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Population dynamics of the sandwich-tail whipray *Brevitrygon manjajiae* (Dasyatidae) from the north-eastern Arabian Sea, India

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Abstract

Sandwich-tail whipray, *Brevitrygon manjajiae* Last, Weigmann and Naylor 2023 (Family: Dasyatidae) is a small-sized, batoid species having restricted distribution in the northern Indian Ocean. The species is landed in huge quantities as bycatch in trawlers operating in the shelf areas of north-west coast of India. Disc width (DW) frequency-based stock assessment using FiSAT was conducted for *B. manjajiae* landed at New Ferry Wharf and Versova landing centres, trawled at 20-50 m depths off Maharashtra coast in the Arabian Sea from August 2016 to May 2018. A total of 1720 individuals of *B. manjajiae* (121-310 mm DW) were sampled for the study, of which males contributed 50.6% (n=870) and females 49.4% (n=850), with a sex ratio of 1:0.97. Population characteristics of *B. manjajiae* revealed that the species has a relatively faster growth rate with an estimated K value of 0.54 y^{-1}, t_0 of -0.72 y; asymptotic disc width (DW_∞) of 347 mm with a longevity of 5.5 yrs and is overexploited (E=0.80).

Introduction

Elasmobranchs are one of the most vulnerable fauna in the oceans (Dulvy *et al.,* 2021). In recent asessments, 32.6% of them were identified as threatened with extinction (Dulvy *et al.,* 2021; Jabado, 2024). Elasmobranchs maintain balance and stability of an ecosystem and are thus essential for ecosystem health (Bornatowski *et al.,* 2014). Overexploitation, bycatch, climate change, habitat depletion and degradation reduce the stocks of elasmobranchs like all other exploited fishery resources (Morgan and Burgess, 2007; Mandelman *et al*., 2008). Globally, there is a worldwide concern about the vulnerability of batoids, due to poor recovery rates because of their life history traits (Cortes, 1999; Heppell *et al*., 1999; Cortes, 2002; Cortes, 2004; Musick, 2005). Indiscriminate exploitation can increase the extinction risk of a species, and there is an urgent need for science-based conservation actions, action plans, and ground-level implementable policies to reduce risk. Jabado *et al*. (2017) recorded that elasmobranchs from Arabian Sea Region (ASR), including west coast of India are at high risk of extinction in comparison to other regions. This region also has a high dependency on ocean resources for livelihoods, and expectations of the Blue Economy. India has been a leading elasmobranch fishing nation for decades (Kizhakudan *et al*., 2015). Akhilesh *et al*. (2014), Gupta *et al*. (2022) and Akhilesh *et al*. (2023) suggested that studies from India are limited leading to management intervention and available research are dominantly on smaller-sized coastal species. Science-based conservation and specific management actions, integrating ecological information are urgently required for elasmobranch fisheries in India (Akhilesh *et al*., 2014; Kizhakudan *et al*., 2015; Jabado *et al*., 2018; Gupta *et al*., 2022).

Sting rays of the family Dasyatidae (Order: Myliobatiformes) are found in freshwater, marine and brackishwaters. Globally, 101 species are reported in 19 genera (Last *et al.*, 2016a; Fricke *et al.,* 2025). In India, approximately 33 species under 14 genera have been reported and the diversity continues to increase. Batoids are one of the most threatened groups, with five out of seven ray families facing threats worldwide and whip-tail sting rays (Family: Dasyatidae) are particularly vulnerable (Dulvy *et al*., 2021). The Indo-West Pacific stingray genus *Brevitrygon* Last, Naylor & Manjaji-Matsumoto 2016 was erected to fit small coastal stingrays occurring in soft sedimentary habitats of inner continental shelves of the Indo-West Pacific. The taxonomic issues in this genus have been resolved with updated nomenclatural decisions by Last *et al*. (2023).

