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Demographics and length and weight relationships of commercially important sharks along the north-western coast of India

Alissa Barnes[1] | Dipani Sutaria[2] | Alastair V. Harry[2] | Rima W. Jabado[3]

[1] Zoology and Wildlife Department, A.V.C. College, Mayiladuthurai, Tamil Nadu, India
[2] College of Science and Engineering, James Cook University, Townsville, Queensland, Australia
[3] Gulf Elasmo Project, Dubai, United Arab Emirates

Correspondence
Alissa Barnes, Dakshin Foundation, 1808, 9th cross road, 5th main road, Sahakar Nagar, A-Block, Bangalore, Karnataka - 560092.
Email: alissa.barnes@gmail.com

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Abstract

1. Biological data including size, sex ratios, male maturity, and length and weight relationships for four commercially important shark species, including the milk shark (*Rhizoprionodon acutus* Rüppell, 1837), the grey sharpnose shark (*Rhizoprionodon oligolinx* Springer, 1964), the spadenose shark (*Scoliodon laticaudus* Muller & Henle, 1838), and the bigeye smoothhound shark (*Iago omanensis* Norman, 1939), landed in Porbandar, Gujarat, India, are provided.
2. All four species were landed by trawlers and gill-netters across three defined seasons, with seasonal differences. Higher proportions of mature *R. acutus* and *S. laticaudus* were observed in the pre-monsoon season, with neonates caught throughout the year, whereas higher proportions of mature *R. oligolinx* and *I. omanensis* were recorded during the monsoon season, with neonates caught in post-monsoon and pre-monsoon, respectively, showing important species-level differences.
3. These small-bodied shark species (less than 1 m in total length) showed positive allometry in their length and weight relationships. Unlike the other three species, *I. omanensis* showed high disparity in total lengths (L_T) between the sexes, with females being larger than males, and with males maturing faster, with the smallest mature male of 33.58 cm L_T. Females outnumbered males except in *R. acutus*, and pregnant females of all species were recorded at least once. Of the 971 males recorded across species, 55.1% were mature and 44.9% were immature.
4. Results from this study indicate that there is substantial overlap between the distributions of these species and fishing activities, and show that most, if not all, life stages are susceptible to mortality as a result of fishing.
5. This study provides managers with a better understanding of the life-history traits of these commercially important species to support future quantitative population assessments, and provides a baseline of trends in fishing-related mortality.

KEYWORDS
biodiversity, coastal, fish, fishing, monitoring, ocean

1 | INTRODUCTION

Since the 1980s, India has reported the second or third largest chondrichthyan catches (sharks, rays, and chimaeras) in the world, and currently contributes up to 9% of reported global landings (Bineesh et al., 2014; Dent & Clarke, 2015; Kizhakudan, Zacharia, Thomas, Vivekanandan, & Muktha, 2015). Between 2000 and 2011, reports of Indian chondrichthyan catches to the United Nations Food and Agriculture Organization (FAO) averaged 73842 tonnes per year, having peaked at 103246 tonnes in 2007 (Dent & Clarke, 2015). Scientific studies and anecdotal information from Indian fishermen indicate that the biomass of sharks, as well as the average size of the animals landed, has considerably diminished over the same time period (Kizhakudan et al., 2015). This raises concerns over the status of these resources and the long-term sustainability of the Indian shark fishery, especially considering that data on catches and landings remain limited (Bineesh et al., 2014).

Understanding the composition of landings and the biology of exploited species is crucial for the development and implementation of effective management and conservation measures. This is particularly important because many shark species have conservative biological traits (including slow growth and low fecundity), suggesting that only a relatively small proportion of the population can be sustainably harvested annually (Stevens, Bonfil, Dulvy, & Walker, 2000; Walker, 1998). Furthermore, different shark populations belonging to the same species are known to show both temporal and spatial variations in life-history traits, including growth rate, weight, age at maturity, and fecundity, as well as the timing and frequency of reproduction (Kasim, 1991; Krishnamoorthi & Jagadis, 1986; Strasburg, 1958; Walker, 2007; Yamaguchi, Taniuchi, & Shimizu, 2000). Therefore, the potential for such variations make it necessary to collect data on the biological traits of sharks at a regional or local level.

The state of Gujarat has been recognized as one of the three top shark harvest locations in India (Central Marine Fisheries Research Institute (CMFRI), 2013; Kizhakudan et al., 2015), where its current shark catch constitutes 71% of the total chondrichthyans harvested (13040 tonnes; CMFRI, 2016). A recent rapid stock assessment indicated that between 1985 and 2013, the historical maximum catch was recorded at 1412 tonnes, peaking in the year 2000, with an average decline to 1132 tonnes between 2011 and 2013 (Kizhakudan et al., 2015). Several types of fishing vessels operate in Porbandar (the largest port in the state of Gujarat), including 2428 mechanized vessels (i.e. vessels that consist of an inboard engine with mechanically operated gear, comprising 2313 trawlers and 115 gill-netters), 2288 motorized vessels (i.e. fibre-reinforced plastic speedboats with either an inboard or outboard engine, with manually operated fishing gear), and 133 non-motorized boats (CMFRI, 2010a; Ministry of Micro, Small and Medium Enterprise - (M/o MSME), 2017). An assessment of shark landings in Porbandar from 2014 to 2015 found that of the 23 species landed during the study period, the grey sharpnose shark (*Rhizoprionodon oligolinx* Springer. 1964), the milk shark (*Rhizoprionodon acutus* Rüppell, 1837), the spadenose shark (*Scoliodon laticaudus* Muller & Henle. 1838), and the bigeye houndshark (*Iago omanensis* Norman, 1939) were the dominant species (Sutaria, Gangal and Karnad, unpubl. data). All four species are small-sized sharks (with a maximum total length of less than 1 m) and, in areas where they occur across the Arabian Sea and adjacent waters, are important components of commercial shark fisheries (Appukuttan & Nair, 1988; Henderson, McIlwain, Al-Oufi, Al-Sheile, & Al-Abri, 2009; Jabado, Al Ghais, Hamza, Robinson, & Henderson, 2016; Jayaprakash, Pillai, & Elayathu, 2002; Joshi, Balachandran, & Raje, 2008; Moore, Mccarthy, Carvalho, & Peirce, 2012; Raje, Das, & Sundaram, 2012). Despite their high proportion in landings, current knowledge of their life-history traits remains limited, with existing information on these species largely based on studies from the 1970s and 1980s, or conducted in other regions of India.

