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Dynamics of the Bombay duck (*Harpodon nehereus*) stock along the northwest coast of India

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ABSTRACT

The fishery for the Bombay duck, (*Harpodon nehereus*) along the northwest coast of India was studied from the data for the annual catch, effort and length-at-age composition for the period 1947 to 1986. Three models, viz., the Beverton and Holt analytical model, Cushing's stock-recruitment relation, the surplus production models of Schaefer and of Fox and the prediction model of Roff were applied to describe the state of the stock. The length growth parameters; L_c ranged from 37.45 cm (1985) to 60.97 cm (1958), annual k ranged from 0.29 (1958) t_0 0.77 (1948) and t_0 ranged from –0.12 year (1948) to 0.06 year (1985), while the weight growth parameters; W_c ranged from 319.14 g (1948) to 1,910.65 g (1950-'51), annual k ranged from 0.26 (1984 and 1985) to 0.85 (1948) and t_0 ranged from –0.08 year (1948) to 0.03 (1950-'51). The length at first capture, l_c, was 3.00 cm (t_c = 0.13 year) while the length at recruitment, l_r, was 2.00 cm (t_r = 0.08 year). Total annual mortality, Z, ranged from 2.32 (1985) to 8.29 (1948), natural mortality, M, ranged from 0.93 (1950-'51) to 1.20 (1948-'49) while fishing mortality, F, ranged from 1.32 (1985) to 2.70(1983). Cohort analysis indicated maximum F at 4+age group in 1983 (=2.70) and at 3+ age group in 1984 (=1.77). The stock-recruitment data indicated a linear relation with density dependence (b) ranging from 0.32 to 1.03 with an average of 0.68. The MSY estimated according to the analytical model was found to be 189,844 t which according to the Schaefer and Fox models was 101,158 t and 103,483 t respectively. The prediction model indicated an estimated catch of 92,189 t in the year 2000 if the effort remained a constant.

Introduction

Harpodon nehereus, commonly known as the Bombay duck is one of the most important commercial species landed along the northwest coast of India comprising the states of Gujarat and Maharashtra, particularly between the latitudes of Alibag (18° 38'N) in Maharashtra and Porbander (21° 68'N) in Gujarat, a distance of about 500 km.

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Earlier studies on *Harpodon nehereus* have dealt with certain aspects of biology, ecology, ecotypic variations and stock estimation (Bapat *et al.*, 1951; Bapat, 1970; Bapat and Alawani, 1973; Deshmukh and Kurien, 1980; Savania, 1984; Khan, 1985; Batcha, 1986). The present study deals with the dynamics of the Bombay duck stock along the northwest coast of India for the 1947 to 1986 period on the basis of the analytical model of Beverton and Holt (1957), the stock-recruitment relation of Cushing (1971), the surplus production models of Schaefer (1954) and Fox (1970) and the prediction model of Roff (1983).

Materials and methods

Length frequency of 6,562 Bombay duck for the periods 1947-'51, 1958-'59 and 1983-'86 formed the basic material for the determination of age, growth, mortality and gear selection. Out of these 3,660 for 1983-'86 were sampled from the 3 major landing centres at the Sassoon Docks, the New Ferry Wharf and the Versova village and from the catches of the marine fishing vessels 'Saraswathi' and 'Narmada' of the Central Institute of Fisheries Education, Bombay. The data for the earlier periods were taken from the contributions of Bapat (1970). The catch and effort data were compiled from the various reports and publications of the Central Marine Fisheries Research Institute, Cochin.

The parameters of Beverton and Holt (1957) analytical model were estimated from the length frequency data. The modes in the length frequency data for successive months, as resolved by the Bhattacharya (1967) plot were plotted in the form of a scatter diagram, and their progression traced by eye-fitted lines, thereby, to determine the length-at-age in months for the successive broods. Recruitment pattern was fitted according to Pauly (1982). The methods of Bagenal (1955), Gulland and Holt (1959) and Sparre (1985) were employed for the estimation of L_c, k and t_o of the von Bertalanffy Growth Function. The constants in the length in cm (L) - weight in g (W) relation were used for the conversion of length-at-age to weight -at-age. The total mortality coefficient (Z) was calculated from the age composition data to Jackson (1939) and Ricker (1958) and from the growth parameters and mean length statistics according to Beverton and Holt (1956). Estimates of natural mortality coefficient (M) were made according to Pauly (1984), Cushing (1968), Caddy and Csirke (1983) and from the M/k ratio. F for various age groups was calculated using Pope's (1972) age cohort analysis. From length at first capture (l_c) and the length at recruitment (l_r), determined arbitrarily from the annual length frequency histograms, the age at first capture (t_c) and the age at recruitment (t_r) were calculated using the age-length key. The annual fishing mortality (F) for 1956 to 1984 was calculated using the following equation,