Brevitrygon manjajiae Last, Weigmann & Naylor 2023 commonly known as sandwich-tail whipray, is one of the smallest sting rays, inhabiting the marine ecosystems of the north-western and north-eastern Arabian Sea including the north-west coast of India (Rigby *et al*., 2023). Earlier this species from the north-west coast of India was known by various names but was commonly reported as *B. imbricata* or *B. walga* (Raje, 2003; Raje and Zacharia, 2009; Last *et al*., 2016b; Gladston *et al*., 2018). The recent detailed taxonomic study with molecular phylogeny of the genus *Brevitrygon* confirms the species identity in the region (Last *et al*., 2023).

Understanding the population dynamics of exploited fishes is very much important in understanding the dynamics of the species in relation to fishery dependent and independent factors and also in implementing effective management measures for sustainable exploitation. Successful fishery management policy inputs need information on age, growth and mortality, to assess stock abundance; *i.e.,* whether it is below or above a given target reference point (TRP). This data helps to determine the exploitation status of the stock; identify overexploitation and predict whether catch levels will sustain or alter stock abundance (Bonfil, 2005). Progress in stock assessment and population dynamics studies has been severely hampered by the lack of species-specific catch data (Camhi *et al*., 2008; Gebremedhin *et al.,* 2021). Further, the size structure, biological parameters and spatial dynamics of most elasmobranch stocks remain largely unknown (Bonfil, 2005). In this study, a disc width (DW) frequency-based stock assessment study was conducted for *B. manjajiae* from the north-west coast of India.

Materials and methods

The specimens of *B. manjajiae* were collected from the bycatch landed during August 2016-May 2018 by trawlers operating in the Arabian Sea from New Ferry Wharf (18°57'29"N; 72°51'01"E) and Versova (19°08'33"N; 72°48'11"E) fish landing centres of Mumbai. The trawl nets had cod end mesh size of 17-30 mm and were operated at a depth of 20-50 m. A total of 1720 specimens of *B. manjajiae* were sampled for the study, of which males contributed 50.6% (n = 870) and females 49.4% (n = 850) with a sex ratio of 1:0.97. Total disc width (DW) range observed was 121 to 264 mm for male specimens and 122 to 310 mm for female specimens. The DW frequency data of *B. manjajiae* were recorded weekly from the two landing centres and raised to the total landing of the species on each day of sampling and further for the month (Sekharan, 1962). Life history parameters (growth, mortality and exploitation) were estimated by employing FiSAT II (Gayanilo *et al*., 2005). The scaling coefficient "*a*" and the shape coefficient "*b*" of the fish were ascertained from the disc width-weight relationship (DWR), calculated using log-transformed data, logW= log a+b log DW (Le Cren, 1951; Froese, 2006), where W is total weight (g) and DW is the disc width (cm). These "*a*" and "*b*" values were used for further analysis. The von Bertalanffy growth parameters (von Bertalanffy, 1934) *viz*. asymptotic disc width (DW_∞) and growth coefficient (K) were estimated using monthly raised frequency data in the ELEFAN-I module of FiSAT II (Gayanilo *et al*., 2005). Age at length zero (t_0) was back-calculated using a modified von Bertalanffy growth equation suggested by Alagaraja (1984) *i.e*. t_0= -1/K log [1-(DW_0/DW_∞), where, t_0 is the age at which the disc width of ray was theoretically zero, K is the growth coefficient, DW_0 is disc width at birth and DW_∞ is asymptotic disc width. For the calculation of t_0, 120 mm DW was used as DW_0, which was assumed from the length of the largest embryo and smallest free-swimming individuals observed from the fishery. From the growth parameters, the mortality and exploitation parameters were derived. For the assessment of the natural mortality parameter (M), Cushing (1968), and Rikhter and Effanov (1976) formulae were used. Total mortality, Z was calculated based on the length-converted catch curve with the help of FiSAT II (Pauly, 1983; 1984). According to Cushing (1968), natural mortality, M = ln 100/ (T_{max} – 1), where T_{max} is the longevity of the fish (here, T_{max} was directly taken). In Rikhter and Effanov (1976), M = 1.521/ ($T_{m50\%}$ $^{0.720}$) - 0.155 per year (Tm- Age at massive maturation) showed a close association between M and $T_{m50\%}$, the age when 50% of the population is mature (also called "the age of massive maturation").

