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Fishery and population dynamics of *Harpadon nehereus* (Ham.) off the Saurashtra coast

SHUBHADEEP GHOSH, N. G. K. PILLAI AND H. K. DHOKIA
Veraval Regional Centre of Central Marine Fisheries Research Institute,
Matsya Bhavan, Bhidiya, Veraval, Gujarat – 362269, India
e-mail: subhadeep_1977@yahoo.com

ABSTRACT

The fishery and population dynamics of Bombay duck (*Harpadon nehereus* Ham.) from Nawabunder, Rajpara and Jaffrabad were studied for the period from 2003 to 2006. The average annual landings of *Harpadon nehereus* was 25,079 t, which contributed 31.12 % to the total dol net catches. The seasonal peak in catch was recorded during September – January and in May. The length–weight relationship showed that growth was isometric and there was no significant variation between the sexes. The overall sex ratio was 1:0.99 with gravid and ripe females encountered in most months with a peak during September – December. The length at first maturity of female was 20.2 cm. The growth parameters were estimated as L_α = 35.39 cm and K = 0.86 and the length attained at the end of 1, 2 and 3 years were 20.66 cm, 29.16 cm and 32.75 cm respectively. The length at first capture was 3.42 cm with recruitment occurring in most months of the year with a peak during February – June. The natural mortality, fishing mortality and total mortality were 1.52, 1.73 and 3.25 respectively and the exploitation ratio was 0.53. The maximum sustainable yield was 23,557 t, which was lower than the average annual catch indicating overexploitation of the species. The yield per recruit and biomass per recruit was 6.565 g and 3.79 g and increase in relative yield by 111.45 % would be obtained by decreasing the present level of fishing by 40 %.

Key words: *Harpadon nehereus*, Bombay duck, Fishery, Population dynamics, Saurashtra coast

Introduction

Bombay duck (*Harpadon nehereus* Ham.) forms one of the most important commercial fishery along the Saurashtra coast of India wherein it accounted for 13% of the total catch during 2002-2006 (Mohanraj *et al*., 2007). However, bulk of the fishery is concentrated within a narrow belt of 45 km at the depth range of 20 – 70 m and the important landing centres are Nawabunder, Rajpara and Jaffrabad.

The Bombay duck resource along the Saurashtra coast is of an independent stock (Bapat, 1970; Zafar Khan, 1983). The species is primarily caught with the bag-net, better known as "dol" net of 35 – 60 m length and with a cod-end mesh of 20 mm. The operation of this gear is timed to a strong tidal current. The bag with the mouth set against the current strains the fish which is being retained therein by the strength of the current and the net is then retrieved. Bombay duck is a very soft fish and is highly perishable due to its body composition. A large part of the catch particularly during the peak fishing season is sundried on raised bamboo platforms by hanging them on ropes and the dried fish is exported. As the fishery is labour intensive, the fishing effort is regulated during the fishing season. In the beginning of the season when the catch rate is high, only a single haul is taken but as the catch rate comes down, 2-3 hauls are taken. However, when the catch is very poor the fishing is suspended due to economic reasons.

The fishery, biology and population characteristics of the species from the Saurashtra coast was extensively studied (Bapat, 1970; Zafar Khan, 1985; 1986a,b; 1987; 1989). The present study attempts to reassess the fishery and status of the resource based on detailed data collected from the dol net catches of all the three centres along the Saurashtra coast.