$$F = qf$$

where q is the catchability (or availability) coefficient for the period 1983-'84 and f, the annual fishing effort in man hours for 1956-'84. In this method, the q for 1983-'84 is assumed to be constant and valid for the 1956-'84 period. The yield in weight per recruit (Y_w/R), yield in number per recruit (Y_n/R), biomass in weight per recruit (P_w/R), biomass in number per recruit (P_n/R) and the total number of fish in the population (P_n) were estimated for each year from 1956-'84 for the respective values of M, F, t_r and t_c.

Stock in number (P_n), recruits (R_c) (the two basic inputs to determine the stock-recruitment relationship) and the stock in weight were estimated from the values of the annual yield (Y), yield per recruit, biomass per recruit, f and E. Stock-recruitment relationship was fitted by the model given by Cushing (1971). The maximum sustainable yield (MSY) and the biologically optimum level of effort (f_{msy}) were estimated using the surplus production models of Schaefer (1954) and Fox (1970). The state of the future stock was predicted using Roff's (1983) simple auto-regressive model.

Results and discussion

Age and growth

The modal components identified by subjecting the length frequency data (by months) to the Bhattacharya's (1967) plot, were traced for their progression through successive months following Devaraj (1983) (Fig.1). The modal progression revealed that each year class was comprised of 6 to 7 broods, released mainly in the months of January, February, April, June, August and October. The growth pattern was found to be the same for the 3 periods of the study: 1947-'51, 1958-'59 and 1983-'86 (Fig.1). The recruitment pattern was more or less continuous with irregular peaks from January to November (Fig. 2). The Gulland and Holt (1959) plot values of L_c ranged from 37.45 cm in 1985 to 60.97 cm in 1958 and the annual k from 0.29 in 1958 to 0.77 in 1948, while the Sparre (1985) method yielded values of t_0 ranging from –0.12 in 1948 to 0.06 year in 1985. Bagenal's (1955) least square method was applied for the estimation of the length growth characteristics for 1986 as the age-length data was not amenable to the Gulland and Holt (1959) plot. The disparity in the values of L_c could primarily be due to the scarcity of data for 1958 and 1985 or even due to subtle variations in growth between a span of about 25 and 30 years. However, it should be noted that the values of 37.5 cm (1985) and 61.0 cm (1958) are not very widely apart when seen in comparison with the rest of the values. Values of W_c ranged from 319.14 g in 1948 to 1,910.65 g in 1950-'51, annual k from 0.26 in 1984 and 1985 to 0.85 in 1948 and t_0 from –0.08 year in 1948 to 0.03 year in 1950-'51 (Table 1). The 1948 value (319.14 g) is comparatively the lowest compared to the rest of the W_c values, the reason primarily being the scarcity of data for this period.

The length at first capture, l_c, and the corresponding t_c were found to be 3.00 cm and 0.13 year respectively, while the length at recruitment, l_r, and the corresponding t_r were found to be 2.00 cm and 0.08 year respectively.