The relative yield per recruit (Y/R) and relative biomass per recruit (B/R) at different exploitation levels were estimated with the FiSAT II package using relative yield per recruit analysis as described by Beverton and Holt (1966). Exploitation rate (E) = F/Z and Exploitation ratio (U) = (F/Z) *[1- exp^{-z}] were calculated in which F is Fishing mortality and Z is Total mortality (Sparreand Venema, 1998).

Results

The size range recorded in fishery was 121-310 mm DW, disc width class 210-219 mm contributed maximum number of individuals in the fishery. The landings included rays from the entire size range, All sizes of rays were caught in fisheries showing limited escape from fishing (Fig. 1). Disc width-weight relationship parameters such as "*a*" and "*b*" were calculated as 0.0206 and 3.1860 with a coefficient of determination (r^2) of 0.8863. The calculated DW_∞ and K values selected as the best fitting estimates of growth parameters for *B. manjajiae* was 347 mm and 0.54 y^{-1}, respectively, obtained using t_0 of -0.72 y.. The von Bertalanffy growth curve constructed using the above parameters resulted in DW_0 as 120 mm for *B. manjajiae*. The growth performance index (φ') and t_{max} of *B. manjajiae* were estimated as 2.81 and 5.55 y, respectively. The growth curve constructed using these parameters showed that *B. manjajiae* grows to a DW of 210 mm in the first year, and 267 mm in 2^{nd} year, after which the growth slows down considerably registering a DW of 300 mm in the 3^{rd} year, 320 mm in the 4^{th} year and 331 mm in the 5^{th} year.

The natural mortality rate (M), total mortality rate (Z), fishing mortality rate (F) and current exploitation rate (E) and exploitation ratio (U) were 0.65 y^{-1}, 3.31 y^{-1}, 2.66 y^{-1}, 0.80 and 0.77 respectively (Table 1). The length-based cohort analysis showed that F exceeded M when the fish attained 205 mm DW (Fig. 1). From the length-frequency data, a cumulative frequency curve was constructed to find the DW_{C50} (Disc width at which 50% of the fish were caught). The value of DW_{C50} was obtained as 215 mm.

