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Length-weight Relationship of the Endangered Devil Ray *Mobula mobular* (Bonnaterre, 1778) off Gulf of Mannar, India

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Abstract

Mobulids are amongst the highly endangered elasmobranchs which are extremely vulnerable to the expanding fisheries owing to their most conservative life cycle. They are susceptible to incidental capture in a wide range of gears including gillnets, purse seines, trawl nets, and occasionally long lines. The study provides a preliminary estimate of the length–weight relationship (LWR) for the endangered batoid species *Mobula mobular*, from the Gulf of Mannar India, between July 2017 and October 2018. A total of 355 specimens were sampled and measured for their total length (TL), disc width (DW) and total weight (TW) considering the sex ratio. The TL recorded were within size range of 43.0 – 122.0 cm and 40.0 – 124.0 cm, the DW of 96.0 – 248.0 cm and 60.0 – 232.0cm; while the TW observed was 9000– 129000 g and 5000 – 111000 g, respectively for males and females. The growth pattern was negative allometry for both sexes ascertained from the slope (*b*) values (2.49 to 2.69). The Length–weight / Disc width-weight relationship showed a good fit with r^2 values varying from 0.82 to 0.88, indicating a high degree of positive correlation. Across the study areas, the devil ray population trend increased during June - August and October - December, attributable to the increased food availability strongly influenced by the North-East and South-West monsoon. This contemporary status of the LWR for the species *Mobula mobular* is a key approach towards ecological and biogeographical evaluation of the diversity and abundance of this threatened fauna in the Indian waters.

Keywords: Mobula, bycatch, monsoon, upwelling, tuna gillnet

Introduction

Devil rays (Mobulids) are the largest and amongst the most charismatic groups of cartilaginous fishes, inhabiting tropical, subtropical and temperate waters (Stevens 2011; Ward-Paige, Davis, & Worm, 2013; Stewart et al., 2018). The majority of the devil rays are categorized as Endangered by the IUCN Red list, and grouped under the Convention on International Trade in Endangered Species of Wild Fauna and flora (CITES) Appendix II. They are indeed captured by commercial and artisanal fishers of the Atlantic, Pacific, and Indian Oceans. Despite the ban on mobula fishery, illegal capture continues to be ambiguous and unreported in many regions (Alava, Dolumbaló, Yaptinchay, & Trono, 2002; Smith, Punt, Dowling, Smith, Tuck, & Knuckey, 2009; Erisman, Mascarenas, Paredes, de Mitcheson, Aburto-Oropeza, & Hastings, 2010). As a result, dramatic declines in devil ray catch and landing counts have occurred in the Philippines, Indonesia, Mexico, India, and Mozambique (Couturier et al., 2012). Targeted fisheries are prevalent in many locations around India, some of which are highly organized following high demand for their products (Rajapackiam, Mohan, & Rudramurthy, 2007; Lack & Sant, 2008). Although the existence of mobulids dates back to the 17^{th} century (Shirke, Nashad,

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Sukham, & Pradeep, 2017), there is a dearth of species-specific fisheries information. The existing trade dynamics, limited literature and data on these threatened megafauna are hampering conservation actions, particularly in developing countries.

These gentle giants are filter-feeding planktivores and piscivores, widely dispersed in tropical and warm-temperate waters. Their conservative life history characteristics and ecological traits make them highly susceptible to overexploitation. The gillnets, purse seines, and drift nets that target tuna and other pelagic resources often retain the incidentally captured mobulids (White, Giles, Dharmadi, & Potter, 2006; Fernando & Stevens, 2011; Hall & Roman, 2013). Moreover, studies suggest that incidental catches may have a significant contribution towards fishing mortality (Croll et al., 2016). Gillnets are a commonly used gear type in small-scale and artisanal fisheries as they are economical, easily manufactured and can effectively capture a wide range of target species, with a considerable fraction of bycatch (Peckham, Maldonado Diaz, Walli, & Ruiz, 2007; Berninsone, Bordino, Gnecco, Foutel, Mackay, & Werner, 2020). The retained bycatch especially those comprising elasmobranchs fetch higher value compared to the targeted catch due to the global demand for their derivatives (Ardill, Itano, & Gillett, 2011; Couturier et al., 2012). Furthermore, factors such as climate change, pollution, ingestion of microplastics, trace metals and unmanaged rapidly growing tourism (Essumang, 2009 & 2010; Deakos, Baker, & Bejder, 2011) are other potential threats that jeopardize mobulids at a global scale.

