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Biology of the Bombayduck *Harpadon nehereus* (Hamilton, 1822) from the north-eastern Arabian Sea, India

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Abstract

The Bombayduck *Harpadon nehereus* (Hamilton, 1822) is a common species and major contributor to the fishery in the northern Arabian Sea. The biology of *H. nehereus,* exploited by set bagnets (SBN, *dol* netters) and trawlers from the northern Arabian Sea coast of India (Gujarat and Maharashtra) was investigated during 2014 to 2019. Fishes with a size range of 30-408 mm mainly contributed to the fish landing. The sex ratio (male: female) was 1:1.5. Length at maturity (L_m) for females was estimated at 207 mm TL. Mature ovaries contained ova of all maturity stages indicating the species to be a continuous spawner. The absolute fecundity ranged from 23,444 to 1,34,432 eggs per fish and relative fecundity ranged from 235-430 eggs g^{-1}. The gonadosomatic index and monthly maturity stages suggested that *H. nehereus* is a continuous spawner with peaks occurring from February to April. The 'b' value in the length-weight relationship was 3.31 showing a positive allometric growth. The diet analysis showed *H. nehereus* to be a highly carnivorous predator which fed mainly on crustaceans (Index of Relative Importance, IRI = 82.7%) followed by teleosts (17.3%). The present article discusses the biology of *H. nehereus* in the north-eastern Arabian Sea.

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Introduction

Bombayduck *Harpadon nehereus* (Hamilton, 1822) (Synodontidae: Aulopiformes) is a benthopelagic marine fish, that inhabits shallow coastal waters, with muddy bottom and it often enters creeks and estuaries. It is a widely distributed commercially important fish occurring in the Indo-Pacific waters (Ganga *et al.,* 2016; Froese and Pauly, 2021). In the northern parts of the Indian EEZ [Gujarat and Maharashtra (Arabian Sea) and West Bengal (Bay of Bengal)], *H. nehereus* forms a major component of the fishery, supporting the traditional, small-scale, commercial fishery and occurs as bycatch in all fishing gears operating in these regions. *H. nehereus* locally known as "bombil" in Maharashtra and "Bumla" or "Bumli" in Gujarat, contributed 1,12,705 t forming 3.2% of all India (mainland) estimated marine fish landings. Moreover, 78% of the total Bombayduck landing is from the Arabian Sea (CMFRI, 2019), making it one of the dominant single fisheries of the Indian coast after Indian oil sardine and Indian mackerel.

H. nehereus is dominantly found in the northern regions of the Indian EEZ and this restricted latitudinal distribution is attributed to several factors by various researchers. Hora (1934) attempted to relate the distribution of the species with salinity and Raj (1954) correlated the occurrence of Bombayduck with the 80°F isotherm and the monsoon conditions in the areas of its distribution. Bapat (1970) reported that the sea surface temperature is the principal factor influencing the peculiar distribution of Bombayduck along the coasts of India.

Though considered a widely distributed species in the Indian and Pacific oceans, detailed investigations have indicated regional variations in *H. nehereus,* suggesting that the species is complex with hidden diversity. The phylogeny, distribution and biogeography patterns of *Harpadon* spp. continues to be debated and is under further investigations (Zhu *et al.,* 2014; Ganga *et al.,* 2016; Wang *et al.,* 2021; Yang *et al.,* 2021). Three stocks of *H. nehereus* are believed to exist in Indian waters (Bapat, 1970; Pazhayamodam *et al.,* 2015), whose biogeographic boundaries are yet to be defined.

Despite being a common coastal water species with a good fishery and commercial importance, detailed investigation of its fishery, biology and reproductive biology from the Arabian Sea in recent years are limited for *H. nehereus*. Further, many of these studies are restricted to small regions of its known distribution (Bapat, 1970; Deshmukh and Kurian, 1980; Khan *et al.,* 1992; Balli *et al.,* 2006; Ghosh, 2014; Vase *et al.,* 2021)

Detailed information on the biological characteristics is important in the preparation of successful fishery management plans and in understanding the natural and anthropogenic impacts on the stock. The present study was conducted to understand the biological aspects of *H. nehereus* exploited from the north-eastern Arabian Sea, India.

Materials and methods

Profile of marine fisheries of the Northern Arabian Sea

The coastal states (Gujarat and Maharashtra) in the Northern Arabian Sea (NAS) have diverse ecological and environmental features including an extended shelf and tide-based high coastal turbidity that support a different and unique marine fish community structure and fisheries compared to the south Indian coastal states (Madhupratap *et al.,* 2001; Monalisha *et al.,* 2017; George *et al.,* 2018; Vase *et al.,* 2021). To enable the harvest of these fisheries resources, the NAS states deploy diverse crafts which form the largest proportion (23%) of the mechanised crafts of India (Table 1), Further, several of these crafts have been modified recently to keep up with the current competitive nature of fishing in this area. The NAS majorly accounts for the regionally abundant iconic species, such as Bombayduck, golden anchovy, unicorn cod and paste shrimp, which play vital roles in providing nutrition and socio-economic security to the fishers and consumers, including those, with a high preference for consumption of dried fish. The NAS states account for 79 to 92% of India's estimated landing of these groups (CMFRI, 2019).

Sample collection

Bombayduck samples were collected weekly from Sassoon Dock, New Ferry wharf in Maharashtra, and at Veraval and monthly from Arnala (MH) and Jafarabad (GUJ) during 2014-2019 (Fig. 1). Dol netters and trawlers that operated in the north-eastern Arabian Sea up to 70-90 m depths were the major crafts landing Bombayduck at these landing centres. The samples collected were transported in ice to the laboratory in insulated boxes for detailed analyses.