Materials and methods

Data on catch and effort expended for *Harpodon nehereus* were collected weekly from the dol net landing centres of Nawabunder, Rajpara and Jaffrabad for the four year study period from January 2003 to December 2006. The monthly and annual estimates of catches were made following the procedure adopted by the Fishery Resources Assessment Division of Central Marine Fisheries Research Institute. A total of 12,335 specimens of *H. nehereus* in the size range of 3 to 34.4 cm collected randomly each week from Nawabunder, Rajpara and Jaffrabad were sampled for recording total length (in cm) and body weight (in grams

to 0.01 g precision). The length-weight relationship of *H. nehereus* was calculated following the formula, $W=aL^b$ (Le Cren, 1951) separately for both sexes and then if no significant difference in the slopes of the regression lines for males and females were established by ANACOVA (Snedecor and Cochran, 1967), a combined length-weight relationship by pooling both the sexes was arrived at. A total of 496 (226 male, 251 female and 19 intermediate) specimens in the length range of 9 – 34.4 cm were used for determining the length-weight relationship. The month-wise sex ratio was determined from 2,348 specimens and Chi-square test was performed to test the homogeneity of male and female distribution. The size at first maturity (L_{50}) was determined from 1,162 female specimens by plotting the percentage of mature specimens (stage III and above) against the total length. Proportion of gravid and ripe females (V and VI) over time were taken to determine the spawning season. During monsoon (June – August) due to suspension of the dol net fishery, there was no data available on catch, effort, length, weight, sex ratio and maturity stages of *H. nehereus*.

For estimating von Bertalanffy growth parameters *viz*., asymptotic length (L_α) and growth co-efficient (K), the length measurements of four years data were pooled and grouped with 1.5 cm class interval, month-wise and analyzed using the ELEFAN I module of FiSAT software (Gayanilo *et al*., 1996). An additional estimate of L_α and Z/K values obtained using the Powell – Wetherall plot was compared with that obtained from ELEFAN before arriving at final values. The output of the growth curve was obtained and length based growth performance index Ø was calculated from the final estimates of L_α and K (Pauly and Munro, 1984). The probability of capture and size at first capture (L_c) were estimated as in Pauly (1984) and the age at zero length (t_0) from Pauly's (1979) empirical equation, $\text{Log}(-t_0) = -0.392 - 0.275 \text{ Log } L_\alpha - 1.038K$. The growth and age were estimated using the von Bertalanffy growth equation, $L_t = L_\alpha (1-e^{-k(t-t0)})$. The L_c value was converted to t_c value using the inverse von Bertalanffy growth equation. The mid point of the smallest length group in the catch was taken as length at recruitment (L_r). The recruitment pattern was studied from recruitment curves using final estimated values of L_α, K and t_0. The value of asymptotic weight (W_α) was derived from the value of L_α and the estimated length-weight relationship. Longevity was estimated from $t_{max} = 3/K + t_0$ (Pauly, 1983a).

Natural mortality (M) was estimated as in Pauly (1980), by taking the mean sea surface temperature as 27 ºC and total mortality (Z) from length converted catch curve (Pauly, 1983b) using FiSAT software. Fishing mortality (F) was estimated by F = Z - M. Length structured virtual population analysis (VPA) of FiSAT was used to obtain fishing mortalities per length class. Exploitation ratio was estimated from the equation, E = F/Z and exploitation rate from $U = F/Z*(1-e^{-z})$; where, F is the fishing mortality rate.

Total stock (P) and biomass (B) were estimated from the ratios Y/U and Y/F respectively; where Y is the annual average yield in tonnes. Maximum sustainable yield was calculated by the equation (Gulland, 1979) for exploited fish stocks, MSY = Z*0.5*B. The relative yield per recruit (Y'/R) and biomass per recruit (B'/R) at different levels of F was estimated using LFSA package (Sparre, 1987).

Results

Fishery

The average annual catch of *H. nehereus* for the period 2003 – 2006 was 25,079 t, which contributed to 31.12 % of the total dol net catches at Nawabunder, Rajpara and Jaffrabad. An annual catch of 28,989 t recorded in 2003 was followed by a steep decline to 16,722 t in 2004 and then the catches steadily increased to 24,357 t in 2005 and further to 30,247 t in 2006, which was the highest catch during the entire period. The reduction in effort during 2004 and 2005 is the reason for the decline observed in the landings. The estimated effort decreased from 73.64 thousand units in 2003 to 55.59 thousand units in 2004 and 41.52 thousand units in 2005, before finally increasing to 74.15 thousand units in 2006. The catch rate (CPUE) fluctuated widely over the years with the maximum of 586.68 kg recorded in 2005 and the minimum of 300.82 kg recorded in 2004 (Fig. 1). The average CPUE was 409.64 kg. The percentage contribution of *H. nehereus* to total fish catch by dol nets decreased sharply from 40.04 % in 2003 to 21.42 % in 2006 (Fig. 1).

