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APPLICATION OF SYNTHETIC MODELS FOR THE ASSESSMENT OF BOMBAY DUCK, *HARPODON NEHEREUS* (HAM.) STOCK OFF THE MAHARASHTRA COAST

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ABSTRACT

For the formulation of a conceptual basis for future decision process and to evaluate the relation between catch and effort for the Bombay duck stock off the Maharashtra coast linear, exponential, hyperbolic and power forms are considered. The hyperbolic form fitted well to the data indicating that the relation between catch and effort will be asymptotic within the normal range of effort. The significance of the asymptotic yield model is discussed in relation to dynamic pool model. The conclusions emerging from this study are that chances of biological and economical overfishing are rather remote for the Bombay duck stock off the Maharashtra coast.

INTRODUCTION

Stock assessment is defined as "any scientific study to determine the productivity of a fishery resource and the impact (on the resource and the fishery) of changing patterns of fishing" (Gulland, 1983). The primary objective of fisheries management is to maintian a balance between under utilization and overexploitation of the resource leading to sustained yields and economic catch rates. Stock assessment is basic to all programmes envisaged for attainment of such a balance.

The existing stock assessment methods are based on theories originally developed by Baranov (1918) and Russell (1931) which were translated into workable methods by Thompson and Bell (1934), Graham (1935), Beverton and Holt (1957), Schaefer (1954 a, 1954 b and 1957) and Ricker (1954, 1958) resulting in three conceptual approaches. They were: (1) stock production theory; (2) yield pre-recruit model and (3) the stock recruitment approach. The simplest of the three, the stock production theory, led to the formulation of synthetic models, otherwise known as surplus proudction models or global models. Synthetic models consider the relationship between total catch, total effort and catch per unit of effort. These models assume that surpluses are produced as a function of stock size, and maximum surplus may occur at some stock size depending on the type of relationship considered. If the fishery removes this surplus alone, then the yield can be maintained indefinitely at a sustainable level.

HISTORY OF THE FISHERY

The history of the Bombay duck fishery in Maharashtra indicates two phases of exploitation: first, between 1958 and 1974 with an average annual yield of 28,493 tonnes and the second, between 1975 and 1984 with an average annual catch of 56,854 tonnes. Based on the data for the sixties and the early seventies, fears of a possible collapse of the fishery were expressed by Banerji (1969),

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Nair (1970) and Prasad (1971). Bapat and Alawani (1973) strongly suggested the possibility of imminent overfishing in Maharashtra based on the reduction inthe average size of the Bombay duck. The maximum potential yield from Maharashtra was estimated to be 33,600 tonnes (Banerji, 1973). Interestingly, during the second phase, the actual yield has considerably exceeded the estimated potential yield.

The State of Maharashtra contributes between forty five and fifty per cent of the all India Bombay duck catches. Fishing for Bombay duck is carried out by the 'dol' net which is a highly specilalized gear, both in construction and operation. It is a stationary bag net worked entirely by the force of the tide. Among the five maritime districts of Maharashtra, the 'dol' is the most prominent gear in the district of Thane, contributing nearly eighty five per cent to the total Bombay duck production in the state. Arnala is an important centre for the Bombay duck fishery in the district of Thane.

Background Information

From biweekly observations at Arnala, information on the total catch, effort in hauls and the size and age structure of the exploited Bomaby duck stock were collected from 1974 to 1985. Annual estimates of catch, effort and catch per unit of effort were made by well established methods. Growth in length was assumed to follow von Bertalanffy's growth formula. The mean total instantaneous mortality ($\underline{Z}$) estimated by various methods gave the value of 1.70 with 0.8 as the natural mortality coefficient ($\underline{M}$) and 0.9 as the fishing mortality coefficient ($\underline{F}$) on an annual basis.

A fish stock is said to be optimally exploited when $\underline{F}$ = M or exploitation rate, $\underline{E} = \underline{F}/\underline{Z}$, is 0.5. When $\underline{E}$ is greater than 0.5, the stock is considered to be rather extensively exploited (Gulland, 1971). The Bombay duck stock is near optimally exploited as evident from $\underline{E}$ = 0.52. The fishery should, therefore, be managed at its current level of optimum exploitation so as to sustain it in perpetuity.