The aim of this study was to describe the life-history characteristics of these four most commonly encountered shark species – *I. omanensis*, *R. acutus*, *R. oligolinx*, and *S. laticaudus* – at the Porbandar landing sites by providing biological information needed for quantitative population assessments, specifically the relationships among length, weight, and male maturity stage. These data will give managers a better understanding of their life-history traits, inform future analysis of trends in fishing pressure faced by these species, and are an essential first step towards the sustainable management of shark fisheries in this region.

2 | MATERIALS AND METHODS

2.1 | Study area

The state of Gujarat has one of the longest coastlines in India (1600 km), with its inshore waters believed to be some of the most over-fished in the country (CMFRI, 2010b). From a countrywide perspective, the largest fleet of trawlers (32.9%) and the second highest number of gill-net vessels (20.4%) operate within these waters (CMFRI, 2010b). Lying between 21°38′19.64″N and 69°35′33.02″E, (Figure 1), Porbandar is one of the 121 fish landing centres in the state, accounting for 9% of the total fishing population (approximately 218000 active fishers) of Gujarat (CMFRI, 2010a; Shrivastava & Akolkat, 2015). The fishery craft and gear in Porbandar include trawlers (very few of which have long lines), gill nets, and dol nets (a fixed-bag net that catches fish along moving tides in estuaries; these were not sampled in this study). Each type of vessel has a designated landing site, with landings either transported directly to sorting units or sold at the auction market.

2.2 | Data collection

Data were collected in Porbandar from December 2014 to October 2015 from sharks landed at trawl and gill-net landing sites, as well as from the auction market. Sampling was carried out between 06:30 and 15:00 h. In order to avoid any replication of data by measuring the same sharks twice, the landing sites and the auction market were sampled on separate days. The sampling period was divided into three seasons, including pre-monsoon (January–May), monsoon (June–September), and post-monsoon (October–December), to explore seasonal differences in landings. Monsoon samples were mostly from gill-net landings. Although trawl operations are banned

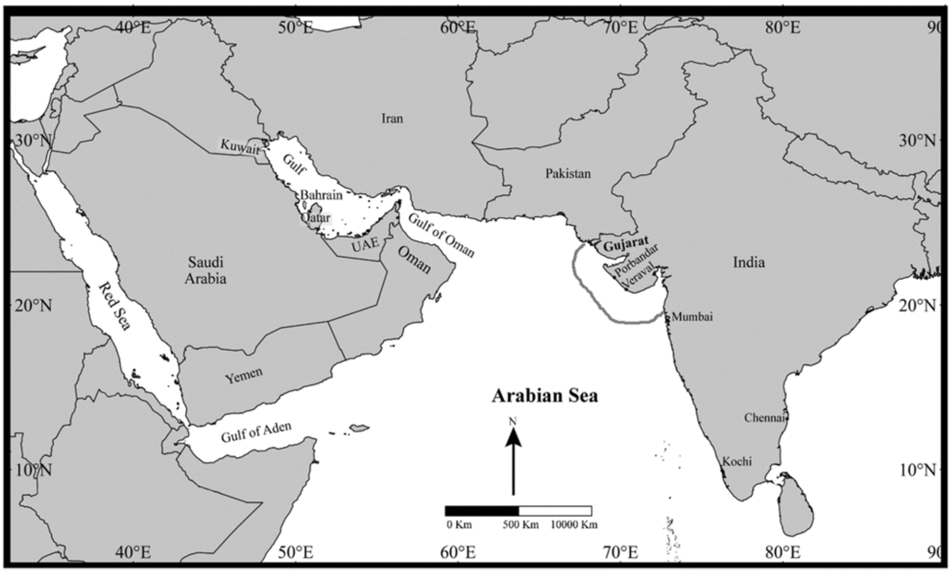

FIGURE 1 Study area. Map showing Porbandar in north-west India in a regional context, indicating the fishing grounds and other major important ports in the Arabian Sea

between 15th May and 15th August, some samples were also collected from 13 trawl vessels still found to be operating.

During a sampling session, a random pile of sharks was identified from which a minimum of 15 sharks were sampled. Shark specimens were identified using morphological characteristics as described by Ebert, Fowler, and Compagno (2013) and all individuals were measured, sexed, and weighed. The total length (L_T) was measured to the nearest centimetre by stretching the body along a straight axis, such that the snout and the upper caudal were approximately in a straight line. A minimum of 60 individuals of each species were weighed to the nearest gram by inserting the hook of a digital balance into the first gill slit. Males and females were differentiated by the presence or absence of claspers, and maturity was recorded in males by examining the extent of the calcification of the claspers and categorizing them as either immature (claspers not calcified), maturing (claspers partially calcified), or mature (claspers fully calcified). Gravid females, identified when young pups were seen emerging from the cloaca, or if they could clearly be observed by pressing the stomach, were also recorded. Neonate specimens were recorded opportunistically, based on the presence of open umbilical scars.