Mortality estimates

Jackson's (1939) method applied to the age composition data in half year groups (Table 2) yielded annual Z ranging from 2.32 in 1985 to 8.29 in 1948 while Ricker's (1958) method yielded Z ranging from 0.61 in 1986 to 1.85 in 1948. The Beverton and Holt (1956) method yielded unrealistically low estimates of Z. Among these 3 different estimates, those according to Jackson (1939) seem realistic enough as compared to Ricker (1958) and Beverton and Holt (1956). Ricker's (1958) estimates seem rather too low to be true for the highly exploited Bombay duck stock. The mean overexploitation by 17.6%

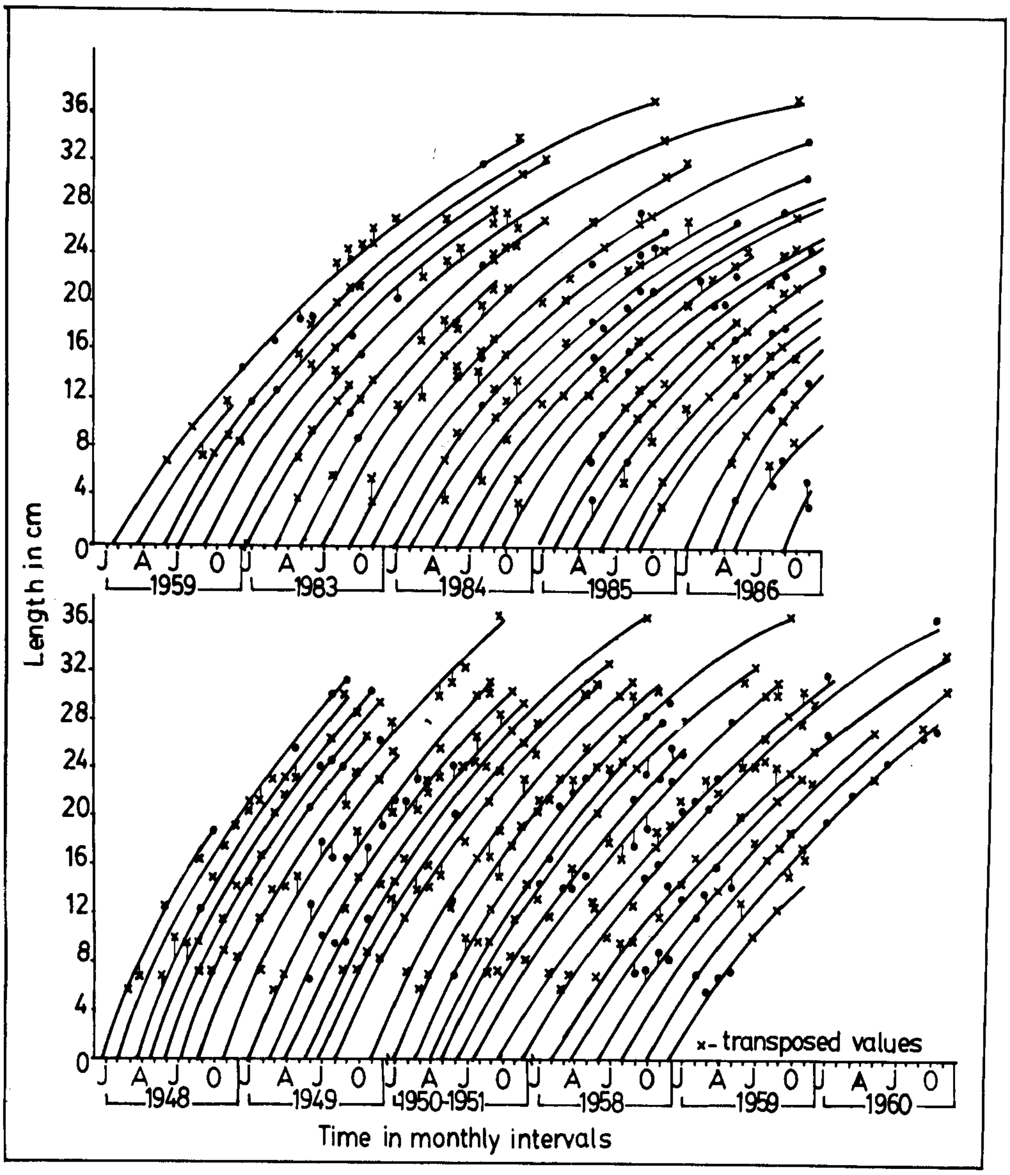

Fig. 1. Modal progression analysis.

(Table 3) would suggest higher values of Z as obtained from the Jackson (1939) method.