The Data Base

From the catch-per-unit of effort estimated for Arnala, the total effort involved in the Bombay duck fishery was estimated by dividing the annual estimated catch for the state by the catch-per-unit of effort for Arnala. This has resulted in time series data for catch, effort and catch-per-unit of effort for Maharashtra from 1974 to 1984 (Table 1). Since meristic studies by Bapat (1970) and electophoretic and biochemical studies on the enzymes and proteins (Kurian, 1986) conclusively proved that the Bombay duck fishery in Maharashtra was supported by a single stock, the application of parameters estimated for Arnala were considered to be valid for the entire state.

TABLE 1. *Estimated catch, effort and catch per unit of effort for the Bombay duck*

Year	Estimated catch (Y) for Maharashtra (t)	Catch per unit effort (YF) (kg)	Estimated effort (f) Maharashtra (Hauls)
1974	29,989	93.39	3,21,150
1975	51,645	47.14	10,95,566
1976	49,470	50.24	9,84,674
1977	50,803	34.05	14,92,012
1978	68,781	30.43	2,26,032
1979	59,667	17.73	33,65,313
1980	57,393	32.47	17,67,570
1981	82,136	94.54	8,68,796
1982	45,162	17.51	25,79,212
1983	45,113	25.36	17,18,904
1984	58,367	119.45	4,88,631

Methods

The scheme of study was based on the response of catch-per-unit of effort to the fishery. In an attempt to explain the reaction of the stock to fishing, synthetic models were applied and the data in Table 1, was analysed assuming four forms of simple relationships between catch-per-unit of effort (Y_f) and effort (f). It may be pertinent to mention that the forms of relationships applied are similar to the generalized stock production model of Pella and Tomlinson (1969) with M taking the values : 2, 1 and 0. This has been discussed in detail by Fox (1974 , 1975).

The first form considered the relation between catch-per-unit of effort (Y_f) and effort (f) as linear, popularly known as the Schaefer model,

$$Y_f = a - bf \qquad \text{.................. (1)}$$

The second form was analogus to the Gulland - Fox exponential model (Gulland, 1961 ; Fox, 1970),

$$Y_f = a \exp. (-bf) \qquad \text{.................. (2)}$$

An hyperbolic relation was considered with the following expression,

$$Y_f = 1/a+bf \qquad \text{..................(3)}$$

Finally, the power relationship was expressed by,

$$Y_f = af^b \qquad \text{..................(4)}$$

The statistical criteria used to evaluate the relationship was the coefficient of determination, r^2 for the evaluation of this criteria and for fitting the data, expressions (1) to (4) were rendered into linear forms as follows :

$$Y_f = a - bf \qquad \text{..................(5)}$$

$$\ln Y_f = a - bf \qquad \text{..................(6)}$$

$$1/Y_f = a + bf \qquad \text{..................(7)}$$

$$\ln Y_f = \ln a + b \ln f \qquad \text{..................(8)}$$

The constants a and b in Eqs (5) to (8) were determined by least squares (Table 2).

TABLE 2. *Regression constants and statistical criteria for linear transformation of four forms of relation between cpue(Y_f) and effort (f)*

	Linear	Exponential	Hyperbolic	Power
a	99.8143	4.7475	-0.001852	8327718
b	-0.0000315	-0.000000658	-0.000000017	-0.87
r^2	0.6889	0.8281	0.9025	0.8649

