Arab Gulf J. Scient. Res., 7 (2), pp. 155-173 (1989)

Application of Yield Model to the Hamoor, *Epinephelus tauvina* (Forsskal, 1775) Stock Exploited in the Arabian Gulf

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ABSTRACT. The yield-per-recruit analysis of the hamoor, *Epinephelus tauvina* (Forsskal, 1775) stock showed that this fishery is exploited at an appropriate level. However, a higher age at first capture would optimize the maximum yield-per-recruit of this fish stock at the current level of fishing mortality. The mean size at first maturity was bigger than the present size at first capture.

Hamoor, *Epinephelus tauvina* (Forsskal 1775), a major component of the grouper species distributed mainly in the areas of the Arabian Gulf, the Indian Ocean and East Indies (Kuronuma and Abe 1986), is the most important fin fish resource in Kuwait not only in terms of production but also on economic point of view. The average annual landing of this species of fish amounted to about 1,600 t, resulting mainly from fish traps (locally known as gargoor) and constituting the major portion (about 27%) of Kuwait's commercial fish landings of approximately 6,000 t per annum (Lee, in press). The previous studies in terms of stock assessment of hamoor were carried out by Baddar and Morgan (1984), Morgan (1984) and Mathews and Samuel (1985). Biological information on this fish stock is available from Hussain and Abdullah (1977) and Abu-Hakima *et al.* (1982). The dynamic pool model is a suitable tool for fish stock assessment and its management studies in which reliable information on growth parameters, size at recruitment and size at entry into fishing gear, fishing mortality and natural mortality can be obtained. Although available data on the hamoor stock have been used for the stock assessment purposes, no comprehensive analysis has been carried out as yet. This study thoroughly evaluates this fish stock, assesses any effect of the spawning stock on yield optimization and advises on future management strategies.

Materials and Methods

Data Collection

The data used in this report are the length frequency distribution of samples (Fig. 1) and the length at age data for 1981-1986. Approximately 500 to 1,000 fish per month were measured to the nearest cm (total length, TL) at the Kuwait's fish markets. These data were used to construct selection pattern for estimating mean selection length. In addition, 30-50 fish were purchased monthly during the same period along with information such as fishing areas where fish were caught and fishing gear used. The sagittal otoliths were collected from the monthly samples and were used to age fish. Maturity stages by sex were determined to estimate size at first maturity of this fish species.

Growth Analysis

The whole sagittal otoliths obtained from the monthly samples were broken through the center of nucleus and the broken surface of the otolith was gently burned in a very low flame of a small lamp until it is slightly charred (Williams, 1986). Ageing was carried out on the surface with reflected light by using a stereomicroscope. The data obtained from age determinations were fitted to the von Bertalanffy growth equation: $L_t = L_\infty (1-e^{-K(t-t_o)})$, where L_t = mean length at age t; L_∞ = asymptotic length; K = growth coefficient and t_o = age at zero length. Asymptotic length was estimated by the graphic method of Walford (1946).

Mean Selection Length

No mesh selectivity studies were made for trap fishery in Kuwait. Thus, a linear regression fitted to the right hand-limb of the length-converted catch curve was used for estimation of the mean selection length of the hamoor stock. Each size class in the length frequency distribution of the sample (Fig. 1) was grouped into 5 cm length intervals. The mid-length of each size interval was converted to the relative age from the growth equation.

To estimate the adjusted number of fish sampled each length class, the number of fish (N) in each length class was divided by the time (Δt) required by the fish to grow from lower to upper limit of the corresponding class. The natural logarithm of $N/\Delta t$ was plotted against the respective age. A linear regression was fitted to the dispersion of the right hand-limb of the catch curve and was projected straight backward. The selection pattern (Pauly *et al.* 1984) was obtained from the ratios between the anti-logarithms of the observed and expected values of ln $(N/\Delta t)$. The mean selection size of the length was extracted from the point at which 50% of fish were retained.