The annual catch (Y) and Z data were not amenable to the Caddy and Csirke (1983) model for the estimation of M. Independent estimate of annual M by Pauly's (1984) equation ranged narrowly from 0.93 for 1950-'51 to 1.20 for 1948-'49. The M/k ratio based estimate ranged from 0.68 (for 1950-'51 and 1983-'86) to 0.99 (for 1948) when the M/k ratio was taken as 1.5; 0.91 (for 1950-'51) to 1.32 (for 1948-'49) when the M/k ratio was 2.00; and 1.14 (for 1948-'49).

TABLE 1. *Estimates of population parameters*

Period	Length growth parameters			Weight growth parameters			Mortality estimates		
	L_∞ (cm)	k (yr)	t_0 (yr)	W_∞ (g)	k (yr)	t_0 (yr)	Z	M	F (Z-M)
1948	44.0	0.8	–0.1	319.1	0.9	–0.1	8.3	1.2	7.1
1949	48.6	0.6	–0.1	1542.8	0.4	0.01	2.8	1.2	1.6
1950–'51	48.4	0.5	–0.1	1910.7	0.3	0.03	5.5	0.9	4.6
1958	61.0	0.3	–0.1	—	—	—	3.2	1.1	2.1
1959	42.8	0.5	–0.01	745.1	0.4	–0.1	2.8	1.1	1.7
1983	41.7	0.5	–0.1	826.8	0.4	0.02	3.7	1.0	2.7
1984	41.6	0.5	–0.01	1034.0	0.3	–0.02	2.8	1.0	1.8
1985	37.5	0.6	0.1	1360.4	0.3	–0.02	2.3	1.0	1.3
1986	56.2	0.4	–0.02	826.8	0.4	0.02	2.1	1.0	1.1

M based on Cushing's (1968) method was found to be 4.61 for 1948-'49 and 1.54 for 1983-'86. The estimates from Pauly's (1984) method agree very well with those based on M/k ratios (when the ratios were maintained at 1.50 and 2.00). The M values from the former method were used for fitting the analytical model in this study because of their compatibility within the M values for 1.5 and 2.0 M/k ratios in respect of predators facing least competition from other predators in the ecosystem.

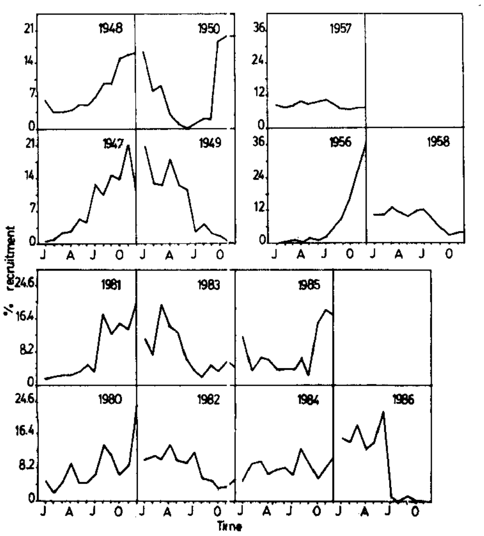

Fig. 2. Recruitment pattern.

The fishing mortality using equation 1 ranged from 0.76 in 1965 to 2.70 in 1983.

Cohort analysis

From cohort analysis of Pope (1972), F was found to be maximum at 4+ age in 1983 (=2.70) and 1985 (=1.32) and 3+ age in 1984 (=1.77). The analysis was carried out with M = 1.04 for 1983 and 1.00 for 1984 and 1985. Numbers (N_t) attaining 0+ age (0 to 5 months) ranged from 57.2x10^9 in 1983 to 188x10^9 in 1985; 1/2+ age (6 to 11 months) from 20x10^9 in 1983 to 68.7 x 10^9 in 1985; 1+ age (12 to 17 months) from 6.81x10^9 to 24.8x10^9 in 1985; 1 1/2+ age (18 to 23 months) from 2.09x10^9 in 1983 to 8.57 x 10^9 in 1985; 2+ age (24 to 29 months) from 0.41 x 10^9 in 1983 to 2.75 x 10^9 in