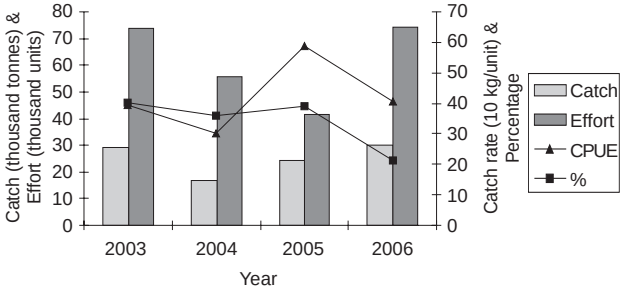


Fig. 1. Annual catch of Bombay duck by dolnetters at Nawabunder, Rajpara and Jaffrabad

Seasonal abundance

The analysis on seasonal abundance of *H. nehereus* revealed the occurrence of two peaks in the average monthly landings. The primary peak in catch was observed in September to January and the secondary peak during May.

The month-wise fluctuation in the effort showed that it was highest during October – January and lowest in February. The CPUE of *H. nehereus* in different months ranged between 152.49 kg in March and 567.9 kg in November with comparatively higher catch rate being observed in May and from September to December (Fig. 2). The average monthwise proportion of *H. nehereus* in the dol net landings was similarly higher in the months of May and from September to February (Fig. 2).

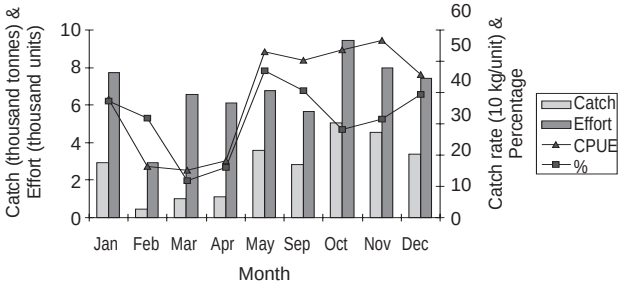


Fig. 2. Seasonal abundance of Bombay duck at Nawabunder, Rajpara and Jaffrabad

Length composition

The mean length of fish witnessed an increasing trend during the four-year study period. Though the mean length of 16.59 cm recorded in 2003 decreased to 15.16 cm in 2004, henceforth it increased steadily to 17.93 cm and 19.92 cm in 2005 and 2006, respectively. The highest mean length was recorded in the months of April – May and September – December and the lowest during January – March.

Length-Weight relationship

Male: log W = -1.97493 + 2.80966 log L (r = 0.90)

Female: log W = -2.0620 + 2.87099 log L (r = 0.90)

Since there was no significant difference between the slopes at 5 % level, a combined relationship of males and females with indeterminates was obtained.

log W = -2.271659 + 3.0243 log L (r = 0.93)

Sex Ratio

Males dominated the commercial catches in the months of January - April while the females outnumbered males in May and September - December. The overall sex ratio was 1:0.99. The chi-square values indicated significant (5 %) dominance by males in the months of February, March and April and by females in the months of November and December.

Size at first maturity and spawning season

H. nehereus attained sexual maturity in the first year at the age of eleven and half months and at the size of 20.2 cm total length (Fig. 3). However, gonadal development and sexual maturity in the species was observed to commence from 17.7 cm onwards.