Length-weight relationship

Length measurements (Total length-TL, Standard length-SL) and weight measurements were taken to the nearest millimetre (mm) and gram (g) respectively, with a digital scale and balance. The length-weight relationship was calculated as $W = aL^b$ (LeCren, 1951), where W is the weight of the fish in grams and L is its total length in cm; 'a' being the regression intercept and 'b' the slope. A significant difference between regression coefficients of the sexes was tested by ANOVA (Snedecor and Cohran, 1967).

Reproductive biology

Gonadosomatic index (GSI) was calculated using the formula GSI = Gonad weight/Bodyweight *100 (Vladykov, 1956). Gonad stages were assessed using macroscopic as well as microscopic characters (Wallace and Selman, 1981). Whole oocyte diameter measurements from representative fresh ovaries of each stage were made using an image analyser (Motic BA 310). The sex ratio was estimated based on the number of females and males in the sample and the homogeneity was tested using the Chi-square test.

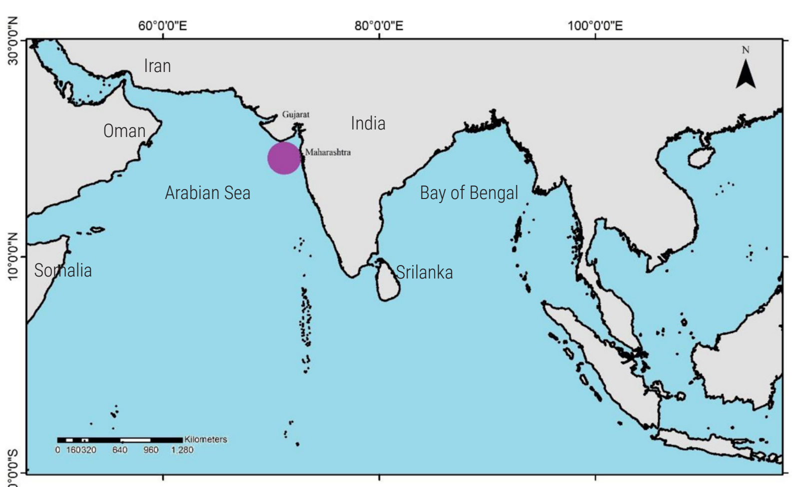

Fig.1. Study location in the Indian Ocean

Table. 1. Fishery characteristics of the northern Arabian Sea

	Maharashtra	Gujarat	Pooled (NEAS)	All India	NW in All India %
Coastline (km)	720	1600	2320	6068	38.2
Fish landing centres	155	107	262	1363	19.2
Fisher family	87717	67610	155327	893258	17.4
Catch (2018) t					
Total	295398	780312	1075710	3487614	30.8
Bombayduck	16576	72949	89525	112705	79.4
Non-penaeid shrimps	37121	141442	178563	194011	92.0
Penaeid shrimps	33754	33742	67496	192240	35.1
Ribbonfish	15006	87186	102192	193822	52.7
Crafts (CMFRI-FSI-DoF, 2020).					
Trawler	3408	9905	13313	30772	43.3
Gillnet	584	2602	3186	6548	48.7
Bagnet	1637	1557	3194	3396	94.1
Purse seines	230		230	1189	19.3
Total mechanised	5867	14061	19928	42985	46.4
Motorised	5979	3541	9520	31409	30.3
Non-motorised	809	9284	10093	66250	15.2
Total crafts	15520	27642	43162	166333	25.9

(Source: CMFRI, 2018; CMFRI-FSI-DoF, 2020)

Fecundity was estimated for ripe ovaries which are characterised by hydrated translucent oocytes. Subsamples weighing 03 - 0.5 g equally distributed from the anterior, middle and posterior regions from each ovary were used to assess fecundity using the equation F = [gonad weight × (subsample egg count/gonad subsample weight)].

The length at which 50% of females and males attained maturity (L_m) was calculated using *size Mat,:* an R Package to estimate size at sexual maturity (https://cran.r-project.org/web/packages/sizeMat/vignettes/sizeMat.html).

Gut content analysis

The gastrointestinal tract from each specimen was carefully removed and dissected and the contents were examined, observed under stereomicroscope to identify contents. The food items were identified to the lowest possible taxon using standard identification keys (Psomadakis *et al*., 2015). The state of fullness of the stomach was assessed and classified as gorged or distended and empty. Stomach fullness was recorded using a five-point scale (0: empty; 1: 0-25% full; 2: 25-50% full; 3: 50-75% full and 4: 75-100% full) (Braccini *et al*., 2005). Diet analysis based on the Index of Relative Importance (IRI) was calculated as IRI= (%N+% W) *%O (Pinkas *et al.,* 1971) where, the percentage frequency of occurrence (%O), percentage composition of number (%N) and the percentage composition by weight (%W) were taken into account. IRI was expressed as a percentage (% IRI) following % IRI = (IRI/ Σ IRI) *100 to allow for a comparison of values between prey groups (Cortes, 1999). The feeding strategy was determined with the modified Costello (1990) method as suggested by Amundsen *et al.* (1996) where prey-specific abundance (Pi) is plotted against the frequency of occurrence.

The Prey-Specific Index of relative importance (%PSIRI), a standardised measure of prey contribution with IRI (Pinkas *et al.*, 1971), was calculated to estimate the prey contribution to the diet (Brown *et al.,* 2012; Silva-Garay *et al.,* 2018) using the formula:

PSIRIi=(%Ni+%Wi)/2PSIRi=%FOi × (%PNi + %PWi)/2

Trophic level (TL) was estimated using the formula (Cortes, 1999):

$$TL = 1 + \sum_{(i=1)}^{n} Pi \times TLi$$

where TL is the trophic level, Pi is the proportion of prey category *i* in the diet in terms of %Ni, n is the total number of prey categories and TL*i* is the trophic level of the prey category *i.*

Results

Size composition in fishery

The size range of *H. nehereus* in the fishery ranged between 30 and 408 mm TL (Fig. 2) with the modal class between 190 to 270 mm TL. The unsexed length frequency of 10 mm TL class intervals of 5,809 sampled fishes pooled for the entire study period showed that all size classes were landed in all months (Fig. 3). Larger-sized fishes (>150 mm TL) with a higher modal length were observed during March-May and October-January (Table 2). Juveniles formed 52% of the total samples examined. The commercial fishery and trade were supported by fishes having a length of more than 150 mm TL. The smaller-sized fishes were often discarded onboard or at the landing centre, or during the trade, while the species were being sorted.