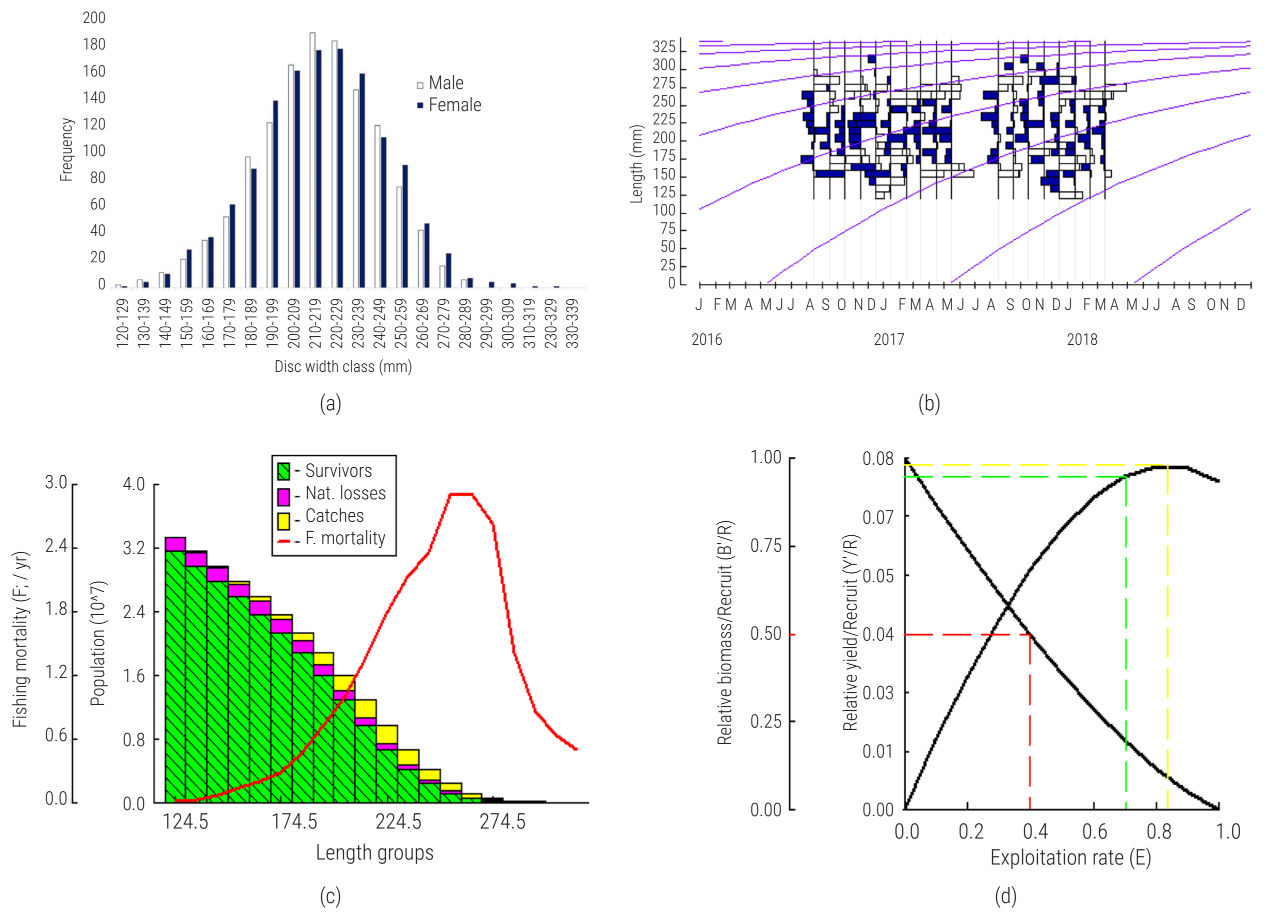

Fig 1. (a) Length frequency distribution of *B. manjajiae* from north-eastern Arabian sea; (b) Re-structured growth curve; (c) Disc width structured virtual population analysis; (d) Relative yield per recruit and relative biomass per recruit analysis using Knife-Edge selection

Table 1. Growth, mortality and exploitation parameters of *B. manjajiae* exploited along north-eastern Arabian Sea, India

Parameters	Value
$D_{W\infty}$ (mm)	347
$K(y^{-1})$	0.54
$t_0(y)$	-0.72
D_{W0} (mm)	120
$t_{max}(y)$	5.55
Φ'	2.81
$M(y^{-1})$	0.65
$F(y^{-1})$	2.66
$Z(y^{-1})$	3.31
E	0.80
E_{max}	0.83
$E_{0.1}$	0.70
$E_{0.5}$	0.40
U (y^{-1})	0.77

ELEFAN- I: Electronic Length Frequency Analysis- I method; VBGF: von Bertalanffy growth curve (equation); DW_{∞}: Maximum theoretical disc width, the animal can reach; K: Growth coefficient; t_0: Time when length of the animal is theoretically zero; DW_0: Disc width of animal at birth and t_{max}: Longevity of the fish, Φ' : Growth performance index, M: Natural mortality, F: Fishing mortality, Z: Total mortality, E: Exploitation rate (current), E_{max}: Maximum exploitation rate of the fishery, $E_{0.1}$: The exploitation level at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase, $E_{0.5}$:The exploitation level that could result in the reduction of B/R to 50% compared to virgin biomass, U: Exploitation ratio.

The input parameters used for analysis were DW_{C50}/DW_{∞} and M/K values of 0.62 and 1.20 respectively. The results indicated that the exploitation rate that maximises the yield per recruit (E_{max}) was 0.83 for *B. manjajiae*. The exploitation level at which the marginal increase in yield per recruit reaches 1/10 of the marginal increase computed at a meagre value of E ($E_{0.1}$) was 0.70 for the species. The exploitation level that could result in the reduction of B/R to 50% compared to virgin biomass ($E_{0.5}$) was 0.40 for *B. manjajiae*. The disc width at birth (DW_0) in the present study was estimated at 120 mm for *B. manjajiae*. Since direct estimation of DW_0 was difficult, the largest embryo size and smallest free-swimming individuals taken out from the pregnant female were used as DW_0.