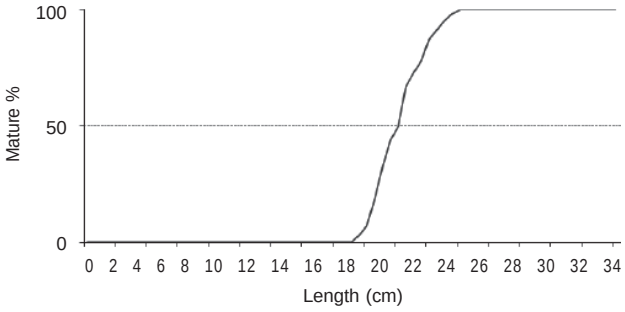


Fig. 3. Size at first maturity of females of *Harpadon nehereus*

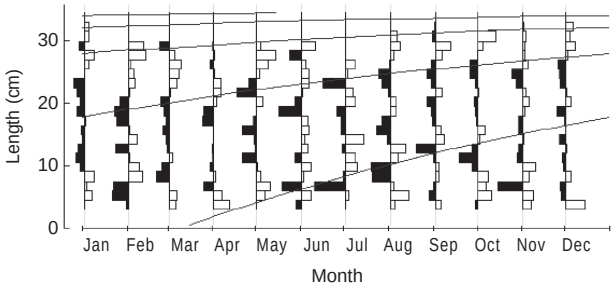
Gravid and ripe females were recorded in all the months except February, with their peak occurrence observed during September – December followed by a secondary minor peak in March – May. This suggests a prolonged spawning season for *H. nehereus*.

Growth

The growth parameters, L_α and K estimated using the ELEFAN I programme were 35.39 cm and 0.86 year^{-1} with Rn value of 0.159. The additional estimates of L_α and Z/K obtained from the Powell – Wetherall plot were 35.54 cm and 3.837, respectively which was slightly higher than the L_α estimated through ELEFAN I. The results of growth parameters obtained by ELEFAN were selected for further application in population studies. The computed growth curve over its restructured length frequency histograms is shown in Fig. 4. The growth performance index Ø was found to be 3.032 and t_0 was calculated at -0.0195 years. The growth can be described by von Bertalanffy growth equation as:

$$L_t = 35.39\ [1 - e^{-0.86\ (t + 0.0195)}]$$

The relationship showed that the fish attained a size of 20.66 cm, 29.16 cm and 32.75 cm, respectively by the



L_α = 35.39 cm, K = 0.86, C = 0, WP = 0 and Rn = 0.159

Fig. 4. Restructured growth curve of *H. nehereus*

end of 1, 2 and 3 years. The longevity of *H. nehereus* was estimated to be 3.5 years. The fishery was dominated by fishes of 0 and 1 year classes. The length at first capture (Lc) was estimated at 3.42 cm, which corresponds to an age (t_c) of 0.099 year. The asymptotic weight (W_α) was estimated as 258.61 g from the length-weight relationship.

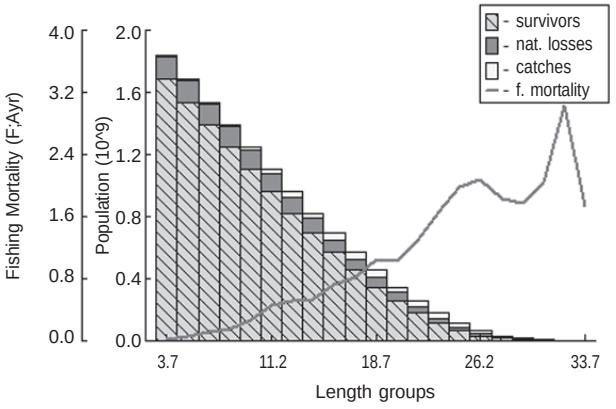
Recruitment pattern

The recruitment pattern demonstrated that *H. nehereus* was recruited in the fishery during most of the months in the year with a peak during February – June. The peak pulse on an average produced 67.5 % of the recruits. The smallest length of recruitment was found to be 3.7 cm.