Length-weight relationship

A total of 2,704 individuals, consisting of 1,413 females (153-362 mm TL) and 991 males (156-305 mm TL) and 300 indeterminates

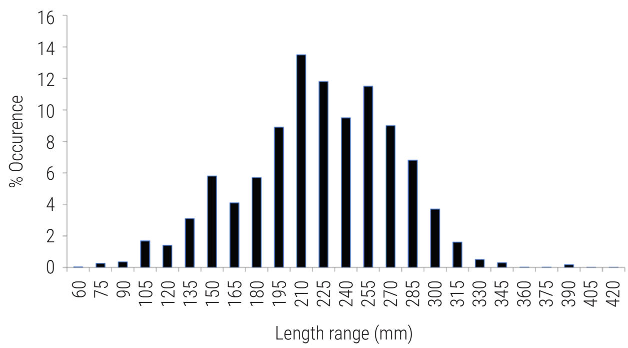

Fig. 2. Size class frequency (%) in *H. nehereus* (pooled data)

Table 2. Monthly sex ratio of *H. nehereus* from north-eastern Arabian Sea

Month	Sex ratio	Chi square value
January	1.53	5.9
February	2.85	17.8
March	2.53	11.9
April	0.69	3.4
May	0.93	0.2
June	0.93	0.1
July	1.74	1.9
August	1.40	3.6
September	0.70	1.8
October	1.52	6.2
November	1.99	15.6
December	1.66	10.8

(95-200 mm TL) were used for the calculation of the length-weight relationship. The relationship between weight (g) and TL (cm) for males, females and combined sexes is expressed by the following equations:

Length-weight relation (Indeterminants): $W = 0.129 \times TL^{1.04}$ ($r^2 = 0.79$)

Length-weight relation (Males): $W = 0.000000775 \times TL^{3.3}$ ($r^2 = 0.79$)

Length-weight relation (Females): $W = 0.00000143 \times TL^{3.28}$ ($r^2 = 0.71$)

Analysis of covariance showed no significant difference in the regression coefficients of males and females at 1 and 5% levels. Hence the sexes were pooled and a length-weight relation was calculated and expressed as:

Length-weight relation (pooled sexes): $W = 0.000000867 \times TL^{3.31}$ ($r^2 = 0{\cdot}75$)

The b value estimated was greater than 3 and the fish showed positive allometric growth.

Sex ratio and condition factor

Biological observations were based on 3,124 individuals of *H. nehereus* examined in the laboratory, comprising 1,563 females,

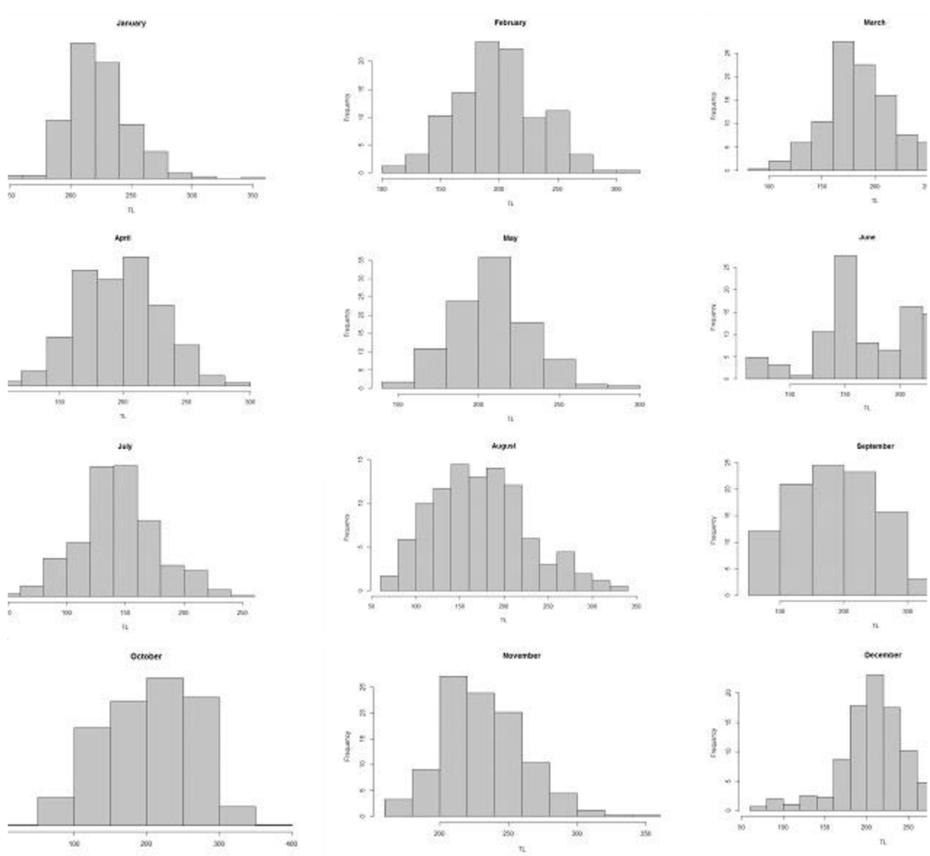

Fig. 3. Monthly size class of *H. nehereus* from north-eastern Arabian Sea

1,010 males and 451 indeterminate specimens. Females ranged in length from 153 to 408 mm TL and 13 to 182 g in weight and males from 156 to 305 mm TL and 16 to 360 g in weight, respectively. Females attained a larger size than males. The overall sex ratio during the period of study was 1:1.5. The chi-square test revealed a significant dominance of females from October to March (Table 2).