2.3 | Data analyses

Descriptive analyses were carried out using Microsoft EXCEL 2007 to explore size-class frequency distributions by sex and across seasons. Sex ratios were calculated using the goodness-of-fit test (χ^2 at a 5% significance). The length at maturity for 50% of male individuals (L_{T50}) of each species was calculated using SOLVER in EXCEL and fitting the following logistic function to the proportion of mature individuals in 5-cm or 10-cm size categories, $P = 1/(1 + \exp(-r(L_{Tmid} - L_{T50})))$, where P is the proportion of mature fish in each length class, L_{Tmid} is the midpoint of the length class, L_{T50} is the mean size at sexual maturity, and r is a constant that increases in value with the steepness of the maturation schedule. To calculate the length and weight relationships for the four species, the equation $W(l) = al^b e^{\varepsilon}$, was used, where W is the body mass, l is the length, a and b are fixed parameters, and ~$N(0, \sigma^2)$ is a normally distributed random variable that varies among individuals (Froese, 2006). The equation was then log-transformed to become a simple linear equation: $\ln(W) = \ln(a) + b\ln(l) + \varepsilon$.

3 | RESULTS

3.1 | Species composition and size distributions

Sampling across trawl, gill-net, and auction sites was undertaken over 147 days, including 77 pre-monsoon days, 35 monsoon days, and 35 post-monsoon days. Data were collected from 2678 individuals: *S. laticaudus* (n = 1094, comprising 41% of landings of these four species); *R. oligolinx* (n = 734, comprising 27.4% of landings of these species); *I. omanensis* (n = 664, comprising 25% of landings of these species); and *R. acutus* (n = 186, comprising 7% of landings of these species). Size-class ranges for males and females as well as combined size-class ranges (mean ± SD) are summarized in Table 1. The maximum lengths recorded indicated that females were larger in size for all species (Figure 2a–d).

The seasonal distribution of the number of individuals landed revealed that larger *R. acutus* females and males (50–90 cm L_T) were landed pre-monsoon, with more females than males (Figure 2a). *Rhizoprionodon oligolinx* had a high number of large females (60–70 cm L_T) during the monsoon, mature males (50–88 cm L_T) pre-monsoon, and a higher number of neonates post-monsoon (Figure 2b). Fewer *S. laticaudus* (n = 191) were landed during the monsoon, yet landings included some mature male individuals (35.6–58.5 cm L_T) across all seasons, which peaked during the post-monsoon season (Figure 2c). Similarly, mature males of *I. omanensis* were landed throughout the year, but showed greater numbers post-monsoon, whereas neonates (18.8–19.5 cm L_T) were only observed pre-monsoon. Gravid females of all four species were recorded during

TABLE 1 Size ranges (total length, L_T, in cm) along with mean (±SD), and percentage of male (M) and female (F) for *Rhizoprionodon acutus*, *Rhizoprionodon oligolinx*, *Scoliodon laticaudus*, and *Iago omanensis*

Species		*n*	Mean ± SD	Size range L_T (cm)	Percentage of M/F for each species	Additional notes
R. acutus	**Total**	**186**	**60.45 ± 13.66**	**27–88**		1 gravid female pre-monsoon, L_T 60.5 cm
	F	96	58.2 ± 13.41	28–88	52	
	M	90	62.7 ± 13.55	27–88	48	
R. oligolinx	**Total**	**734**	**52 ± 13.67**	**21–88**		8 gravid females pre-monsoon, L_T 52.5–73 cm
	F	412	53.2 ± 14.32	23.5–84	56	
	M	324	50.4 ± 12.65	21–88	44	
S. laticaudus	**Total**	**1094**	**45.8 ± 7.54**	**20–70**		5, 2, and 3 gravid females during monsoon, post-monsoon, and pre-monsoon, respectively (L_T 37.3–59 cm). Five neonates, 9.5–10.5 cm
	F	649	47.5 ± 7.92	20–70	59	
	M	445	43.4 ± 6.22	25–58.5	41	
I. omanensis	**Total**	**664**	**52.4 ± 11.07**	**22.5–83**		12, 6, and 58 gravid females during monsoon, post-monsoons, and pre-monsoon, respectively (L_T 43–81 cm). Ten neonates, 18.8–19.5 cm pre-monsoon
	F	462	55.9 ± 10.55	28.5–83	70	
	M	202	44.1 ± 7.14	22.5–59	30	