RESULTS

The fitted relation between Y_f and f for Eqs (5) to (8) is as follows,

$$\text{Linear } Y_f = 99.81 - 0.0000315 f \qquad \text{......(9)}$$

$$\text{Exp. } Yf = 115.30 \exp. (-0.000000658f) \qquad \text{...(10)}$$

$$\text{Hyperbolic } Y_f = \frac{1}{0.001852 + 0.00000017 f} \qquad \text{....(11)}$$

$$\text{Power } Y_f = 8327718 \ f^{-0.87} \qquad \text{..........(12)}$$

The yield in tonnes (Y_E) for the four forms of relationships was computed as follows,

$$\text{Linear } Y_E = 99.81 f - 0.0000315 f^2 \qquad \text{...(13)}$$

$$\text{Exp,} Y_E = 115.30 f \exp(-0.000000658 f) \qquad \text{......(14)}$$

$$\text{Hyperbolic } YE = \frac{f}{0.001852 + 0.00000017 f} \qquad \text{... (15)}$$

$$\text{Power } Y_E = 8327718 f^{0.13} \qquad \text{..........(16)}$$

The curves for the relation between Y_f and f (Eqs. (9) to (12)) are shown in Figures (1) to (4) and the yield curves (Eqs. (13) to(16)) are shown in Figures (5) to (8).

The yield curves for Eqs. (1) and (2) are symmetrical and asymmetrical parabolas respectively with the maxima indicating the MSY and the effort at MSY is taken as the optimal effort (f_{opt}).

For the linear model, the MSY was

estimated to be 79,064 tonnes for an optimum effort of 1,584,286 hauls; whereas for the exponential model, MSY was estimated at 64,454 tonnes for an optimal effort of 1,519,757 hauls. Since the yield curves for the hyperbolic and the power forms were asymptotic, it was not possible to locate the maxima. However, the equilibrium yield (EY) is found to be approximately 55,000 tonnes for an effort of 1,300,000 hauls onwards.

Discussion

The best fits were obtained with the linear transformation of hyperbolic (r^2 = 0.9025), power (r^2= 0.8649) and exponential (r^2= 0.8281) forms. The linear form gave a poor fit (r^2 = 0.6889). The present data suggest that the hyperbolic model describes the dynamics of Bombay duck very well.

