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THE EFFECTS OF REGULATIONS OF THE MACKEREL FISHERY IN THE NORTH SEA

By

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INTRODUCTION

Since 1970 the Norwegian mackerel fishery for meal and oil has been regulated by a minimum legal size of 30 cm, closed season during winter and spring, and annual catch quotas for reducing the fishing mortality (HAMRE 1970 and 1971).

The present paper is a theoretical study of the effects of the various regulation measures on stock and yield. For this analysis a simulation model has been developed. The paper also gives a brief account of the present state of the mackerel stock and the regulation measures imposed on the fishery in 1972.

THE MODEL

In order to study the effect of seasonal distribution of fishing effort, all calculations in the model are done on a monthly basis. Input data is monthly mean weight of fish by age, total number in each yearclass at the beginning of the first year run, recruitment to the stock during the time period included in the analysis, monthly fishing mortality (F_t) coefficients and coefficients accounting for reduced fishing mortality of the age groups not fully

recruited to the fishery.

The model calculates the yield in number (C) and weight (Y) by yearclasses and month (t) by the equations:

$$C_t = \frac{N_t \cdot F_t}{F_t + M} \left[1 - e^{-(F_t + M)} \right]$$

$$Y_t = W_t \cdot C_t$$

and the number in the yearclasses (N) at the beginning of the next month by

$$N_{t+1} = N_t \cdot e^{-(F_t + M)}$$

The programmes are run with a constant natural mortality rate (M) of 0.2. W_t is the monthly mean weight of fish.

The model summarizes size and composition of the catch, and the corresponding stock size during the time interval under study. The weight of the stock in June, including the yearclasses 2 years and older, is used as index of the spawning stock. January 1 is regarded as the birthday of the fish.

For constant recruitment a simpler programme has been used. Input data of growth and mortality is also arranged here on a monthly basis, and the programme calculates yield per recruit and spawning stock per recruit for equilibrium state of stock and yield.

EFFECTS OF CLOSED SEASON

The effects of closed season regulations on stock and yield have been analysed by using the programme for constant recruitment. The results are illustrated in Fig. 1 (A, B and C).

Fig. 1A shows yield per recruit (Y/R) in percent of the corresponding yield when F is equally distributed throughout the year. Fig. 1B shows similar figures of weight of spawning stock, and Fig. 1C the average weight of fish in the catch. The programme is run for two ages at first capture (t_c).

For illustration purposes two alternatives of closed season regulations are selected, those which yield maximum and minimum catch per recruit respectively. The first one (the solid line) illustrates the case when the fishery is restricted to July-August only, and the latter (the dotted line) to the period January-March. In practice the selected seasons correspond to the Norwegian purse seine fishery during summer in the Shetland area and the winter fishery on the Viking Bank. Any other seasonal distribution of fishing effort lies between these two curves.

The figure shows that restricting the harvesting of the stock to particular seasons may effect the obtainable yield per recruit within a range of some $\pm 20\%$ compared with equal distribution of effort throughout the year. It is further seen that the variation range increases with increasing F when t_c is low, but becomes more or less independent of F for $t_c = 3$ or above. In general, it can be concluded that restrictions on unfavourable fishing seasons may increase the yield per recruit considerably, particularly when the fishery exploits younger age groups.

The closed season regulations have a similar effect on the size of the spawning stock, but the effects are more influenced by the rate of exploitation (Fig. 1B). Thus for $t_c = 2$ and $F = 0.2$, S/R may vary within a range of $\pm 10\%$ compared to equal seasonal distribution of effort, but the range may increase to $\pm 30\%$ if F is increased to 0.6. For low values of F , the effect of closing unfavourable fishing seasons is naturally low and not significantly influenced by t_c . But when the stock is heavily exploited the closed season regulations are also important for maintaining a high

level of stock size during the spawning season, and most important when the fishery exploits younger age groups.