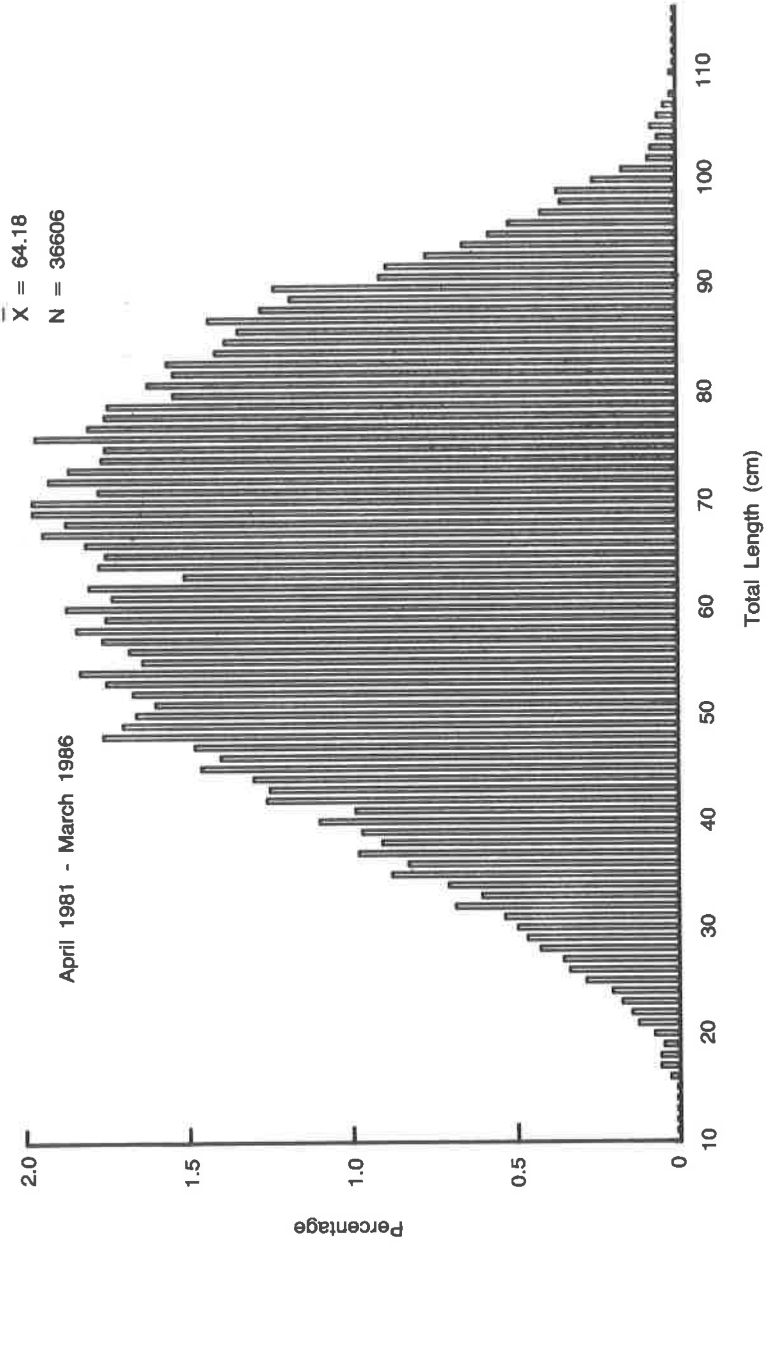


Fig. 1. Length composition of hamoor, *Epinephelus tauvina,* combined during 1981-1986.

Mean Size at First Maturity

The Spearman-Karber method developed by Udupe (1986) was employed to estimate mean size at first maturity with 95% confidence limit, based on observations of gonadal phase of the fish samples.

The log size at first maturity of a species is given by

$$L_m = L_k + (L/2) - L \Sigma P_i \qquad (1)$$

where L_m = the log size at first maturity; L_k = the log size at which 100% of fish are fully mature; L = the log size increment; P_i = the proportion of fully mature fish in the i-th size group.

The (1 - α)% confidence limit in the log size is given by

$$L_m \pm Z(\alpha/2)\sqrt{L^2(p_i q_i/(n_i - 1))}$$

where $Z(\alpha/2)$ = confidence coefficient at a α level of risk; $q_i = 1 - p_i$ and n_i = number of samples in the i-th size group.

The scale describd by Laevastu (1965) was utilized to determine the phase of maturity in both ovary and testis from stage I (virgin) to stage VIII (resting). Each maturity stage of fish was observed for different length groups with equal class intervals. In applying data determined by each maturity stage of the sample by this method, fish identified from stage I to IV (developed) were considered as immature and fish above stage V (gravid) as mature. The mean size at first maturity was estimated from data on females only during the spawning season, March-June (Abu-Hakima *et al.* 1982) since reproductive performance of the stock depends mainly on their condition.

Total Mortality Coefficient (Z)

The instantaneous total mortality coefficient (Z) was estimated from the age frequency distribution by plotting the natural logarithm of the number of fish (ln N) against the corresponding age. From the relationship between values of ln N and each age, a linear regression was fitted to the straight descending right hand-limb of the catch curve. The slope was regarded as the total mortality coefficient, Z

$$\ln N_t = \ln N_0 - Z_t \qquad (2)$$

where N_t and N_0 are the numbers of fish at age t and the numbers at age zero from the age distribution.

Natural Mortality (M) and Fishing Mortality (F) Coefficients

In exploited fish stocks, the relationship between M, F and Z is expressed as Z = M + F, assuming that rates of emigration and immigration remain constant and F = qf, where q is catchability and f is fishing effort. This method for separating M and F directly from the relationship between Z and f (Widrig 1954) was not used in this study because there were no reliable data on fishing efforts on this fish stock and time-series data on Z. Therefore, indirect methods below were used to estimate M.

Using a method described by Alverson and Carney (1975), M was estimated from the information on the maximum age (t_{max}) and K, one of the von Bertalanffy growth parameters. The relationship is as follows:

$$t_{max} \times 0.38 = (1/K) \ln \{(M+3K)/M\} \quad (3)$$

In Pauly's method (Pauly, 1980), the relationship between the growth parameters (L_∞ and K) of the von Bertalanffy equation and mean annual water temperature (T, °C) was used to estimate M

$$\log_{10} M = -0.0066 - 0.279 \log_{10} L_\infty + 0.6543 \log_{10} K + 0.4634 \log_{10} T \quad (4)$$

With the predicted value of M based on above methods, the value of F was obtained from the expression: F = Z − M.

Yield-Per-Recruit Analysis

The yield-per-recruit model of Beverton and Holt (1957) was applied to the data on t_o and K of the von Bertalanffy growth function, age at recruitment (t_r) and age at first capture (t_c), F and M, and the asymptotic weight (W_∞) of the fish species. Relative spawning stock-per-recruit was estimated by the method of Thompson and Bell (1934) based on the size at first maturity. The yield-per-recruit isopleth diagram was constructed using different values of F and t_c to obtain the maximum yield-per-recruit for this fish stock. When differences in the yield patterns occurred, the changes in the spawning stock size-per-recruit were examined to determine any effect on the spawning stock as fishing effort is intensified.

Results and Discussion

Growth Analysis

It was not possible to determine when the rings on the sagittal otolith of hamoor were formed because variations of marginal growth rate (otolith radius *vs.* ring radius) could not be calibrated during the age determination. Thus, it was assumed that the annual ring formation would be formed at the spawning season once a year. Based on the Walford plot to estimate asymptotic length (L_∞), linear regression was obtained from the relationship between L_n and L_{n+1} ($L_{n+1} = 12.377 + 0.875\ L_n$, $r^2 = 0.995$, where L_n and L_{n+1} are mean lengths at age n and n+1, respectively) using all aged data (2,283 fish) for 1981-1986 commencing at the spawning season (Fig. 2). L_∞ was estimated as 99.06 cm TL. The hypothetical age at zero length (t_o) and growth coefficient (K) of the von Bertalanffy growth equation were estimated as −0.345 and 0.153, respectively (Fig. 3).