Mobula mobular (Bonnaterre, 1788) the spinetail devil ray is considered to be the largest ray species due to its maximum disc width of five meters (Notarbartolo-di-Sciara, 1987). *M. mobular* is one of the least studied elasmobranch species due to its elusiveness. It is known to have one of the lowest known fecundities of all elasmobranchs (Couturier et al., 2012). They are pelagic or epipelagic encountered in the shallow inshore environments and also deeper offshore waters usually preferring temperatures of 20–26°C (Couturier et al., 2012; Lawson et al., 2017). Although they are documented in a range of targeted and by-catch fisheries, their abundance or species composition has been poorly understood. In India targeted mobula fishery has been reported along the coast of Chennai, Tuticorin, Mumbai, Veraval, within the Union Territory of Lakshadweep, Andhra Pradesh and Kerala regions (Sivaprakasam, 1964; Koya, Savaria, & Vanvi, 1993; Rajapackiam, Balasubramanian, Hamsa, & Kasim, 1994; Pillai, 1998; Nair & Venugopal, 2003; Rajapackiam, Gomathy, & Jaiganesh, 2007; CMFRI, 2009; Zacharia & Kandan, 2010; Mohanraj & Shanmugavel, 2014). There have been reports on 'mass stranding' of dozens (nearly 500 numbers) of *M. mobular* on beaches of the Gaza Strip in Palestine as a result of recently developed unregulated fishery taking advantage of winter aggregations (Couturier, Bennett, & Richardson, 2013). The rising demand for mobulid gill plates has fuelled the emergence and extension of fisheries targeting this species (Lewis et al. 2015). The dramatic increase in fishing pressure coupled with paucity of information demands the urgent need to assess their current status. The length weight relationship is the most studied biological characteristic of fish stocks; however, rays are under represented especially from the Indian waters. Hence the study addresses length–based analysis of giant devil ray *M. mobular* captured from the south-east coast of India.

Materials and Methods

The Southern coast of India contributes a notable quantity of annual elasmobranch landings each year largely due to the bycatch within the tuna gillnet fishery. The survey was conducted fortnightly at two major tuna fishing zones located along the southeast coast of India *viz*, Therespuram (8.7642° N, 78.1348° E) and Tharuvaikulam (8.8922° N, 78.1707° E) (Fig. 1). Therespuram is an important fish landing centre that generates a substantial number of mobulid ray landings during the period from April to September. Tharuvaikulam has a year-round landing of mobula species due to the extensive use of tuna gill nets operated by various crafts such as canoes and tuna gill netters. Surveys on the morphometric data of the spine tail devil ray *M. mobular* were collected between July 2017 and October 2018. The witnessed specimens of *M. mobular* were measured for detailed biological variables such as total body length (TL) and total disc width (DW) in cm (Fig. 2) and total body weight (TW) in kg. Photographs of all available whole-bodied rays were taken and identified accurately (Compagno & Last 1999).

The relationship between TL-TW and DW-TW was estimated based on the formula, W = a Lb (Le Cren, 1951), where W is total body weight (g), L is the total length (cm), a and b are the coefficients of the