TABLE 2. *Age composition data classified half yearly in percentage*

Period	Age composition								
	0+ (0-5 mts)	1/2+ (6-11 mts)	1+ (12-17 mts)	1 1/2+ (18-23 mts)	2+ (24-29 mts)	2 1/2+ (30-35 mts)	3+ (36-41 mts)	3 1/2+ (42-47 mts)	4+ (48-53 mts)
1948	5.1	45.6	48.5	0.8	—	—	—	—	—
1949	30.3	27.1	32.3	9.8	0.4	—	—	—	—
1950-'51	17.8	15.8	62.5	4.0	—	—	—	—	—
1958	11.7	40.7	38.1	8.7	0.9	—	—	—	—
1959	17.2	37.9	33.9	10.0	1.0	—	—	—	—
1983	9.7	23.0	31.4	30.4	4.4	1.0	0.2	0.05	0.05
1984	0.8	7.4	38.5	40.1	8.8	2.2	2.2	—	—
1985	13.8	22.9	29.5	22.9	8.1	2.0	0.3	—	0.7
1986	17.1	53.4	18.4	9.2	1.0	0.7	—	0.2	—

1985; 2 1/2+ age (30 to 35 months) from 0.09×10^9 in 1983 to 0.87×10^9 in 1985; 3+ age (36 to 41 months) from 0.02×10^9 in 1983 to 0.28×10^9 in 1985; 3 1/2+ age (42 to 47 months) from 0.01×10^9 in 1983 to 0.10×10^9 in 1985; and, 4+ age (48 to 52 months) from 0.001×10^9 in 1983 to 0.04×10^9 in 1985.

Analytical model

M did not show much variation, but was also not a constant for the 3 periods of study while F did show slight variations ranging from 0.76 in 1965 to 2.70 in 1983. Since the M and F values were available for individual years, the dynamics of the Bombay duck stock on a constant value of M, as normally used in the Beverton and Holt model was not employed, instead was worked out for individual years (Table 3). The exploitation ratio (E = F/Z) based on F defined from equation 1 for the 1956-'83 period ranged from 0.42 for 1965 to 0.73 in 1983 while the exploitation ratio at the maximum sustainable yield per recruit (E_{msy}) remained constant at 0.40. A comparison of E with E_{msy} suggested over exploitation in all the years since 1956 by 2 to 33%, but there was no signs of depletion of the stock. The yield in weight per recruit (Y_w/R) ranged from 1.66 g in 1983 to 8.20 g in 1965 with the mean value at 5.95 g, the yield in number per recruit (Y_n/R) ranged from 0.41 in 1965 to 0.72 in 1983 with the mean at 0.57, the MSY per recruit ranged from 6.13 g in 1984 to 12.42 g in 1960-'82 with a mean of 11.88 g, while the absolute MSY ranged from 64.2×10^3 t. in 1959 to 351×10^3 t in 1983 with the mean at 189.84×10^3 t. The population weight (biomass) per recruit (P_w/R) ranged from 0.53 g in 1984 to 10.80 g in 1965 with the mean at 4.61 g while the population number per recruit (P_n/R) ranged from 0.27 in 1983 to 0.55 in 1965 with a mean value of 0.40 (Table 3). The mean Y_w/R for 1956-'83 (5.95 g) in relation to the MSY/R (11.88 g) indicates an over exploitation by 17.62% over and above the E_{msy} of 40% (Fig. 3). By reducing the mean annual f = $53{,}942 \times 10^3$ man hours and F = 1.62 (total inshore effort) and E = 0.58 for 1956-'84 by 7.93% to reduce f to