Discussion

Population dynamics and stock assessments are the benchmark when it comes to providing science-based advisories for fisheries management. Nearly 180 species of chondrichthyans are reported from India, of which information of current exploitation was available for only a few species (Table 2). In the most recent comprehensive stock assessment from Indian waters, four species of chondrichthyans were assessed (CMFRI, 2023). Given that elasmobranch landings are on a declining trend in India (Kizhakudan *et al.,* 2015; Akhilesh *et al.,* 2023), management

Table 2. Population parameters of elasmobranchs from India

Authors	Species	Study period	Sex	Region	DW_∞/L_∞ (mm)	K (y^{-1})	t_0 (y)	DW_0/L_0 (mm)	Z (y^{-1})	F(y^{-1})	M (y^{-1})	E	DW_{c50}/Lc_{50} (mm)	Inference/ Remarks
Nair (1976)	*Scoliodon laticaudus*	1972 -1974	P	Mumbai	755	0.27	-0.566	140	-	-	-	-	-	Small sized medium growing elasmobranch
Krishnamoorthi and Jagadis (1986)	*Rhizoprionodon acutus*	1984	P	Chennai	1000	0.2	-1.78	300	0.44	0.16	0.38			Medium sized shark with slow growth rate with limited fishing mortality
Kasim (1991)	*S. laticaudus*	1979-1981	M	Gujarat	749	0.88	-0.012	-	3.32	1.79	1.53	0.54	288.7	Exploitation level of the fishery reached MSY
			F		680	1.08	-0.012	-	3.39	1.63	1.76	0.48	335	
Kasim (1991)	*R. acutus*	1979-1981	M	Gujarat	1065	0.60	-0.604	-	2.03	0.963	1.12			Medium sized shark with medium growth rate
			F		1054	0.65	-0.052	-	2.44	1.042	1.01			
Mathew and Devaraj (1997)	*S. laticaudus*	1986-1988	P	Mumbai	740	0.68	-0.01	140	4.15	2.2	1.95	0.53	270	Exploitation level of the fishery reached MSY
Chakraborty *et al.* (1998)	*S. laticaudus*	1987-1990	M	Mumbai	726	0.48	-	-	3	2.1	0.9	0.7	559	Stocks are in overexploited condition
			F		740	0.63	-	-	3	2.1	0.9	0.7	340	
Devadoss (1998)	*S. laticaudus*	-	M	Calicut	715	0.36	0.59	140	1.45	0.73	0.72	0.5	185	Exploitation level of the fishery reached MSY
			F		676	0.41	0.59	140						
Marichamy *et al.* (1999)	*Pateobatis bleekeri*	1991-1996	M	Thoothukudi	1242	0.56	-0.013	-	-	-	-	-	-	Large sting rays in Indian waters have slow growth rate
			F		1303	0.51	-0.015	-	-	-	-	-	-	
Kasim *et al.* (1999)	*Carcharhinus sorrah*	1990-1993	M	Thoothukudi	1459	0.40	0.07		3.09	2.46	0.63		575	Large sized shark species having high fishing mortality
			F		1658	0.33	-0.09		4.92	4.38	0.54			
Manojkumar *et al.* (2012)	*Carcharhinus limbatus*	2001-2011	P	Malabar coast	3020	0.45	-1.2	-	2.21	1.68	0.54	0.75	945	Stocks are in overexploited condition
Purushottama *et al.* (2017)	*Rhizoprionodon oligolinx*	2012-2015	P	Mumbai	971	0.47	-0.79	300	2.16	1.48	0.69	0.68	497	Stocks are in overexploited condition
Sen *et al.* (2017)	*R. acutus*	2012-2014	P	Gujarat	938	0.32	-1.3	320	1.0	0.39	0.61	0.39	500	Stock of *R. acutus* in Gujarat waters under-exploited
Muktha (2018)	*Gymnura poecilura*	2012-2015	M	Visakhapatnam	680	0.78	-0.09	-	3.72	2.51	1.21	0.67	343.7	Stocks are in overexploited condition
			F		1000	0.55	-0.02		2.09	1.23	0.86	0.59	506.7	
Sen *et al.* (2019)	*S. laticaudus*	2012-2016	P	Gujarat	761	0.54	-0.41	150	1.95	1.04	0.91	0.53	397	Exploitation level of the fishery reached MSY
Akhilesh *et al.* (2020)	*Echinorhinus brucus*	2009-2011		Kerala	3330	0.12			0.39	0.22	0.17	0.56		Deepsea shark, overexploited
Manojkumar *et al.* (2021)	*Alopias superciliosus*	2015-2019	P	Thoothukudi	3670	0.39	0.12	-	1.20	0.70	0.50	0.58	1200	Exploitation level of the fishery reached MSY
Gurugubelli *et al.* (2025)	*Galeocerdo cuvier*	2023-2024	P	Kerala	4905.5	0.25	-0.37	-	1.09	0.76	0.33	0.70	1715.8	Stocks are in overexploited condition
Sen *et al.* (2025)	*Rhinobatos lionotus*	2018-2021	P	North-western Bay of Bengal	843	0.43	-0.45	148	2.06	1.18	0.88	0.57	349	Stocks are in overexploited condition
Present study	*Brevitrygon manjajiae*	2016-2018	P	Mumbai	347	0.54	-0.72	120	3.31	2.66	0.65	0.80	215	Stocks are in overexploited condition