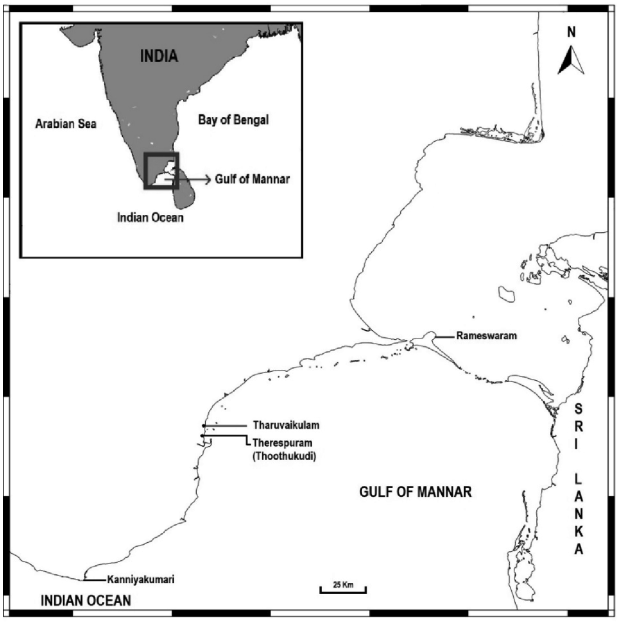

Fig. 1. Map depicting the two landing stations of spinetail devil ray along the south-east coast of India

functional regression between W and L (Beckman, 1948; Ricker, 1973). The values of constants a and b were estimated by the least-square linear regression from the log-transformed values of length and weight: log W = log *a* + *b* log L (Stergiou & Politou, 1995). The regression was carried out using Excel software and all data analysis was carried out separately for male and female. The value *b* obtained through the linear regression was used to identify the type of growth as either isometric if *b* is equal or very close to 3, or allometric if *b* is significantly different from 3 (negative allometric if b < 3 and positive allometric if b > 3) (Bagenal & Tesch, 1978).

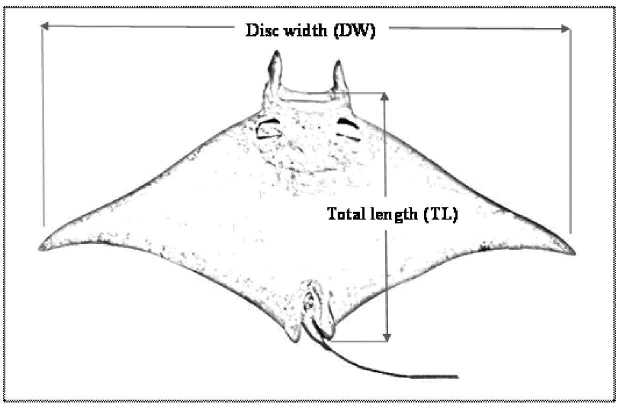

Fig. 2. Morphometric (length) measurements taken for *M. mobular*

Results and Discussion

The study represents a succinct evaluation of *M.mobular*fishery along the Indian sub-continent. India with an extensive coastline of nearly 7,516 km, and having multi-gear nature of fisheries proves challenging in monitoring ray landings. The declining mobulid population and the lack of fishery information were the key to assess their existing demographic status, typically towards the western Bay of Bengal. Gulf of Mannar is one of the most ecologically active and unique ecosystems in the northern Indian Ocean that promotes high biological productivity and oceanographic mixing, thereby providing an ideal habitat for the pelagic planktivorous filter feeding devil rays (Adnet et al. 2012; Amaral et al. 2017).

A total of 355 (male = 196; female = 159) mobulids were recorded throughout the study period. *M. mobular* is not the primary target in the study area but rather is opportunistically captured by the fishermen who target pelagic tuna that holds considerable market value. Moreover, spinetail devil ray (*M. mobular*), Giant oceanic manta ray (*M. birostris*), Chilean devil ray (*M. tarapacana*), Bentfin devil ray (*M. thurstoni*), and Pygmy devil ray (*M. eregoodootenkee*) are other mobula species recorded from the study site, however in least numerical abundance (Plate 1).