TABLE 3. *Yield and stock estimates*

Period	Y (tons)	F	M	Z	E	L_∞ (cm)	Over-exploit.	Y_w/R (g)	MSY/R (g)	R_c ($\$10^6$) (nos)	P_n ($\$10^6$) (nos)	B (=Y/F) (tons)	P (=Y/E) (tons)	Y_n ($\$10^6$) (nos)	MSY (tons)	P_{msy} (MSY/E_{msy}) (tons)
1956	125,298	2.0	1.1	3.1	0.7	48.4	25	5.5	11.0	23,730	7,244	62,499	192,766	14,522	249,180	622,950
1957	117,459	2.3	1.1	3.4	0.7	48.4	28	4.8	11.0	24,368	7,089	51,049	172,734	16,310	267,135	667,838
1958	66,721	2.1	1.1	3.2	0.7	61.0	26	4.6	12.1	14,600	4,380	31,924	101,092	9,053	177,241	443,103
1959	56,554	1.7	1.1	2.8	0.6	42.8	21	6.6	12.7	8,566	3,049	33,649	92,711	5,124	108,366	270,913
1960	107,721	1.2	1.1	2.3	0.5	49.2	14	6.8	12.4	15,844	6,908	88,484	199,483	8,410	196,757	491,892
1961	93,127	1.3	1.1	2.3	0.6	49.2	15	6.6	12.4	14,110	6,026	73,659	169,322	7,619	175,219	438,047
1962	83,289	1.2	1.1	2.2	0.5	49.2	13	6.9	12.4	12,099	5,418	71,975	157,149	6,270	150,625	378,562
1963	90,213	1.2	1.1	2.3	0.5	49.2	14	6.7	12.4	13,472	5,852	73,528	167,061	7,174	167,300	418,250
1964	77,639	1.1	1.1	2.1	0.5	49.2	11	7.3	12.4	10,715	4,960	71,543	152,233	5,384	133,055	332,637
1965	73,232	1.0	1.1	1.9	0.4	49.2	2	8.2	12.4	8,931	4,882	96,498	174,362	3,705	110,104	227,260
1966	76,633	1.0	1.1	1.9	0.4	49.2	4	8.1	12.4	9,412	4,983	93,695	174,166	4,075	116,896	292,189
1967	72,929	1.2	1.1	2.3	0.5	49.2	13	6.7	12.4	10,909	4,800	60,921	137,602	5,746	135,467	338,668
1968	79,380	1.1	1.1	2.2	0.5	49.2	12	7.0	12.4	11,190	5,089	70,642	152,654	5,718	138,957	347,393
1969	74,655	1.1	1.1	2.1	0.5	49.2	10	7.5	12.4	10,083	4,703	69,778	149,310	5,033	125,218	313,044
1970	77,348	0.9	1.1	2.0	0.5	49.2	7	7.7	12.4	10,038	5,004	82,867	164,570	4,671	124,652	311,629
1971	69,673	1.3	1.1	2.4	0.6	49.2	16	6.3	12.4	11,096	4,616	52,536	124,416	6,122	137,989	344,473
1972	50,257	1.2	1.1	2.2	0.5	49.2	13	6.9	12.4	7,266	3,247	43,224	94,825	3,774	90,232	225,579
1973	61,843	1.3	1.1	2.3	0.6	49.2	15	6.5	12.4	9,450	4,055	49,332	112,442	5,083	117,352	293,379
1974	59,664	1.4	1.1	2.4	0.6	49.2	17	6.4	12.4	9,319	3,779	42,992	104,674	5,245	115,724	289,311
1975	96,199	1.6	1.1	2.6	0.6	49.2	20	5.5	12.4	17,408	6,568	61,289	160,332	10,309	216,176	540,439
1976	84,468	1.5	1.1	2.6	0.6	49.2	19	5.9	12.4	14,406	5,565	55,969	143,166	8,398	178,904	447,260
1977	83,092	1.8	1.1	2.9	0.6	49.2	24	4.9	12.4	16,896	5,775	45,127	129,831	10,634	209,814	524,535
1978	122,651	1.7	1.1	2.7	0.6	49.2	22	5.3	12.4	23,187	8,408	73,190	197,824	14,088	287,936	719,839
1979	123,651	1.9	1.1	2.9	0.6	49.2	24	4.7	12.4	26,145	8,894	66,655	193,205	16,497	324,667	811,666
1980	94,064	1.4	1.1	2.5	0.6	49.2	18	6.0	12.4	15,797	6,263	65,204	162,179	9,036	196,167	490,417
1981	136,250	2.2	1.1	3.2	0.7	49.2	27	4.0	12.4	34,467	10,574	62,765	203,358	21,231	428,010	10,70,024
1982	87,270	1.9	1.1	2.9	0.6	49.2	24	4.9	12.4	17,648	6,011	47,137	136,359	11,131	216,161	540,402
1983	94,964	2.7	1.0	3.7	0.7	41.7	33	1.7	6.1	57,363	15,327	35,203	130,088	41,347	351,209	878,023
1981	114,254	1.8	1.0	2.8	0.6	41.5	24	2.7	6.1	42,173	15,060	64,700	178,522	26,594	258,392	645,979
Mean	87,948.2	1.5	1.1	2.6	0.6	48.8	17.6	6.0	11.9	17,265	6,363	62,001	152,705	10,286	189,844	592,217

t_c=0.13yr; l_c =3.00cm; E_{msy}=0.40.