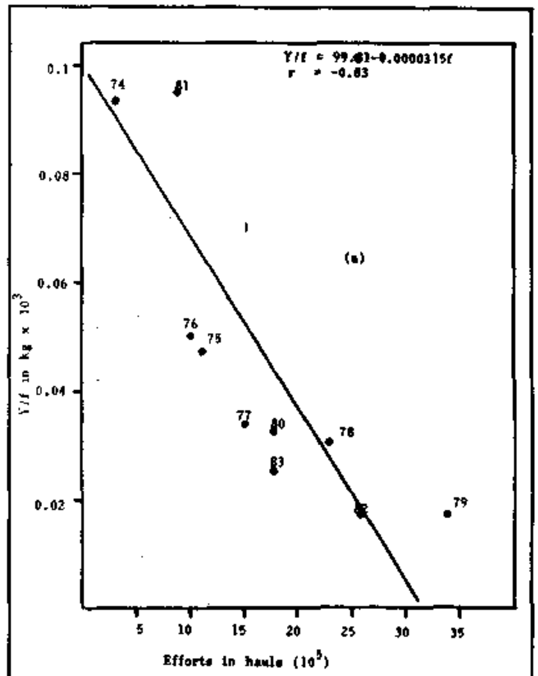


Fig. 1. Relationship between CPUE and effort - LINEAR

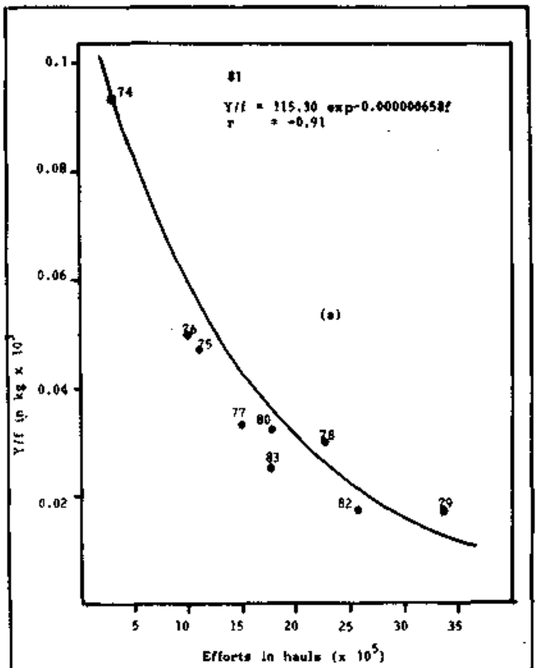
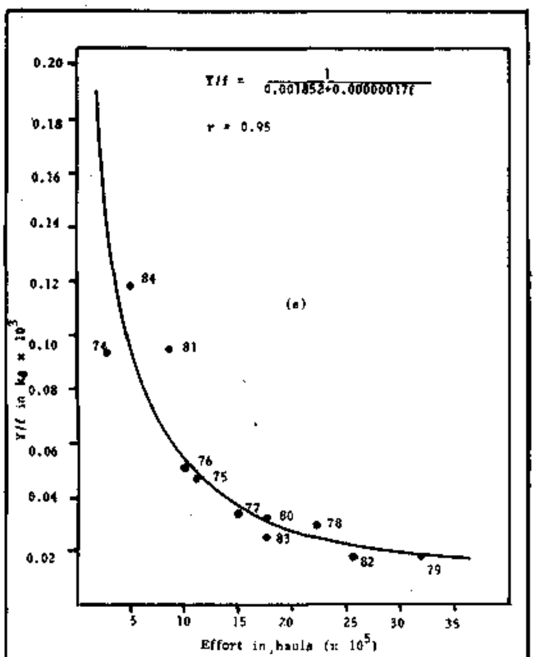


Fig. 2. Relationship between CPUE and effort - EXPONENTIAL

The Bombay duck fishery, from 1974 to 1984 has yielded an average annual catch of 54,000 tonnes which is very close to equilibrium yield estimated by the hyperbolic model for an average annual effort of 1.5 X 10^6 hauls. This effort level is close to the f_{opt} _ for the linear and exponential models. During 1978, 1979, 1980, 1982 and 1983 the effort had exceded the f_{opt} but had not caused any perceptible decline in the yield as is expected in the hyperbolic model.

By definition, the MSY estimate from the parabolic forms is considered as largest sustainable catch which can be taken from a stock over a reasonable length of time. However, MSY may vary considerably depending on temporal and spatial changes in the ecosystem, and therefore need not necessarily be always a very useful index of stock productivity except as a rough measure



3. Relationship between CPUE and effort – HYPERBOLIC

of the maximum potential (Larkin, 1977). On the contrary, equilibrium yield associated with non-parabolic models is the annual harvest which allows the stock to be maintained at approximately the same level of abundance in successive years within reasonable limits of variations in total effort. Normally total effort variations in the fishery is seldom drastic. Therefore, EY could be considered as a more useful measure of the present productive potential of the stock. For these reasons, a non-parabolic production model, despite possible theoretical objections, would be the most appropriate for a fishery like that for the Bombay duck.

Despite wide variations in effort, the yield has been fairly stable over the past ten years which indicates that recruitment has perhaps remained more or less constant. Stable recruitment also denotes that there has not been any cognizable recruitment over fishing, as also evident from the fact that the fishery had been operating along the flat top of the production curve. In the absence of any information regarding stock recruitment relation and also considering the asymptotic relation between catch and effort it could be assumed that the stock recruitment relationship is possibly asymptotic, similar to the Beverton and Holt (1957) asymptotic form. Thus, the possibility for recruitment over fishing, where fishing mortality reduces the spawning stock to the point where the yield declines through reduced recruitment, is rather remote for the Bombay duck fishery in Maharashtra.