The effects of either winter or summer fishery on the average weight of the fish in the catch are illustrated in Fig. 1C. The variation range of \bar{W} is some $\pm 20\%$ and is little influenced by F and t_c , except for very high values of F when t_c is low.

The regulations imposed on the Norwegian mackerel fishery in 1970 and 1971 prohibited meal and oil production from January to July and during the last months of the year when the allowed catch quota was filled. This resulted in an approximate percentage distribution of the fishing mortality (F) as follows:

January-March 0%, April-June 6%, July-August 14%, September-October 80% and November-December 0%. These figures refer to the North Sea stock only, and are derived from the Norwegian catch statistics after subtracting the estimated contribution to the catch from the Irish stock (HAMRE 1971). The broken curves in Fig. 1 show the effect of the above mentioned actual distribution of fishing mortality on the stock and yield. The figure shows that the present restrictions on the fishery for meal and oil has resulted in a fishing strategy which approaches the expected optimum catch as far as seasonal distribution of effort is concerned. Since the stock has been very heavily exploited in recent years the closed season regulation during winter and spring is regarded as a very important conservation measure because it contributes significantly, both to obtain optimum yield per recruit and to maintain a high level of spawning stock.

Further studies are based on the observed seasonal distribution of F outlined above.

EFFECTS OF MINIMUM LEGAL SIZE

According to previous studies it is found that the gain in yield per recruit by, increasing the age at first capture, is rather insignificant (POSTUMA 1969, HAMRE 1970). This is also the case

when the distribution of F is regulated by closed seasons (Fig. 2). As the figure shows, the Y/R does not increase significantly by increasing age at recruitment (t_c), at least not for F -values below 0.4. The parameter, t_c , has however a considerable effect on the size of the spawning stock when the population is heavily exploited. This is shown in Fig. 3. The figure shows the size of spawning stock per recruit for constant recruitment at equilibrium state of stock for different values of age at first capture (t_c), as a function of F . It is seen that an increase in t_c from 1 to 3 may double the size of the spawning stock when F approaches the level of optimum yield per recruit (0.4). Therefore, if a positive correlation exists between recruitment and the stock size at the corresponding level of exploitation, a minimum legal size regulation will be quite decisive for the obtainable sustained yield. It may further be noted that the curves are rather steep in the interval below $F = 0.4$, but flatten out above that value. This means that under the conditions that the recruitment is reduced by reduced stock size, the loss in yield per recruit by reducing F may be more than compensated by the increased probability of recruitment. The stock-recruitment relationship is thus one of the most important factors in the consideration of the relationship fishing mortality / sustained yield.

SUSTAINED YIELD

Hamre (1970) estimated the size of the North Sea mackerel stock to a level of 4 million tons before the purse seine fishery was introduced in 1964. Before that time the stock was very poorly exploited (less than 3% annual fishing mortality). The yearclasses 1962 to 1966, which were recruited from that stock size level of spawning stock, were estimated to an average of 1910 million recruits at 2 years of age. From these figures, together with an estimated yield per recruit under the most favourable seasonal distribution of effort, he concluded that the expected sustained yield would approach a maximum of 400 thousand tons when F approached 0.4, provided that the reduced stock size did not influence the recruitment.

The recruitment to the mackerel stock since 1966 has been far below the said value. The 1967 and 1968 yearclasses were extremely poor and are estimated to some two and four hundred million recruits (HAMRE 1971). The parent stock was estimated to 2.7 and 1.8 million tons respectively (HAMRE 1970). This low recruitment has no doubt been due to unfavourable conditions of reproduction. Compared to these yearclasses the 1969-yearclass is however strong, and a preliminary estimate referring to August 1971 indicates a yearclass strength of 1200 million individuals (HAMRE 1972). The data on which the estimate is based is poor, and may also be biased towards an underestimate of the real value. The parent stock of the 1969-yearclass has been estimated to 1.1 million tons. The 1970-yearclass has not so far shown up in the Norwegian catches and may thus be very poor. The spawning stock in 1970 is estimated to about 0.7 million tons.