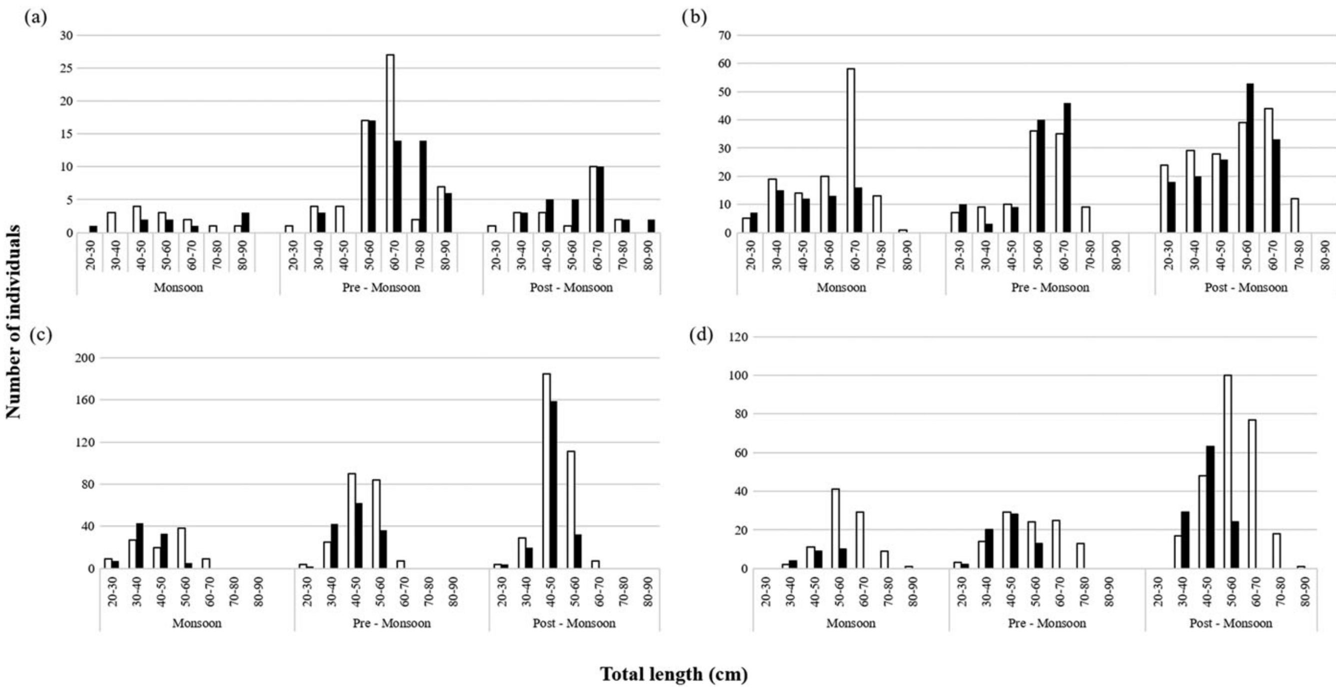

FIGURE 2 Size class distributions. Size class indicated by total length (L_T) of male (black) and female (white) individuals of the following species, across seasons: (a) *Rhizoprionodon acutus*, *n* = 186; (b) *Rhizoprionodon oligolinx*, *n* = 733; (c) *Scoliodon laticaudus*, *n* = 1094; and (d) *Iago omanensis*, *n* = 571

the pre-monsoon season, whereas gravid females of *S. laticaudus* and *I. omanensis* were also present across the monsoon and post-monsoon seasons.

The highest percentage (55%) of large females (>40 cm L_T) belonged to *S. laticaudus* pre-monsoon, followed by *R. acutus*, *I. omanensis*, and *R. oligolinx*. During the monsoon, large females of *R. oligolinx* dominated the landings of this species, followed by *I. omanensis*. The highest percentage of mature males (75%) landed across seasons was that of *S. laticaudus* post-monsoon. A small percentage of male and female neonates belonging to *R. oligolinx* and *S. laticaudus* were landed across all seasons. Sex ratios favoured females away from parity, and were statistically significant except for *R. acutus* (df = 1; χ^2 = 0.0967; $P > 0.05$; Table 2).

TABLE 2 Sex ratios with respective chi-square values of four commercially important species in Porbandar, India

Species	Sex ratios F: M	χ^2	*P*
Rhizoprionodon acutus	1: 0.94	0.09677	0.755
Rhizoprionodon oligolinx	1: 0.79	5.26086	0.0218*
Scoliodon laticaudus	1: 0.68	19.0201	0.00001*
Iago omanensis	1: 0.44	50.9036	0.000001*

*$P < 0.05$.

3.2 | Male maturity

A summary of male maturity is presented in Table 3. Of the 971 males recorded across species, 55.1% were mature and 44.9% were

TABLE 3 Size ranges at maturity and L_{T50} for males of four commercially important species in Porbandar, India

Species	No. of males (*n*)	Size range (L_T) (cm)	Size range at maturity (cm)	L_{T50} (cm)
Rhizoprionodon acutus	90	27–88	55–88	68.69
Rhizoprionodon oligolinx	296	21–84.5	50–84.5	56.4
Scoliodon laticaudus	384	25–58.5	36–58.5	43.38
Iago omanensis	201	22.5–58.8	31–59	33.58

immature. Sizes at maturity varied greatly between species, with *I. omanensis* maturing at the smallest size, whereas *R. acutus* males matured at larger sizes (Figure 3a–d).

3.3 | Length and weight relationships

Data from 541 individuals (*R. acutus*, *n* = 50; *R. oligolinx*, *n* = 95; *S. laticaudus*, *n* = 179; and *I. omanensis*, *n* = 217) were used to establish the relationships between length and weight (Figure 4). Across the study, the smallest individual measured was a 30-g male *I. omanensis*, whereas the largest individual was a 2.6-kg *R. acutus* (Table 4). The three carcharhinid species had very similar relationships between length and weight. In each case, males and females did not differ significantly in their average weight for a given length, and weight increased in a near perfectly allometric manner ($b \sim 3$), in proportion with the cube of the length (Table 4). For these species, the longest females were between 18 and 61% heavier than the longest males.

Iago omanensis, the only non-carcharhinid in this study, differed in its length and weight relationship relative to the other species: there was a strongly positive allometric relationship between length and weight ($b = 3.302$), with weight increasing more rapidly with increasing length (Table 4). The substantially greater difference in maximum length between males and females also resulted in the largest female being 135% greater in mass than the largest male. Although there was a strongly significant difference between male and female weight at the same length (ANOVA: $F = 21.1$; df = 1, 214; $P < 0.01$), there was nonetheless little discernible visible difference (Figure 4).

