Catch composition and life history characteristics of sharks and rays (Elasmobranchii) landed in the Andaman and Nicobar Islands, India.

Zoya Tyabji[1,2,*], Tanmay Wagh[2], Vardhan Patankar[2], Rima W. Jabado[3], Dipani Sutaria[4]

[1]Andaman Nicobar Environment Team, North Wandoor, South Andaman, Andaman and Nicobar Island 744103, India

[2]Wildlife Conservation Society, 551, 7th Main Road, Rajiv Gandhi Nagar, 2nd Phase, Kodigehalli, Bengaluru, Karnataka 560097, India

[3]Elasmo Project, P.O. Box 29588, Dubai, United Arab Emirates

[4]College of Science and Engineering, James Cook University, Townsville, Australia

*Corresponding author

Email: zoya.tyabji@gmail.com

Running title: Biological data of elasmobranchs landed in the Andaman and Nicobar Islands

Keywords: fisheries-dependent surveys; elasmobranch; sex ratios; length-weight relationship; management

ABSTRACT

The scientific literature on the diversity and biological characteristics of sharks and rays from the Andaman and Nicobar Archipelago fishing grounds is scarce and compromised by species misidentifications. We carried out systematic fish landing surveys in South Andamans from January 2017 to May 2018, a comprehensive and cost-effective way to fill this data gap. We sampled 5,742 individuals representing 57 shark and ray species. Of the 36 species of sharks and 21 species of rays landed, six species of sharks - *Loxodon macrorhinus, Carcharhinus amblyrhynchos, Sphyrna lewini, Carcharhinus albimarginatus*, *Carcharhinus brevipinna,* and *Paragaelus randalli* dominated landings and comprised 83.35 % of shark landings, while three species of rays were most abundant – *Pateobatis jenkinsii*, *Himantura leoparda* and *H. tutul*, and comprised 48.82 % of ray landings. We report size extensions for seven shark species as well as three previously unreported ray species, increasing the known diversity for the islands and for India. For sharks, mature individuals of small-bodied species (63.48 % males of total landings of species less than 1.5 m total length) and immature individuals of larger species (84.79 % males of total landings of species larger than 1.5 m total length) were mostly landed; whereas for rays, mature individuals were predominantly landed (80.71 % males of total landings) likely reflecting differences in fishing patterns as well as habitat preferences and life history stages across species. Further, juvenile sharks and gravid females were landed in large quantities which might be unsustainable in the long-term. Landings were female-biased in *C. amblyrhynchos, S. lewini* and *P. jenkinsii,* and male-biased in *L. macrorhinus* and *H. leoparda*, indicating either spatio-temporal or gear specific sexual segregation in these species. Understanding these nuances - the composition and biology of sharks and rays landed in different fisheries seasonally will inform future conservation and fishery management measures for these species in the Andaman and Nicobar Islands.

INTRODUCTION

Elasmobranchs (sharks and rays) are recognized as one of the marine taxa with the highest extinction risk and need for urgent conservation measures [1]. Despite considerable inter and intra-specific life history variation [2, 3], most species have relatively low productivity making them highly susceptible to anthropogenic and natural stressors [4]. Populations of many species have drastically declined globally due to overfishing and habitat degradation raising concerns about their long-term survival [1].

In the past few decades, India has consistently been one of the top three shark and ray harvesters in the world [5, 6]. Here, sharks and rays are primarily caught as bycatch [7 - 11] in a large fishing fleet of 238,772 registered commercial and artisanal fishing crafts [12]. However, a few targeted shark fisheries that formed in the 1980's remain including in the Andaman and Nicobar Islands [13,14]. Anecdotal information from interviews with fishers on these islands indicate that shark and ray populations have declined [15] but there have been few systematic surveys of landings carried out to assess the current situation. This limited information on species and stocks may have detrimental effects not only on the ecology of these animals but also on the sustainability of these fisheries and the food security they provide as well as the socio-economic dependence of fisher communities [16, 17].

Over the years, with growing reports of declining populations of sharks and rays, the Government of India has implemented several conservation policies. In 2001, ten species of sharks and rays, including the Whale shark *Rhincodon typus,* Knifetooth sawfish *Anoxypristis cuspidata*, Pondicherry shark *Carcharhinus hemiodon,* Gangetic shark *Glyphis gangeticus,* Speartooth shark *G. glyphis,* Ganges stingray *Himantura fluviatilis,* Freshwater sawfish *Pristis microdon* (= *P. pristis*)*,* Green sawfish *P. zijsron*, Giant guitarfish *Rhynchobatus djiddensis*, and Porcupine ray *Urogymnus asperrimus* were listed under Schedule I of the Indian Wildlife (Protection) Act, 1972 (WLPA). In 2009, the Andaman and Nicobar Islands Fisheries Regulation declared a 45-day closed season for shark fishing from April 15th to May 31st around the islands through the prohibition of the use of shark and tuna pelagic longlines and trawl nets. In 2013, the Ministry of Environment, Forest and Climate Change (MoEF&CC) declared a 'Fin-attached Policy' where sharks have to be landed whole, with their fins naturally attached to their bodies. In 2015, India's Ministry of Commerce and Industry issued a notification prohibiting the export of all shark fins. While these legislations, if properly implemented, are a positive step for shark conservation in India, there appears to be an agenda mismatch between the MoEF&CC and the Ministry of Animal Husbandry, Dairying and Fisheries, with the latter having recently developed a strategy to expand fisheries and increase yield. This includes developing new schemes and projects to harness fishing potential and create employment opportunities, by issuing additional fishing licenses, building infrastructure such as cold storage centers, blast freezers and ice plants, and increasing introduction of deep-sea, motorized and mechanized boats [18].

In order to develop best management practices, basic life-history information such as age, growth, and maturity is required to form the basis of population assessments. However, in many developing countries, landings remain unmonitored and unregulated with little species-specific data collected, which hampers population assessments, and does not provide indication of the status of a population [17]. Additionally, since different species can show variances in biological traits across geographical regions, such as size at birth, size at maturity, maximum size, litter size, and breeding cycle [19 - 21], it is important to undertake region-specific studies so they can inform local management strategies.

Most past literature on sharks and rays from the Andaman and Nicobar Islands has been limited to species identification and taxonomy [22 - 27]. A large knowledge gap exists in our understanding of the catch composition of commercial species landed, their population trends, biological characteristics across seasons. Here, we aim to address this gap by assessing sharks and rays landed in the Andaman and Nicobar Islands and exploring 1) the species composition including relative abundance across seasons, 2) the biological information, including size frequency, sex ratio, maturity and length-weight relationships, and 3) the characteristics of fishing gears and grounds where sharks and rays were reportedly fished.

MATERIALS AND METHODS

Study area

The Andaman and Nicobar Islands (6°N–14°N and 92°E–94°E) are located in the Bay of Bengal and constitute 29.7 % of the total Economic Exclusive Zone (EEZ) area of India (Fig 1), covering a coastline of 1,962 km (contributing to 26.10 % of India's coastline) and a continental shelf area of approximately 35,000 km^2 [18]. The islands experience heavy monsoon from end of May to September when the south-west monsoon sets in as well as intermittent or light to heavy rainfall when the north-east monsoon sets in November. For the duration of our study, we characterized landings according to the following seasons: north-east monsoon (NE) (October–January), dry season (DS) (February–May), and south-west monsoon (SW) (June–September).

Fig 1. Map of the sampling sites and fishing grounds of the Andaman and Nicobar Islands, India. Top left: Map of India with the Exclusive Economic Zone boundaries of Andaman and Nicobar Islands demarcated in blue; Bottom left: Map of South Andaman with red triangles indicating sampled fish landing centers; Right: Map of the Andaman and Nicobar Islands showing fishing gear utilization across fishing grounds around the Islands, South Andaman is demarcated by the red inset.

A total of 2,784 fishing vessels are currently active with 7,034 licensed fishers [18]. Here, sharks and rays are targeted using pelagic and deep-sea longlines; and are caught as bycatch in demersal longlines, trawl nets, gillnets, and hook and line. Pelagic longliners and trawlers are permitted to exclusively fish beyond six nautical miles and up to 12 nautical miles from the coast. Demersal longliners as well as hook and line and gillnet fisheries operate near the coast and shallow seamounts. Fishers from the Andaman Islands fish across the waters of the Andaman and Nicobar Islands while the communities on the Nicobar Islands, due to their seclusion, only fish for subsistence or fishing for sale in local markets [27, 28].

Exploratory visits to landing sites in 2016 across South Andaman Islands revealed that the majority of sharks and rays fished throughout the Andaman and Nicobar Islands are landed at Junglighat (Fig 1). Junglighat, located in Port Blair, the main city of the Andaman Islands, is the largest fish landing center of the islands with proximity to storage centers and export facilities (Fig 1). We therefore focused our sampling at this location. However, opportunistic surveys were also undertaken at the fish landing sites of Burmanallah, Wandoor, and Dignabad (Fig 1) when fishers or informants reported landings of sharks and rays to the survey team.

Sampling effort

Systematic surveys were undertaken from January 2017 to May 2018 for sharks and from October 2017 to May 2018 for rays. Junglighat was visited every alternate day or when weather permitted from 0600 to 1000 hrs, whereas the remaining site visits were dependent on reports by the informants. As the pelagic longliners from Junglighat directly offload and transport their landings to the processing and storage units, sampling of landings from these vessels was conducted at these units between 1000 to 1400 hrs.

Sharks and rays landed were identified to the species level using the available literature and photo-documented [29 - 32]. Rays were often landed with their tails cut, in piles, and, in a few cases, when landings were large, accurate pictures and/or measurements were not possible. Therefore, species which were difficult to differentiate morphologically, such as *Neotrygon* sp. and *Pastinachus* sp. were grouped at the genus level, and have therefore been excluded from the analysis of the full data set.

For sharks, guitarfishes, and wedgefishes, the total length (TL, a straight line from the tip of the snout to the tip of the tail, with tail flexed down to midline) was measured, whereas for rays, the disc width (DW, a straight line at the widest region of the disc) was measured to the nearest millimeter [30, 31].

Sex was determined by the presence of claspers indicative of males or the absence of claspers indicative of females. For males, the degree of calcification and length of claspers determined the maturity levels. This was categorized from 1 to 3 where (1) refers to immature individuals whose claspers were non-calcified and pliable, and whose length was less than the pelvic fins, (2) refers to maturing individuals whose claspers were partially calcified and semi-pliable, and whose length was longer than the pelvic fins, and (3) refers to fully mature individuals whose claspers were fully calcified and non-pliable.

Gravid females were recorded by the presence of emerging embryos or if these could be clearly observed by pressing the stomach. Whenever possible, gravid females were dissected to record the sex and size of embryos. Young-of-the-year (YOY) individuals were identified by the presence of open umbilical scars which usually close after the first few months of life.

Weights were recorded to the nearest gram using a hand-held digital weighing balance for smaller individuals or whenever possible, when weights were provided by the fishers using a circular weighing balance for larger individuals (> 50 kg).

For each boat that landings were sampled from, we approached fishers for information on the fishing gears used to catch the sharks and rays, and the fishing grounds.

Data analysis

A species accumulation curve over time, trends in mean abundance of landings across months, and patterns in species, sex, and sizes caught across various gears were produced in Microsoft Excel 2017. Tentative fishing grounds, including usage of fishing gears, were mapped on QGIS based on locations provided during discussions with fishers.

The hypothesis of equal sex ratios for species where ≥ 50 individuals were sampled, was tested using Chi-square where significance was considered at $p < 0.05$ [33]. The hypothesis of shark TL getting equally caught across different fishing gears was tested using one-way ANOVA where significance was considered at $p < 0.05$ [33].

For sharks, species where > 150 individuals were sampled, size-class frequency distributions by sex and seasons were plotted while the size at 50 % maturity (TL_{50}) for males was calculated. This was done by fitting the following logistic function to the proportion of mature individuals in 10 or 20 cm size categories: $P = 1 / (1 + \exp(-r (LT_{mid} - LT_{50})))$, where P is the proportion of mature fish in each length class, LT_{mid} is the midpoint of the length class, LT_{50} is the mean size at sexual maturity, and r is a constant that increases in value with the steepness of the maturation schedule.

Finally, length-weight relationships were determined using regression analysis. The equation $W=aL^b$ was converted into a linear form $\ln(W) = \ln(a) + b \ln(L)$, where W is the weight, L is the length, ln(a) is the intercept and (b) the slope or regression coefficient. Gravid females were excluded from this analysis.

RESULTS

Sampling was conducted on 216 days with landings recorded from 567 boats and a total of 5,742 sharks and rays representing 57 species. Of these, 4,632 individuals represented 36 shark species from 18 genera and 11 families while 1,110 individuals represented 21 ray species, 14 genera and eight families.

The species accumulation curve reached a threshold for sharks but not for rays (Fig 2). A species list and summary of biological data for all specimens is provided in Table 1.