The condition factor (K) for females plotted against months showed that October had the highest K (0.6) value and March had the lowest K (0.4) value. K value increased from October to December (Table. 3). There was a decline in K value during April which coincided with the peak spawning period of this species.

Reproductive biology

H. nehereus is a gonochoristic fish and visual identification of sexes by external characters is difficult in the species. Based on visual and microscopic examination of ovaries, the maturity stages were classified as immature (stages I & II), maturing (stages III & IV), mature (stage V), ripe (stage VI) and spent (stage VII). During the present study, developing stages were observed in all months. The ova diameter frequency polygon is given in Fig. 4. In stage I, only one batch of immature ova with a mode at 0.07 mm was observed. In Stage II, as development progressed, the ova diameter increased to 0.39 mm with a mode of 0.16 mm, at Stage III the ova diameter increased to 0.54 mm with a mode of 0.26 mm indicating the presence of maturing ova. The diameter of maturing ova progressed to 0.6 mm with a mode of 0.49 mm in stage IV. In Stage V, the mode moved to 0.53 mm, representing mature ova. In stage V, another mode of developing/immature eggs appeared in the ovary. In stage VI, the mode shifted to 0.64 mm. The ova size increased up to 0.88 mm in stage VI and a distinct mode representing ripe ova in the ovary was observed. Another mode of immature eggs in the stages II and III was visible. The ripe ova were transparent with oil globules and the pattern of ova development showed a single dominant mode in stage VI. In stage VII, ovaries were shrunk and bag-like with presence of only a few stage II, III and decaying ova.

Length at maturity

Length at maturity for females estimated with the logistic equation showed that 50% of the fishes attained maturity at the size of 207 mm TL (Fig. 5). The smallest mature female observed was 160 mm TL. Male testes are very thin and other than for mature testes, assigning maturity stages to males was difficult. Mature males were observed from 160 mm onwards and the estimated L_m was 180 mm TL. Mature and immature fishes were observed in all months (Fig. 6).

Gondosomatic index

GSI varied significantly between months and ranged from 0.1 to 6.9. The peak value was observed in March and a higher percentage of mature specimens were observed during November-May indicating the peak spawning season of the species (Table 4). Mature ovaries

Table. 3. Monthly K values of *H. nehereus* from the north-eastern Arabian Sea

Month	K factor
January	0.458
February	0.414
March	0.413
April	0.427
May	0.428
June	0.471
July	0.479
August	0.469
September	0.468
October	0.575
November	0.537
December	0.523

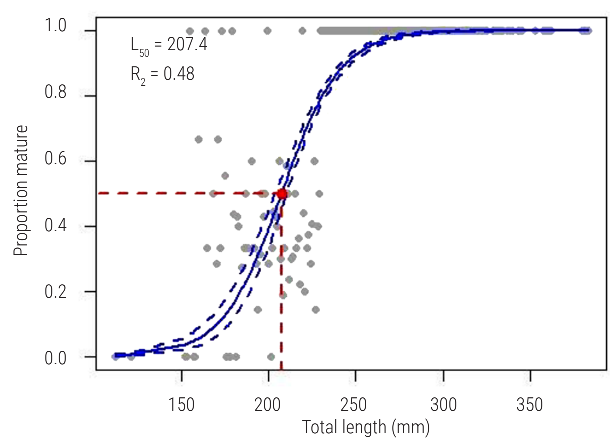

Fig. 5. Length at maturity of female *H. nehereus*

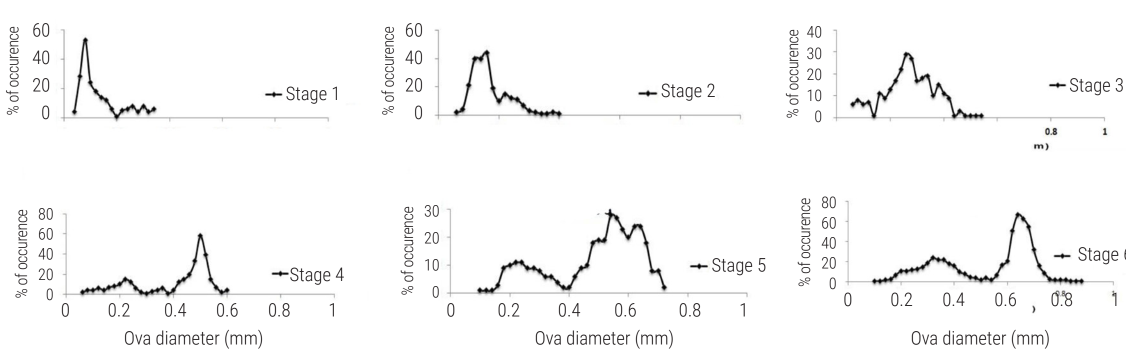

Fig.4. Ova diameter frequency of different maturity stages of female *H. nehereus*

contained ova of all stages, indicating the species is a continuous spawner.

Absolute fecundity (F) is the total number of ripe eggs in the ovaries just before spawning. The absolute fecundity ranged from 23,444 to 1,34,432 eggs per fish and relative fecundity from 235-430 eggs per gram.

Food and feeding

Diet analysis was undertaken to understand the prey preference and habitat utilisation by the species. *H. nehereus* was observed to be a voracious, cannibalistic feeder feeding mostly on crustaceans. The feeding intensity during the study period showed a high percentage of empty stomach (46.2%) followed by, 22% with trace conditions in the stomach, 13.4% quarter full, 8.4% half full, 4% three-quarters full and 5% full. Only 1% of the gut was in the gorged stage. Monthly feeding intensity exhibited significant variations between months with low feeding intensity in February (5.5%) and August (13.9%) (Fig. 7).