Growth over fishing occurs when fishing mortality causes a decline in the average size of the fish resulting in reduced yields. Though fluctuations in the average size of the Bombay duck had caused concern, it has not manifested itself in declining yields. Since

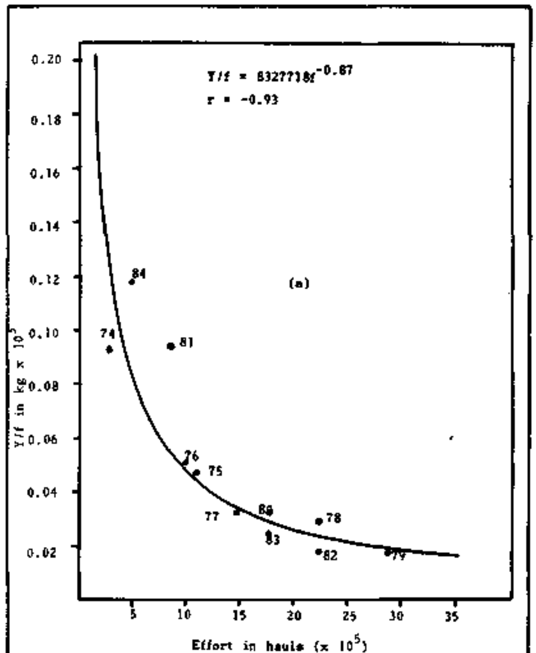


Fig. 4 Relationship between CPUE and effort – POWER

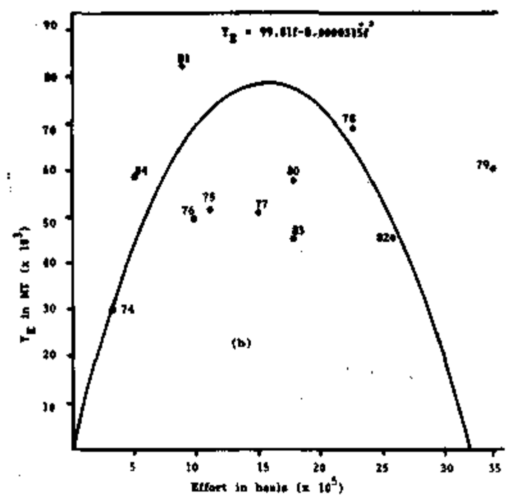


Fig. 5. Yield curve of Bombay duck - LINEAR

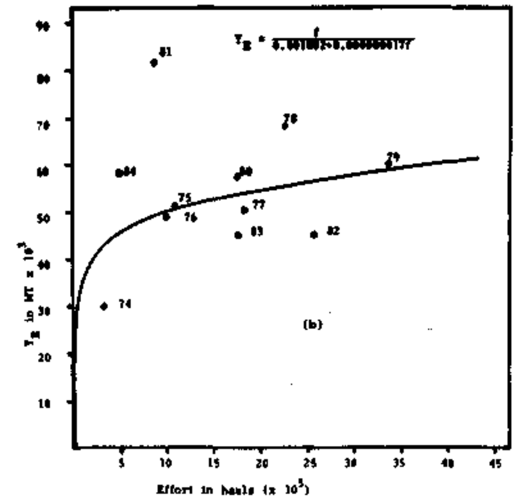


Fig. 7. Yield curve of Bombay duck - HYPERBOLIC

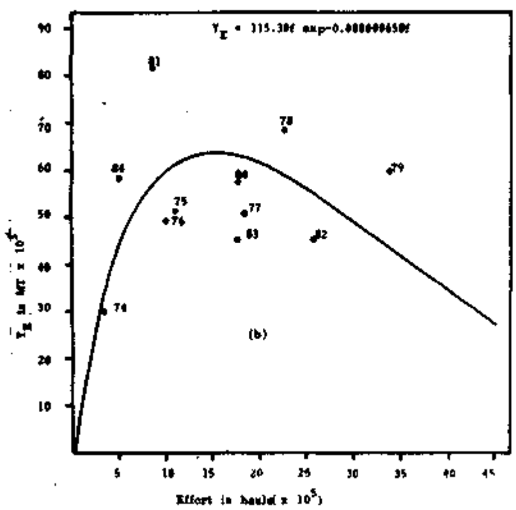


Fig. 6. Yield curve of Bombay duck - EXPONENTIAL

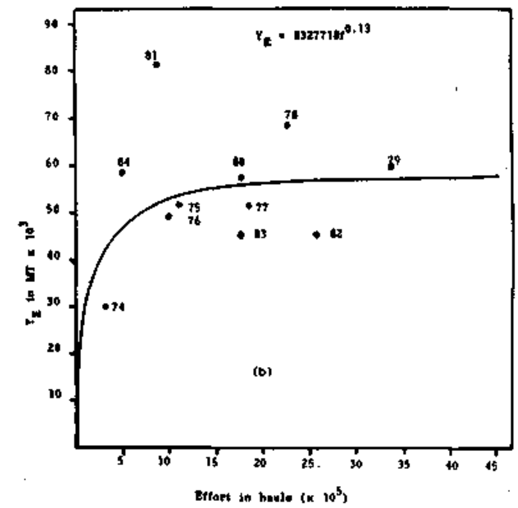


Fig. 8 Yield curve of Bombay duck - POWER

the synthetic models do not take explicit account of the effect of fishing on different size groups, a cross check on the problem of growth over fishing has been carried out with the yield-per-recruit anlaysis. The main objective of the yield-per-recruit analysis is to examine the effect of changing size at first capture, mortality rate and growth rate upon the relation between catch and effort. Considering the mean age of recruitment ($\underline{t}_r$) as 0.28 year, the mean age at selection ($\underline{t}_c$) as 0.41 year, the growth coefficient ($\underline{k}$) as 0.4956 (annual basis) and W_∞ as 253 grams, the yield per recruit ($\underline{Y}_w$/R) was calculated for various values of $\underline{F}$ for a natural mortality coefficient of 0.8, applying the Beverton and Holt (1957) dynamic pool model. The fitted Y_w/R curve is shown in Fig. 9 which is a