Fig 2. Species accumulation curve of sharks and rays landed. The curve shows the number of cumulative species across 17 months of sampling from January 2017 to May 2018. The dotted line represents both shark and ray species, the grey line represents shark species and the black line represents ray species.

Table 1. Summary of biological data for sharks and rays landed. The table includes total number of individuals; International Union for Conservation of Nature (IUCN) Red List of Threatened Species status (as of December 2019), where the categories are CR – Critically Endangered, EN – Endangered, VU – Vulnerable, NT – Near Threatened, LC – Least Concern, DD – Data Deficient, NE – Not Evaluated, and year of assessment in parentheses; and sizes (total length for sharks (TL) and disc width (DW) for rays) by sex (F – female; M – male; UK – unknown), presence of gravid females and young of year (YOY). Results of Chi-square tests of parity in sex ratios for shark and ray species are provided for species with ≥ 50 individuals recorded, and fishing gears used to catch the species are provided where applicable.

Species	**Common name**	**IUCN status**	**n**	**n by sex of individuals**	**Size (TL cm / DW cm)**	**Additional notes**
SQUALIFORMES						
Squalidae						
Squalus hemipinnis	Indonesian Shortnose Spurdog	NT (2008)	1	F: 1	F: 66	Specimen caught using hook and line.
Centrophoridae						
Centrophorus atromarginatus	Dwarf Gulper Shark	DD (2008)	1	M: 1	M: 72.5	Specimen caught using deep-sea longline.
Centrophorus granulosus	Needle Dogfish	DD (200	6	F: 3, M: 3	F: 93.5 - 103 (97 ±	All specimens caught using deep-

		6)			5.22) M: 82.5 - 92.5 (87.66 ± 7.68)	sea longline.
ORECTOLOBIFORMES						
Hemiscyllidae						
Chiloscyllium griseum	Grey Bambooshark	NT (2003)	2	F: 1, M: 1	F: 86, M: 84	Both specimens caught using hook and line.
Chiloscyllium hasseltii	Indonesian Bambooshark	NT (2008)	1	F: 1	F: 88	Specimen caught using trawl net.
Ginglymostomatidae						
Nebrius ferrugineus	Tawny Nurse Shark	VU (2003)	8	F: 3, M: 4, UK: 1	F: 198 - 273.5 (247.5 ± 42.88) M: 175.9 - 367.2 (261.15 ± 59.10)	Seven of the eight individuals landed in February and March 2017 and 2018. Size extension by 47.2 cm recorded.
LAMNIFORMES						
Odontaspididae						
Carcharias taurus	Sandtiger Shark	VU	1	F: 1	F: 129.4	

		(2005)				
Alopiidae						
Alopias pelagicus	Pelagic Thresher	EN (2018)	28	F: 11, M: 9, UK: 8	F: 131.4 - 272.6 (224.2 ± 66.96) M: 138.8 - 270.5 (215.76 ± 59.67)	Twenty-two of the 28 specimens caught in February. All specimens caught in pelagic longlines.
Alopias superciliosus	Bigeye Thresher	VU (2018)	6	F: 3, M: 3	F: 210 - 306.5 (258.25 ± 36.12) M: 235 - 292 (266.86 ± 34.41)	Four of the six specimens caught in February. All specimens caught in pelagic longlines.
Lamnidae						
Isurus oxyrinchus	Shortfin Mako	EN (2018)	2	M: 2	M: 178.5 - 182.5 (180.5 ± 43.97)	Specimens caught in gillnet and pelagic longline.
CARCHARHINIFORMES						

Triakidae						
Hemitriakis indroyonoi	Indonesian Houndshark	NE	2	F: 2	F: 100.6 - 105 (102.8 ± 3.11)	Two females landed in December 2017 and February 2018. Both specimens caught from Campbell Bay in Nicobar using pelagic longlines.
Mustelus mosis	Arabian Smoothhound Shark	NT (2018)	7	F: 7	F: 85.2 - 108.5 (97.6 ± 8.60)	Three individuals landed together in March 2017 and four landed together in April 2018. All specimens caught using hook and line.
Hemigaleidae						
Hemigaleus microstoma	Sicklefin Weasel Shark	VU (2007)	24	F: 7, M: 15, UK: 2	F: 65 - 109.9 (96.25 ± 17.19) M: 70.8 -	All specimens caught using trawl net, demersal longline and hook and line.

					103.2 (94.42 ± 9.72)	
Hemipristis elongata	Snaggletooth Shark	VU (2015)	29	F: 10, M: 18, UK: 1	F: 93.1 - 211.1 (155.94 ± 42.17) M: 95 - 183 (144.11 ± 22.77)	Four specimens caught using hook and line, four in demersal longline and seven in pelagic longlines.
Paragaleus randalli	Slender Weasel Shark	NT (2008)	169	F: 78, M: 91	F: 46 - 97.5 (86.44 ± 9.57) M: 43.5 - 102.5 (86.34 ± 8.75)	Fourteen gravid females (n = 10 in April) recorded ranging from TL 87.5 to 97.5 cm, dissection of two gravid females revealed a litter size of two; three fully-developed embryos recorded ranging between TL 43.5 to 47.5 cm. Sex ratios of

						landings did not differ significantly from parity (F: M = 1: 1.16, χ^2 [1, n = 169] =1, p > 0.05). Size extension by 6.7 cm recorded.
Carcharhinidae						
Carcharhinus albimarginatus	Silvertip Shark	VU (2015)	295	F: 150, M: 137, UK: 8	F: 60.7 - 243.5 (103.41 ± 30.52) M: 21.5 - 249 (105.93 ± 30.49)	One gravid female landed in February measuring TL 199.5 cm and 1 embryo of TL 21.5 cm landed in December, caught in pelagic longline; 25 recorded YOY ranging from TL 60.7 to 94 cm landed in March and April 2017, and Jan, Feb, April 2018. In April, more than 150 YOY of less than

						one meter landed by a pelagic longline - it was not possible to sample all these due to time constraints prior to the auction and only data from 24 specimens were recorded. Sex ratios of landings did not differ significantly from parity (F: M = 1: 0.91, χ^2 [1, n = 287] = 0.588, p > 0.05).
Carcharhinus altimus	Bignose Shark	DD (2008)	4	F: 1, M: 3	F: 90 M: 103 - 237.5 (156.16 ± 33.49)	Three YOY landed in March and April 2017 ranging from TL 90 to 128 cm. One specimen caught in pelagic longline and one in gillnet.

Carcharhinus amblyrhynchoides	Graceful Shark	NT (2005)	7	F: 3, M: 2, UK: 2	F: 94 - 167.4 (138.46 ± 39.40) M: 194 - 206 (200 ± 56.93)	One specimen caught in pelagic longline, gillnet and trawl net each.
Carcharhinus amblyrhynchos	Grey Reef Shark	NT (2005)	1215	F: 652, M: 555, UK: 8	F: 51 - 217 (97.46 ± 30.73) M: 55 - 206 (95.45 ± 27.44)	Four gravid females landed in January and February ranging between TL 157.5 and 186.5 cm. A total of 293 YOY ranging from TL 51 to 101 cm were recorded throughout the year. Significantly more females were landed than males (F: M = 1: 0.85, χ^2 [1, n = 1207] = 7.79, $p < 0.05$).
Carcharhinus	Pigeye Shark	DD	38	F: 21,	F: 134.5 -	Five gravid

amboinensis		(2005)		M: 17	295 (222.58 ± 35.98) M: 138 - 233.2 (196.78 ± 36.08)	females landed in February, July 2017, and April 2018, ranging from TL 217 to 295 cm. Size extension by 15 cm recorded.
Carcharhinus brevipinna	Spinner Shark	NT (2005)	212	F: 95, M: 116, UK: 1	F: 59.7 - 284.5 (100.93 ± 32.5) M: 62.6 - 212 (94.07 ± 32.20)	One gravid female of TL 206.5 cm and weighing 111 kg landed in April, caught in a gillnet; 49 YOY ranging from 59.7 to 84.7 TL cm landed in March and April. Sex ratios of landings did not differ significantly from parity (F: M = 1: 1.22, χ^2 [1, n = 211] = 2.09, $p > 0.05$).
Carcharhinus dussumieri	Whitecheek Shark	EN (201	80	F: 47, M: 33	F: 54.5 - 93.1	Six gravid females ranging from TL

		8)			(82.79 ± 35.20) M: 22.3 - 92.5 (77.41 ± 35.45)	84.7 to 93.1 cm were landed between November 2017 and February 2018. Sex ratios of landings did not differ significantly from parity (F: M = 1: 0.70, χ^2 [1, n = 80] = 2.45, p > 0.05).
Carcharhinus falciformis	Silky Shark	VU (2017)	71	F: 34, M: 34, UK: 3	F: 104 - 376.5 (181.69 ± 35.34) M: 121 - 290.8 (180.33 ± 40.54)	One gravid female of TL 235.5 cm landed in February 2017, caught in gillnet. Sex ratios of landings shows parity (F: M = 1: 1, χ^2 [1, n = 68] = 0 p > 0.05). Size extension by 26 cm recorded.
Carcharhinus leucas	Bull Shark	NT (200	32	F: 17, M: 14,	F: 146 - 351	Three gravid females of TL 309

		5)		UK: 1	(265.61 ± 37.48)	to 351 cm landed in February and March 2018, in pelagic longlines and trawl nets.
					M: 124.5 - 274.8 (206.6 ± 35.71)	
Carcharhinus limbatus	Blacktip Shark	NT (2005)	108	F: 54, M: 53, UK: 1	F: 62.6 - 281 (112.6 ± 35.23)	Seventeen YOY landed in March and April 2018, with TL 61.5 to 77 cm. Sex ratios of landings did not differ significantly from parity (F: M = 1: 0.98, χ^2 [1, n = 107] = 0.00934, p > 0.05). Size extension by 10 cm recorded.
					M: 61.5 - 231.8 (106.46 ± 35.34)	
Carcharhinus longimanus	Oceanic Whitetip Shark	CR (2018)	19	F: 10, M: 9	F: 99.5 - 200 (137.89 ± 32.91)	One immature male landed in December of TL 96 cm. All specimens caught in pelagic longlines.
					M: 96 - 198.2	

					(141.53 ± 35.74)	
Carcharhinus macloti	Hardnose Shark	NT (2003)	5	F: 3, M: 2	F: 81.5 - 88.5 (85 ± 37.24) M: 85 - 85.5 (85.25 ± 36.38)	Two specimens caught in gillnet, one in hook and line.
Carcharhinus melanopterus	Blacktip Reef Shark	NT (2005)	30	F: 13, M: 20, UK: 2	F: 57.5 - 152.5 (84.88 ± 27.1) M: 57.5 - 129 (86.72 ± 28.98)	One gravid female landed in March 2017 measuring TL 133 cm, caught in a gillnet; four male and two female YOY landed in May with TL 57.5 to 63 cm, six caught by hook and line.
Carcharhinus plumbeus	Sandbar Shark	VU (2007)	1	M: 1	M: 81	YOY, caught by hook and line.
Carcharhinus sorrah	Spottail Shark	NT (200	48	F: 20, M: 26,	F: 74 - 173.7	Size extension by 3.5 cm recorded.

		7)		UK: 2	(118.37 ± 25.35) M: 72.5 - 199.5 (116.45 ± 28.88)	Two specimens caught in trawl net, 17 in pelagic longline, seven in demersal longline, two in hook and line, nine in gillnet.
Loxodon macrorhinus	Sliteye Shark	LC (2003)	1549	F: 678, M: 852, UK: 19	F: 39.2 - 103.2 (84.24 ± 10.04) M: 25 - 102 (84.46 ± 9.41)	Thirty-four gravid females landed between November 2017 to April 2018, with TL 85.5 to 98 cm; dissection of four gravid females revealed a litter size of two. Six fully-developed embryos pulled out from the gravid female measured TL 45.1 to 49.2 cm; 6 YOY of TL 32.6 to 54 cm, with open umbilical

						scars landed in March 2017 and 2018. Significantly more males than females were landed (F: M = 1: 1.25, χ^2 [1, n = 1530] = 14.3771, p < 0.05). A size extension by 4.3 cm was recorded.
Negaprion acutidens	Sharptooth Lemon Shark	VU (2003)	9	F: 5, M: 4	F: 66.7 - 265 (165.18 ± 92.62)	Three male YOY landed in March ranging from 63.4 to 70.6 TL. Three specimens caught in pelagic longline.
					M: 63.4 - 210 (76.2 ± 16.33)	
Rhizoprionodon acutus	Milk Shark	LC (2003)	102	F: 54, M: 47, UK: 1	F: 49.4 - 96.5 (77.69 ± 10.87)	Three gravid females landed ranging from TL 90 to 92.8 cm, one YOY of TL 61.5 cm, with a half healed umbilical
					M: 66 - 93.7 (76.90 ±	

					7.53)	scar landed in March 2018. Sex ratios of landings did not differ significantly from parity (F: M = 1: 0.87, χ^2 [1, n = 101] = 0.485, p > 0.05).
Triaenodon obesus	Whitetip Reef Shark	NT (2005)	14	F: 6, M: 8	F: 62 - 150.5 (91 ± 31.84) M: 91.5 - 136 (105.75 ± 14.09)	One YOY with healing umbilical scar of TL 62 cm landed in December 2017. Two specimens were caught in gillnet, three in hook and line, one in demersal longline, two in pelagic longline.
Sphyrnidae						
Sphyrna lewini	Scalloped Hammerhead	CR (2018)	421	F: 229, M:	F: 50 - 276 (100.57 ±	Forty YOY ranging from TL of 61 to 86 cm were observed

				177, UK: 14	35.41) M: 35.5 - 238 (106.18 ± 35.25)	while no gravid females were recorded. Sex ratios of landings differed significantly from parity towards females (F: M = 1: 0.77, χ^2 [1, n = 406] = 6.66, $p < 0.05$).
Sphyrna mokarran	Great Hammerhead	CR (2018)	2	F: 1, M: 1	F: 158.5, M: 64.5	Both specimens caught in trawl nets.
RHINOPRISTIFORMES						
Rhinidae						
Rhynchobatus sp.	Wedgefish	CR (2019)	3	F: 1, M: 2		Head and fins were cut prior to landing so species-level identification was not possible.
Glaucostegidae						
Glaucostegus typus	Giant Guitarfish	CR (2019)	14	F: 7, M: 7	F: 187.5 - 230.2 (210.64 ±	All specimens caught in trawl nets.