Table 1 provides summary of observed length and weight estimates, *a* and *b* components and the coefficient of determination (r^2) for *M. mobular*. The landed rays which were measured for their TL ranged from 43 - 122.0 cm (males) and 40 - 124.0 cm (females), DW of 96 - 248.0 cm (males) and 60 - 232.0 cm (females), while the TW was 9000 - 129000 g for males and 5000 - 111000 g in females. The mean number of mobula rays seen per survey were 20 and the dominant size class recorded during the landings were 160-220 cm (pooled) (Fig. 3). The largest recorded specimen during this study was a male having a DW of 248 cm and the largest recorded female had a DW of 232cm. The length–weight relationship calculated for the TL-TW and DW-TW shows slope values (b) ranging between 2.49 and 2.69 (Table 1), signifying a negative allometric growth pattern (Fig. 4, Table 1). The estimated b values were found within the normal expected range of 2.5–3.5 (Froese, 2006). All regressions were highly significant, with the coefficient of determination (r^2) ranging between 0.82 to 0.88 ($p < 0.01$). It was observed that males were

Table 1. Length-weight relationship parameters for *M. mobular* from Gulf of Mannar, India (TL-total length, DW-disc width)

Species	n	Sex	Size range (in cm)	Total Weight (in gm)	*a*	*b*	r^2
M. mobular	196	Male	43-122 TL	9000-129000	-3.05	2.49	0.84
			96-248 DW		-4.29	2.69	0.88
(Bonnaterre, 1778)	159	Female	40-124 TL	5000-111000	-3.19	2.55	0.82
			60-232 DW		-3.95	2.56	0.87

