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Some aspects of fishing patterns in relation to fishery management[1]

by

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1. Introduction

The development in fishing gears and fish detecting equipment during the last one or two decades and the far distant fleets ability to seek out the best fishconcentrations have in many cases lead to important changes in fishing patterns. Extention of the seasons and areas fished have increased the fishing pressure on many fish stocks, and the pressure may have increased especially on certain components of the stocks wich in earlier years were exploited only lightly. A stock wich traditionally was fished mainly during the spawning season may for example be fished more heavily during the whole year over its whole distribution area, one of the concequences often being that much more young (immature) fish are caught.

A heavy fishery on immature fish is a common factor for many stocks wich are overexploited or, in the worst cases, fished down to allmost complete extinction. In this paper fishery management is discussed especially in relation to those aspects of fishing pattern which implies heavy fishery on young

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(immature) fish. The discussion will be on a "one species basis", and the important problems in management connected with mixed fisheries and species interactions will thus not be dealt with.

2. Growth and recruitment overfishing

A heavy fishery on young (immature) fish will in most cases lead to a lower yield per recruit value than the maximum obtainable one, and in all cases to a strong decrease in the spawning stock per recruit (fishing on juveniles will reduce the spawning stock per recruit by the factor $\exp(-\sum_i F_i)$ where *i* is summed over the juvenile age-groups). The effect on the total long term sustainable yield will be the combined effect of the changes in yield per recruit and possible changes in recruitment level caused by changes in the size of the spawning stock biomass.

CUSHING (1972) distinguished "growth overfishing" from "recruitment overfishing". In the first, yield per recruit is reduced by too much fishing, but recruitment is not affected. In the second recruitment is affected as a result of a too low spawning stock.

Growth overfishing results in a lower long term sustainable yield than the maximum obtainable one. Also the catch per unit of effort will be reduced, and in addition the annual variation in yield will be higher than if the stock size was kept at a higher level because the catch will depend strongly on the strength of a few yearclasses.

Recruitment overfishing may very rapidly cause total collapse in stock because a reduced recruitment will cause a further decline in the spawning stock if management actions are not taken immediately.

A heavy young fish fishery will usually result in growth overfishing and in addition increase the danger for recruitment overfishing. Once it is observed that the spawning stock is too low to produce a yearclass of normal strength, it may be too late to take management actions, particularly in a situation where there is heavy fishing on immature fish. This was illustrated by the collapse of the Atlanto-Scandian herring stock. In 1969-1970 it became clear that the spawning stock was reduced to an alarmingly low level. Cohort analysis shows that the main reason for the strong reduction in the stock was the heavy fishery on immature herring in the late 1960's which completely stopped the recruitment to the spawning stock (DRAGESUND and ULLTANG, 1975). When the very low level of the spawning stock was observed in 1969 - 1970 the collapse was a reality because there was almost no immature herring left which could build up the spawning stock in the coming years. Suddenly one was in a situation where there was no spawning stock to produce recruits, and no immatures to build up the spawning stock. (The situation could have been a little improved if there had been a complete stop in the young herring fisheries from 1969 onwards which would have saved more of the not too poor 1969 yearclass).

3. The "maximum sustainable yield (MSY)" concept

Before embarking on the particular problems of fishing patterns in relation to management the author would like to briefly discuss the MSY-concept because of its broad usage and key position in management context.

It has become common in international fishery regulations to agree on total allowable catches corresponding to the level of fishing mortality giving the "maximum sustainable yield". In the way "MSY" in most situations have been calculated it is the yield corresponding to the fishing mortality "F_{MSY}" which gives the maximum yield per recruit under the existing selection pattern or age of first capture. This "MSY"-level of fishing does not necessarely give the maximum obtainable long term yield from the stock. Firstly, if the selection pattern or age of first capture is changed, "MSY" may change (and also the "F_{MSY}").

Secondly, it may well happen that a "F_{MSY}" causes decrease in recruitment (and therefore in yield) through a too low spawning stock, especially if the given selection pattern or age of first capture implies that a lot of immature fish are caught. This may in the worst cases cause total collapse in the stock. Thirdly, the yield a stock is able to maintain may be dependent on environmental conditions and the state of other stocks and therefore may vary from one time period to another.