					15.51)	
					M: 198.2 - 235.5 (217.4 ± 11.90)	
MYLIOBATIFORMES						
Gymnuridae						
Gymnura poecilura	Longtail Butterfly Ray	NT (2006)	3	F: 3	F: 98 - 105.1 (90.57 ± 17.36)	Two specimens caught in trawl nets and one in demersal longline.
Dasyatidae						
Himantura leoparda	Leopard Whipray	VU (2015)	206	F: 83, M: 121, UK: 2	F: 42 - 136.5 (94.24 ± 25.19) M: 41.7 - 153.2 (96.84 ± 19.15)	Sex ratios of landings differed significantly from parity towards males (F: M = 1: 1.45, χ^2 [1, n = 204] = 7.07, $p < 0.05$). Caught in trawl nets, gillnet, hook and line and demersal longlines.

Himantura tutul	Fine-spotted Leopard Whipray	NE	95	F: 55, M: 39, UK: 1	F: 26.5 - 145 (119.03 ± 24.39) M: 65.5 – 138.4 (115.2 ± 13.30)	Sex ratios of landings did not differ significantly from parity (F: M = 1: 0.70, χ^2 [1, n = 94] = 2.72, p > 0.05). Caught in trawl nets, gillnet, hook and line and demersal longlines.
Himantura uarnak	Reticulate Whipray	VU (2015)	27	F: 15, M: 12	F: 56.6 – 128 (95.64 ± 23.06) M: 72 - 123.3 (102.23 ± 15.45)	Caught in demersal longline, hook and line and trawl net.
Himantura undulata	Honeycomb Whipray	VU (2011)	2	F: 2	F: 108 - 119.1 (113.55 ± 7.84)	Specimens caught in demersal longlines.
Maculabatis gerrardi	Whitespotted Whipray	VU (2004)	13	F: 7, M: 6	F: 21 - 107 (82.52 ± 29.67)	Five specimens caught in trawl nets.

					M: 60 - 81 (72.03 ± 8.03)	
Neotrygon sp.	Blue-spotted Mask Ray		19	F: 7, M: 11, UK: 1	F: 39 - 52.5 (44.82 ± 4.02) M: 35 - 45.5 (39.05 ± 3.48)	Individuals could not be identified to the species level and likely comprised of three species - *N. orientalis, N. caerulopunctata, N. indica*.
Pastinachus sp.	Cowtail Rays		35	F: 11, M: 23, UK: 1	F: 73 - 126.2 (101.78 ± 19.39) M: 60.8 - 228.5 (108.59 ± 31.88)	Individuals could not be identified to the species level and likely comprised of two species - *P. ater* and *P. gracilicaudus*.
Pateobatis fai	Pink Whipray	VU (2015)	58	F: 31, M: 26, UK: 1	F: 62 - 152.5 (122.61 ± 20.16) M: 76.5 -	Sex ratios of landings did not differ significantly from parity (F: M = 1: 0.83, χ^2 [1, n =

					194 (122.06 ± 28.95)	57] = 0.43, p > 0.05). Caught in trawl nets, gillnets, hook and line and demersal longline.
Pateobatis jenkinsii	Jenkins Whipray	VU (2015)	241	F: 144, M: 96, UK: 1	F: 37.5 - 138.5 (98.96 ± 31.56) M: 64.3 - 122.4 (98.94 ± 31.55)	Sex ratios of landings differed significantly from parity towards females (F: M = 1: 0.66, χ^2 [1, n = 240] = 9.6, p < 0.05). Caught in trawl nets, gillnet, hook and line and demersal longlines.
Taeniurops meyeni	Black-blotched Stingray	VU (2015)	2	F: 1, M: 1	F: 108.5, M: 100.4	Landings in the month of December 2017 and January 2018. Both specimens caught in demersal longline.
Urogymnus	Porcupine Ray	VU	2	F: 1,	F: 109, M:	Landings in the

asperrimus		(2015)		M: 1	97	month of February and May 2018.
Myliobatidae						
Aetomylaeus vespertilio	Ornate Eagle Ray	EN (2015)	2	F: 1, M: 1	F: 166, M: 100.4	Landings in the month of January and March 2018. Both specimens caught in trawl nets.
Aetobatidae						
Aetobatus flagellum	Longheaded Eagle Ray	EN (2006)	2	F: 2	F: 133.5 - 136.5 (135 ± 2.12)	Both specimens caught in demersal longlines.
Aetobatus ocellatus	Ocellated Eagle Ray	VU (2015)	38	F: 24, M: 13, UK: 1	F: 62.5 - 156.2 (122.03 ± 26.58) M: 89 - 153.5 (118 ± 24.1)	Caught in gillnet, trawl net, hook and line, and demersal longline.
Rhinopteridae						
Rhinoptera jayakari	Oman Cownose Ray	NE	19	F: 9, M: 9, UK: 1	F: 75.2 - 100.5 (98.96 ± 31.60)	One gravid female landed in January measuring DW 96 cm. Two

					M: 84.4 - 96 (99.33 ± 34.19)	specimens were caught in trawl nets, one in gillnet, one in demersal longline.
Mobulidae						
Mobula kuhlii	Shortfin Devil Ray	DD (2007)	8	F: 8	F: 59.5 - 125 (107.36 ± 20.56)	Two specimens caught in gillnets, two in hook and line.
Mobula mobular	Giant Devil Ray	EN (2018)	3	F: 1, M: 2	F: 205 M: 205.5 - 213 (209.25 ± 5.30)	One specimen caught in demersal longline and one in gillnet.
Mobula thurstoni	Bentfin Devil Ray	EN (2018)	13	F: 5, M: 7, UK: 1	F: 78 - 167 (131.32 ± 33.72) M: 126.5 - 158.7 (149.31 ± 10.77)	One specimen caught in demersal longline, one in trawl net.
Mobula sp.	Devil Ray		27	F: 13, M: 9,	F: 113 - 270.5	Individuals could not be identified to

				UK: 5	(163.76 ± 51.04)	the species level due to improper photo documentation
					M: 112.3 - 218.3 (153.86 ± 38.07)	

The next section first provides an overview of the information collected on sharks and then rays separately including species composition, species susceptibility to fishing gear, and biological data of the most abundant species recorded.

CHONDRICHTHYES: ELAMOBRANCHII: EUSELACHII: SELACHIMORPHA

Species composition

Species from the Carcharhinidae family dominated landings and accounted for 19 of the 36 species (82.98 %). The six most dominant shark species landed were *Loxodon macrorhinus* (n = 1,549, 33.44 %), *Carcharhinus amblyrhynchos* (n = 1,215, 26.23 %), *Sphyrna lewini* (n = 421, 9.09 %), *C. albimarginatus* (n = 295, 6.36 %), *C. brevipinna* (n = 212, 4.57 %), and *Paragaleus randalii* (n = 169, 3.64 %), constituting 83.35 % of all landings.

The number of sharks sampled across the year ranged from a mean abundance of 41.61 ± 11.58 sharks per day in January to 0.5 ± 0.93 sharks per day in May with landings peaking from November (41.36 ± 11.11 sharks per day) to April (18.90 ± 3.08 sharks per day) (Fig 3).

Fig 3. Trends in the mean abundance of daily shark and ray individuals landed across months. Shark abundance is represented in black, and rays in white. The seasons are north-east monsoon (NE) (October–January), dry season (DS) (February–May) and south-west monsoon (SW) (June–September). Error bars indicate standard error.

Use of fishing gears and fishing grounds

Twenty-one species were recorded interacting with gillnets, hook and line, and pelagic longlines each, 18 species were recorded interacting with demersal longlines, 14 species with trawl nets and two species (*Centrophorus atromarginatus* (n=1) and *C. granulosus* (n = 6)) with deep-sea longlines.

Certain species were only recorded in one type of gear. For example, *Alopias pelagicus* (n = 28), *A. superciliosus* (n = 6), *C. longimanus* (n = 19) and *Hemitriakis indroyonoi* (n = 2) were only associated with pelagic longlines; *Mustelus mosis* (n = 7) were only recorded from hook and line; and *S. mokarran* (n = 2) were only recorded in trawl nets.

Further, there was a significant difference between the TL of sharks caught depending on the type of fishing gears used (f (5, 2,146) = 88.66, $p < 0.005$). Sharks landed in pelagic longliners had a high TL range from 21.5 to 376.5 cm (mean of 124.90 ± 49.83); those in demersal longlines had a TL range from 42 to 214.5 cm (mean 18.81 ± 93.76); those in deep-sea longlines (>200 m) had a TL range from 72.5 to 103 cm (mean of 88.3 ± 10.80); those in gillnets had a TL range from 25 to 312.5 cm (mean of 97.49 ± 34.26); those in trawl nets had a TL range from 50 to 297.9 cm (mean of 47.67 ± 97.65); and those from hook and line had a TL range of 46 to 266.7 cm (mean of 47.67 ± 97.65) (Fig 4). The fishing grounds with frequency of each fishing gear used across the islands is provided in Fig 1.

Fig 4. Total length (in cm) of sharks landed across the different fishing gear used on the islands.

Seasonality, size frequency, and length-weight relationships

The following section provides details of the size frequency, seasonality and length-weight relationships of the six dominant shark species landed. Additional information on all species, including sex ratios where applicable and recorded size extensions for seven species, are provided in Table 1. For the non-dominant shark species in landings, of the 2,258 male individuals whose maturity was recorded, 35.93 % of sharks were mature. The majority of specimens from small-bodied species (TL < 1.5 m) were mature (63.48%) whereas the majority of specimens from large-bodied species (TL > 1.5 m) were immature (84.79%).

CARCHARHINIFORMES - CARCHARHINIDAE - *Loxodon macrorhinus*

The size frequency of *L. macrorhinus* followed a unimodal size distribution where mature individuals of TL 85 - 95 cm (n = 830, 54.35 %) were dominantly landed across both sexes (Fig 5). Landings were variable across seasons with a peak during the dry season (n = 909) followed by NE monsoon (n = 632) and low landings during the SW monsoon (n = 8) (Fig 6).

Fig 5. Size frequency distribution for males and females for the six most commonly landed shark species. (a) *Loxodon macrorhinus*, (b) *Carcharhinus amblyrhynchos*, (c) *Sphyrna lewini,* (d) *Carcharhinus albimarginatus,* (e) *Carcharhinus brevipinna,* and (f) *Paragaleus randalli*. The black bars represent males and the white bars represent females. The arrows represent the smallest individual representing young of year with the presence of an umbilical scar 'U', 'F' the smallest gravid females recorded, and 'M' the smallest recorded mature males.

Fig 6. The seasonal size distribution of male and females for the six most commonly landed shark species. (a) *Loxodon macrorhinus*, (b) *Carcharhinus amblyrhynchos*, (c) *Sphyrna lewini,* (d) *Carcharhinus albimarginatus,* (e) *Carcharhinus brevipinna,* and (f) *Paragaleus randalli.* The seasons are north-east monsoon (NE) (October–January), dry season (DS) (February–May) and south-west monsoon (SW) (June–September). The black bars represent males and the white bars represent females.

Of the 852 males, 75.94 % were mature. The smallest immature male was 32.6 cm whereas the largest was 78.1 cm. The smallest mature male was 67.3 cm, whereas the largest was 102 cm with a TL_{50} of 70.61 cm (Fig 7). Landings of gravid females at various stages of embryo development were observed throughout the year, whereas YOY were observed in the month of March and April 2017 and 2018, with one individual observed in January 2018.