Mortality, exploitation and Virtual Population Analysis (VPA)

The mortality rates M, F and Z computed were 1.52, 1.73 and 3.25 respectively. The rate of exploitation of *H. nehereus* was 0.512. The exploitation ratio was 0.53, which was higher than the E_{max} of 0.4 obtained from the selection curve, indicating overexploitation of the species.

The VPA (Fig. 5) indicated that up to 8.2 cm size natural mortality was higher than fishing mortality. Fishes became more vulnerable to the gear after this size and from 23.2 cm onwards fishing mortality exceeded natural mortality. The maximum fishing mortality of 3.03 was recorded at size of 32.2 cm.



L_∞ = 35.39 cm, K = 0.86, M = 1.52,

Term. F = 1.73, Mean F = 1.103, Mean E = 0.339

Fig. 5. Length structured VPA for *H. nehereus* for the years 2003 - 2006

Estimation of stock and MSY

The annual total stock, biomass and MSY of *H. nehereus* were estimated at 49,014 t, 14,496 t and 23,557 t respectively.

Yield/recruit

The yield and biomass/recruit and yield and biomass curves showed that the maximum yield and yield/recruit could be obtained by decreasing the present level of fishing by 40 % (Fig. 6 and 7). The maximum yield and yield per recruit that can be obtained at 60 % of the present fishing effort is 27,951 t and 7.317 g, respectively (Fig. 6 and 7). At the present level of fishing, it is 25,079 t and 6.565 g (Fig. 6 and 7). The biomass and biomass per recruit achieved at 60 % of the present effort is 26,928 t and 7.05 g, respectively but with the present rate, the biomass and biomass per recruit is a very lowly 14,496 t and 3.79 g (Fig. 6 and 7). At the reduced effort, the increase in relative yield would be 111.45 %. So to get optimum yield and biomass per recruit, the present fishing effort has to be reduced by 40 %.

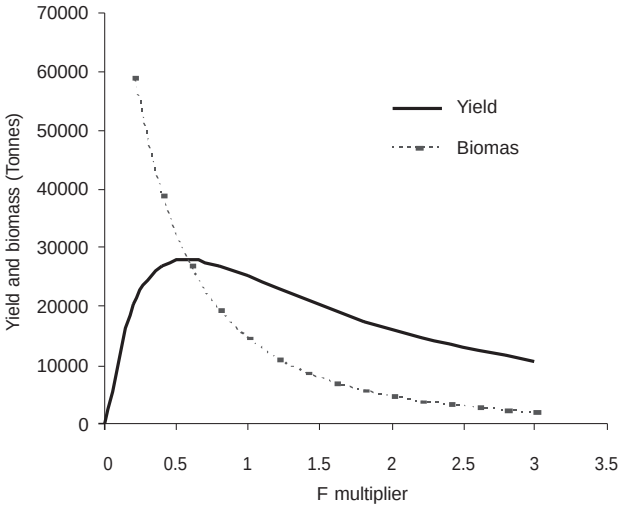


Fig. 6. Yield and biomass of *H. nehereus* for different multiples of F

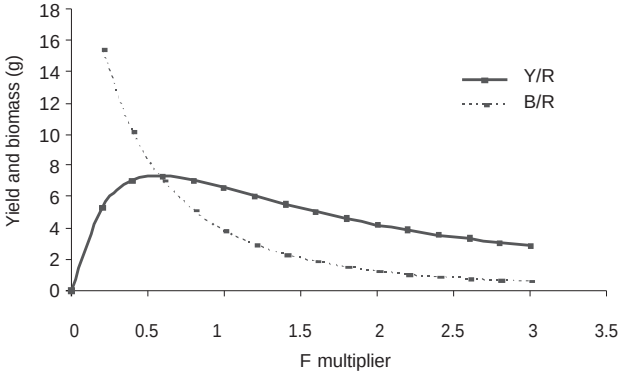


Fig. 7. Yield per recruit and biomass per recruit of *H. nehereus* for different multiples of F