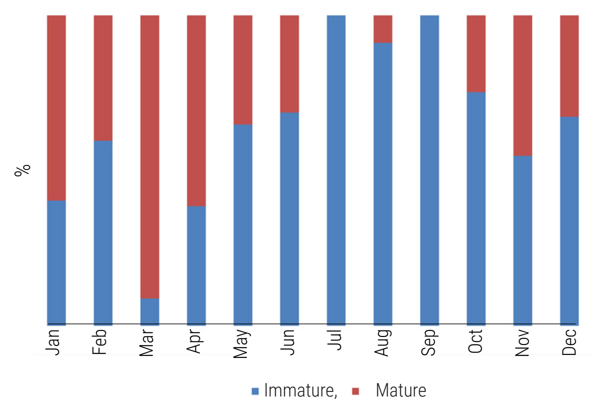

Fig. 6. Monthly maturity status (%) of *H. nehereus* (pooled data)

Table 4. Monthly GSI for *H. nehereus* (pooled)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GSI	4.0	2.1	6.9	4.5	2.6	0.7	0.2	0.5	0.1	0.6	2.3	2.1

Detailed gut content analysis revealed that a total of 35 species of prey belonging to 21 different families constituted the food of *H. nehereus*. The prey identified from the gut of the Bombayduck was represented by at least 18 teleosts, more than 10 crustaceans, and 1 cephalopod genera. Crustaceans (82.7%) were the major prey items followed by teleosts (17.3%) (Table 5). Cephalopods and unidentified groups (digested matter) contributed a very low share. The index of relative importance (%IRI) among identified crustaceans revealed that the non-penaeid shrimps especially *Nematopalaemon tenuipes* (54.9%) of the Palaemonidae family was the major food followed by *Acetus* spp. (27.3%) (Sergestidae). *N. tenuipes* was the dominant food item having the highest percentage of IRI. Other families of crustaceans that contributed to the diet were Solenoceridae, Lysmatidae and Squillidae. The teleosts identified in the gut represented both pelagic and demersal fishes under the family Synodontidae (6.4%), Engraulidae (2.4%), Bregmacerotidae (0.32%), Sciaenidae (0.07%), Gobiidae (0.04%), Trichiuridae (0.03%) and fishes belonging to Clupeidae, Apogonidae, Polynemidae and Cynoglossidae. Unidentified semi-digested fishes formed about 8% of the IRI. The highest average IRI was recorded for juveniles of *H. nehereus* (6.4%) and *Coilia dussumieri* (2.4%). High cannibalism was observed, with a sizeable proportion of juvenile Bombayduck regularly forming a part of the diet.

Analysis of the feeding strategy of Bombayduck showed that most of the prey items were situated in the upper left corner of the graph indicating a strong phenotypic contribution to the niche width with individual specialisation (Fig. 8). However, the specific prey selected by each individual differed. The data points scattered in the central part of the graph indicated a mixed feeding strategy, suggesting that, occasionally, the population would feed on the same species opportunistically.

Discussion

The high fishing effort (CMFRI-FSI-DoF, 2020) along with the impact of climate change (Prasannakumar *et al.*, 2009; Dineshbabu *et al.*, 2020) is affecting fish populations in the northern Arabian Sea. Biological traits, environmental features, and anthropogenic impacts determine the vulnerability of fish species. Some species are highly vulnerable due to life-history traits (Mohamed *et al.*, 2021). *H. nehereus* is a species with a high climate vulnerability ranking

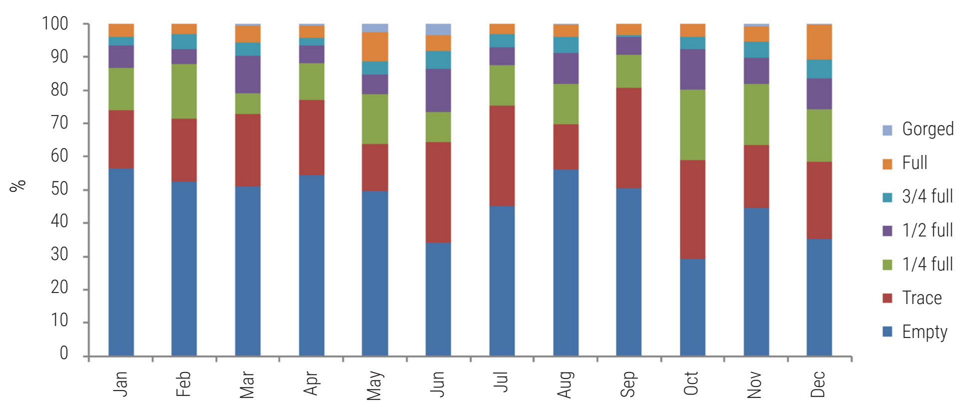

Fig. 7. Monthly feeding intensity (%) in *H. nehereus* (pooled data)