Fig 7. Percentage of mature males with total length (TL) for sharks at 50% and 100% maturity for the six most commonly landed shark species. (a) *Loxodon macrorhinus* (n = 820), (b) *Carcharhinus amblyrhynchos* (n = 518), (c) *Sphyrna lewini* (n = 176), (d) *Carcharhinus albimarginatus* (n = 124), (e) *Carcharhinus brevipinna* (n = 87), and (f) *Paragaleus randalli* (n = 91)

The length-weight relationships differed between sexes, where females showed positive allometry (b = 3.40), whereas for males, the weight increased in an almost allometric manner (b = 2.99), in proportion with the cube of the length (Fig 8, S1 Table).

Fig 8. Length and weight relationships between total body mass (kg) and total length (cm) for the six most commonly landed shark species. (a) *Loxodon macrorhinus*, (b) *Carcharhinus amblyrhynchos*, (c) *Sphyrna lewini,* (d) *Carcharhinus albimarginatus,* (e) *Carcharhinus brevipinna,* and (f) *Paragaleus randalli.*

CARCHARHINIFORMES - CARCHARHINIDAE - *Carcharhinus amblyrhynchos*

Immature individuals of size class TL 61 - 81 cm dominated landings across both sexes (n = 441, 38.28 %), followed by size class 81 - 100.9 cm (n = 310, 26.90 %) (Fig 5). Landings were variable across seasons with a peak during the dry season (n = 633) followed by NE monsoon (n = 559) and a lower number of individuals landed during the SW monsoon (n = 23) (Fig 6).

Of the 555 males, 16.19 % were mature. The smallest mature male was TL 126.3 cm whereas the largest was 206 cm. The TL_{50} of males was 131.69 cm (Fig 7).

The length-weight relationships did not differ between sexes, where both the sexes showed a positive allometric relationship (female b = 3.45; male b = 3.29), in proportion with the cube of the length (Fig 8, S1 Table).

CARCHARHINIFORMES - SPHYRNIDAE- *Sphyrna lewini*

Landings of *S. lewini* were dominated by the size class TL 91 to 120.9 cm (n = 204, 50.37 %), followed by size class 61 - 90.9 cm (n = 150, 37.03 %) (Fig 5). Landings were variable across seasons with a peak during the dry season (n = 211) followed by NE monsoon (n = 189) whereas comparatively fewer landings were recorded during the SW monsoon (n = 21) (Fig 6).

Of 177 males, 9.65 % were mature. Immature individuals measured 35.5 to 170.4 cm TL, whereas mature individuals measured 177 to 238 cm TL with a TL_{50} of 173 cm (Fig 7).

The length-weight relationships did not differ between sexes, where both the sexes showed a positive allometric relationship (female b = 2.91; male b = 2.60), in proportion with the cube of the length (Fig 8, S1 Table).

CARCHARHINIFORMES - CARCHARHINIDAE - *Carcharhinus albimarginatus*

The size frequency of *C. albimarginatus* followed a unimodal size distribution where immature individuals of size class TL 91 - 121 cm dominated landings (n = 109, 40.37 %) across both sexes (Fig 5). Landings were variable across seasons with a peak during the dry season (n = 177), followed by NE monsoon (n = 118) with none recorded during the SW monsoons (Fig 6).

Of the 137 males, 4.47 % were mature. The smallest mature male was 173 cm whereas the largest was 249 cm. The TL_{50} of males was 178.98 cm (Fig 7).

The length-weight relationships showed that males and females did not differ significantly in their average weight for a given length, and weight increased in a positive allometric manner (female b = 3.65; male b = 3.55), in proportion with the cube of the length (Fig 8, S1 Table).

CARCHARHINIFORMES - CARCHARHINIDAE - *Carcharhinus brevipinna*

Juveniles of the size class TL 51 - 80.9 cm (n = 110, 52.88 %) dominated landings, followed by size class 81 - 110.9 cm (n = 54, 25.96 %) where male YOY (n = 62) were more abundant than females (n = 48) (Fig 5). Landings were variable across seasons and differed in sex and size. Landings peaked during the dry season (n = 159) followed by NE monsoon (n = 52) with low landings during the SW monsoon (n = 1) (Fig 6).

Of the 116 males sampled, 10.11 % were mature. Mature males ranged from TL 172 to 212 cm, whereas immature males ranged from TL 62.6 to 175.78 cm. The TL_{50} of males was 175.78 cm (Fig 7).

The length-weight relationships differed between sexes, where the female showed positive allometry (b = 3.20), whereas for males, the weight increased in a near perfectly allometric manner (b = 3.23), in proportion with the cube of the length (Fig 8, S1 Table).

CARCHARHINIFORMES - HEMIGALEIDAE - *Paragaleus randalli*

The size frequency followed a unimodal distribution where females of size classes TL 81 - 90.9 cm (n = 87, 51.47 %) dominated landings, followed by 91 - 100.9 cm (n = 46, 27.2 %) (Fig 5). Landings peaked during the dry season (n = 120) followed by a decrease in NE monsoon (n = 49) whereas no landings were observed during the SW monsoons (Fig 6).

Of 91 males recoded, 93.4 % were mature. The smallest immature individual measured 43.5 cm whereas the largest measured 76.5 cm. The smallest mature individual measured 74.5 cm, whereas the largest measured 106.2 cm with a TL_{50} of 69.6 cm (Fig 7).

The length-weight relationships showed that males and females did not differ significantly in their average weight for a given length, and weight increased in a positive allometric manner (female b = 2.65; male b = 2.59), in proportion with the cube of the length (Fig 8, S1 Table).

RAYS

CHONDRICHTHYES: ELASMOBRANCHII: BATOIDEA

Species composition

Species from the *Dasyatidae* family dominated landings, accounting for 11 of the 21 species, and 63.06 % of the total landings. The three most common rays landed were *Pateobatis jenkinsii* (n = 241, 21.71 %), *Himantura leoparda* (n = 206, 18.55 %) and *H. tutul* (n = 95, 8.55 %); representing 48.82 % of the total ray landings.

The number of rays sampled across the year ranged from 11.2 ± 3.45 rays per day in February to 3.07 ± 3.66 rays per day in November with no pattern observed in landings (Fig 3).

New species records

Three species of rays, *Aetobatus flagellum*, *H. tutul*, and *P. fai*, were recorded for the first time from the Andaman and Nicobar Islands (Table 1, S1 Fig).

Eight species previously not confirmed but reported as possibly occurring on the islands by Kumar et al. [24] have been confirmed: *Aetomylaeus vespertilio, Glaucostegus typus, H. undulata, Mobula kuhlii*, *M. tarapacana, Pastinachus ater*, *P. jenkinsii*, and *Urogymnus asperrimus.*

Use of fishing gears and fishing grounds

Sixteen species of rays were captured in demersal longlines, 14 species in trawl nets, ten in gill nets, seven in hook and line, and two in pelagic longlines. No rays were captured in deep-sea longlines. Certain species were caught exclusively in certain gears. For example, *A. vespertilio* (n = 2), and *Maculabatis gerrardi* (n = 13) were only caught in trawl nets.

Biological traits for rays

Of the 513 male individuals recorded, 80.71 % were mature. Sex ratios were calculated for four rays, *H. tutul*, *H. leoparda*, *P. fai* and *P. jenkinsii* (Table 1).

DISCUSSION

This is the first systematic landing survey carried out for sharks and rays in the Andaman and Nicobar Islands, contributing to the current knowledge of species diversity and biology for the south and south-east Asian region. Three ray species are new records for the Andaman and Nicobar Islands, including one new record for India, increasing the elasmobranch diversity for the Andaman and Nicobar Islands from 103 to 106, and for India to 152 [24]. A threshold was reached in terms of shark species recorded, but additional efforts are required to fully document ray diversity. The diversity and high number of species recorded around the islands reflect the diverse habitats they support and yet that also overlap with important fishing zones.

Only two species of deep-sea sharks were recorded in this study despite recent additions of seven new records from the region [14, 23 - 25]. This was due to the logistical difficulties in sampling the large quantities of deep-sea sharks landed, along with time constraints between landings and transport to the storage units. Currently, there is an ongoing targeted deep-sea shark fishery in the Andaman Islands that supplies the demand for shark liver oil [15]. Deep-sea sharks have rates of population increase, that are on average, less than half those of shelf and pelagic species and some of the lowest levels recorded to date [34]. These life history traits do not allow them to sustain intense fishing pressure which can lead to rapid population declines. This has been previously documented in the Indian Ocean region with the collapse of deep-sea fisheries along the west coast of India and the Maldives occurring within a short time period after the beginning of their exploitation [17, 35]. In addition, population recovery rates also decrease with increasing depth, suggesting that these species are most susceptible to overexploitation [34]. Thus, we emphasise the urgency and importance of assessing the status and monitoring the populations of deep-sea sharks as well as determining the socio-economic benefits and impacts of the trade in shark liver oil so that management measures such as catch limits, and spatial or temporal regulations can be put in place in order to avoid a collapse of this fishery.

Many rays (e.g., *Neotrygon* sp., *Pastinachus* sp.) could not be identified to the species level due to their tails being cut, difficulty in manipulation due to their weight, or traders transporting them before photo documentation was possible. Ongoing taxonomical uncertainty for many ray species currently exists in India, where there is ambiguity in several species complexes. In order to address and resolve this, a robust taxonomic framework needs to be developed which can be used to better understand diversity and potential impacts from fishing pressure on key species. Thus, in the future, a combination of molecular techniques, and long-term fishery-independent surveys need to be established to gain a holistic picture of diversity as well as population trends in the region.

At many sites sampled around the world, smaller size species are predominantly landed, as many of the larger shark species have been overfished [36 - 39]. On peninsular India, shark stocks have also declined over the past decade with smaller, faster-growing shark species displacing larger, slower-growing species [5, 11, 40 - 43]. A decrease in the diversity of species landed has also been documented in areas with high fishing pressure. Indeed, Thailand, closer to Andaman and Nicobar Islands than to mainland India, has recorded a decrease in landings of larger sharks from 41 species in 2004 to 15 species in 2014-15 [44]. Yet our results indicated that this is not yet the case in the Andaman and Nicobar Islands as four of the six dominantly landed sharks are larger bodied shark species. This suggests that we are still at a point where informed management decisions can lead to the conservation of these populations. However, as gravid females, juveniles and YOYs are being fished, the productivity, resilience and sustainability of these populations may have already reduced [45].

The largest size range in sharks was recorded in landings from pelagic longlines and gillnets. While gillnets fish up to seven nautical miles from the coast across the Andaman Islands, pelagic longlines fish exclusively beyond seven nautical miles from the coast and within 12 nautical miles, and are known to fish in waters from South Andaman to Nicobar. The high range of TL and non-specificity of gear catch could be ascribed to the gear size, fishing grounds, or the activity patterns of the diverse species ecology. In future, size - specificity studies in relation to the catch by gears need to be conducted in order to determine gear modifications best suited for the susceptible life history stages of threatened shark and ray populations.

This study emphasizes the overlap between critical habitats and fishing grounds as all life-stages for most species were recording highlighting their susceptibility to fishing pressure. Gravid females of 12 species were reported with fishers confirming that they were fished in the waters of the Andaman and Nicobar Islands. Juveniles of large shark species are being fished intensely, such as *Carcharhinus albimarginatus*, *C. amblyrhynchos*, *C. brevipinna* and *Sphyrna lewini*, which is a reason to be concerned as these species exhibit particularly low productivity and growth rates leading to high susceptibility to anthropogenic pressure and are slow to recover from overexploitation [46]. The presence of high abundance of YOY for these species suggests that these species might be using the islands as pupping or nursery grounds. *Carcharhinus brevipinna* and *S. lewini* have been recorded to use inshore nursery areas for their young [47 - 49]. Thus, we recommend that these breeding and nursery grounds need to be identified and evaluated, following which they can be temporally and spatially managed.

Sex ratios in landings differed across species and fishing gears, which could be due to confounding factors such as gear selectivity, fishing grounds, season, productivity, currents and bathymetry [51]. Significantly more females than males for *C. amblyrhynchos, S. lewini,* and *P. jenkinsii* suggests that females of these species dominate the populations in these waters. These are also aggregating species often exhibiting some degree of side fidelity [52 - 56] another ecological character that needs to be considered in spatial management. Similarly, for *L. macrorhinus,* and *H. leoparda,* significantly more males were landed than females, whereas parity was recorded for *C. falciformis*. In future, region-specific studies need to be carried out to assess sex-mediated spatial ecology for sharks and rays. Systematic sampling from fishing vessels across seasons would also be required to get fine-scale overlap between temporal and spatial distribution of shark and rays as well as fishing gear specificity.

Landings for sharks peaked from November to April, coinciding with pelagic longlines targeting sharks during this time. Landings in December were unpredictable where sampling differed from the highest number of sharks to a complete absence of sharks resulting in a higher standard error. Seasonal differences during the year could be ascribed to various factors such as the weather, access to fishing grounds, fishing gears used, and the ecology of the species fished. During the SW monsoon (May to September), the absence of landings at the Junglighat site could be due to the weather which makes it risky for fishers to go out fishing or the seasonal ban on trawlers and pelagic longliners.