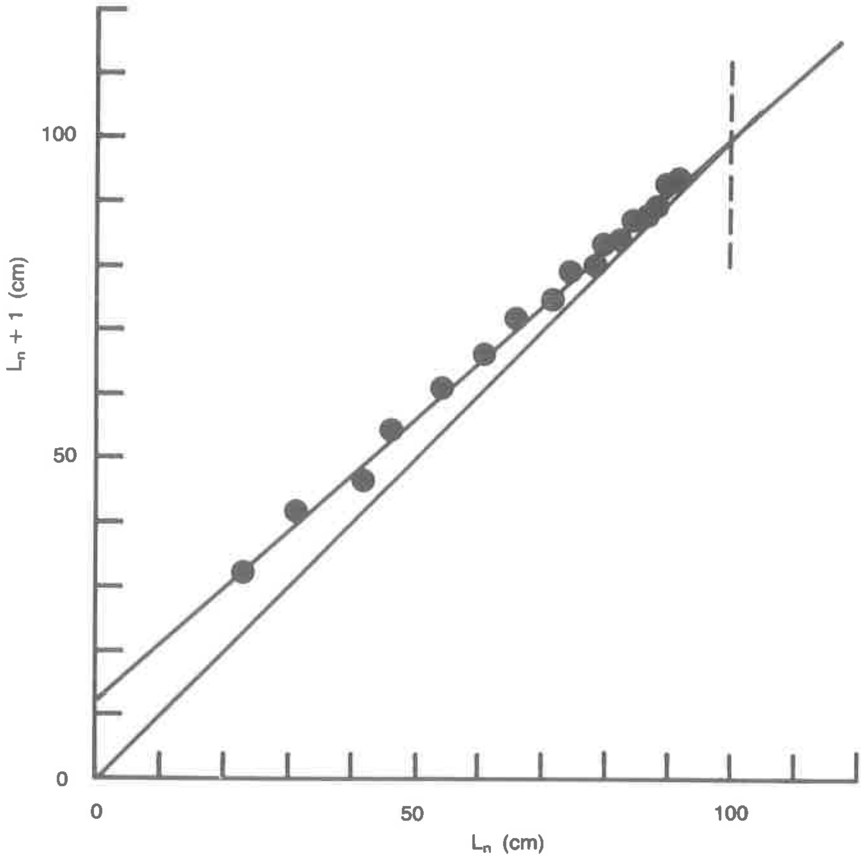


Fig. 2. Walford plot of L_{n+1} against L_n for ages 1-21 of hamoor, *Epinephelus tauvina.*

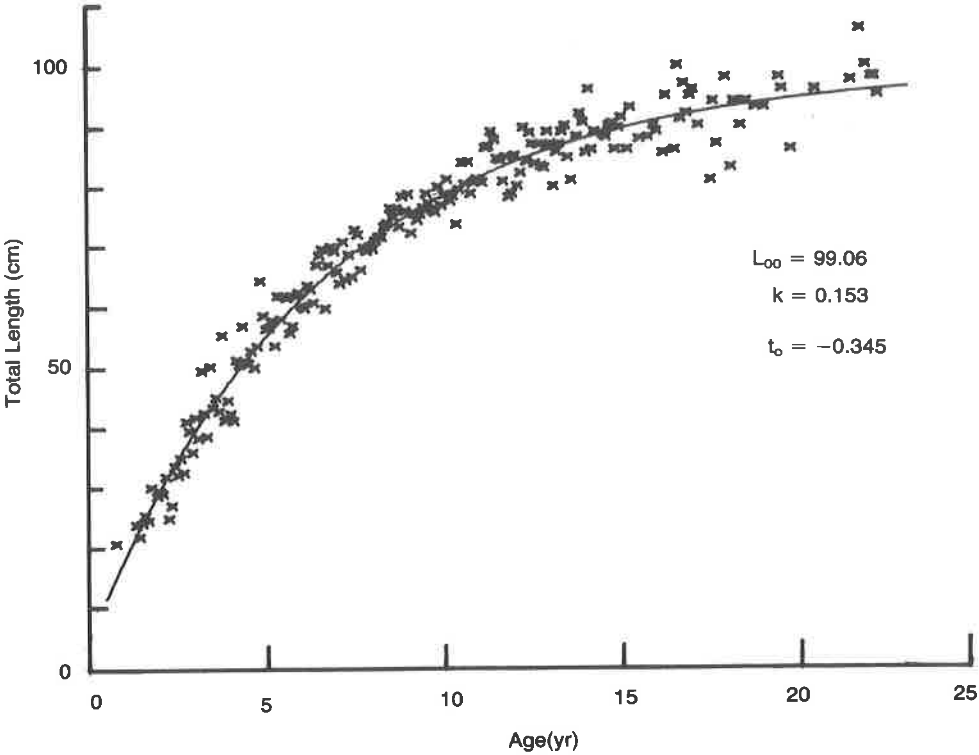


Fig. 3. Growth curve of hamoor, *Epinephelus tauvina,* fitted by the von Bertalanffy growth formula.

Size at Recruitment and Mean Selection Length

The smallest length class, 11cm TL in the length frequency distribution during 1981-1986 (Fig. 1) was chosen as an estimate of size at recruitment (L_r) and t_r was calculated to be 0.77 when $t_o = 0$ in the von Bertalanffy growth equation. The length-converted catch curve using the data on the length composition combined for 1981-1986 (Fig. 1) was built to estimate the proportions between the observed and expected values of ln ($N/\Delta t$) in each length class (Fig. 4a). The diagram of selection pattern obtained from these data is given in Fig. 4b. Mean selection size extracted at 50% retention was 39.8 cm TL and converted to the corresponding age, 3.4 years. These values were considered as the size and age at first capture (L_c and t_c) of the fish species during the year examined. However, a more valid estimate of this size can only be obtained from gear selectivity studies.