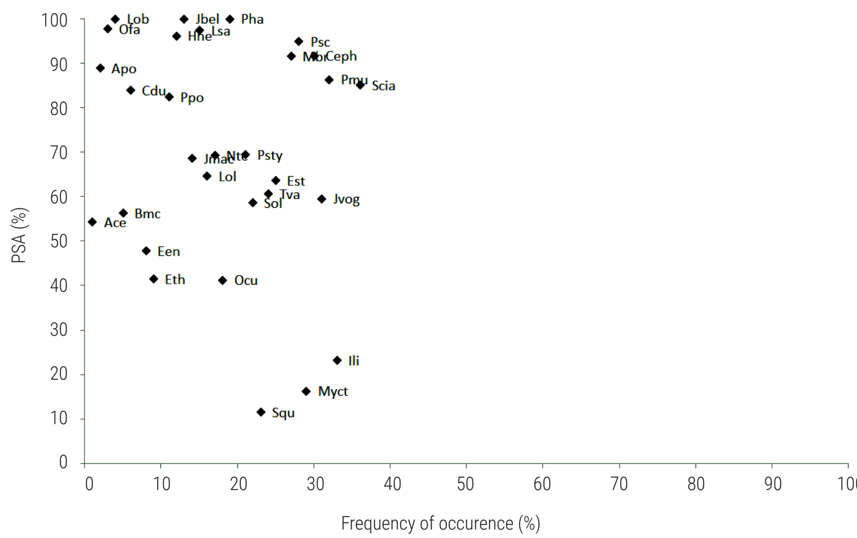

Fig. 8. Prey specific abundance (PSA) of *H. nehereus*

and low adaptive capacity (Dineshbabu *et al.,* 2020) and can be described as a non-hardy species found in coastal waters and under multiple stress conditions. The length-frequency analysis and fishery observation show that a huge quantity of juveniles is caught in the fishery, mostly in SBN, small meshed dol nets, and trawls. These juvenile landings are often not represented in the regular scenarios which are mostly comprised of tradeable sizes. The fish has a recorded size of 30-408 mm in the fishery however, large-sized fishes above 370 mm were rare.

Understanding the LWR is important in stock assessments as it is one of the basic inputs used and provides information on the growth, well-being and fitness of the fish (Froese, 1998; Abdurahiman *et al.,* 2004). The length-weight relationship of *H. nehereus* showed positive allometric growth. The estimated '*b*' value in both males and females was greater than 3 and did not differ significantly. The length-weight relationship reported by earlier authors is provided in Table 6. The present result is comparable to the earlier results from the north-eastern Arabian Sea (Bapat *et al.,* 1970; Balli *et al.,* 2006; Ghosh, 2014). Variations observed in the '*b*' value by different authors may be due to the changes in the ecological condition, seasonal variations, feeding, variations in composition and the number of adults/juveniles sampled. The exclusion of mature and ripe specimens in the analysis could influence the estimation and result in variations in the b value. Ghosh (2014) observed higher 'b' values in well-fed and mature fish, which was attributed to the rapid growth of the ovary during the advanced maturity stage and the feeding intensity. The highest 'b' value (3.7) was reported by Bapat (1970) and the lowest (2.03) was by Kurian and Kurup (1992). Interestingly both the studies were conducted in the same location. In the present study, a significant difference in the "b" value for males and females was not observed, which is also supported by earlier works.

The sex ratio shows a slight dominance of females in the fishery. Earlier reports on the distribution of males and females in the fishery are provided in Table. 7. Progressive reduction of males with an increase in size was reported earlier (Kurien and Kurup, 1992; Balli *et al.* 2006). Ghosh *et al.* (2009) reported that the difference in the sex ratio may be due to the ecosystem as well as biological factors like maturity stages, feeding behaviour and competition for food.

The length at maturity estimated in the present study was 207 mm TL. Length at maturity reported for the species from the same region varied between 202-266 mm TL (Table 8). Bombayduck is a non-hardy species with high water content (87.5% moisture) in its body (Mohanty *et al*., 2016) and appears to have highly varying biological features according to varying environmental parameters in its spatial and temporal scale. Bapat (1970) observed that *H. nehereus* attains maturity for the first time in its life between 200-210 mm TL. Khan (1986) observed mature females from a length of 200 mm onwards. Ghosh *et al*. (2009) reported that *H. nehereus* matured when it attained a TL of 177 mm and in a later study, Ghosh *et al*. (2014) observed mature fishes starting from 145 mm TL. In the present study, mature specimens were observed from 160 mm. A timeline perusal of the earlier studies has indicated that the estimated L_m and size at the first maturity of *H. nehereus* varied widely. These variations in the minimum and size at maturity can be attributed to variations in the environmental parameters (Vollestad, 1992; Queiros *et al*., 2013) or sampling biases due absence of standardised methodologies in early research or the variation in the frequency of adults and juvenile composition, or with the geographical location of catch, local population densities as well as temporal scale growth variations. In addition, fishing can induce evolutionary changes in the life history of fishes (Fenberg and Roy. 2008; Jorgensen *et al.,* 2008; Meithe *et al*., 2010) (Table 1). So, these differences in the size at first maturity cannot be attributed to a single-point effect of the environment, its impact on the biology of the fish and their food availability, or increasing fishing pressure, for which detailed historical studies may be needed.

Studies have reported two spawning seasons for *H. nehereus* during April-July and November-December (Bapat, 1951; Palekar and Karandikar, 1952; Bapat, 1970; Kurian and Kurup 1992), with peak spawning from December-March (Bapat, 1970; Khan *et al.,* 1992), from November to March (Balli *et al*., 2006) and from September to December followed by a second minor peak in March-May (Ghosh

Table 5. IRI for *H. nehereus* (pooled)