Although the present knowledge of reproduction is far from adequate to formulate a density dependent relationship of recruits and stock, some valuable information can be obtained by incorporating such a relationship in the stock model. For this study we have used the stock-recruitment relationship of Beverton and Holt (1957):

$$R = \frac{S}{aS + b}$$

where R denotes recruits, S stock size and a and b are constants.

In accordance with the existing data on recruitment in the years when exploitation was low (1962-1966), the asymptotic value $\frac{1}{a}$ was set to 2000 million individuals. The constant b determines the curvature of the stock-recruitment curve, and the aim of the study is to investigate how this parameter may effect the sustained yield. In this respect three values of b are selected, and the corresponding curves are shown in Fig. 4. The upper curve (b = 0.1) illustrates a stock-recruitment relationship where the reproduction is very slightly effected by exploitation rates below F = 0.4.

The two lower curves postulate that a reduction in recruitment does exist. Incorporating the said stock-recruitment relationship into the model, the expected yield at equilibrium state is calculated and the results are shown in Fig. 5, for the respective values of b . The important conclusion which may be drawn from this study is that the risk of over-exploiting the stock is considerably reduced by maintaining a high t_c , even when the exploitation is high and the recruitment is significantly effected. It is thus seen that a control on the fishing mortality, limiting F to 0.4, may be adequate if the age at first capture could be kept as high as 3 years, even if the recruitment is considerably reduced at that level of exploitation. This high exploitation rate may on the other hand be fatal if the immature fish are unprotected (Fig. 5), and even with the present t_c in force (2 years), the danger of over-exploiting the stock can not be ruled out when F approaches 0.4. Since an increase in t_c above 2 years of age may not be practical, and the possible loss in yield may in any case be rather small by reducing F to 0.3, it is felt that this level of exploitation is preferable for the future exploitation policy, rather than the level on which the fishery has been regulated in the past ($F = 0.4$).

THE PRESENT STATE OF STOCK

As mentioned previously, the 1969-yearclass seems to be relatively strong compared to the yearclasses 1967 and 1968. Due to the depletion of older yearclasses, the 1969-yearclass is now dominating the mature stock. This yearclass contributed with 80% in weight on the purse seine catches landed from the North Sea south of 59°N during autumn 1971. A preliminary estimate of the yearclass strength amounts to 1200 million individuals, the estimate referring to August 1971. This is however regarded as an underestimate, because the yearclass may not yet be fully recruited to the catchable stock. The total stock size was estimated to 460 thousand tons. The Norwegian catch after 1971 amounted to some 23 thousand tons and the bulk of this catch originated from the North Sea stock.

The prospects of recruitment from the yearclasses 1970 and 1971 are rather poor. The 1970-yearclass which was expected to turn up in

the autumn catches in 1971 seems to be extremely poor. The strength of the 1971-yearclass is more uncertain but may also be far below average. This is indicated by the fact that no occurrence of the 0-group in the Norwegian fjords was reported during late autumn 1971, which is usual when a good yearclass is recruited. It is therefore fair to assume that at least two years will pass without substantial recruitment to the mature stock, and under these circumstances the fishery must be kept under strict control if the stock shall not be further depleted.

CONSERVATION MEASURES IN 1972

An analysis of expected catch and size of spawning stock, by various rates of exploitation, has been carried out by simulating a fishery strategy which corresponds to the distribution of fishing effort by age groups, season and area, resulting from the regulation measures imposed in 1971. Size and age structure of the mature stock was established on the basis of data obtained during 1971. The future recruitment was set to 500 million individuals at 2 years of age or about 1/4 of the estimated average recruitment from the yearclasses 1962-1966.

The programme was run through the years 1972-1975 for various rates of exploitation on a constant annual basis and the calculated catch and corresponding stock size are shown in Table 1. The table shows that if F exceeds 0.2 the spawning stock may continue to decline unless the recruitment should turn out to be substantially better than anticipated. The failing recruitment in recent years gives reason to fear that the stock size is already brought down to the level where the recruitment is effected, and the exploitation policy suggested for the coming years is therefore aimed at rebuilding the stock, disregarding expected loss in catch per recruit.