M: Male; F: Female; P: Pooled data of both male and female advisories for elasmobranch fisheries based on stock assessments is critically needed. Cautious approach in data interpretation and data collection is called for considering the high dynamic patterns and variable drivers of the fishery in India ranging from local environmental condition and fish abundance to export demand for several species. In such conditions long term data is highly recommended. Advisories based on stock assessment of a species should be tempered with the fact that India has a multi-species fishery and managing one species alone may not result in the desired result. Gupta *et al*. (2020) indicated the complexity and challenges of tropical elasmobranch fishery management.

B. manjajiae, a small-sized sting ray, is a common species in the coastal waters of the north-eastern Arabian Sea that is landed as bycatch by trawlers along the north-west coast of India in considerable quantities (CMFRI, 2016; 2017; 2018; 2019; 2020; 2021; 2022). The region accounted for 8.6% of the total landing of rays in India (Raje and Zacharia, 2009). Population dynamics, stock assessment and demographic studies are essential for the formulation of fishery management and conservation plans. There are limited length/age-based growth studies in batoids (Martin and Cailli, 1988; Smith, *et al*., 2007; Hale and Lowe, 2008; Pierce and Bennet, 2009; Jacobsen and Bennett, 2010; Jacobsen and Bennett, 2011; Yigin and Ismen, 2012; O'Shea *et al*., 2013; Basusta and Gokhan, 2016; Basusta and Aslan, 2018; Charvet *et al*., 2018; Hayne *et al*., 2018; Parsons *et al*., 2018) to inform management.

The coefficient of growth K was estimated at 0.54 y^{-1} in the present study. The growth rate of another batoid species *Urotrygon rogersi* from the tropical waters of the Colombian coast was estimated as 0.65 y^{-1} (Mejía-Falla *et al*., 2014). Marichamy *et al*. (1999) recorded a growth rate of 0.56 and 0.50 y^{-1} for male and female *Pateobatis bleekeri* from the south-east coast of India. These studies suggest a relatively faster growth in small to medium-sized batoids in tropical waters, as compared to other elasmobranchs in temperate waters. The estimated value of t_0 of *B. manjajiae* in the present study was -0.72 years and it indicates the gestational period of the fish (Tokunaga *et al*., 2022). The estimated theoretical maximum size (DW_{∞}) of *B. manjajiae* distributed along the north-eastern Arabian sea was 347 mm whereas the largest sized individual observed in the fishery was 310 mm. For *Urotrygon rogersi* and *U. aspidura* the two small-sized sting ray species of Columbian waters, the estimated DW_{∞} were 155 and 247 mm respectively and their growth rate (K) estimated more than that of 0.65 and 0.47 y^{-1} respectively (Mejía-Falla *et al.,* 2014; Torres-Palacios *et al*., 2019). The growth, mortality and exploitation parameters estimated for different elasmobranch species landed along the Indian coast are given in Table 2.