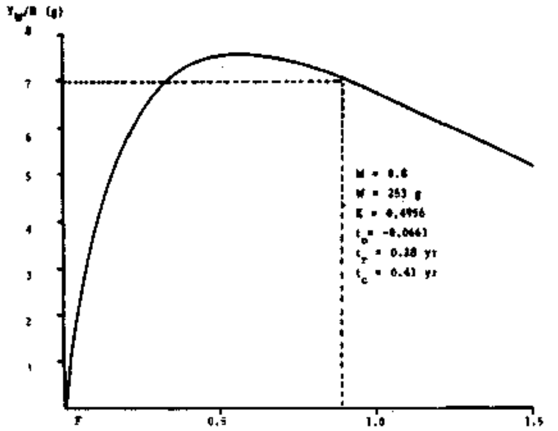


Fig. 9. Relationship between annual equilibarium yield in weight per recruit and fishing mortality coefficient

gentle sloping curve without a prominent peak. So long as recruitment over fishing is ruled out, for a gently sloping yield-per-recruit curve, as in the present case, growth over fishing is unlikely to occur. Between the current value of F of 0.9 (1.5 X 10^6 hauls) and possible maximum at F of 0.6 (1.0 X 10^6 hauls) the difference in yield per recruit is only 0.5 g which is suggestive of the absence of a maximum. Detailed examination of yield in number and weight that could be realized from an year class as it passes through the fishery (Y_{nr}/R') and (Y_{wr}/R')further strengthens the assumption that growth over fishing is very unlikely. The calculated values of (Y_{nr}/R') and (Y_{wr}/R') based on the expression given by Beverton (1954), are presented in Fig. 10 together with the mean weight. Maximum yield in number and weight are obtained when the age at first capture is maintained at less than one year. The fishermen seem to have realised the disadvantage of a larger size at first capture as evident from the smaller mesh that has consistently been in vogue in the fishery (Kurian, MS.).