The regulations of the Norwegian mackerel fishery refers to the conservation of the stock spawning in the Skagerak and North Sea only.

Since 1970 a purse seine fishery for mackerel has been developing in the area around Shetland during late summer. According to results obtained from tagging, this fishery is based on mixed stocks, and the contribution from the North Sea mackerel stock has so far been of minor importance (HAMRE 1971).

The restricted area includes the Skagerak and North Sea east of 4°W . In order to exclude the Shetland fishery during summer this area has been divided in a northern and southern part using 59°N as boundary. In the area south of 59°N industrial fishing will not be permitted in 1972, whereas the fishery north of 59°N has been open for the industrial fishery from July 17. No catch quota for reduction purposes has been set, but should the contribution from the North Sea mackerel stock become dominant the fishery can be closed with short notice.

Purse seining for mackerel for human consumption has been prohibited for vessels above 70 ft during most of the period January-June 1972. Due to this, and to the market conditions, the quantity landed for human consumption is limited.

It is expected that the regulations in force will keep the total Norwegian catch of mackerel from the North Sea stock below 100 thousand tons in 1972.

SUMMARY AND CONCLUSIONS

1. The paper deals with a study of the effects of regulating the mackerel fishery by minimum legal size, closed seasons and annual catch quotas for reducing the fishing mortality. The future exploitation policy is considered in view of the present state of the North Sea mackerel stock. For this analysis a simulation model has been developed.

2. Regulations by closed seasons have a considerable effect on the yield per recruit, the spawning stock per recruit and the average weight of fish in the catch, especially when the fishing mortality is high and the younger age groups are unprotected (Fig. 1). Fishing during summer is most favourable, the winter

fishery represents the most unfavourable fishing strategy. The seasonal distribution of effort resulting from the regulations in force is close to the distribution giving optimum values of stock and yield.

3. The gain in yield per recruit obtained by increasing age at first capture is rather small (Fig. 2). This parameter, however, effects the size of the spawning stock, especially when the stock is heavily exploited (Fig. 3). More than a 100% increase in stock size may theoretically be obtained by increasing age at first capture from 1 to 3 years when the fishing mortality is above 0.4.

4. Optimum sustained yield is considered by assuming density dependent recruitment (Fig. 4). It is found that the probability of overexploiting the stock is low if an age of 3 years at first capture could be maintained (Fig. 5). This is however impractical, and under the present circumstances the risk of overexploitation can not be ruled out if the fishing mortality exceeds 0.3. Since the expected gain in sustained yield by increasing fishing mortality above 0.3 in any case is rather small, this value is suggested as the limit chosen as a basis for a system of catch quota regulation of the fishery.

5. A prognosis of catch and stock size for the years 1972-1975 is given in Table 1. With the present regulations in force it is expected that the Norwegian catch of the North Sea mackerel stock in 1972 will be kept below 100 thousand tons.

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Table 1. Prognosis of catch and spawning stock of North Sea mackerel 1972-1975 for values of fishing mortality (F). For further explanation see text.

Year	Spawning stock (in 1000 tons)				Catch (in 1000 tons)				Mean weight (in grams)			
	72	73	74	75	72	73	74	75	72	73	74	75
F = 0.12	650	690	720	740	42	52	60	63	420	450	460	480
F = 0.20	650	660	660	660	81	89	94	94	420	450	460	470
F = 0.28	650	630	600	590	117	119	118	115	430	450	460	470
F = 0.36	650	600	560	530	151	143	135	128	430	450	460	460
F = 0.44	650	570	520	490	182	162	147	137	430	450	450	450