Mean Size at First Maturity

Mature female fish began to appear at the 40-45 cm length group and fish at

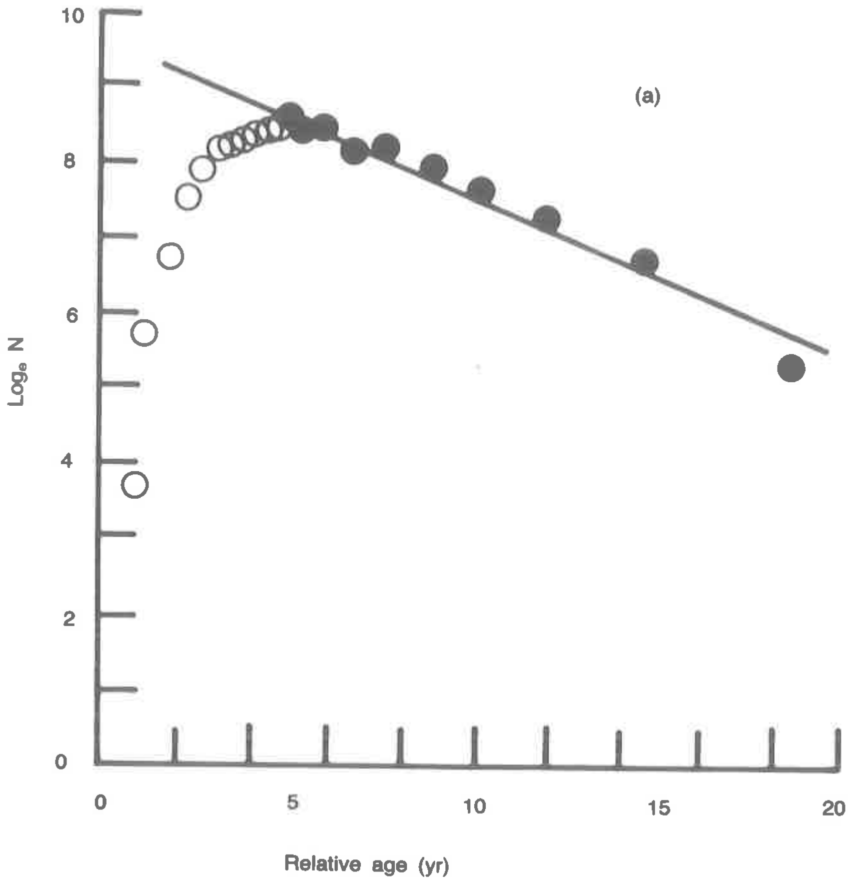


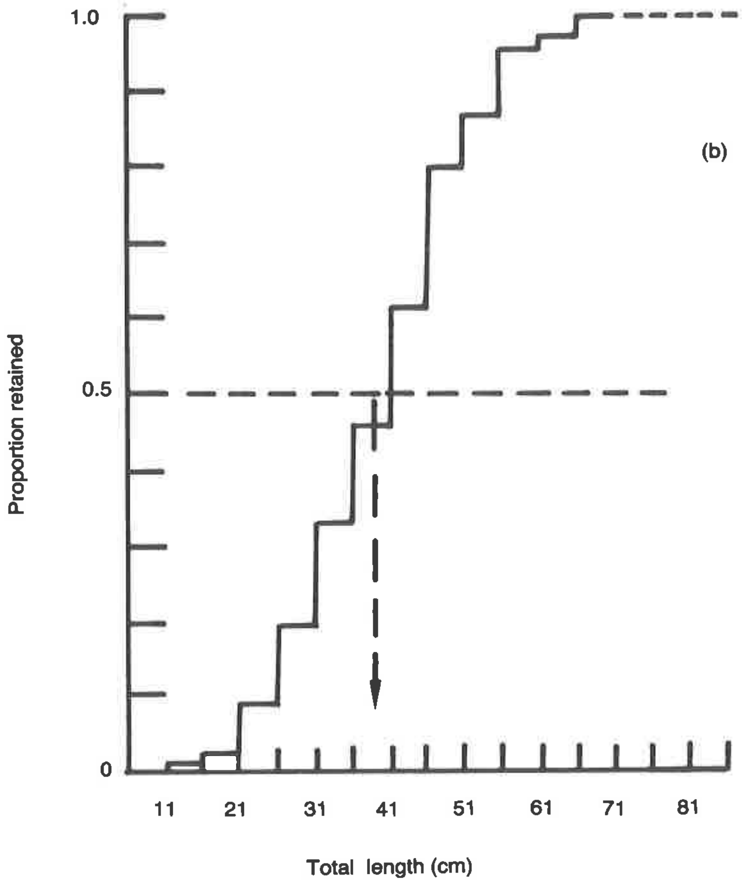
Fig. 4. Construction of selection patterns from length-converted catch curve for estimating mean selection size of hamoor, *Epinephelus tauvina.*

(a) Backward projection of straight descending right hand-limb of the curve and estimation of the expected values. Closed circles were used and open circles not used for the regression.

the size > 85 cm length class were fully mature (Fig. 5). Since the lengths were grouped into 5 cm intervals, the mid-lengths were converted to log values to fulfil equation (1). Using the proportion of mature fish in each length group and the log value, the mean size at first maturity was calculated to be 61.1 cm TL with a range of 57.4–65.0 cm for 95% confidence limit and a corresponding age of 5-6 years.