It is noteworthy to highlight species diversity, quantities landed and TL ranges were highest in pelagic longlines. Landings from these gears included threatened species such as *Alopias pelagicus, A. superciliosus*, *C. falciformis*, *C. longimanus*, and *S. lewini* which are migratory species. These species are listed under Appendix I (*C. longimanus*) and II of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), for international cooperation for conservation of migratory species and to regulate their trade, respectively. Since India is a signatory to these conventions, there is an urgent need for regional cooperation to ensure their protection as well as trade controls. CITES specifically requires the development of a Non-Detrimental Findings to assure that trade is not adversely impacting populations [59], something that has yet to be done in India. Given India's long coastline of nearly 7,516 km, along with the multi-stakeholder and multi-gear nature of fisheries, it is challenging to comprehensively monitor the trends in landings of sharks and rays. While the Central Marine Fisheries Research Institute (CMFRI) in India has the most comprehensive fisheries database dating back to 1947, it is restricted to peninsular India, with no presence in the Andaman and Nicobar Islands. Here, the monitoring is undertaken by the Andaman and Nicobar Islands Directorate of Fisheries who broadly focuses on commercial fish stocks and does not include species-specific categories for sharks and rays [15]. Additionally, the Zoological Society of India (ZSI), Fisheries Survey of India (FSI) and Central Island Agricultural Research Institute (ICAR) conduct opportunistic surveys to document species diversity. We conducted this study in the Andaman Islands to fill this gap, however, additional studies are required to address ongoing taxonomic ambiguities, improve knowledge of species by expanding fisheries independent monitoring, and to facilitate long-term species-specific monitoring. The latter would benefit the government as it would ensure traceability and control of onward trade. This in turn could help determine management and conservation measures for implementing CITES.

Shark and ray species protected under the WLPA were rarely landed (only two individuals of *U. asperrimus* were recorded). Most of the species listed in the WLPA are found in estuarine habitats and are not likely to occur around the islands, including *Anoxypristis cuspidata*, *Glyphis gangeticus*, and *G. glyphis*. *Rhynchobatus djiddensis* listed in the WLPA does not appear to occur in India and the species complex could include *R. australiae* and *R. laevis* [60]. However, the latter two species are not protected under the WLPA. Anecdotal reports from fishers state that a few of these species (e.g., *Pristis* sp.) have not been seen or landed for over a decade (Z. Tyabji unpubl. data). This highlights the urgent need for amending the WLPA and to include Critically Endangered and Endangered species that occur in India to the list of protected species. However, species-selective bans in non-selective multi-gear fishery are difficult to implement, thus amending the WLPA has to be combined with stakeholder engagement and other regulations such as fishing gear modifications and spatial closures.

While there exists a 45-day shark fishing ban, there are no regulations for ray fishing, despite them being predominantly threatened species. Of the 19 ray species identified, 15 species (85.17 %) are listed on the IUCN Red List of Threatened Species as threatened (Critically Endangered, Endangered, or Vulnerable), one species (0.4 %) as Near Threatened, one species (1.08 %) as Data Deficient, and two species (13.33 %) have not been evaluated. Rays are extremely susceptible to overexploitation, with wedgefishes and giant guitarfishes being the most imperiled marine taxa globally [1, 60]. Susceptibility studies on the various sharks and ray species in Papua New Guinea, deemed *P. jenkinsii* at the highest risk in trawl fisheries [61]. This was one of the most dominant species landed in the Andaman and Nicobar Islands. This is concerning as most ray species utilize coastal areas which overlap with the majority of fisheries. Additionally, there is a developing targeted ray fishery in the islands (Z. Tyabji unpubl. data) due to the local demand for their meat and trade in their skins. Studies regarding the local population status and exploitation rate of rays on the islands are urgently required, following which a prioritizing exercise needs to be conducted which takes into account the life history traits, susceptibility to fishing pressures, and population recovery rate. Based on this, ray species that are most susceptible to overexploitation need to be identified and a management plan needs to be developed and implemented.

While sustainability can be attained by a combination of policy changes such as the identification and protection of critical shark and ray habitats and populations, gear modifications, and implementing seasonal and temporal bans, it is a daunting task due to the lack of data on which to base these management strategies. We recommend additional studies and continued long-term monitoring with a focus on threatened species in order to establish appropriate management measures. We also need to understand the socio-economic importance of shark and ray fisheries for the range of stakeholders and communities on the islands; and the role of these fisheries in the supply chain of both domestic and global markets while designing management strategies. It is essential that policy formulation and changes are carried out with the involvement of fishers and local stakeholders for effective implementation. Thus, we suggest adapting science-based management techniques with the inclusiveness of stakeholders involved so as to avoid overexploitation of sharks and rays and aid in their conservation.

ACKNOWLEDGEMENT

We would like to thank the fishers, traders and processing unit managers at the study sites for their help and support. We are grateful to Nairika Barucha, Vishwanath K. G., Harsh Narola, Mahi Mankeshwar, Anushka Rege, Evan Nazareth, Mahadev, Sachin Vaishampayan, and Sitara Hussain for helping with data collection. Lastly, we are thankful to Andaman Nicobar Environment Team for their logistical support.

REFERENCES

1. Dulvy NK, Fowler SL, Musick JA, Cavanagh RD, Kyne PM, Harrison LR, Carlson JK, Davidson LN, Fordham SV, Francis MP, Pollock CM. Extinction risk and conservation of the world's sharks and rays. elife. 2014 Jan 21;3:e00590.
2. Compagno L, Dando M, Fowler S. A field guide to the sharks of the world.
3. Bradley D, Conklin E, Papastamatiou YP, McCauley DJ, Pollock K, Kendall BE, Gaines SD, Caselle JE. Growth and life history variability of the grey reef shark *(Carcharhinus amblyrhynchos*) across its range. PLoS One. 2017;12(2).
4. Stevens JD, Bonfil R, Dulvy NK, Walker PA. The effects of fishing on sharks, rays, and chimaeras (chondrichthyans), and the implications for marine ecosystems. ICES Journal of Marine Science. 2000 Jun 1;57(3):476-94.
5. Zacharia PU, Kizhakudan SJ, Thomas S, Manojkumar PP, Nair RJ, Najmudeen TM, Purushottama GB, Muktha M, Dash SS, Akhilesh KV, Remya L. CMFRI Marine Fisheries Policy Series No-6; Non-Detriment Findings (NDF) for the export of Shark and Ray species listed in Appendix II of the CITES and harvested from Indian waters. CMFRI Marine Fisheries Policy Series. 2017(6):1-02.
6. Okes N, Sant G. An overview of major shark traders, catchers and species. TRAFFIC, Cambridge, UK.
7. Bhargava AK, Somvanshi VS, Varghese S. Pelagic sharks by-catch in the tuna longline fishery of the Indian EEZ. Management of Scombroid fisheries. 2002:165-76.
8. Jayaprakash AA, Pillai NG, Elayathu MN. Drift gill net fishery for large pelagics at Cochin-A case study on by-catch of pelagic sharks. Management of Scombroid fisheries. 2002:155-64.
9. Varghese S, Somvanshi VS, Varghese SP. Bycatch of sharks and Incidental catches of sea turtle in the long line fishery of Indian waters as observed during tuna resources survey. Indian Ocean Tuna Commission Working Party on Ecosystems and Bycatch, Victoria, Seychelles. 2007.

10. Kar AB, Govindaraj K, Ramalingam L, Prasad GV. Bycatch in tuna longline fishery in the Indian EEZ around Andaman and Nicobar Islands. Indian Ocean Tuna Commission Working Party on Ecosystems and Bycatch. 2011;19.
11. Karnad D, Sutaria D, Jabado RW. Local drivers of declining shark fisheries in India. Ambio. 2020 Feb 1;49(2):616-27.
12. CMFRI. Marine Fisheries Census India Report. 2010. Retrieved from http://eprints.cmfri.org.in/8998/1/India_report_full.pdf
13. Rajan PT, Mishra SS, Kumar RR, Basheer VS, Bineesh KK, Venu S. First incidence of three sharks off Andaman Islands, India. Journal of the Andaman Science Association. 2016;21(2):221-8.
14. Tyabji Z, Jabado RW, Sutaria D. New records of sharks (Elasmobranchii) from the Andaman and Nicobar Archipelago in India with notes on current checklists. Biodiversity data journal. 2018(6).
15. Advani S, Sridhar A, Namboothri N, Chandi M, Oommen MA. Emergence and transformation of marine fisheries in the Andaman Islands. Dakshin Foundation and ANET. 2013:1-50.
16. Christensen J, Tull M. Introduction: Historical perspectives of fisheries exploitation in the Indo-Pacific. In Historical Perspectives of Fisheries Exploitation in the Indo-Pacific 2014 (pp. 1-12). Springer, Dordrecht.
17. Jabado RW, Kyne PM, Pollom RA, Ebert DA, Simpfendorfer CA, Ralph GM, Al Dhaheri SS, Akhilesh KV, Ali K, Ali MH, Al Mamari TM. Troubled waters: Threats and extinction risk of the sharks, rays and chimaeras of the Arabian Sea and adjacent waters. Fish and Fisheries. 2018 Nov;19(6):1043-62.
18. Andaman and Nicobar Islands Fisheries Policy 2018. http://www.and.nic.in/pdf/policydocument.pdf

19. Mohamad Kasim H. Shark fishery of Veraval coast with special reference to population dynamics of *Scoliodon laticaudus* (Muller Andhenle) and *Rhizoprionodon acutu*s (Ruppell). Journal of the Marine Biological Association of India. 1991;33(172):213-28.
20. Yamaguchi A, Taniuchi T, Shimizu M. Geographic variations in reproductive parameters of the starspotted dogfish, *Mustelus manazo*, from five localities in Japan and in Taiwan. Environmental Biology of Fishes. 2000 Feb 1;57(2):221-33.
21. Walker TI. Spatial and temporal variation in the reproductive biology of gummy shark *Mustelus antarcticus* (Chondrichthyes: Triakidae) harvested off southern Australia. Marine and Freshwater Research. 2007 Feb 21;58(1):67-97.
22. Kumar RR, Venu S, Akhilesh KV. First Report of Magnificent Catshark, *Proscyllium magnificum* Last and Vongpanich, 2004 (Proscylliidae: Carcharhiniformes) from Bay of Bengal, Indian EEZ. World Journal of Fish and Marine Sciences. 2015;7(6):479-81.
23. Kumar RR, Venu S, Bineesh KK, Basheer VS. New biogeographic data and DNA barcodes for the Indian swellshark, *Cephaloscyllium silasi* (Talwar, 1974) (Elasmobranchii: Carcharhiniformes: Scyliorhinidae), from Andaman waters. Acta Ichthyologica et Piscatoria. 2016 Jul 1;46(2).
24. Kumar RR, Venu S, Akhilesh KV, Bineesh KK. First report of four deep-sea chondrichthyans (Elasmobranchii and Holocephali) from Andaman waters, India with an updated checklist from the region. Acta Ichthyologica et Piscatoria. 2018;48(3):289-301.
25. Pradeep HD, Shirke SS, Nashad M, Sukham MD. A first record of the smallfin gulper shark *Centrophorus moluccensis* Bleeker, 1860 (Chondrichthyes: Squaliformes: Centrophoridae) from the Andaman & Nicobar waters, Indian EEZ. Journal of Threatened Taxa. 2017 Nov 26;9(11):10899-903.
26. Pradeep HD, Swapnil SS, Ramachandran S, Pattnayak SK. Report of the crocodile shark *Pseudocarcharias kamoharai* (Matsubara, 1936) from deep waters of the Andaman Sea. Marine Biodiversity. 2017 Jun 1;47(2):535-8.

27. Jaini M, Advani S, Shanker K, Oommen MA, Namboothri N. History, culture, infrastructure and export markets shape fisheries and reef accessibility in India's contrasting oceanic islands. Environmental Conservation. 2018 Mar;45(1):41-8.
28. Patankar V, D'Souza E, Alcoverro T, Arthur R. Erosion of traditional marine management systems in the face of disturbances in the Nicobar Archipelago. Human ecology. 2015 Oct 1;43(5):697-707.
29. Ebert DA. A pocket guide to sharks of the world. Princeton University Press; 2015.
30. Jabado RW, Ebert DA. Sharks of the Arabian Seas: an identification guide. IFAW, Dubai. 2015.
31. Last P, Naylor G, Séret B, White W, de Carvalho M, Stehmann M, editors. Rays of the World. CSIRO publishing; 2016.
32. Jabado RW. Wedgefishes and giant guitarfishes: a guide to species identification. Wildlife Conservation Society, New York. 2019.
33. Zar JH. Biostatistical analysis. Pearson Education India; 1999.
34. Simpfendorfer CA, Kyne PM. Limited potential to recover from overfishing raises concerns for deep-sea sharks, rays and chimaeras. Environmental Conservation. 2009 Jun;36(2):97-103.
35. Akhilesh KV, Ganga U, Pillai NG, Vivekanandan E, Bineesh KK, Shanis CR, Hashim M. Deep-sea fishing for chondrichthyan resources and sustainability concerns—a case study from southwest coast of India. NISCAIR-CSIR; 2011.
36. Henderson A, Al-Oufi H, McIlwain J. Survey, status and utilization of the elasmobranch fishery resources of the Sultanate of Oman. Sultan Qaboos University, Muscat. 2007.
37. Valinassab T, Daryanabard R, Dehghani R, Pierce GJ. Abundance of demersal fish resources in the Persian Gulf and Oman Sea. Journal of the Marine Biological Association of the United Kingdom. 2006 Dec;86(6):1455-62.