Prey items		Numbers (N)	Mass (M)	Occurrence (O)	%IRI	Alimetary Index	Prey-Specific Index of relative importance
		(% N)	(%M()	(% O)		(IAi)	(%PSIRIi)
Prey	Family/Group						
	Crustacea						
Acetes spp.	Sergestidae	38.0	5.7	22.4	27.3	1.3	21.8
P. hardwickii	Penaeidae	0.1	0.1	0.1	0.0	0.0	0.1
P. stylifera	Penaeidae	0.4	0.6	0.6	0.0	0.0	0.5
P. sculptilis	Penaeidae	0.1	0.3	0.2	0.0	0.0	0.2
M. brevicornis	Penaeidae	0.1	0.7	0.2	0.0	0.0	0.4
Parapenaeopsis spp.	Penaeidae	0.4	0.4	0.7	0.0	0.0	0.4
Solenocera spp.	Solenoceridae	1.8	2.6	3.2	0.4	0.1	2.2
E. styliferus	Palaemonidae	0.1	0.2	0.2	0.0	0.0	0.2
N. tenuipes	Palaemonidae	32.3	31.9	30.7	54.9	9.8	32.1
Oratosquilla spp.	Squillidae	0.1	0.0	0.3	0.0	0.0	0.1
Lobster larvae	Scyllaridae	0.0	0.0	0.1	0.0	0.0	0.0
E. ensirostris	Lysmatidae	0.9	1.3	1.6	0.1	0.0	1.1
Unidentified shrimps	Penaeidae	0.5	0.3	0.8	0.0	0.0	0.4
Portunus sp.	Portunidae	0.1	0.0	0.1	0.0	0.0	0.0
Charybdis sp.	Portunidae	0.0	0.0	0.1	0.0	0.0	0.0
	Mollusca	0.0	0.0	0.0	0.0	0.0	0.0
Loligo spp.	Cephalopods	0.1	0.4	0.1	0.0	0.0	0.2
Unidentified cephalopods	Cephalopods	0.1	0.5	0.2	0.0	0.0	0.3
	Teleostei	0.0	0.0	0.0	0.0	0.0	0.0
E. thoracata	Clupeidae	0.1	0.4	0.2	0.0	0.0	0.2
Ilisha spp.	Clupeidae	0.1	0.2	0.1	0.0	0.0	0.1
Sardinella spp.	Clupeidae	0.1	0.2	0.1	0.0	0.0	0.1
Apogon sp.	Apogonidae	0.4	1.1	0.4	0.0	0.0	0.7
Ostorhinchus fasciatus	Apogonidae	0.0	0.8	0.1	0.0	0.0	0.4
Bregmaceros mcclellandi	Bregmacerotidae	1.8	2.3	2.8	0.3	0.1	2.1
Coilia dussumieri	Engraulidae	3.7	13.6	5.0	2.4	0.7	8.7
Parachaeturichthys polynema	Gobiidae	0.1	0.7	0.1	0.0	0.0	0.4
T. vagina	Gobiidae	0.6	1.3	0.6	0.0	0.0	1.0
H. nehereus	Synodontidae	6.5	19.7	8.7	6.4	1.7	13.1
Myctophum spp.	Myctophidae	0.1	0.1	0.2	0.0	0.0	0.1
P. mullani	Polynemidae	0.3	0.7	0.5	0.0	0.0	0.0
Johnius belangerii	Sciaenidae	0.0	0.3	0.1	0.0	0.0	0.1
J. macrorhynus	Sciaenidae	0.1	0.3	0.1	0.0	0.0	0.2
J. vogleri	Sciaenidae	0.1	0.5	0.2	0.0	0.0	0.3
Otolithes cuvieri	Sciaenidae	0.6	0.9	0.5	0.0	0.0	0.7
Unidentified croakers	Sciaenidae	0.4	1.6	0.8	0.0	0.0	1.0
L. savala	Trichiuridae	0.2	3.2	0.3	0.0	0.0	1.7
E. muticus	Trichiuridae	0.1	0.3	0.1	0.0	0.0	0.2
Cynoglossus sp.	Cynoglossidae	0.2	0.1	0.1	0.0	0.0	0.2
Unidentified fish		9.6	6.6	17.7	8.0	0.5	8.1

et al., 2009). During the present study period, immature, maturing, and mature ova were observed throughout the year in varied frequencies suggesting that spawning is a continuous activity with a peak during November - May and higher values during February - April.

The K value increased from June onwards and then sharply declined after November indicating a high metabolic rate. This could be due to the intensive spawning activity of the species as the major spawning season of the species as observed in the present study is from November - May. Bapat (1970) has also reported lower 'K' values in females during the peak spawning season.

Fecundity was estimated for gravid females and the absolute fecundity ranged from 23,444 to 1,34,432 eggs per fish with a mean of 82,884 egg per fish. The relative fecundity increased with body size and ranged from 235 - 430 g^{-1}. Ghosh (2014) reported a relative fecundity of 388 eggs g^{-1} body weight for the species. The absolute fecundity ranges of 17,075-79,631 were reported by Khan *et al.* (1992) from Saurashtra waters and 21,182-1,16,067 were reported by Balli *et al.* (2006) from Mumbai waters.

Ovaries of stages V and VI contained batches of immature, mature and maturing oocytes. Such observations were made earlier by

Table 6. Length-weight relationship of *H. nehereus* from the Arabian Sea

Authors	'a' and 'b' value	Region
Bapat *et al.* (1951)	$W=0.00001032*L^{2.889}$	Maharashtra
Bapat *et al.* (1970)	$W=0.0000009795*L^{3.7169}$ (Male) $W=0.0000002268*L^{3.444}$ (Female)	Maharashtra
Biradar (1987)	b = 2.915	Off Maharashtra
Khan (1989)	logW= -5.878+3.1446 log L (Male) logW= -5.718+3.194 log L (Female) logW= -5.915+3.279 log L (Pooled)	Off Saurashtra
Kurian and Kurup (1992)	log W= -2.933 +2.0279 log L	Off Maharashtra
Balli *et al.* (2006)	log W= -3.181+3.638 log L (Male) log W= -3.068+3.558 log L (Female) log W= -3.136+3.606 log L (Pooled)	Mumbai
Ghosh *et al.* (2009)	log W= -1.975+2.8097 log L (Male) log W= -2.0620+2.871 log L (Female) log W= -2.2717+3.024 log L (Pooled)	Off Saurashtra
Ghosh (2014)	log W = -3.1806 + 3.638 log L (Male) logW=-3.0675 + 3.558 log L (Female) log W = -3.1362 + 3.606 log L (Pooled)	Saurashtra
Present study	$W = 0.000000417 * TL^{3.44}$ (Male) $W = 0.000000143 * TL^{3.64}$ (Female) $W= 0.000000237 * TL^{3.53}$ (Pooled)	Mumbai