Total Mortality Coefficient (Z)

The catch curve of hamoor was derived from the age composition during the years from 1981 to 1986 (Fig. 6). The linear regression was fitted to the points



(b) Selection curve fitted to proportions between the observed value and the expected value obtained from the linear regression.

distributed on the right hand-limb of the catch curve from fully recruited age groups. According to equation (2), the slope of the regression as the estimate of Z was determined to be −0.344.

Natural Mortality (M) and Fishing Mortality (F) Coefficients

The instantaneous natural mortality coefficients were estimated from equations (3) and (4). Maximum age (t_{max}) was considered as 24 which was obtained from the age determination during the study period (Fig. 3) with the growth parameters, L_∞ = 99.06 cm and K = 0.153. A representative mean annual water temperature, T = 22.8 °C observed from Kuwait waters at bottom (15-20 m) in

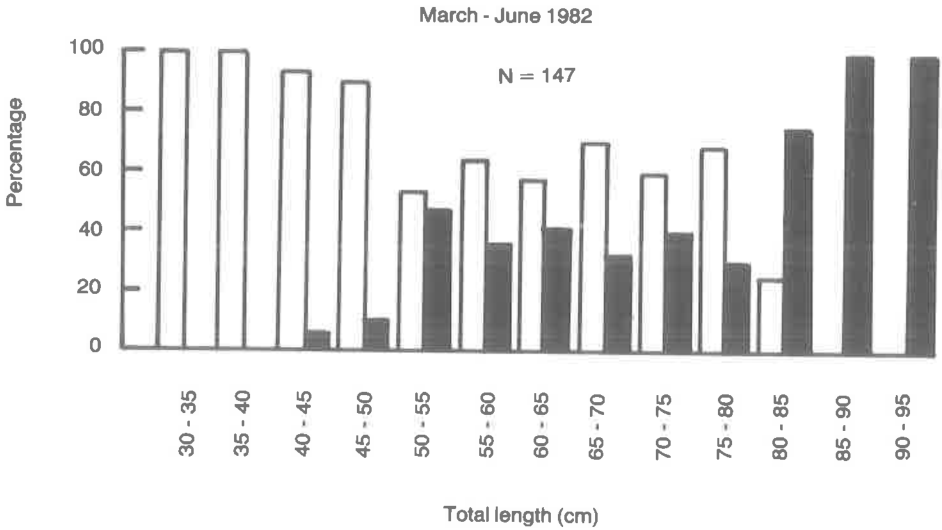


Fig. 5. Proportion of mature (shaded) and immature (open) fish to total number of female sample of hamoor, *Epinephelus tauvina.*

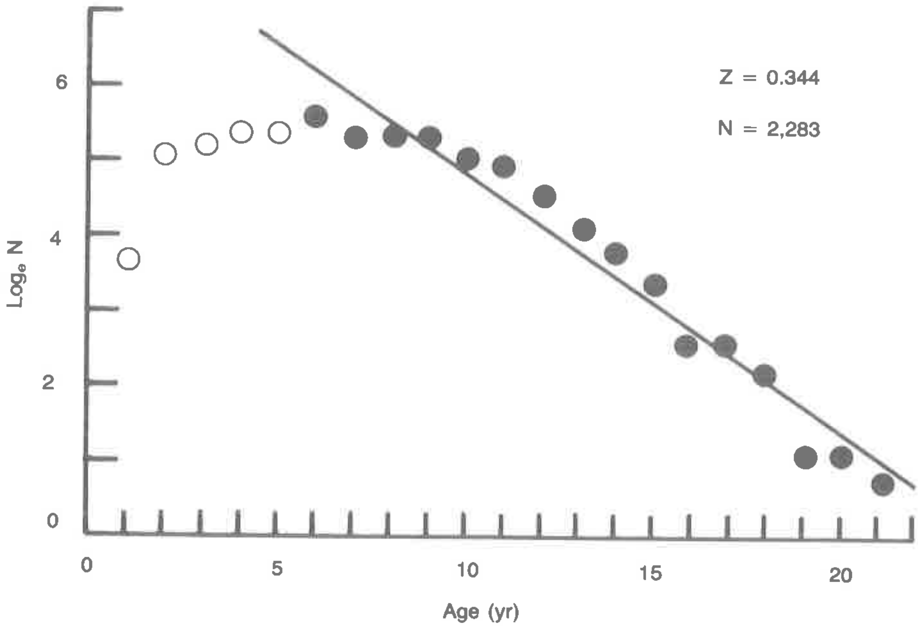


Fig. 6. Catch curve of hamoor, *Epinephelus tauvina*, using age composition data for 1981-1986. Closed circles were used and open circles not used for the regression.

1982, was used. The values of estimated M were 0.15 and 0.34, respectively. From these estimates, a value of M = 0.15 was used in this study because the value estimated from equation (4) showed $Z \simeq M$. Using this value for M, F = 0.194.

Yield-Per-Recruit Analysis

The population parameters for applying the yield-per-recruit model are listed in Table 1, assuming that fishing and natural mortality coefficients were constant for ages greater than the age at recruitment. The relative spawning stock-per-recruit was estimated with an initial population of 1,000 individuals for all ages from age at first maturity to maximum age. Changes in yield-per-recruit at various levels of fishing mortality were estimated together with various ages at first capture as well as the patterns of relative spawning stock-per-recruit (Fig. 7). Yield-per-recruit reached the maximum level at the current fishing mortality of 0.19, with the present value of t_c = 3.4, then decreased with increase in F. When t_c = 4.0 and 5.0, the maximum yield-per-recruit occurred between F = 0.2 and 0.3, and when t_c = 6.0 and 7.0, the maximum yield-per-recruit was achieved at F = 0.4. The curves show a pronounced dome shape at F = 0.1 to 0.3 when t_c ranges from 1.0 to 4.0 but they show nearly a parallel pattern when t_c = 5.0 and from F = 0.3 onwards, respectively. It should be mentioned however, that when fishing mortality increases, the spawning stock of this fish species declines much faster than the yield.