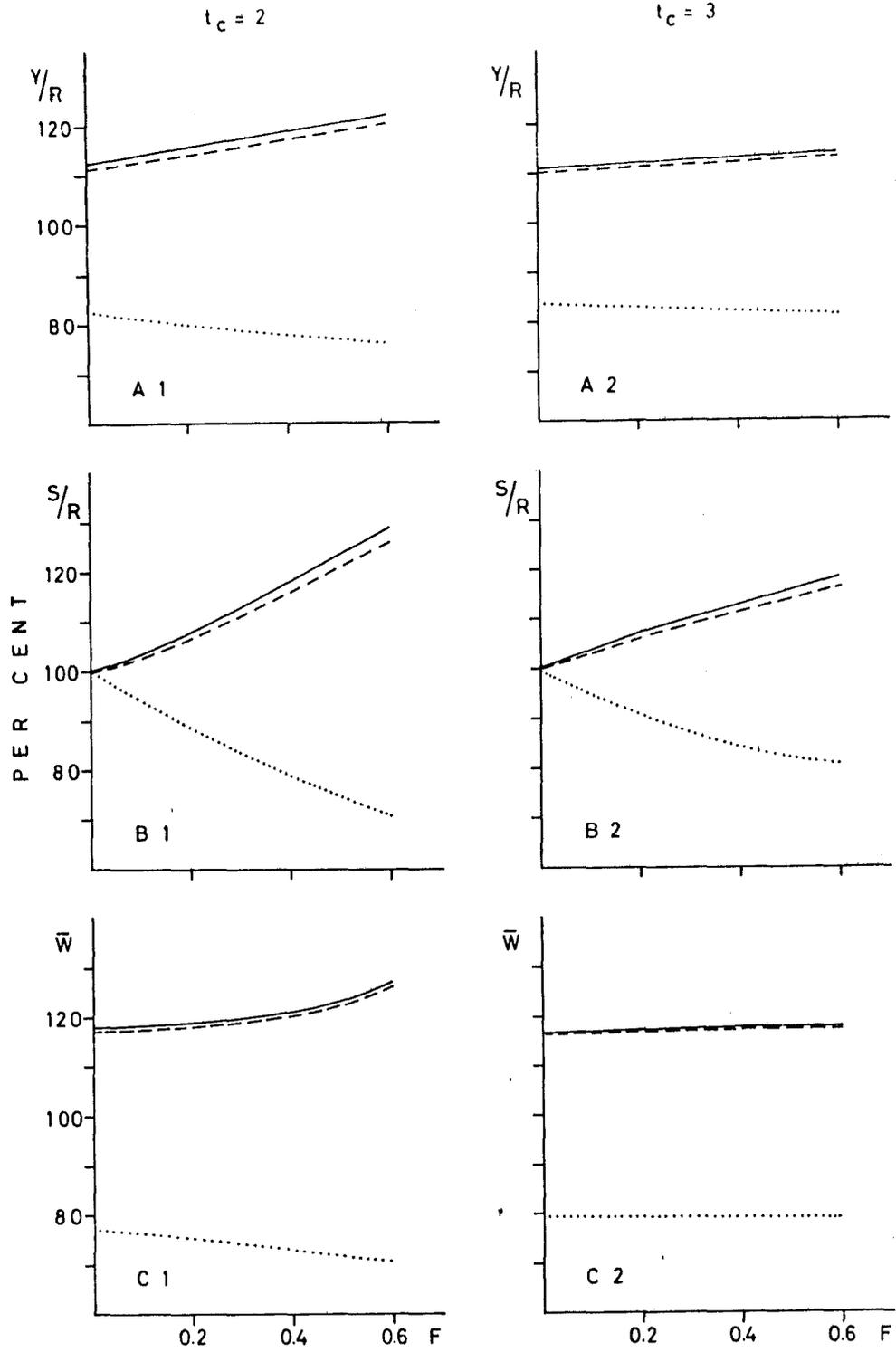


Fig. 1. Effects of closed season regulations by fishing mortality (F) and age at first capture (t_c) on yield per recruit (Y/R), spawning stock per recruit (S/R) and mean weight of fish in the catches (\bar{W}), in percent of the corresponding figures when fishing mortality is equally distributed throughout the year. The solid line illustrates a fishery limited to July-August only, the dotted line January-March. The broken line represents a fishing strategy corresponding to the closed season regulation in force.