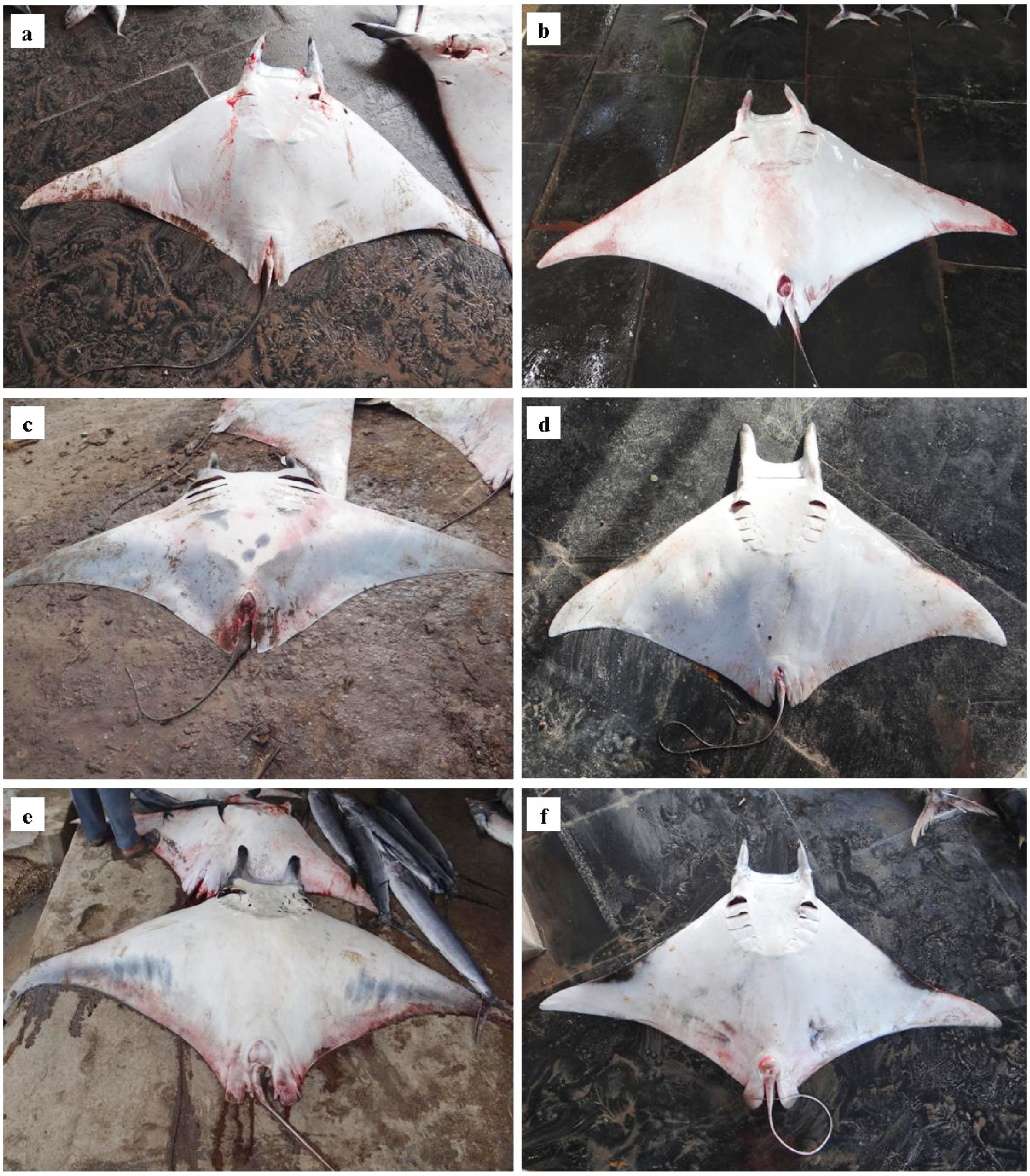

Plate 1. Ventral view of the mobulid species recorded from the study sites: *M. mobular* (a-male, b-female), *Mobula birostris* (c), *M. eregoodootenkee* (d), *M. tarapacana* (e) and *M. thurstoni* (f)

significantly numerous in catches than females, and that males were significantly heavier, similar to the observation made by Demirhan, Engin, Seyhan, & Akamca (2005).

Based on earlier investigations, the largest known *M. mobular* has a DW of 350 cm (Notarbartolo di Sciara, Stevens, & Fernando, 2020) with the female and male measuring 340 cm (Notarbartolo-di-Sciara & Serena, 1988) and 306 cm (Abudaya, Ulman, Salah, Fernando, Wor, & di Sciara, 2018) respectively. Raje, Sivakami, Mohanraj, Manoj Kumar, Raju, & Joshi (2007) observed *M. mobular* specimens from the landings of trawl and gill nets in the size class 62 - 112 cm, 57 - 167 cm, and 240 - 375 cm, from Mangalore, Gulf of Mannar, and Minicoy island, respectively. Sporadic landings of *M. mobular* is observed along the Indian coastline, however, no measures have been undertaken to substantiate the species occurrence consistently. The Length-weight assessment for few batoids are available from the Indian waters. For example, Raje (2003) studied the length-weight relationship and some aspects of biology of five species of rays *Dasyatis uarnak, D. sephen, Trygonwalga, Gymnura micrura* and *Rhinoptera javanica* from Mumbai waters. Sujatha, Shrikanya, & Krishna (2014) studied the length-weight relationship of four torpedo electric rays (*T. fuscomaculata, T. marmorata, T. panthera* and *T. sinuspersici*) off Visakhapatnam coast of India. The fishery and biology of nine species of rays in Mumbai waters investigated by Raje & Zacharia (2009) revealed the occurrence of two peaks in the annual landings, one during September - December and the second peak during February - April. The dominant species that constituted the fishery were *Himantura alcockii* and *Himantura bleekeri*.

Several length-weight studies on Batoids have been carried out at global levels. The LWR calculated for seven rays of families Rajidae, Dasyatidae, Gymnuridae, and Myliobatidae, from Saros Bay,

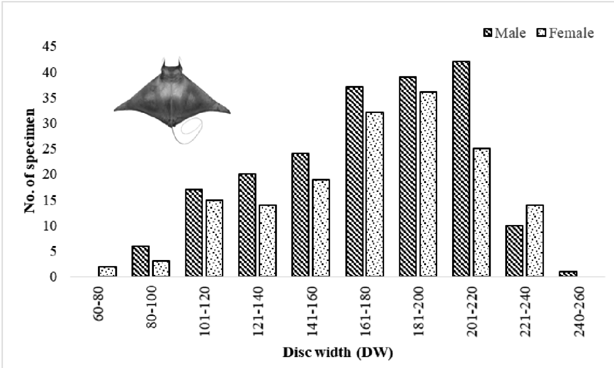

Fig. 3. Size-class distribution graph for *M. mobular* collected from the study sites based on disc width (cm)