38. Jabado RW, Al Ghais SM, Hamza W, Henderson AC, Spaet JL, Shivji MS, Hanner RH. The trade in sharks and their products in the United Arab Emirates. Biological Conservation. 2015 Jan 1;181:190-8.

39. Hasan MDM. Threatened shark biodiversity in the Bay of Bengal, Bangladesh: conservation needs Journal of Aquatic Marine Biology. 2018;7(3):136. DOI: 10.15406/jamb.2018.07.00199.

40. Mohanraj G, Rajapackiam S, Mohan S, Batcha H, Gomathy S. Status of elasmobranchs fishery in Chennai, India. Asian Fisheries Science. 2009;22(2):607-15.

41. Karnad D, Gangal M, Karanth KK. Perceptions matter: how fishermen's perceptions affect trends of sustainability in Indian fisheries. Oryx. 2014 Apr;48(2):218-27.

42. Mohamed KS, Veena S. How long does it take for tropical marine fish stocks to recover after declines? Case studies from the Southwest coast of India. Current Science. 2016 Feb 25:584-94.

43. Barnes A, Sutaria D, Harry AV, Jabado RW. Demographics and length and weight relationships of commercially important sharks along the north-western coast of India. Aquatic Conservation: Marine and Freshwater Ecosystems. 2018 Dec;28(6):1374-83.

44. Arunrugstichai S, True JD, White WT. Catch composition and aspects of the biology of sharks caught by Thai commercial fisheries in the Andaman Sea. Journal of fish biology. 2018 May;92(5):1487-504.

45. Smith WD, Cailliet GM, Cortés E. Demography and elasticity of the diamond stingray, *Dasyatis dipterura*: parameter uncertainty and resilience to fishing pressure. Marine and Freshwater Research. 2008 Aug 14;59(7):575-86.

46. Branstetter S. Age and growth estimates for blacktip, *Carcharhinus limbatus*, and spinner, *C. brevipinna*, sharks from the northwestern Gulf of Mexico. Copeia. 1987 Dec 9:964-74.

47. Castro JI. The sharks of North American waters. College Station: Texas A & M University Press; 1983 Mar.

48. Simpfendorfer CA, Milward NE. Utilisation of a tropical bay as a nursery area by sharks of the families Carcharhinidae and Sphyrnidae. Environmental Biology of Fishes. 1993 Aug 1;37(4):337-45.

49. Duncan KM, Holland KN. Habitat use, growth rates and dispersal patterns of juvenile scalloped hammerhead sharks *Sphyrna lewini* in a nursery habitat. Marine Ecology Progress Series. 2006 Apr 24;312:211-21.

50. Heupel MR, Carlson JK, Simpfendorfer CA. Shark nursery areas: concepts, definition, characterization and assumptions. Marine Ecology Progress Series. 2007 May 14;337:287-97.

51. Moore AB, McCarthy ID, Carvalho GR, Peirce R. Species, sex, size and male maturity composition of previously unreported elasmobranch landings in Kuwait, Qatar and Abu Dhabi Emirate. Journal of Fish Biology. 2012 Apr;80(5):1619-42.

52. Stevens JD. Life-history and ecology of sharks at Aldabra Atoll, Indian Ocean. Proceedings of the Royal society of London. Series B. Biological sciences. 1984 Jul 23;222(1226):79-106.

53. McKibben JN, Nelson DR. Patterns of movement and grouping of gray reef sharks, *Carcharhinus amblyrhynchos*, at Enewetak, Marshall Islands. Bulletin of Marine Science. 1986 Jan 1;38(1):89-110.

54. Vianna GM, Meekan MG, Meeuwig JJ, Speed CW. Environmental influences on patterns of vertical movement and site fidelity of grey reef sharks (*Carcharhinus amblyrhynchos*) at aggregation sites. PloS one. 2013;8(4).

55. Economakis AE, Lobel PS. Aggregation behavior of the grey reef shark, *Carcharhinus amblyrhynchos*, at Johnston Atoll, Central Pacific Ocean. Environmental Biology of Fishes. 1998 Feb 1;51(2):129-39.

56. Nalesso E, Hearn A, Sosa-Nishizaki O, Steiner T, Antoniou A, Reid A, Bessudo S, Soler G, Klimley AP, Lara F, Ketchum JT. Movements of scalloped hammerhead sharks (*Sphyrna*

lewini) at Cocos Island, Costa Rica and between oceanic islands in the Eastern Tropical Pacific. PloS one. 2019;14(3).

57. Stevens JD, McLoughlin KJ. Distribution, size and sex composition, reproductive biology and diet of sharks from northern Australia. Marine and Freshwater Research. 1991;42(2):151-99.
58. Robinson L, Sauer WH. A first description of the artisanal shark fishery in northern Madagascar: implications for management. African Journal of Marine Science. 2013 Mar 1;35(1):9-15.
59. Hacohen-Domené A, Polanco-Vásquez F, Estupiñan-Montaño C, Graham RT. Description and characterization of the artisanal elasmobranch fishery on Guatemala's Caribbean coast. PloS one. 2020 Jan 13;15(1):e0227797.
60. Kyne PM, Jabado RW, Rigby CL, Gore MA, Pollock CM, Herman KB, Cheok J, Ebert DA, Simpfendorfer CA, Dulvy NK. The thin edge of the wedge: extremely high extinction risk in wedgefishes and giant guitarfishes. bioRxiv. 2019 Jan 1:595462.
61. White WT, Baje L, Simpfendorfer CA, Appleyard SA, Chin A, Sabub B, Rochel E, Naylor GJ. Elasmobranch bycatch in the demersal prawn trawl fishery in the Gulf of Papua, Papua New Guinea. Scientific reports. 2019 Jun 25;9(1):1-6.

SUPPORTING INFORMATION

S1 Table. Maximum likelihood estimates of length and weight regression parameters for the six commonly landed shark species.

S1 Fig. 1) *Aetobatus flagellum* (a) dorsal view (b) ventral view of the mouth; **2) Two colourations of *Himantura tutul*** (a) dorsal view (b) denticles on the nuchal area (c) dorsal view (d) denticles on the nuchal area; **3) *Pateobatis fai*** (a) dorsal view (b) ventral view (c) tail

S2 Fig. Sharks and rays landed at the fish landing sites. Clockwise from top left: Deep-sea sharks caught from deep-sea longline landed at Burmanallah; Fishers take out sharks from the pelagic longline boats at Junglighat; Shark fins kept to dry; Landed rays are weighed, following which they will be transported to the storage units; Adult and juvenile sharks of various species landed at Junglighat.