4 | DISCUSSION

Results show that all four shark species assessed in this study are caught across seasons by gill-netters and trawlers in the fishing areas off the coast of Gujarat, India, showing their year-round presence in these waters. This could be related to the availability of preferred habitat and prey in the areas used by fishermen, and suggests that these species do not undergo major seasonal migrations. Across its geographic range, *I. omanensis* is known to occur close to the continental slope and in deeper waters. In contrast, *S. laticaudus* is primarily an inshore species, whereas *R. oligolinx* and *R. acutus* are shelf species (Ebert et al., 2013). The continental shelf of Gujarat extends up to 100 km and more from the shore (Mishra, Pandey, Ramesh, & Clift, 2016), with a very gradual slope offering these four species their preferred range of habitats and thus explaining their presence through the year in these waters.

Although both species of *Rhizoprionodon* are widely distributed and found throughout the water column (Ba, Ba, Diouf, Ndiaye, & Panfili, 2013; Capape et al., 2006; Compagno, 1984), the differing relative abundance at landing sites could result from gear selectivity and habitat preferences. In this study a higher relative abundance of *R. acutus* was observed in gill-nets, yet this cannot be attributed to gear

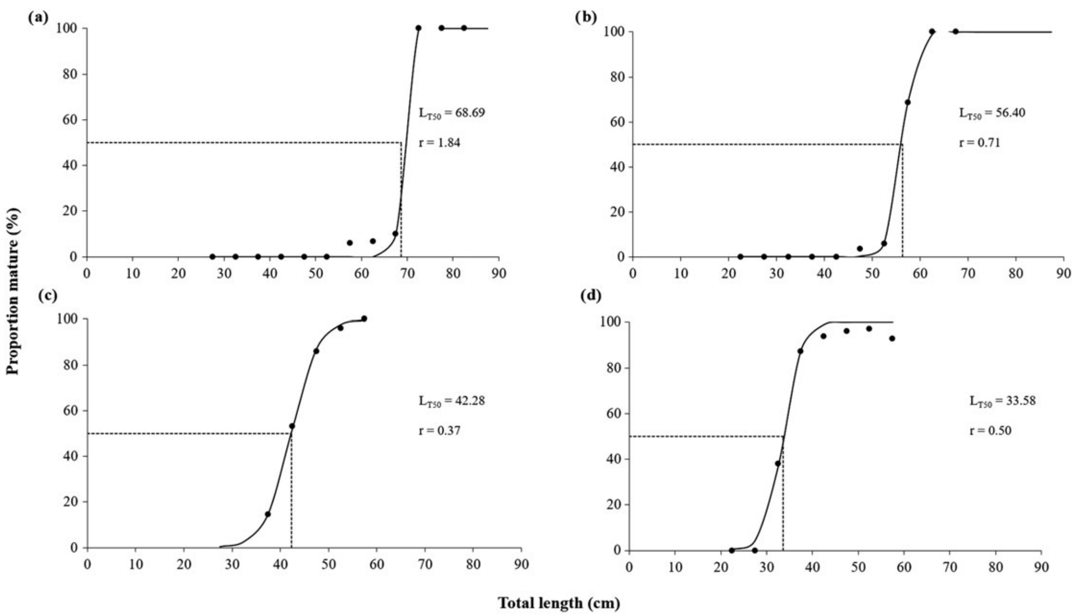

FIGURE 3 Size at maturity of males. Total lengths at which 50% of the individuals (L_{T50}) of (a) *Rhizoprionodon acutus*, (b) *Rhizoprionodon oligolinx*, (c) *Scoliodon laticaudus*, and (d) *Iago omanensis* mature