In the case of yield-per-recruit *vs.* t_c, when F changes to various levels (Fig. 8), no maximum yield-per-recruit may be reached at present level of t_c = 3.4 for any values of F. The maximum level is between t_c = 5.0 and 6.0 when F = 0.1 and 0.2. From F = 0.3 onwards, the maximum yield occurs at t_c = 7.0 and 8.0. These results suggest that the current size at first capture should be increased to at least 5 or 6

Table 1. Population parameters for construction of yield-per-recruit isopleths of the hamoor, *Epinephelus tauvina* stock

Parameter	Value	Remark
M	0.15	Natural mortality
t_r(yr)	0.77	Age at recruitment
t_c(yr)	3.4	Age at first capture
t_o K	−0.345 0.153	Growth parameters in the von Bertalanffy formula
W_∞ (g)	15,637	Maximum weight from $W = 0.0144\ L^{3.0241}$ (Samuel *et al.* 1987)

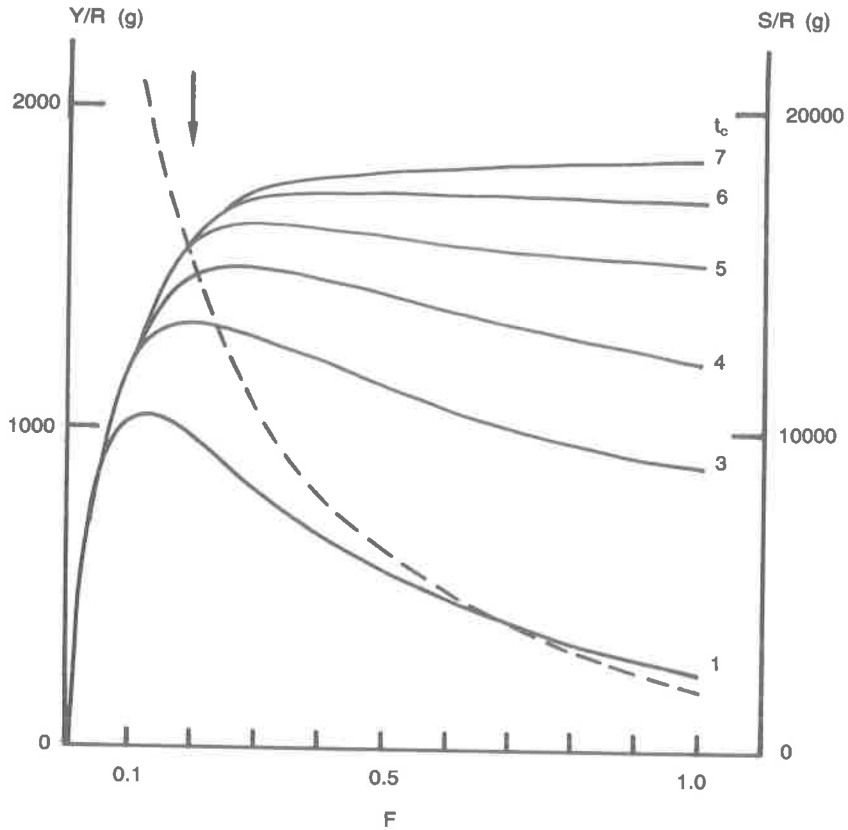


Fig. 7. Yield-per-recruit (Y/R) at various levels of fishing mortality with different age at first capture of hamoor, *Epinephelus tauvina.* Broken line indicates the spawning stock-per-recruit (S/R) and arrow shows the present level of fishing mortality.

years old to achieve the maximum yield-per-recruit, which almost coincides with the age at first maturity.

According to a yield isopleth constructed as a function of t_c and F of the hamoor stock (Fig. 9), the current level of expoitation of this fish stock is less than the maximum yield. This diagram suggests that to gain a higher yield, a wide option of combinations of t_c and F exists. It is clear, however, that increases in fishing effort do not lead to a significant increase in the yield at the present value of t_c. When t_c and F increase simultaneously, a higher yield than the present level is expected. However, an increase in fishing effort at current t_c could cause a spawning stock depletion (Fig. 7). Accordingly, it is obvious that some increase in yield-per-recurit will be obtained by increasing the size at first capture only and