Discussion

The success of *H. nehereus* fishery determines the dol net fishery scenario of the state. The annual and seasonal fluctuations in the catch are an inherent feature of this fishery and are due to several biotic and abiotic factors *viz*., environmental parameters, fishing intensity, fishing techniques, changes in the fishing pattern, fishing ground, food availability, spawning success, etc. The improvement in operating efficiency of dol nets resulted in higher catches during the recent past. The upward trend in catch rate observed in the last two years may be attributed to the extension of fishing activities of dol netters from the over-exploited 20 – 30 m depth to the unexploited 40 - 70 m depth. Zafar Khan (1985; 1989) reported the average catch rate at Nawabunder, Rajpara and Jaffrabad during 1976 – 1982 to vary between 77.5 kg and 114.88 kg, which are much lower as compared to the catch rate recorded in the present study. However, the proportion of Bombay duck in the dol net landings has decreased over the years from 68–81 % recorded in 1976-1982 (Zafar Khan, 1985; 1989) to 40.04 - 21.42 % in the present study period. This is because of the huge landings of non-penaeid prawns, especially *Acetes* sp. by dol nets observed during the present study period. The removal of large quantum of predatory fishes by fishing might have created favourable conditions for the non-penaeid prawns to proliferate.

The seasonal peak of abundance in catch and catch rate during September – January and May and the lowest recorded in February are in full agreement to those reported by earlier workers for Bombay duck landed from Nawabunder, Rajpara and Jaffrabad (Zafar Khan, 1985; 1989). The increased landings in the post-monsoon and winter seasons coincided well with the increased fishing activity during this period. Banerji (1969) stated that the fishery of Bombay duck begins by September along the west coast of India and remains in full swing till the end of January. According to him, the fish move away from the inshore waters by February and reappear in big shoals by next September – October. However in Saurashtra coast, protection is provided to the fishery during June – August when fishing is suspended for the monsoon, which might also have contributed to the usually high catch rates in the post-monsoon season. The increase in mean size of Bombay duck could be correlated with the increase in the depth of operation of the dol netters at Nawabunder, Rajpara and Jaffrabad.

The combined length-weight relationship showed that *H. nehereus* exhibited isometric growth. However, higher b values for the combined population of Bombay duck from Nawabunder, Rajpara and Jaffrabad (3.279) and from the waters of Goa (3.238) were reported by Zafar Khan (1989) and Chatterji *et al*. (1984), respectively. This variation is possibly due to factors related to ecosystem and biological phenomena like maturity stages, feeding behaviour, competition for food, etc.

The differences in the sex ratios observed in different months indicated a differential fishing due to changes in the pattern of migration of sexes to and from the fishing grounds. The length at first maturity observed was 20.2 cm, which was much lower than 26.6 cm and 25 cm reported by Zafar Khan (1986b; 1989). This difference in the size at first maturity is mostly due to the effect of environment on the biology of the fish and their food availability. Zafar Khan (1986b) observed mature females in catch from length of 20.25 cm onwards but in the present study sexual maturity was observed to commence from 17.7 cm. The occurrence of gravid and ripe females in all the months with a peak in September – December indicated that the spawning season was continuous and that the peak spawning was in the post-monsoon period. Bapat *et al*. (1951) and Zafar Khan (1985) reported that Bombay duck breeds throughout the year. The high dominance of males in the catches after the post-monsoon period (January to April) suggested the possibility of post-spawning mortality in females.