AUTHOR CONTRIBUTIONS

Conceptualization: ZT, VP, DS

Data Curation: ZT

Formal Analysis: ZT

Funding Acquisition: ZT

Investigation: ZT, TW

Methodology: ZT, RWJ, DS

Project Administration: ZT

Resources: ZT

Software: ZT, RWJ

Supervision: RWJ, DS

Validation: RWJ, DS

Visualization: ZT, TW

Writing – Original Draft Preparation: ZT

Writing – Review & Editing: ZT, TW, VP, RWJ, DS

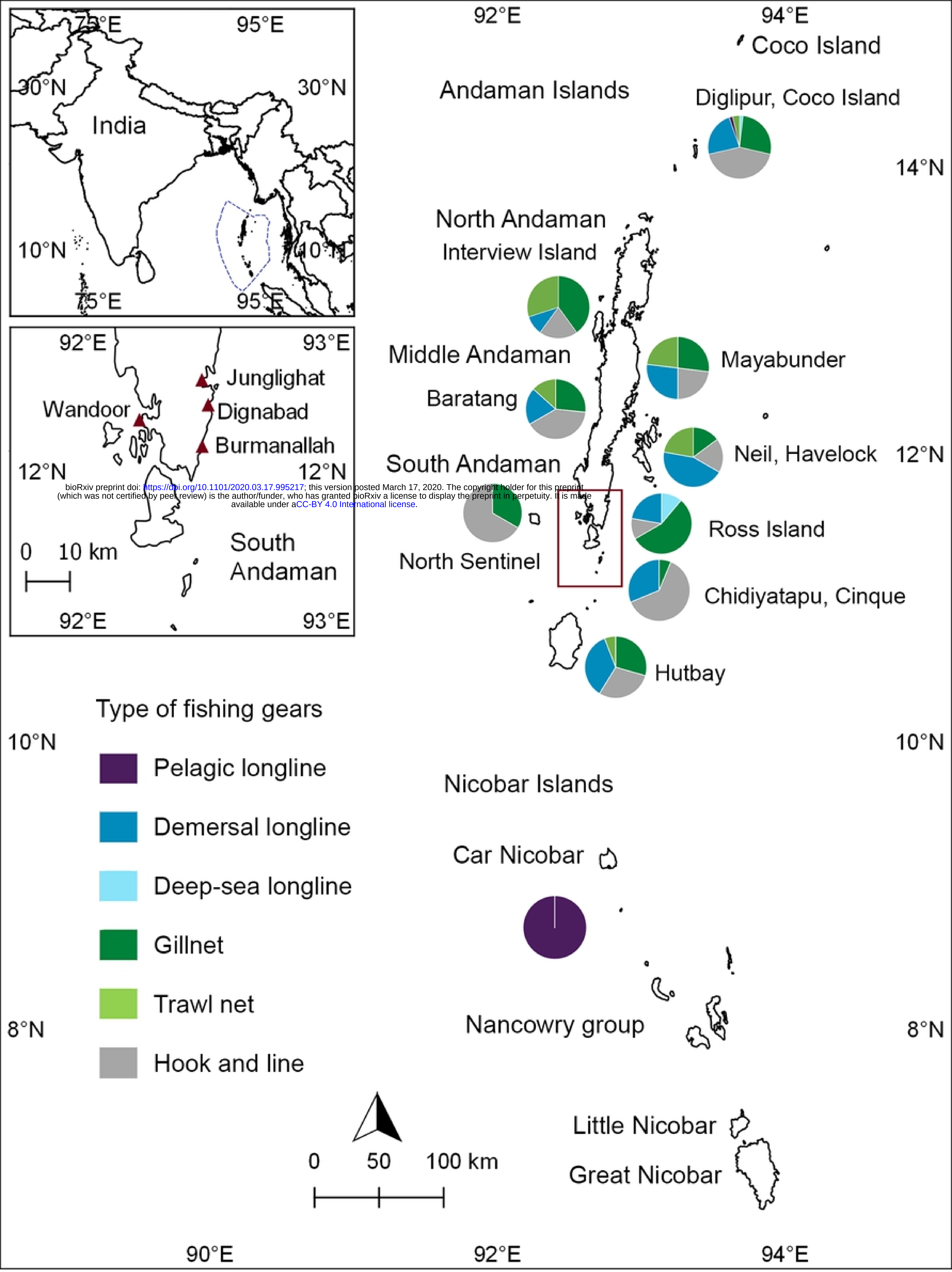

Fig 1. Map of the sampling sites and fishing grounds of the Anda

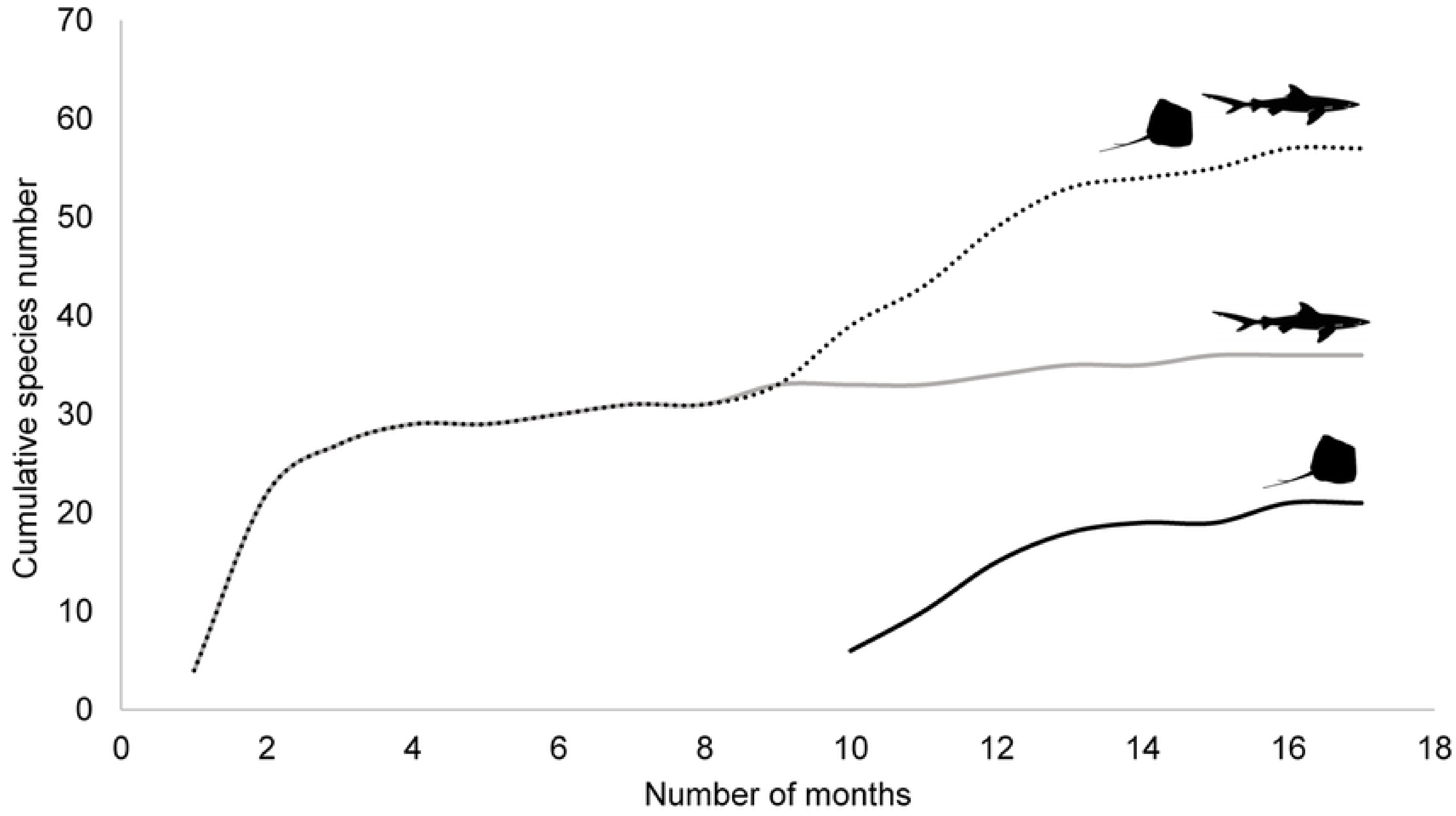

Fig 2. Species accumulation curve of sharks and rays landed

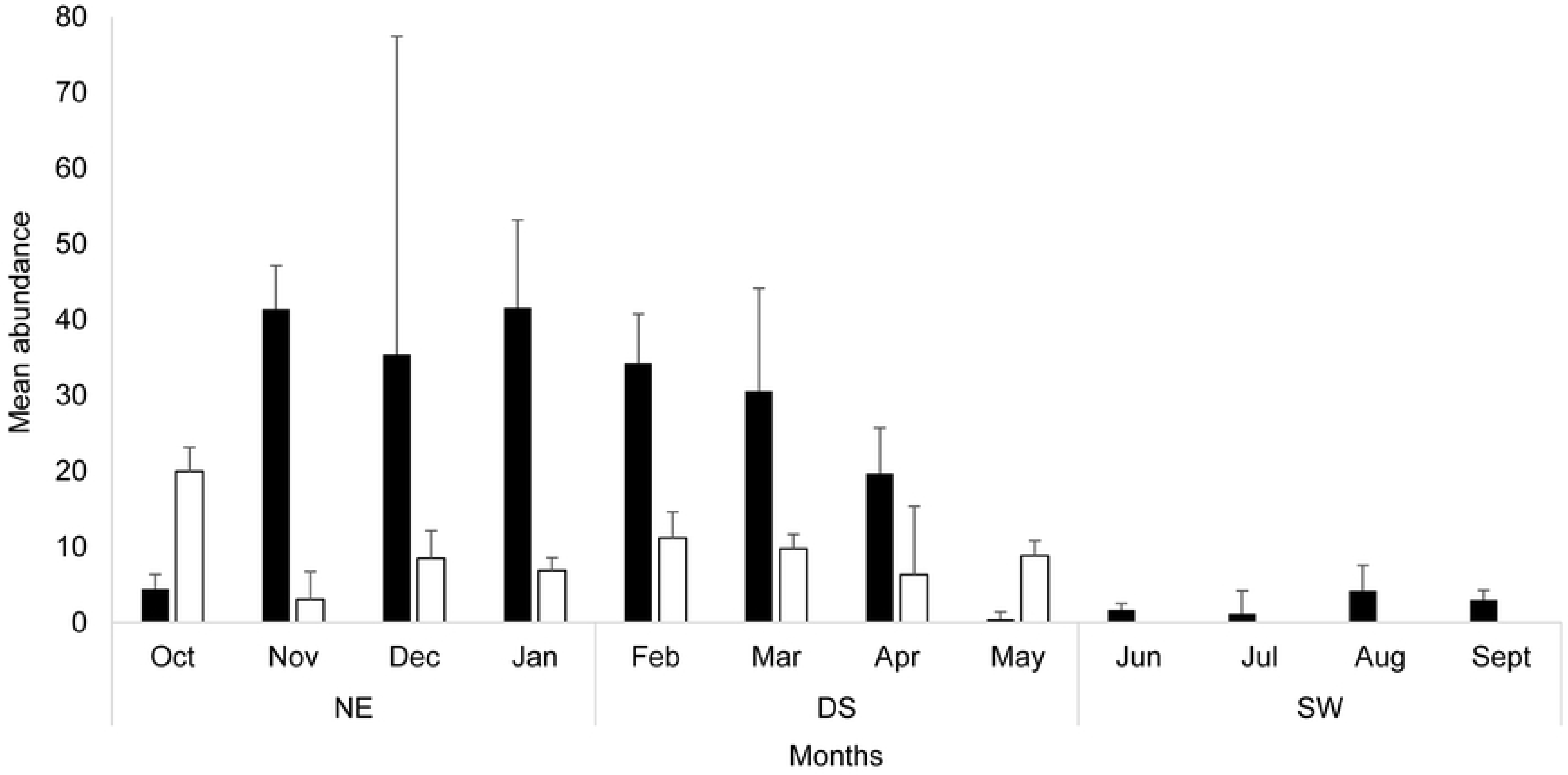