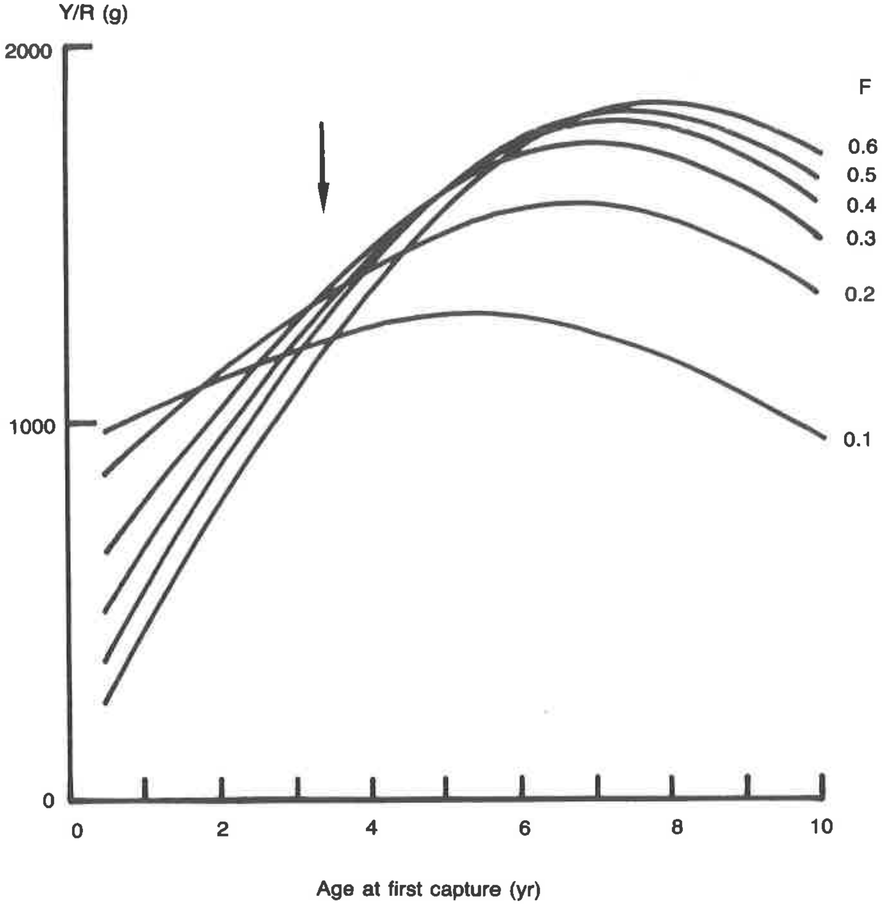


Fig. 8. Yield-per-recruit at various ages at first capture with different levels of fishing mortality of hamoor, *Epinephelus tauvina*. Arrow indicates the present size at first capture.

keeping the current fishing effort constant. Earlier yield-per-recurit analyses for the hamoor stock showed that an increase in yield-per-recruit could be achieved by increasing fishing effort. However, little advantage was evident in altering the size at first capture unless done in conjunction with fishing effort increase (Baddar and Morgan 1984). On the other hand, this stock was considered to be exploited at about the right level, *i.e.*, no change in the present management for this fish stock seemed justified (Mathews and Samuel 1985). It should be pointed out that earlier studies did not consider any effect of spawning stock when the relationship between size at first capture and fishing mortality was discussed.

The statistical foundations of each expression for predicting natural mortality

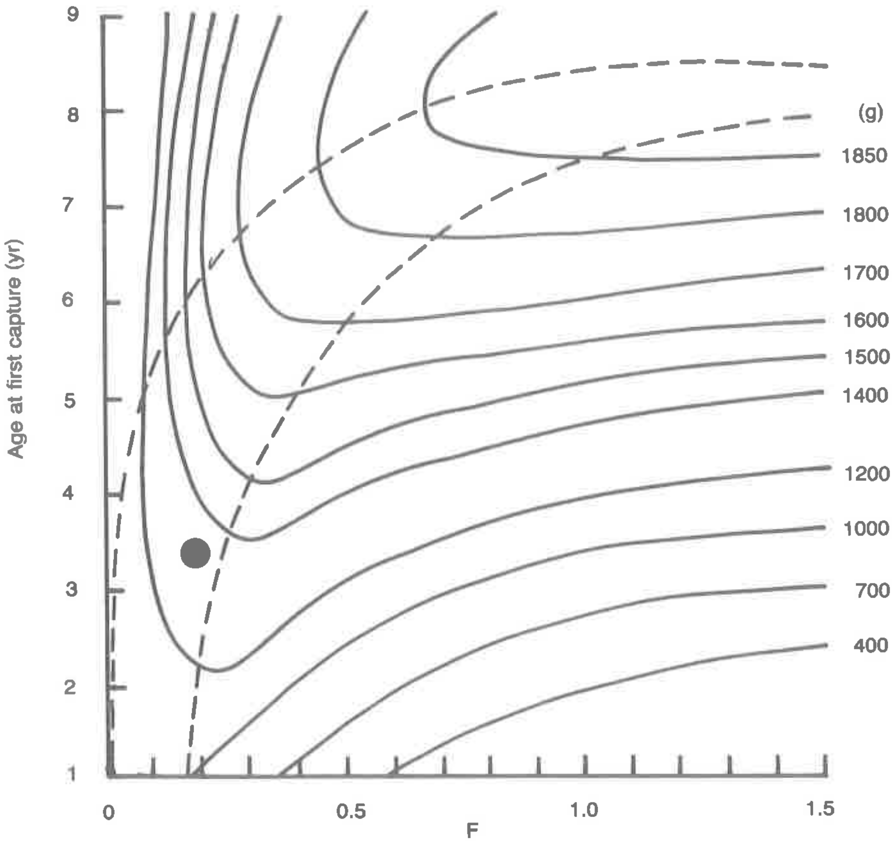


Fig. 9. Yield isopleth diagram in relation to age at first capture and fishing mortality of hamoor, *Epinephelus tauvina*. Closed circle represents the current fishing mortality and the mean size at first capture. Broken lines show the ranges of optimum yield.

rate are limited by the arbitrary assumption that natural mortality is associated with variable growth parameters and water temperature. Accordingly, M = 0.10 and 0.20 were taken to determine if a different choice of M would alter the results obtained when M = 0.15 in this study (Fig. 10). The maximum yield-per-recruit is achieved at a slightly lower fishing mortality than the present fishing level when M was assumed to be 0.10, showing a pronounced dome shape at F = 0.15. In the case of M = 0.20, an increase of fishing mortality rate expects relatively small increases in yield-per-recruit. These results suggest that the present level of exploitation is in an appropriate position. It is obvious, however, that an increase in fishing effort will cause a decrease in spawning stock-per-recruit for any values of natural mortality.