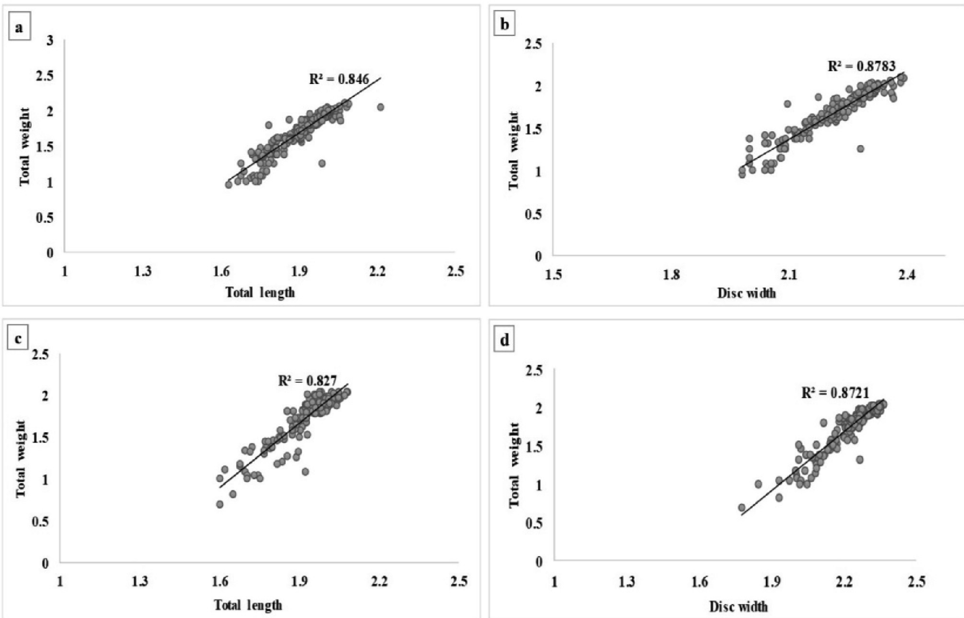

Fig. 4. Length-weight relationship plots for the giant devil ray *Mobula mobular* (a,b-Male, c,d-Female)

North Aegean Sea reports positive allometry for all species (3.27 – 3.56) (Yýðýn & Ismen, 2009). The LWR of co-occurring butterfly rays, *Gymnura poecilura* (N = 94) and *G. zonura* (N = 20), was studied by Leung, Then, & Loh (2023) in Malaysian waters. The results show significant difference in the LWR between sexes for *G. poecilura*. Lteif, Mouawad, Jemaa, Khalaf, Lenfant, & Verdoit-Jarraya (2016) estimated the LWR for 8 elasmobranchs (3 sharks and 5 batoids) from Lebanese marine waters, in the eastern Mediterranean, shows that the value *b* ranged from a minimum of 1.75 for *Torpedo marmorata* to a maximum of 3.33 for *Raja miraletus*. Based on the published literature and FishBase database (Froese & Pauly, 2021), studies on *M. mobular* in the Indian waters are deficient in the biological perspective and no previously published data on LWR of *M. mobular* is available from India. Therefore, this study reports the first-ever LWR estimates for the species from the Indian waters.

Although devil rays are planktivorous filter feeders they also exhibit piscivory thereby foraging upon the nektons and crustaceans in the productive waters (Graham et al., 2012; Hacohen-Domené, Martínez-Rincón, Galván-Magaña, Cárdenas-Palomo, & Herrera-Silveira, 2017). They undergo seasonal migration towards the productive hotspots and the richest zooplankton feeding grounds with concomitant ocean surface currents (Anderson, Adam, & Goes, 2011; Jaine et al., 2014; Armstrong et al., 2016). The seasonal length frequency graph for the study period indicates June-August and October–December comprising the highest numerical abundance and biomass of the species (Fig. 5). The higher prevalence of mobulid catches during SW monsoon strongly correlates with the enhanced food availability facilitated by the upwelling process (Anderson et al., 2011) sustaining their distribution in coastal and epipelagic areas. This migratory behavior overlayed with the tuna fishing grounds makes them vulnerable to capture by an array of fishing gear (Jaine et al., 2014).