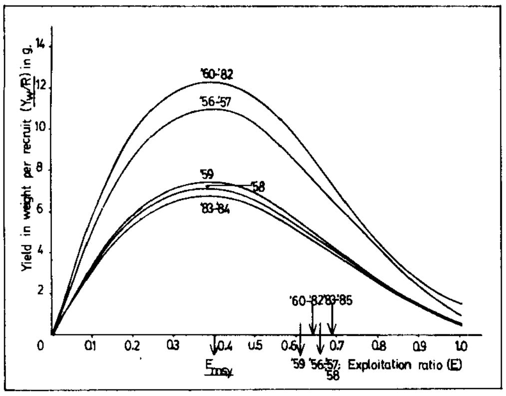

Fig. 3. Yield curves.

49,666.7 x 10^9 man hours, F to 1.49 and E to 0.40, the average annual yield of 87,948.2 t (1956- '84) could be increased to the MSY of 189,844.17 t. Since *dol* netting is the major means of exploiting the Bombay duck fishery, the existing fleet of 2,428 (2,102 in Maharashtra and 326 in Gujarat) *dol* netters could be reduced by 17.59% to the optimum of 2,001 (1,732 in Maharashtra and 268 in Gujarat) *dol* netters to help maximise the yield of Bombay duck at the MSY of 189,844.17 t.

The standing stock ($\bar{B}$=Y/F) ranged from 31.91 x 10^3 in 1958 to 96.5 x 10^3 t in 1965 with the mean at 62.001.14 t while the total stock (P=Y/E) ranged from 92.7 x 10^3 t in 1959 to 203.36 x 10^3 t in 1981 with the mean at 152,704.73 t. The stock in number (P_n) ranged from 3.05 x 10^9 in 1959 to 15.33 x 10^9 in 1983 with a mean value of 6.36 x 10^9 while the recruits (R_c) ranged from 7.27 x 10^9 in 1972 to 57.36 x 10^9 in 1983 with a mean value of 17.26 x 10^9.

Stock recruitment relation

The stock recruitment data indicated a linear relation to which Cushing's (1971) stock recruitment equation was fitted (Fig. 4). The index of density dependence (b) ranged from 0.32 to 1.03 with an average of 0.68. The index corresponds to the rate of recruitment dependence on the parent stock. The index is rather high when compared to the low fecundity ranging from 14,600 to 146,400 eggs per batch per mature fish. Considering the 6 broods per year class to represent the products of 6 successive spawnings per year, the annual fecundity per fish was estimated

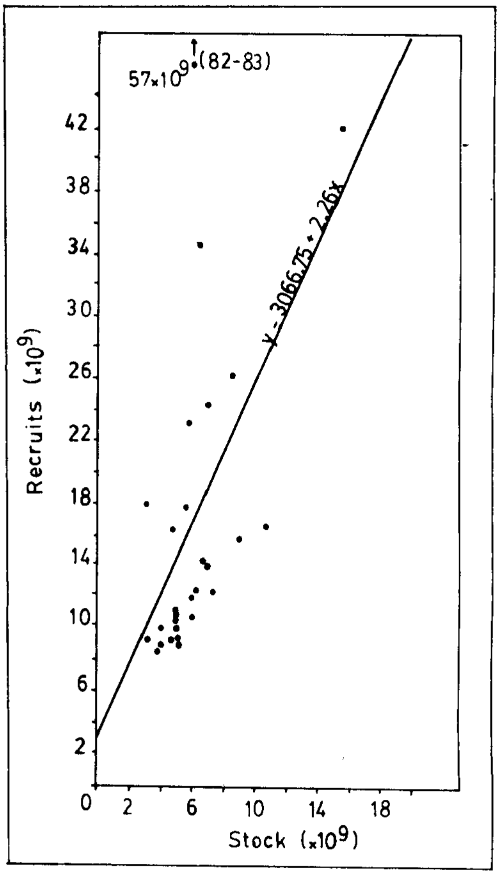

Fig. 4. Stock recruitment relation.