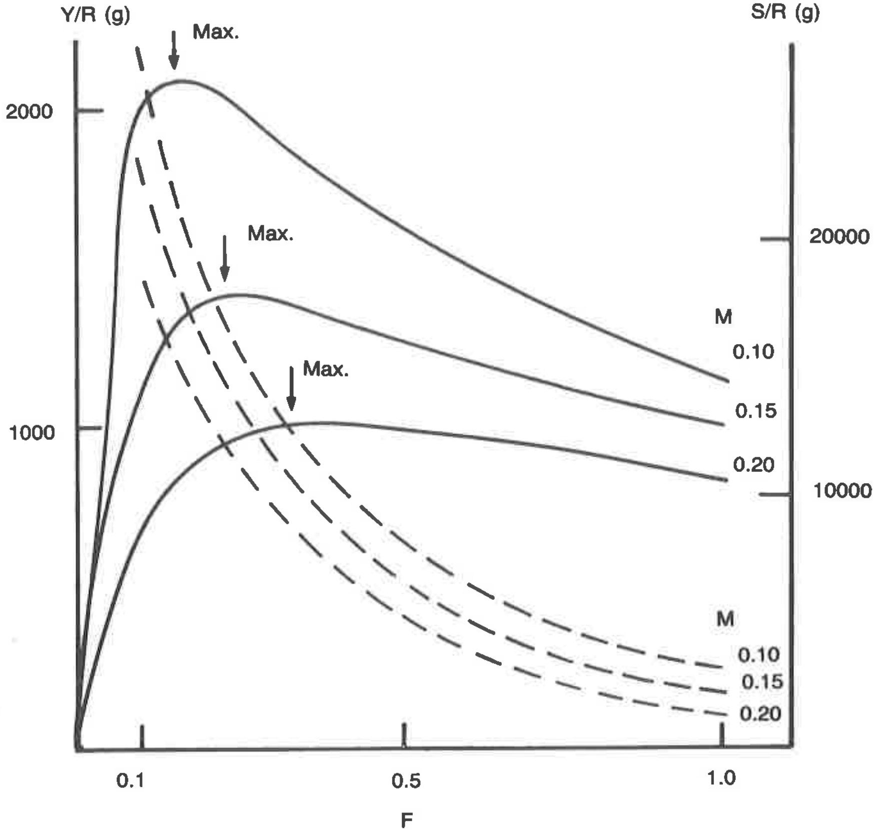


Fig. 10. Patterns of yield-per-recruit (Y/R, solid line) and spawning stock (S/R, broken line) using three different natural mortality rates of hamoor, *Epinephelus tauvina.*

The current age at first capture of this fish species is much lower than the age to achieve the maximum yield-per-recruit (upper broken line in Fig. 9). Therefore, it seems advisable to allow this fish species to take part in reproductive activity at least once. A practical management policy would be to harvest fish older and larger than the current size of t_c, while maintaining the present level of fishing effort.

Acknowledgements

The authors wish to thank Dr. C.P. Mathews, Dr. P.S. Joseph and Mr. M. Samuel, Mariculture and Fisheries Department of Kuwait Institue for Scientific Research, for the useful advice and critical review of this manuscript.

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(Received 15/02/1988;
in revised form 01/02/1989)

تطبيق لنموذج الانتاج على مخزون سمك هامور *(Epinephelus tauvina)* في مياه الخليج العربي

جي. يو. لي و محمد خير بدار

دائرة الزراعة البحرية والثروة السمكية ـ ادارة موارد الغذاء
معهد الكويت للأبحاث العلمية ـ ص. ب: ٢٤٨٨٥ ـ الصفاة ١٣١٠٩ ـ الكويت

لقد تم إجراء دراسة للمظاهر البيولوجية وتقييم مخزون سمك الهامور *Epinephelus tauvaina* في مياه الخليج العربي للفترة من عام (١٩٨١ ـ ١٩٨٦) وذلك باستخدام معايير النمو (الطول الأدنى في المصيد والطول الأدنى للخصوبه) ومعايير النفوق (الكلي والطبيعي) اضافه إلى حجم المخزون النسبي للأسماك البياضة.

وإستناداً إلى هذه المعايير فقد تمت دراسة مستوى الانتاج «للمستغل» بغية معرفة الوضع الحالي لمخزون سمك الهامور في مياه الخليج العربي ومن ثم إبداء النصح والمشورة العلمية والإدارية للحفاظ على هذا المخزون في المستقبل.

لقد تم الحصول على معايير النمو بتطبيق معادلة (voa Bertalanffy) حيث وجد أن Loo (99.06 سم)، K (0.153) و t_0 (0.345 –) . أما الطول الأدنى في المصيد L_c فقد وجد أن قيمته (39.8 سم) مقابلة للعمر (3.4) كما وجد أن الطول الأدنى للخصوبة L_r هو (61.1 سم) ويتراوح مابين (57.4 سم – 65.0 سم) مقابلة للأعمار (5 – 6) وذلك باستخدام الاحصاء الرياضي.

لقد تم إيجاد معدل النفوق السنوي (٪) وقيمته (0·344). وذلك باستخدام التكوين العمري للعينة في حين تم إيجاد معامل النفوق الطبيعي (M) وقيمته (0.15).

هذا ولقد أظهرت تحليلات الانتاج أن استغلال المخزون لسمك الهامور كان ضمن المستوى الامثل المطلوب وذلك عند أدنى عمر في المصيد (T_c) وعندما يكون معدل نفوق الصيد F (0.194) . علماً بأنه اذا ماتم زيادة جهد الصيد عما هو عليه حالياً مع ثبات أدنى عمر في المصيد فإن ذلك لن يؤدي إلى زيادة الانتاج «للمستغل» عما هو عليه حالياً. أما إذا ماتم زيادة جهد الصيد جنباً إلى جنب مع أدنى عمر في المصيد فإن من المحتمل أن ذلك سيؤدي إلى زيادة الانتاج «للمستغل» عما هو عليه حالياً. بيد أنه إذا ماتم زيادة جهد الصيد فإن ذلك سيؤدي إلى تناقص المخزون المتوالد وعليه فإنه ينصح بحصاد أسماك الهامور عند أعمار أكبر في المصيد مع بقاء جهد الصيد كما هو حالياً.