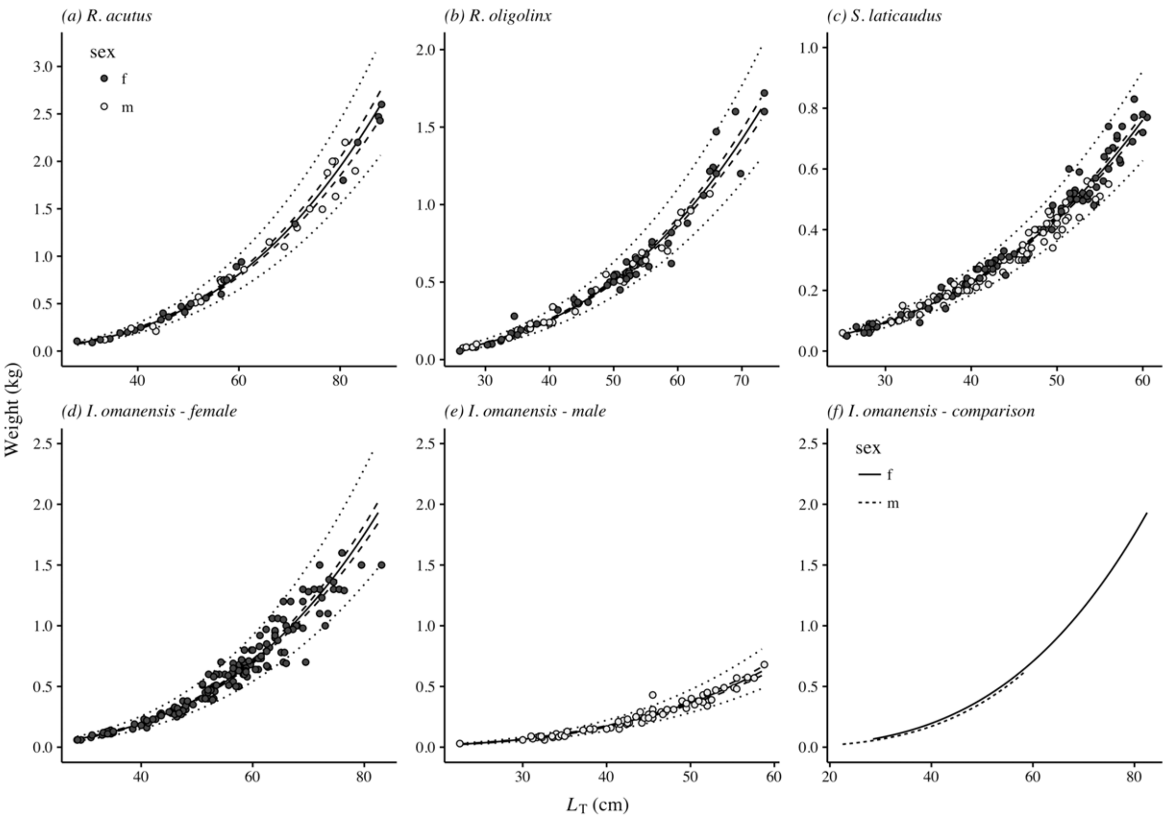

FIGURE 4 Length and weight relationships. Relationships between total body mass and total length for four species of shark: (a) *Rhizoprionodon acutus*; (b) *Rhizoprionodon oligolinx*; (c) *Scoliodon laticaudus*; and (d–f) *Iago omanensis*. Plots are mean body mass at length (solid lines), with 95% confidence intervals (dashed lines), 95% prediction intervals (dotted lines), and raw data, males (○) and females (•)

TABLE 4 Maximum likelihood estimates of length and weight regression parameters for *Rhizoprionodon acutus*, *Rhizoprionodon oligolinx*, *Scoliodon laticaudus*, and *Iago omanensis*. *a*, *b* and *σ* are fixed and random regression parameters, *LL* is the maximum log likelihood, and *n* is the sample size

Species	Sex	*n*	L_T range (cm)	Weight range (kg)	*a*	SE range	*b*	SE	*σ*
R. acutus	F	28	28–88	0.09–2.60	3.60E−06	2.860–4.542	3.011	0.058	0.099
	M	22	33.5–83	0.12–2.20	2.22E−06	1.456–3.369	3.123	0.102	0.123
	Combined	50	28–88	0.09–2.60	3.23E−06	2.634–3.965	3.035	0.051	0.11
R. oligolinx	F	58	26–73.5	0.055–1.72	2.84E−06	2.211–3.645	3.09	0.064	0.122
	M	37	26.5–65	0.075–1.07	3.59E−06	2.937–4.376	3.028	0.053	0.085
	Combined	95	26–73.5	0.055–1.72	3.12E−06	2.648–3.68	3.065	0.043	0.108
S. laticaudus	F	94	25.5–60.5	0.05–0.83	2.72E−06	2.294–3.216	3.07	0.045	0.103
	M	85	25–56	0.06–0.56	5.13E−06	4.307–6.12	2.893	0.047	0.084
	Combined	179	25–60.5	0.05–0.83	3.36E−06	2.971–3.808	3.01	0.033	0.097
I. omanensis	F	150	28.5–83	0.06–1.60	1.69E−06	1.396–2.051	3.159	0.048	0.134
	M	67	22.5–59	0.03–0.68	6.34E−07	4.749–8.473	3.389	0.077	0.126
	Combined	217	22.5–83	0.03–1.60	9.30E−07	7.991–10.816	3.302	0.039	0.139

selectivity alone, and is likely to result from a combination of the 3-month seasonal fishing ban on mechanized fisheries, preferred gillnet fishing grounds, and species habitat preferences. Data from the range of these species in the Arabian Sea suggest that although *S. laticaudus* is common in landings in India (Jayaprakash et al., 2002; Joshi et al., 2008), *R. oligolinx* and *R. acutus* are not as common as one moves towards south-west India and the continental shelf narrows. Both, however, are abundant in landings reported from several countries in the northern Arabian Sea and adjacent waters (Henderson, McIlwain, Al-Oufi, & Al-Sheili, 2007;Jabado et al., 2016; Moore et al., 2012). The distribution of *I. omanensis* is patchier: it is found in large numbers in certain pockets along the northern Arabian Sea (Henderson et al., 2007), but is absent in the shallower waters accessible to the artisanal fishers in the Arabian/Persian Gulf, hereafter referred to as 'the Gulf' (Jabado et al., 2016; Moore et al., 2012).

Similar to other parts of the west coast of India, *S. laticaudus* dominated the shark landings in Porbandar (Akhilesh et al., 2011; Appukuttan & Nair, 1988; Fofandi, Zala, & Koya, 2013; Kasim, 1991; Raje et al., 2012; Rao & Kasim, 1985; Verlecar, Snigdha, & Dhargalkar, 2007). Although long-term population trends for this species are not available, landings of *S. laticaudus* appear to have declined while the fishing effort has increased along the south-west coast of India (Mohamed & Veena, 2016). This is potentially a cause of concern as the species is listed as Near Threatened on the International Union for Conservation of Nature (IUCN) Red List, both at the global and at the regional scale (IUCN, 2016; Jabado et al., 2017). Furthermore, this trend is more worrying given that *S. laticaudus* is likely to be a highly productive species of shark: it has a small maximum length, is highly fecund (with up to 20 embryos per litter), and displays a highly advanced form of matrotrophic viviparity (Wourms, 1993), and is potentially capable of reproducing twice a year (Devadoss, 1979). If fishing intensity has been sufficient to cause population declines in this species, by extension, it may indicate that fishing is occurring at levels greater than most other species of sharks can sustain.