Estimates of natural mortality rate (M) is important to find the rate of stock decay. In the present study, the natural mortality was estimated as 0.65 . The estimation of M appears to be reasonable as M/K value was 1.20, which falls within the range of 1 to 2.5 as suggested by Beverton and Holt (1957). The total mortality Z estimated using the length converted catch curve was 3.31 y^{-1}. The derived fishing mortality (F) of the species was very high (2.66 y^{-1}), indicating that 80% of mortality in the exploited population of *B. manjajiae* in the north-eastern Arabian Sea is due to fishing and 20% due to natural causes, after entering the fishery. The Dwarf whipray (*Brevitrygon heterura*) inhabiting the Malacca Strait, was reported to have an estimated total mortality (Z), fishing mortality (F) and natural mortality (M) of 2.094 y^{-1}, 1.17 y^{-1} and 0.924 y^{-1} (Manurung *et al*., 2022). The fishing mortality of the stock is higher than the natural mortality and estimated E was 0.559; and the species was categorised as overexploited in the region (Manurung *et al*., 2022).

In the present study, the size at capture (DW_{C50}) of the species was estimated as 215 mm. It is less than the reported length at first maturity of the species (220 mm, corresponding to 2.6 y). The analysis revealed that maximum Y/R could be obtained at an exploitation rate (E_{max}) of 0.83. However, exploitation of the stock at E_{max} can decrease the biomass to a critically low level and hence should not be necessarily used as a target reference point. Therefore, as a precautionary approach, it is recommended that the exploitation should be reduced to a lower level. The yield per recruit reaches 1/10 of the marginal increase computed at a very low level of exploitation ($E_{0.1}$), which was found to be 0.70 for *B. manjajiae* and therefore, this value may be used as a relatively safer target reference point. Considering the high estimate of E obtained in the present study, management measures should be adopted for the sustainability of the species. However, as the resource is mainly landed as bycatch by trawlers, management and mitigation measures will need to address actions to reduce fishing in the coastal areas.

Batoids are mostly caught in trawls, irrespective of size. Gupta *et al*. (2020) and Dineshbabu *et al.* (2022) have commented on the bycatch issues in trawls and limited bycatch mitigation measures for smaller species. There are nearly 13313 trawlers operating in the northern Arabian Sea coastal states of Gujarat and Maharashtra together (CMFRI-FSI-DoF, 2020), putting pressure on its habitat. Though current management measures such as. temporal control of fishing efforts through annual fishing ban (01 June-31 July) and spatial management (limiting mechanised fishing beyond 9 nautical miles off Gujarat coast and beyond 5-10 fathom depths in specified areas off Maharashtra coast) mitigate the fishing impact minimally, but not enough to support sustainable fisheries. The present study is a typical example of tropical mixed species fisheries with high batoid bycatch in trawlers, where trawlers contributed more than 85% of total landing of *B. manjajiae* (Gladston, 2019; CMFRI, 2020) while also landing a multitude of other species in the north-eastern Arabian Sea. Based on the results of this study, it is highly recommended that trawl fishing effort should be reduced in the coastal waters and identified critical habitats should be protected to ensure sustainability of *B. manjajiae* stock. Considering the challenges of input control in multi-species and multi-gear fisheries, alternative options like ecosystem-based conservation and management of the species should be considered. More information on food and feeding dynamics, breeding biology, behaviour and habitat preference of *B. manjajiae* are necessary to formulate holistic plans for sustainability of its stock in the region.

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