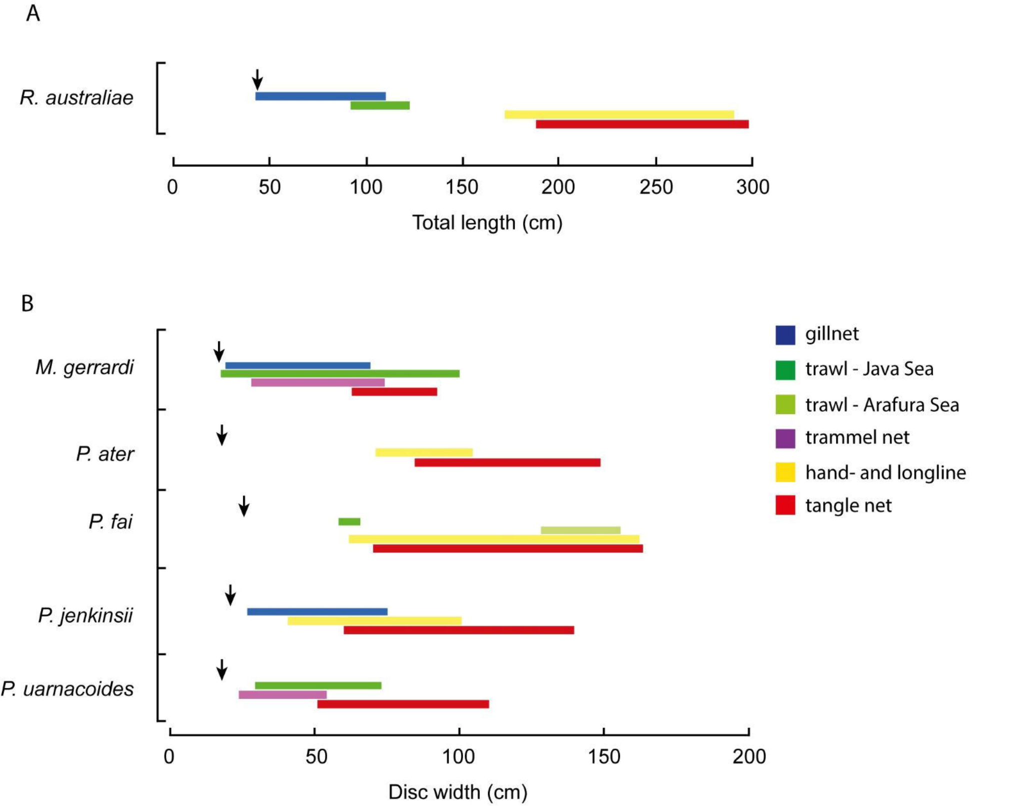
a
Pastinachus jenkinsii
M
n = 40
Frequency
0
10
20
30
0
50
100
150
b
Pastinachus uarnacoides
M
n = 20
0
2
4
6
8
10
0
20
40
60
80
100
120
c
Taeniurops meyeni
M
n = 20
Frequency
0
2
4
6
8
10
0
20
40
60
80
100
120
140
160
180
Disc width (cm)
d
Aetobatus ocellatus
M
F
n = 30
0
2
4
6
8
10
0
50
100
150
200
250
300
Disc width (cm)



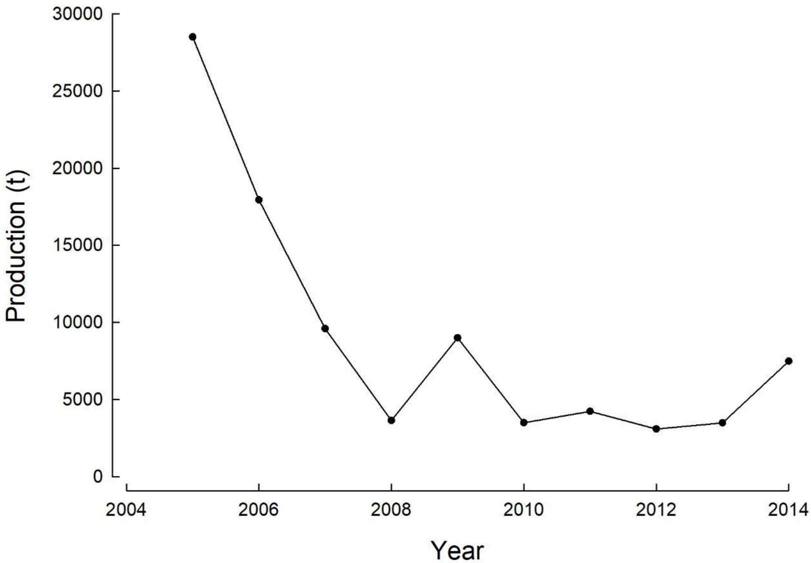
other
21%
18 spp
32%
M. gerrardi
P. jenkinsii
4%
H. uarnak
4%
A. ocellatus
5%
R. ancylostoma
7%
7%
23%
P. ater
R. australiae



Boat 1
Boat 2
% composition
50
40
30
20
10
0
M. gerrardi
R. australiae
P. ater
A. ocellatus
P. jenkinsii
R. ancylostoma
H. uarnak
T. meyeni
P. fai
P. uarnacoides
H. leoparda
Other



A
R. australiae
0
50
100
150
200
250
300
Total length (cm)
B
M. gerrardi
P. ater
P. fai
P. jenkinsii
P. uarnacoides
0
50
100
150
200
Disc width (cm)
gillnet
trawl - Java Sea
trawl - Arafura Sea
trammel net
hand- and longline
tangle net


Production (t)
30000
25000
20000
15000
10000
5000
0
2004
2006
2008
2010
2012
2014
Year