Fig 3. Trends in the mean abundance of daily shark and ray indiv

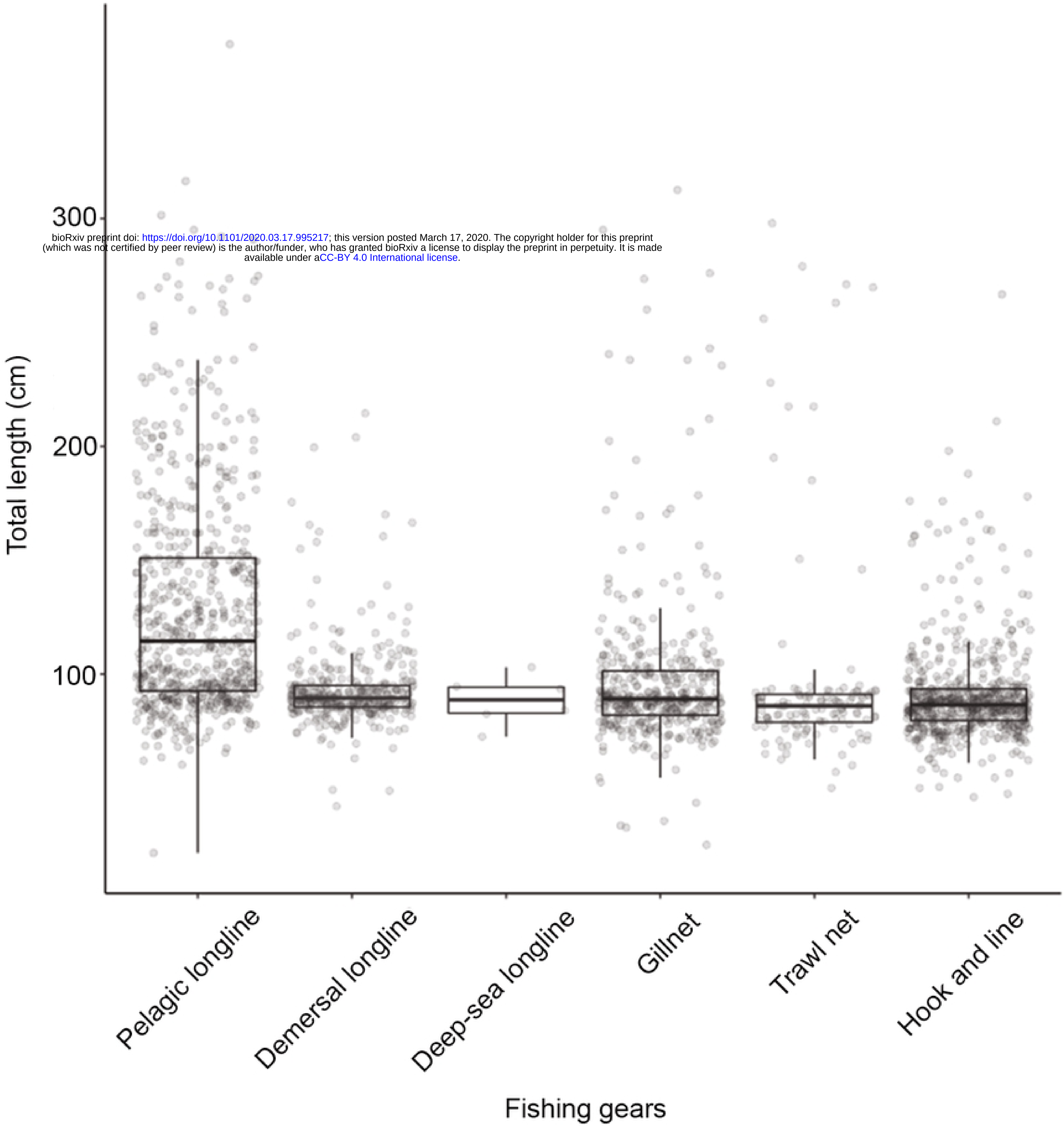

Fig 4. Total length of sharks landed across the different fishing g

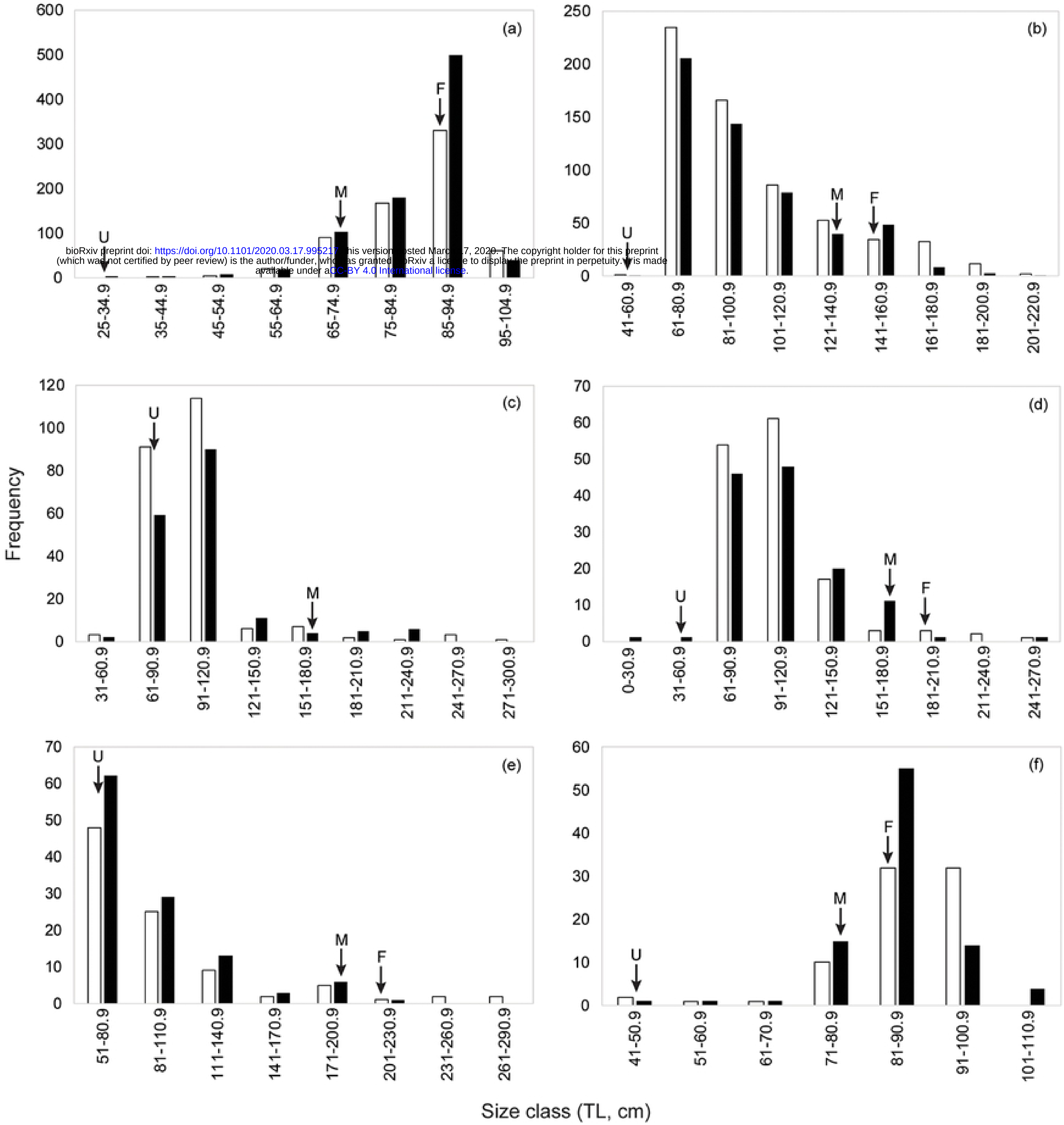

Fig 5. Size frequency distribution for males and females for the s

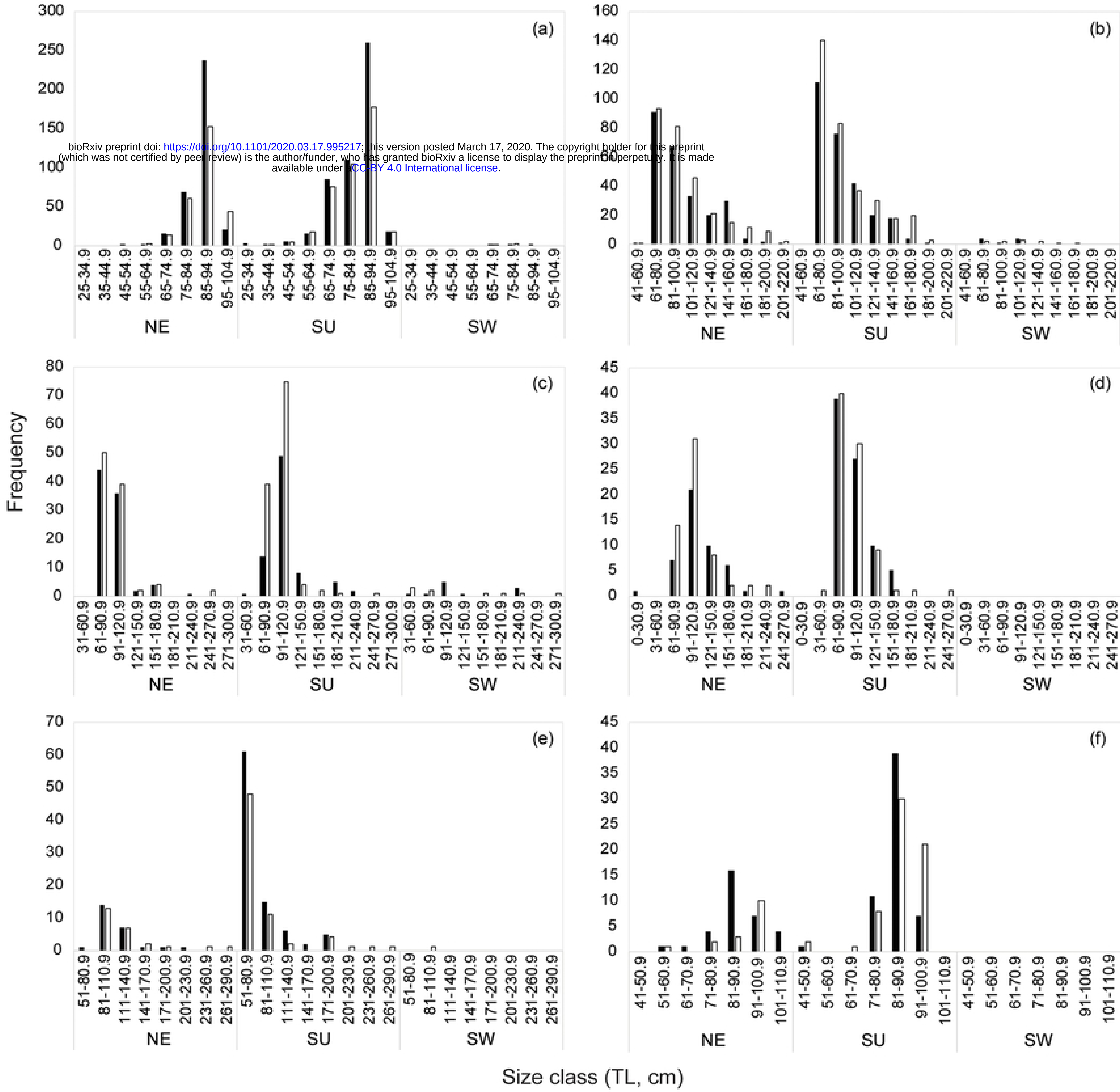

Fig 6. The seasonal size distribution of male and females for the

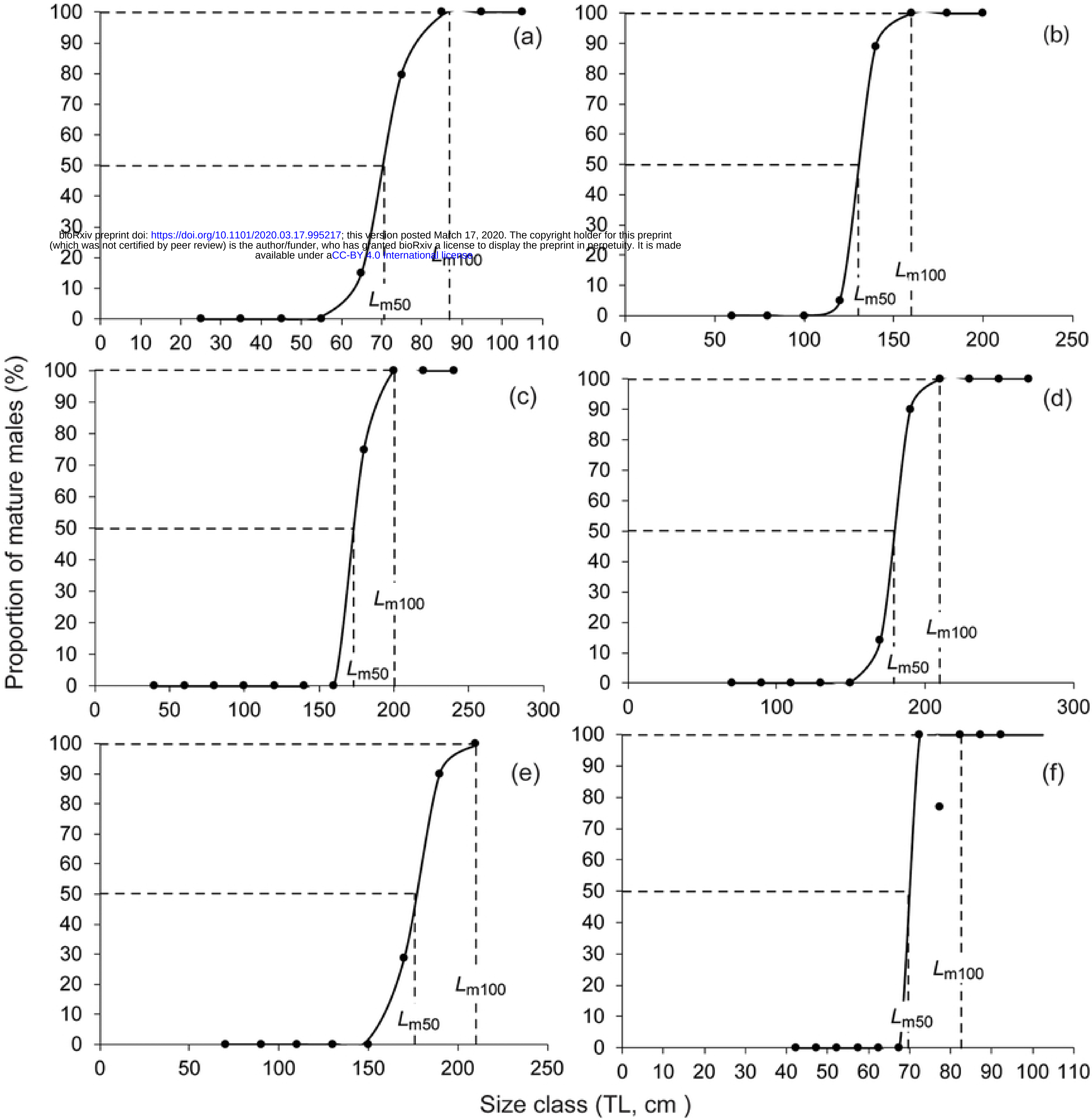

Fig 7. Percentage of mature males with total length (TL) for shar

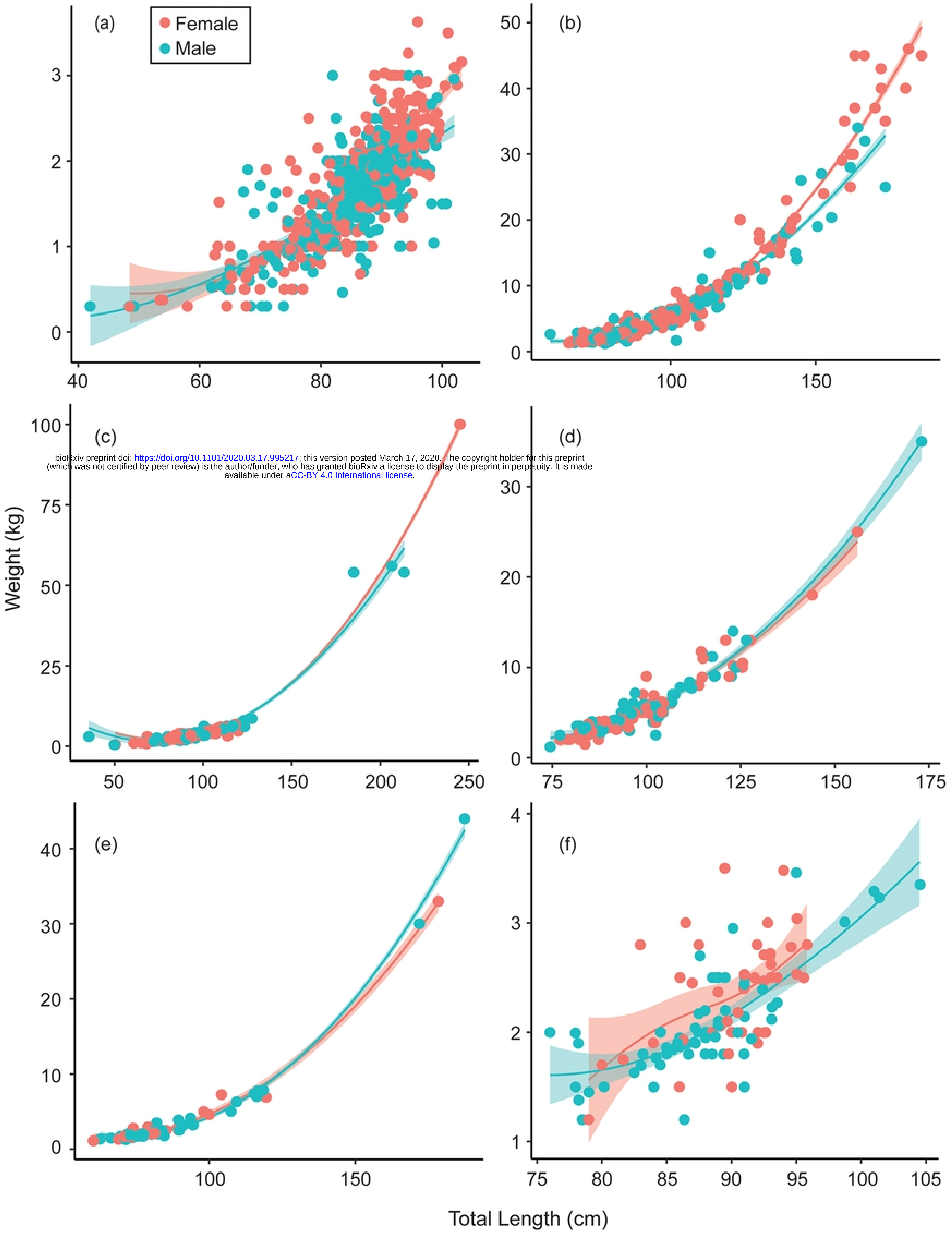

Fig 8. Length and weight relationships between total body mass