Even less is known in the literature about population trends or the stock status of the other species in this study. The presence and high relative abundance of the other three species is probably also linked to their high biological productivity, however, which may have enabled them to persist in this region despite intense fishing. In fact, previous vertebral ageing studies in Australian waters on *R. acutus* and on the Australian sharpnose shark (*Rhizoprionodon taylori* Ogilby, 1915), which attains a similar length to *R. oligolinx*, have shown both of these species grow rapidly, attaining sexual maturity in 1–2 years (Harry, Simpfendorfer, & Tobin, 2010; Simpfendorfer, 1993). *Rhizoprionodon oligolinx*, which seems to occur more frequently in these waters, is heavily fished compared with south-west India and the Gulf (Akhilesh et al., 2011; Jayaprakash et al., 2002; Moore et al., 2012). *Rhizoprionodon acutus* is also heavily fished throughout the region, contributing up to 50% of landings from the northern Arabian Sea and Gulf countries (Henderson et al., 2007; Henderson et al., 2009; Henderson, McIlwain, Al-Oufi, & Ambu-Ali, 2006; Jabado, Al Ghais, Hamza, Shivji, & Henderson, 2015; Jabado et al., 2016; Kasim, 1991; Moore et al., 2012). Both these species, along with *I. omanensis*, are listed as of Least Concern on the IUCN Red of Threatened Species List at the global level, yet these assessments do not consider information on stock status or population information specific to the region, and even more specifically to Gujarat (IUCN, 2016). A recent assessment at the regional level has indicated that both *R. acutus* and *R. oligolinx* populations are showing signs of declines, and are considered as Near Threatened in the Arabian Sea and adjacent waters (Jabado et al., 2017). Similarly, a recent study on *R. acutus* in West African waters, where the species is relatively slower growing, has suggested that it may be overexploited (Ba, Diouf, Guilhaumon, & Panfili, 2015), highlighting that populations at the regional levels could be facing higher threats than at the global level, and showing signs of declines. Monitoring trends in these species over time at the local and regional level is necessary to study the effects of fishing on their life-history and related consequences for population dynamics.

Rhizoprionodon acutus, the largest among the four species, varies considerably in its maximum length throughout its range. In this study, the maximum length was fairly similar (L_T = 88.2 cm) to that recorded in Gulf waters (L_T = 89 cm) (Moore et al., 2012; Moore & Peirce, 2013). Previous studies carried out in India, in Veraval, Mumbai, and Madras, reported larger individuals at 94, 92, and 90 cm L_T, respectively (Kasim, 1991; Krishnamoorthi & Jagadis, 1986; Setna & Sarangdhar, 1949). In the waters of Oman and the Gulf, the maximum total lengths for males were similar to those recorded in this study, but females were far bigger, at around 98 cm L_T (Henderson et al., 2006; Henderson et al., 2009; Jabado et al., 2016). For *R. oligolinx*, the largest maximum total length reported in Indian waters is 90 cm L_T from Kochi waters (Jayaprakash et al., 2002), a similar size to the one recorded in the Gulf (Jabado et al., 2016). Our study reports lengths closer to those from Kuwait waters (L_T = 85 cm) (Moore et al., 2012). The individuals in Bahrain and Indonesia were considerably smaller in size, with the maximum length being 65 and 68 cm L_T, respectively (Moore & Peirce, 2013; White, 2007). *Scoliodon laticaudus* also showed high variation in Indian waters. Sizes on the east coast are larger (47–74 cm L_T; James, 1973; Mahadevan, 1940) in comparison with the west coast (16–65 cm L_T; Devadoss, 1979, 1989; Misra, 1959; Nair, 1976; Raje et al., 2012; Setna & Sarangdhar, 1949). Sizes of *I. omanensis* were similar to those recorded by Henderson et al. (2006), Henderson et al., (2009). Both *I. omanensis* and *R. oligolinx* are species that show a significant intergender size difference, where females are much larger than the males (Henderson et al., 2009; Moore et al., 2012). The differences in sizes across the coasts of India and in regions around the Gulf could be related to the prey they consume, or could result from the type of gear used: for example, trawlers do not operate in fisheries off Oman and the United Arab Emirates (Jabado & Spaet, 2017).

In India, the information available on the seasonal distribution across sizes, sex ratios, and maturity is limited. Mature males and females of all four species were found in high numbers, with females found in larger numbers than males. Females were both larger and heavier than males, significantly so in the case of *I. omanensis*. Gravid females of all species and neonates of three species, *R. acutus*, *R. oligolinx* and *S. laticaudus*, were also recorded. Together, these findings demonstrate that there is substantial overlap between the distributions of these species with fishing activities in the region, and show that most, if not all, life stages are susceptible to fishing pressure. The finding of seasonal differences, such as higher proportions of mature *R. acutus* and *S. laticaudus* in the pre-monsoon season, with neonates all through the year, and the higher proportions of mature *R. oligolinx* and *I. omanensis* in the monsoon season, with neonates recorded in the post-monsoon and pre-monsoon seasons, respectively, show important species-level differences. These, in turn, could be related to prey or to the fishing intensity of different gear types. Both Nair (1976) and Devadoss (1998) recorded *R. acutus* neonates during the monsoon season, and recorded the highest number of large females in the pre-monsoon season, with this latter finding being similar to our study. On the other hand, in the Gulf, large females of *R. acutus* were recorded during spring (March–May; Jabado et al., 2016). Further research on these aspects would inform the temporal management of near-shore fisheries in these waters. Species like *I. omanensis* were found to be low in number during the trawling ban, whereas *R. acutus* were more abundant during this time, showing possible gear-specific differences in catch along with seasonal differences.