Since biological and economic objectives are interlinked, optimization of any one

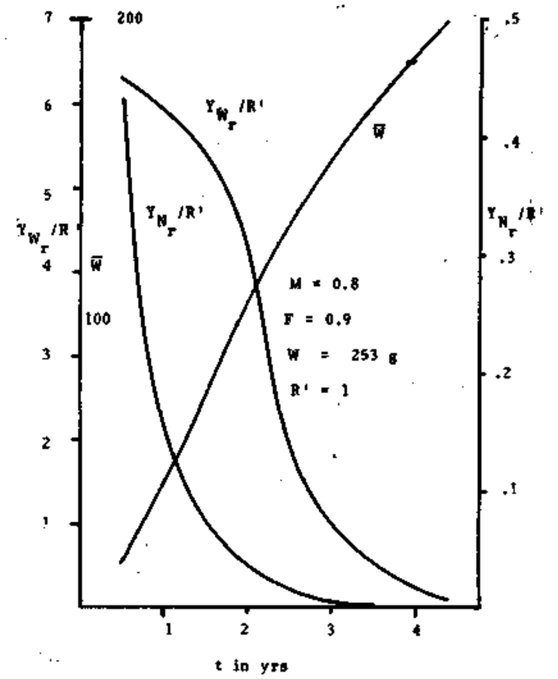


Fig. 10. Yield in number and weight (g) per recruit and weight against age.

alone is neither feasible nor desirable. A fishery represented by an asymptotic model has the tendency for disproportionate increase in effort resulting in lower returns implying economic overfishing. The increase in effort in the 'dol' sector is the direct result of the increase in the number of hauls per trip by carrying more nets during favourable season. Assuming constant price function, the linear, exponential and hyperbolic yield curves (R_1 R_2 and R_3) were considered to be representative of the total revenue curve (Fig. 11), the bionomic equilibrium point, defined here as the zero profit situation, was located where the total cost curve intersects curves R_1, R_2 and R_3. The bionomic equilibrium point for the hyperbolic model was located at an effort level of 1.7 X 10^6 hauls. Though zero profit situation is considered ideal, the small scale sector could afford little waste of effort and manpower. Fishing being their livelihood, the fishermen never staged beyond the bionomic equilibrium point continuously but have always shifted back to lower levels of effort after realizing the futility of increasing the inputs. This type of built-in regulation had ensured fishing for the Bombay duck, a profitable venture for the traditional sector.

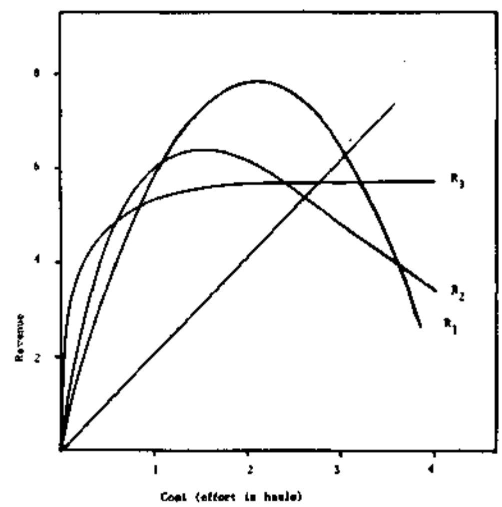


Fig. 11. The bionomic equilibrium point for the Bombay duck fishery represented by linear (R_1); exponential (R_2) and hyperbolic (R_3) revenue curves.

Reproductive longevity, size at maturity and fecundity play an important role in the stabilization of recruitment. The segregation of adult stock from the regular fishing grounds, linear increase in fecundity with weight, absence of refractory and its flexibility as predator, have helped the Bombay duck to be resilient to high rates of fishing. There is little evidence to indicate that an increase in the reporductive output will increase recruitment to the stock. Bagenal (1973) has commented that fecundity changes would "tend to reduce wide fluctuations in recruitment and not be associated with their cause". The possibility of dependence of recruitment and yield on natural mortality caused by a behavioural trait, cannibalism, does exist.

Asymptotic form of synthetic models has been successfully applied for prawns (Brunenmeister, 1984) and fishes (Efimov, 1984) to explain the dynamics of the fishery. The present study, the first of its kind for the Bombay duck, may well explain the trends in yield and sustaining power of the Bombay duck fishery in Maharashtra.

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