Table 7. Sex ratio of *H. nehereus* from the Arabian Sea

Authors	Sex ratio (Male:Female)	Region
Deshmukh and Kurian (1980)	1:1.64	North-west coast
Bapat (1970)	1:1.71	Mumbai waters
Khan *et al.* (1992)	1:0.9	Saurashtra coast
Johnson *et al*, (2006)	1:0.45	Mumbai
Ghosh *et al.* (2009)	1:0.99	Saurashtra
Ghosh (2014)	1:1.05	Saurashtra
Present study	1:1.55	North-west coast

Bapat (1970) and Ghosh (2014) wherein they reported that the mature ovaries contained one batch of immature, one batch of maturing and one batch of mature ova and concluded that *H. nehereus* spawn continuously in a year. However, the size of the mature ova observed in the present study was considerably smaller as compared with the previous study by Ghosh (2014). The earlier study reported the modal size of the mature ova as 0.8 to 0.89 mm, maturing ova as 0.5-0.69 mm and immature ova as 0.2 to 0.39 mm as compared to present values of 0.68, 0.54 and 0.26 mm respectively. The variation in the size of the ova and the increase in the number of eggs may be due to variations in the criteria used for assessing the visual maturity stages and comparisons. The number of oocytes from early and advanced phases in each stage can affect the size composition. Studies have shown that environmental variations can have an impact on egg size, plasticity in egg mass and fecundity (Einum and Fleming, 2002; Damme *et al.*, 2009; Oskarsson *et al.*, 2019). For a species like the Bombayduck, which can be suggested as a model species to study climate and environmental impact on the marine environment, detailed micro-level studies are needed based on fishery-independent as well as advanced tools for reproductive genetic studies and ecophysiology.

The food contents observed in the gut established that Bombayduck is a carnivorous and cannibalistic fish, even though a large proportion of stomachs analysed were empty or with trace food. The prey items included crustaceans (77% IRI) and teleosts (20.8%). Similar findings were reported by Hora (1934) and Bapat *et al.* (1951) and the major prey items were *Bregmaceros* and *Acetes indicus*. Chopra (1939) reported shrimps as major food item of Bombayduck and related their migrations to the movements of shrimp shoals. Bapat *et al.* (1951) found juveniles of *H. nehereus, Bregmaceros mcclellandi, Coilia dussumieri* and *Polydactylus mullani* as the major food items. Bapat (1970) in a detailed study reported the main food items as different species of shrimps and fishes. Ghosh (2014) from Veraval observed that the main food items of Bombayduck consist of non-penaeid shrimps like *Acetes* and *N. tenuipes* followed by sciaenids, unicorn cod and juveniles of Bombayduck. In the current study, 85% of the prey was contributed by the non-penaeid shrimps mostly from Palaemonidae and Sergestidae families. The presence of a good quantity of non-penaeid shrimps in the gut is mainly because the area of Bombayduck fishery is known for the occurrence of non-penaeids (Deshmukh, 1993; Jaiswar and Chakraborty, 2005; Ghosh, 2014;

Table: 8. Length at first maturity (L_m) of *H. nehereus* from the northern Arabian Sea

Author and year	Bapat *et al.* (1951)	Khan (1986)	Khan (1989)	Kurian and Kurup (1992)	Balli *et al.* (2006)	Ghosh *et al.* (2009)	Ghosh (2014)	Present study
Length at maturity (L_m) in TL (mm)	200-230	266	250	230	255	202	214.5	207
Period	1948-1950				2003-2005	2003-2006	2006-2009	2014-2019
Numbers	721				450	1162	857	3124

Vase *et al.,* 2021) and acts as the major connecting link in the food web of the northern Arabian Sea ecosystem. The dominance of a species in the animal's diet is directly proportional to the abundance of the prey in the ecosystem (Kiest, 1993; Rinewalt *et al.,* 2007; Vase *et al.,* 2020). Dietary analysis by size class showed that juveniles fed exclusively on small-sized crustaceans, mostly *Acetes* spp. Prey-Specific Index of relative importance (%PSIRI) also showed the dominance of crustaceans with *N. tenuipes* (32.4%) and *Acetes* spp. (22%) followed by *H. nehereus* (13.2%).

The trophic level (TrL) of *H. nehereus* was estimated as 3.9 in the present study. Previous estimates showed a TrL of 4.1±0.74 (Froese and Pauly, 2021) and 3.7 (Vivekanandan *et al.,* 2009). Song *et al.* (2021) suggested that the Bombayduck has high trophic plasticity in seasons/months and according to size, which ranges from 2.9-4.5. Trophic plasticity in *H. nehereus* has been attributed to the space-time community variation in the ecosystem and prey preferences (Song *et al.,* 2021).

Biological information about exploited fishes is necessary to understand their role in the ecosystem, stock resilience, adaptive capacity and sustainability. *H. nehereus* is a high-water (>85%) content fish, which makes it possible to survive in reduced oxygen environments (Kang *et al.,* 2021) and its restricted distribution has also been attributed to environmental parameters. Kang *et al*. (2021) observed that even when oxygen levels are low in coastal waters, *H. nehereus* thrives well. The Northern Arabian Sea waters are reported to have low oxygen zones (Wajih *et al.,* 2009; Rixen *et al.,* 2020) where Bombayduck can thrive well.

Ecological roles and biology are highly interlinked and cross-disciplinary fishery biological studies are necessary for iconic fishes like the Bombayduck to inform stock management, based on updated biological information. In addition, regular continuous monitoring of fishery and the biology of commercially exploited fishes are necessary to understand changes in biological characteristics as well as fluctuations in landings caused due to overexploitation or impacts of climate change and extreme events. The scientific information generated in the current study will be useful to managers and researchers for supporting sustainable management plans for fisheries exploiting *H. nehereus* in the Arabian Sea.

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