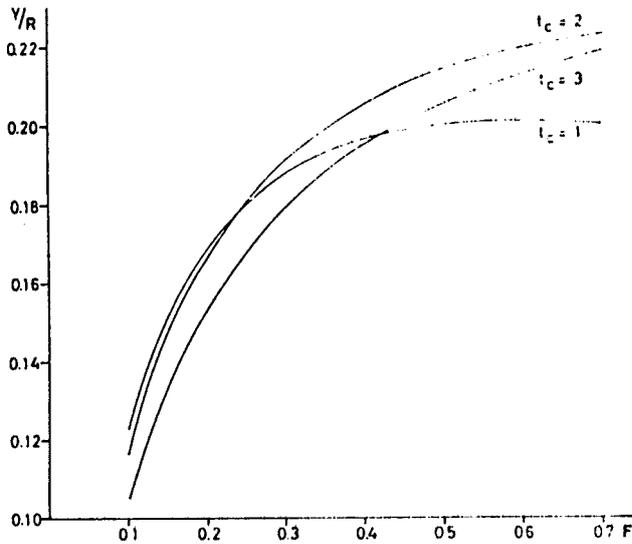


Fig. 2.

Yield per recruit (Y/R in kg) by fishing mortality (F) and age at first capture (t_c). Seasonal distribution of F as at present (see text).

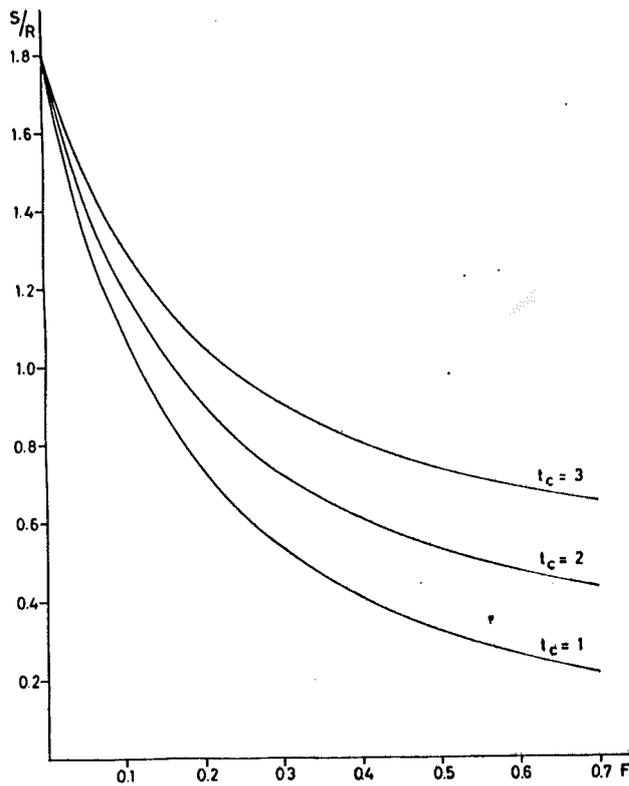


Fig. 3.

Spawning stock per recruit (S/R in kg) by fishing mortality (F) and age at first capture (t_c). Seasonal distribution of F as at present (see text).

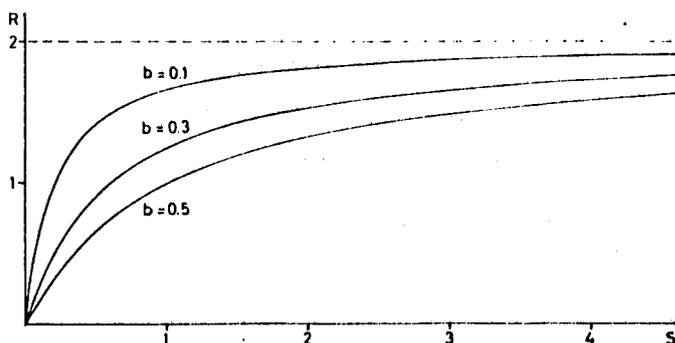


Fig. 4.