to be 89,600 to 878,400 eggs. The effect of the density of parental stock on recruitment is usually exerted through the density of the larvae and their survival as recruits face density dependent competition from the parent stock for food and space as well as compensatory predation (Ricker, 1975). Cannibalism among Bombay duck seemed to maintain the recruits always at a level that was directly proportional to the parent stock. Protracted spawning resulting in continuous recruitment and 6 to 7 successive broods per year class should be viewed as a means of offsetting the loss due to cannibalism. Thus, the effects of protracted spawning on continuous recruitment were so balanced by cannibalism that recruitment became directly dependent on the parent stock.

Surplus production models

Schaefer (1954) and Fox (1970) models indicated the MSY to be 101,158 and 103,483 t respectively for the total inshore effort (f_{msy}) of 76.03 x 10^6 man hours and 98.05 x 10^6 man hours respectively (Fig. 5). Thus, the MSY estimated by the analytical model (189,844.17 t) was significantly higher than that by the surplus production models.

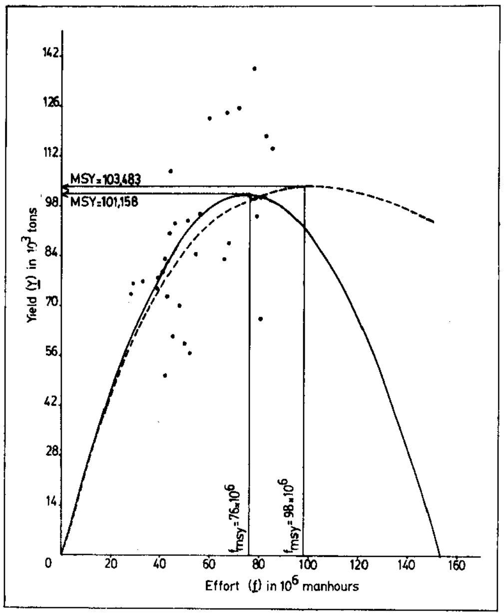

Fig. 5. Surplus production models (—Schaefer; — Fox).

The plot of catch (C(T)) against E(T)C(T-1)/E(T-1) for Roff's (1983) simple autoregressive model is fitted by,

y=48,533.39 - 0.43x

This relation was used to predict catches for the coming years. Assuming effort to be constant for the periods 1989 to 2000, the catch in the year 2000 is estimated to be 92,189 t (Fig. 6).

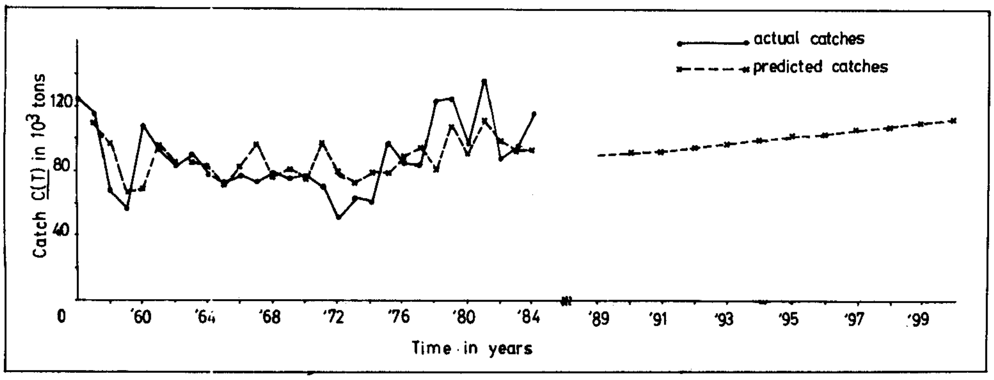

Fig. 6. Simple autoregressive model.

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