The present estimate of L_{α} (35.39 cm) is lower than 36.7 cm and 42.52 cm reported by Zafar Khan (1985; 1989) from Nawabunder, Rajpara and Jaffrabad and 48.8 cm reported by Fernandez and Devaraj (1996) from Bombay. The growth coefficient of 0.86 per year recorded in the present study was higher than 0.7618 and 0.29 – 0.77 reported by Zafar Khan (1989) and Fernandez and Devaraj (1996), respectively. These differences in the L_{α} and K values are because of the differences in the environmental parameters, availability and competition for food and exploitation, predation, the type of fishing gears used and methodology adopted for the study of growth parameters. However, the value of t_0 in the present study conforms fully to that reported by the above workers. The growth rate in length recorded at the end of each year for three years was higher compared to the observations of Krishnayya (1968), Bapat (1970) and Zafar Khan (1985) but lower than that reported by Zafar Khan (1989). The results showed that the maximum growth rate in length was observed during the 1st year of life but after which the annual increment decreased with increasing age. The longevity recorded in the present study was lower when compared to 3.918 years and 3.93 years recorded by Zafar Khan (1986b; 1989). The length at first capture of 3 cm was similar to that reported by Fernandez and Devaraj (1996) but lower than 5.25 cm reported by Zafar Khan (1986b). The length at first capture was very low when compared to the size at first maturity indicating that majority of them were caught before they matured and spawned at least once in their life. This

indicated stress on spawning stock and could be addressed by enhancing their size and age at exploitation, which meant that increase in mesh size of gears is required to avoid the young fishes. The continuous recruitment of *H. nehereus* throughout the year with a peak during February – June was in full conformity to earlier published reports by several authors (Bapat *et al*., 1951; Zafar Khan, 1985; Fernandez and Devaraj, 1996). The length at recruitment of 3.7 cm was however higher when compared to 2.2 cm and 2 cm reported by Zafar Khan (1989) and Fernandez and Devaraj (1996), respectively.

Beverton and Holt (1956) pointed out that the natural mortality coefficient of a fish is directly related to the growth coefficient (K) and inversely related to the asymptotic length (L_α) and the life span. In other words, fishes with higher growth rate coefficient have higher natural mortality and shorter lifespan, hence smaller L_α and those with longer lifespan have lower natural mortality coefficient and growth coefficient. The same appeared to be true for *H. nehereus* which had higher growth coefficient of 0.86 per year and shorter lifespan of 3.5 years was found to have relatively higher natural mortality coefficient of 1.52 per year. Various authors have reported natural mortality as 1.462 (Zafar Khan, 1986b), 1.572 (Zafar Khan, 1989), 0.8 (Kurian, 1989) and 1.1 (Fernandez and Devaraj, 1996) for *H. nehereus*. The M/K ratio obtained in the present study was well within the normal range of 1 – 2.5, as suggested by Beverton and Holt (1959). The fishing mortality (1.73) and total mortality (3.25) of *H. nehereus* recorded was higher than that reported by Zafar Khan (1986b; 1989); Kurian (1989) and Fernandez and Devaraj (1996) and was an indication of intensive fishing of this species which was also revealed by a high exploitation ratio (0.53). Similar ratio of exploitation was reported by Kurian (1989) for Bombay duck caught off the coast of Maharashtra. However, Zafar Khan (1986b; 1989) reported much lower ratios of exploitation (0.454 and 0.435) for the species from the same fishing grounds of Nawabunder, Rajpara and Jaffrabad. It is evident from the results that since the value of E were higher than the E_{max} and MSY lower than the annual catch, the stock is under higher fishing pressure than the sustainable level warranting immediate reduction in fishing effort.

The yield per recruit of 6.565 g obtained in the present study for *H. nehereus* was far lower than 10.819 g reported by Zafar Khan (1989). The yield and biomass/recruit and yield and biomass curves depicted that the stock was subjected to overfishing by 60 % with respect to its optimum fishing effort. Hence to get maximum yield and biomass, the fishing pressure has to be decreased by 40 % from the present condition. It is, therefore suggested that measures be taken for their judicious exploitation on a sustainable basis by reducing the fishing pressure so as to bring the catch to the MSY levels. The reduction in effort and increase in mesh size are therefore suggested as regulations to improve the status of the resource. This will slowly aid in replenishing the fishery to a healthy and sustainable level.

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