Stock-recruitment curves according to Beverton and Holt (1957). S denotes stock in million tons, R denotes number of recruits $\cdot 10^9$. For further explanation see text.

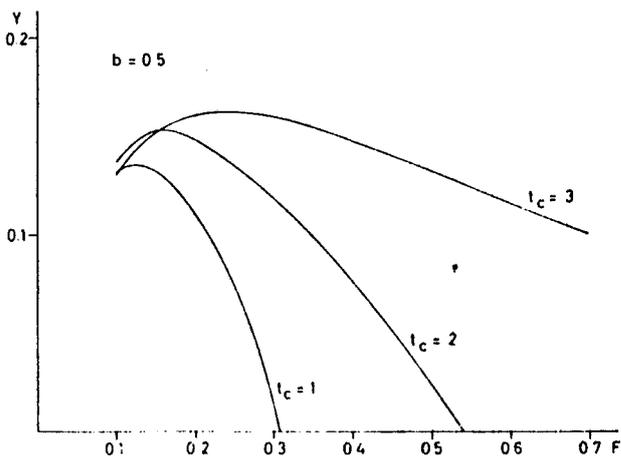
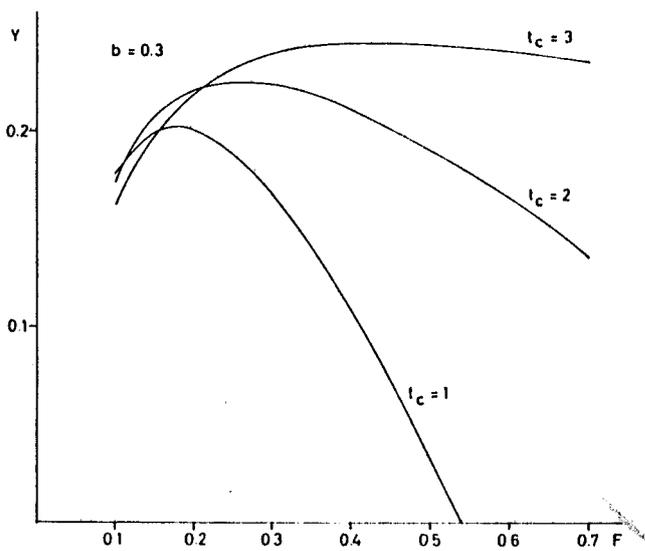
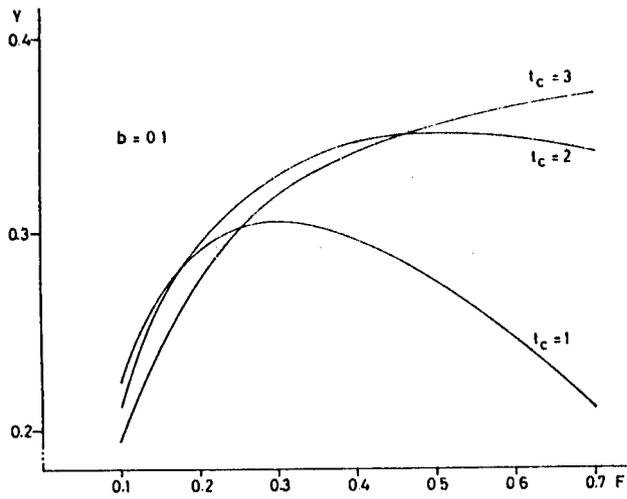


Fig. 5. Estimated sustained yield (Y in million tons) by fishing mortality (F) and age at first capture (t_c) for density dependent recruitment (see text).