In addition to documenting differences in size compositions, documenting sex ratios in sharks is important, as many populations are also strongly sex-structured. During the course of the study, *R. acutus* was the only species that showed parity in sex ratios, whereas the other three species were dominated by females. Landings in the Gulf exhibited inconsistent parity across sites for *R. acutus* (Henderson et al., 2009; Jabado et al., 2016; Moore et al., 2012 ; Moore & Peirce, 2013). In Mumbai, on the west coast of India, Raje et al. (2012) showed that the sex ratio of this species was skewed towards females, whereas further south in Kochi and on the east coast in Chennai, the sex ratio was skewed towards males (Jayaprakash et al., 2002; Krishnamoorthi & Jagadis, 1986; Raje et al., 2012). *Scoliodon laticaudus* landings were dominated by females along the coasts of Mumbai, Saurashtra, and Calicut (Devadoss, 1998; Fofandi et al., 2013; Raje et al., 2012). The sex ratio observed for *R. oligolinx* in this study was also contrary to what was observed in Bahrain and Kuwait (Moore et al., 2012; Moore & Peirce, 2013). In Oman, the landings of *I. omanensis* were also significantly biased towards females (Henderson et al., 2009). Interpreting the observed patterns in sex ratios is difficult, with observations potentially influenced by short-term movements or seasonal effects (e.g. feeding and reproduction), natural mortality, and the fishing gear used. Variability in sex ratios could also be related to habitat or prey, or to the local continental shelf characteristics, which narrows substantially from Gujarat to Maharashtra to Kochi. Further analysis of landings in relation to the movement of fishing vessels would help in assessing the spatial distribution of these species.

The L_{T50} for *R. acutus*, although not identical, lies in a similar size range (61–65 cm L_T), with results from studies carried out along the south-east Indian coast, United Arab Emirates, and Bahrain waters (Henderson et al., 2006; Jabado et al., 2016; Krishnamoorthi & Jagadis, 1986; Moore et al., 2012; Moore & Peirce, 2013). *Rhizoprionodon oligolinx* matured at larger sizes (>45 cm L_T) in the Gulf (Jabado et al., 2016; Moore et al., 2012; Moore & Peirce, 2013). Sizes at maturity recorded for *S. laticaudus* were smaller along the coasts of Calicut and Mumbai: 30–35 and 34 cm L_T, respectively (Devadoss, 1979, 1998; Raje et al., 2012). Populations maturing at smaller sizes are speculated to be coping with fishing pressures (Rochet, 2000). Indeed, Olsen et al. (2004) suggest that the maturation of individuals in a population at smaller sizes could be attributed to individuals showing phenotypic plasticity as a result of overexploitation. A reduction in biomass therefore gives access to additional resources and allows for faster maturation (Lorenzen & Enberg, 2002).

When taking into consideration these biological aspects, there is high variation in all four species when compared with other studies carried out along the Arabian Sea and adjacent waters. The current study addressed several of the information gaps on biological parameters relating to the seasonal distribution of species sizes, maturity, and sex ratios of males and females. Based on the results of this study, it is evident that there is an urgent need to implement a more effective strategy to manage elasmobranch stocks in the region. Until such time as a formal management plan can be implemented, there is also an immediate need to initiate long-term, species-specific monitoring programmes across landing sites in India to acquire baseline data on size, sex, and species compositions, and to establish reference points to monitor future changes in stocks.

Although it is difficult to recommend a detailed management strategy using information from Gujarat alone, the implementation of even relatively simple management measures focused on gear modification and spatial restrictions may be an effective first step if they can be enforced. For example, the Gujarat Fisheries Act, 2003 under the Marine Fishing Regulation Acts (MFRAs) already limits the size of mesh used in trawling nets to a minimum of 40 mm. Although this regulation is rarely taken into account by fishermen, who often using very small mesh sizes (Shotton, 2000), its enforcement would likely increase the size at first capture to above the length at maturity for several of the species in this study.

For vessels operating gill nets, although a minimum mesh size of 150 mm is prescribed, there is still little understanding of the scale at which they operate and their choice of gear configuration in targeting commercially important species. Such research is needed to increase our understanding of interactions with sharks. Based on the sizes of the various shark species reported from this study, it is clear that fishing is occurring at potential nursery grounds in the waters off Gujarat. The higher number of neonates caught pre-and post-monsoon suggests nearshore fishing closures during these times of the year could be used to avoid the capture of juveniles and to reduce fishing mortality.

Along with the availability of scientific data, the voluntary participation of fishers is crucial to the success of any strategy aimed at achieving ecosystem-based management. For example, the formation of the fishery union Kerala Swatantra Malsya Thozhilali Federation, in Kerala, India, brought together legal, economic, and scientific aspects of the management of small-scale fisheries, and has seen small successes along its coasts. By attempting to manage their exclusive zones, fishermen actively apprehend trawlers and other large mechanized gear that violate coastal and fisheries laws established by the Kerala Marine Fisheries Regulation Act (Kurien, 1988). Most fisheries in the coastal states of India are complex and heterogeneous, and as such, it is necessary to integrate biological, ecological, socio-political, and economic considerations, while recognising that stakeholders belonging to each of these sections play a crucial role in the management of the fishery.

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ORCID

Alissa Barnes http://orcid.org/0000-0001-5287-4138
Dipani Sutaria http://orcid.org/0000-0002-6186-0923
Alastair V. Harry http://orcid.org/0000-0002-9905-7909
Rima W. Jabado http://orcid.org/0000-0001-6239-6723

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