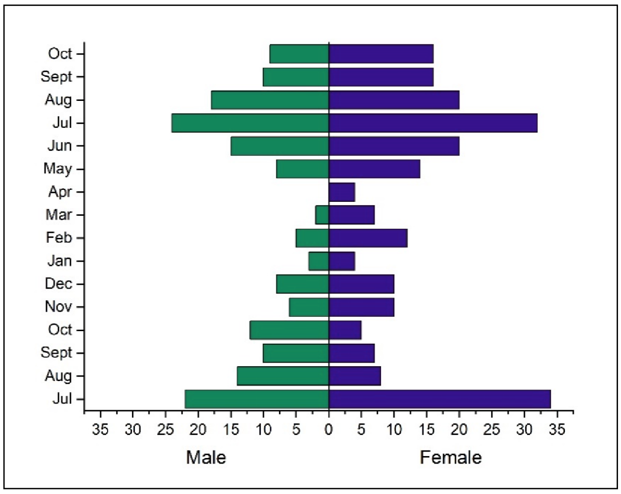

Fig. 5. Seasonal length frequency distribution graph for *M. mobular* (male & female)

Furthermore, it was observed that the gear contributing the highest bycatch is the tuna gillnet (86%), followed by other gillnets (12%) and the least (2%) by other gears (long-lines, ray net, etc). A study by Basusta et al. (2012), reported nine species of batoids that were captured by gillnet, longline, and bottom trawl fishing off the east coast of Iskenderun Bay, Turkey. Similarly, Cruz-Aguero, García-Rodríguez, & Cota-Gómez (2018) studied the LWR of five elasmobranches (rays) along the Pacific west coast of Mexico, that were captured by commercial bottom trawl net and long lines. In the present study tuna gillnet fishery is the major contributor to mobulid bycatch with relatively huge landings in the study sites. This signifies that mobulids are closely associated with areas of high productivity where freely aggregating schools of pelagic fishes occur. Owing to the high degree of distributional overlap with tuna and tuna-like fisheries across epipelagic tropical habitats, mobulids are retained as bycatches (Shahid et al., 2018). It is apparent from the study that the highest catches of *M. mobular* coincided with (1) the onset of SW and NE monsoon season and (2) the seasonal tuna fishery.

Thus, trailing mobulid distributions, migratory routes and their associated fishery resource are imperative for the identification of priority areas for minimizing its bycatch. Moreover, restricting commercial fishing operations above the thermocline layer and setting gears at shallower depths can reduce bycatch rates commensurately (Stewart et al., 2018). These drifting gillnets might pose a significant threat to mobulids and other vulnerable elasmobranch species as well if disregarded. As devil rays are under threat globally, conservation actions and trade control on these species should be a priority; but the lack of baseline morphometric information, risk from fisheries and rising demand in international markets are hampering such efforts (Croll et al., 2016). This work hence extends an approach on the sporadic catch records and size-based analysis of the giant devil ray for which the biological information is lacking, in the Indian waters. This endeavor could be an instigation towards understanding the ecology, effective conservation and management to prevent further population declines of *M. mobular*.

Regional extinctions of most marine elasmobranch species often go undocumented due to lack of exploration, and identification of their critical habitats. The implementation of seasonal or regional ban can mitigate the over-exploitation and monitor the unregulated, underestimated trade in the territorial waters. It is crucial to frame policies that could manage the catch and trade involvement of fishers and local stakeholders for effective conservation. In addition to restricting the target fishery, the release of specimens caught as bycatch should be recommended by outreach programmes for all the locally endangered species of elasmobranchs. Continued long-term monitoring and research is needed on the mobulid rays to assess the overall threats and catch rates in the Indian waters to facilitate tangible conservation outcomes.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

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