For the reasons given above the traditional "MSY"-level of fishing does not necessarely ensure neither a maximum nor a sustainable yield. The "MSY"-concept in the way it has been used has caused a lot of confusion, and it should therefore either be clearly redefined or not used at all.

Because of lack of knowledge about the recruitment mechanism the fishing strategy which gives the maximum long term yield is not known for most of the fish stocks. This does not mean that nothing can be done in order to maximize the yield. If one

(a) minimizes the catch of fish below a certain size in order to take care of the growth potensial of fish,

(b) applies a fishing mortality F which on average is not higher than the F which gives maximum yield per recruit, but which gives a yield per recruit value near the maximum one, for example $F_{0.1}$ (ICNAF 1972),

(c) puts a lower limit on the size of the spawning stock in order to secure future recruitment, basing the choice of limit on historical records of spawning stock size and recruitment,

one would in most cases probably arrive at a fishing strategy giving a long term yield near the maximum obtainable one. Setting the constraint (c) means that in some years, the F may have to be set below the F-value arrived at under (b), while in other years a higher F may be applied, the actual F being chosen by looking both at stock size and agecomposition of the stock. The agecomposition is of importance for utilizing the growth potensial. If one or several strong yearclasses are recruited to the stock, giving a stock size well above the limit set by (c), one could profitably fish with a higher F than the value arrived at by (b) when the strong yearclasses have nearly reached their maximum biomass.

In addition to the constraint set by (c) one could also put an upper limit on the stock size in order to avoid reduced growth or increased natural mortality as a result of a too high stock size. The strongly reduced growth observed on the capelin in the Barents Sea in 1974 - 1975 was probably the result of extraordinary strong yearclasses recruiting the stock (ANON. 1975c). The capelin has been exploited to a rather high extent since 1970, but the main fishery has been on the prespawning and spawning capelin and thus has not significantly reduced yearclass strength in the immature part of the stock.

4. Special assessment and management problems created by fishing patterns with a heavy young fish fishery

When a stock is fished down through "growth overfishing" a bigger part of the fishing effort inevitably will concentrate on younger yearclasses (for the simple reason that there are few old fish) if it is not prevented from doing so. The scientists recommendations on total allowable catch will strongly depend on

a, Their estimates of the strength of the younger yearclasses.

b, Their opinion on how big the spawning stock should be, i.e. how large quantities of fish should be allowed to survive to maturity, in order to secure future recruitment.

Generally the estimates of the strength of the younger yearclasses have very wide confidence limits and often they are nothing more than assumptions or guesses. The ability of fishing fleets to consentrate their fishing on young recruiting fish often leads to a situation where the catch of a certain young yearclass is higher than may have been expected. One has, however, no means to decide whether the reason for this is that the yearclass is stronger than expected or that the fishing mortality is especially high on this yearclass as a result of the fishing pattern. This is especially a problem in many pelagic fisheries. Typical examples will be found in the assessments of the mackerel stocks in the Northwest Atlantic (ICNAF 1974, 1975) and of the North Sea Herring in the Northeast Atlantic (ANON. 1974, 1975a). At the time good estimates of yearclass strength are available very little may be left of the yearclass in question. The situation may be somewhat better in demersal fisheries, but also here changes in fishing pattern through aimed trawling with midwater trawls may make it difficult to get estimates of the strength of the younger yearclasses from the catch composition only (ANON. 1975b).

With a low age of first capture and a relatively high maturity age the spawning stock may be reduced below the critical level where recruitment is affected even with moderate annual fishing mortalities. The scientists advise on total allowable catch will of course have to depend strongly on what is regarded as a critical level for the size of the spawning stock. This problem will not exist to the same extent if there are no, or only a small, fishery on immature fish because the spawning stock will then be maintained at a much higher level.

It has proved to be difficult in for example the two fishery commissions for the northern Atlantic, ICNAF and NEAFC, to get agreement on catch quotas based on conservative estimates of strength of the younger yearclasses and a precautionary approach with respect to the critical level for the size of the spawning stock. Such quotas would often imply a temporary drastic cut back in catch without the managers knowing for sure that this is necessary.

Improvements in science which would enable firmer estimates on

a, the strength of younger yearclasses,

b, the quantities which should be allowed to survive to maturity in order to secure future recruitment,

would without doubt lead to more timely and appropriate management. Until such progress is made fishing of immature fish generally should be kept on a minimum or moderate level. In addition to (in most cases) an increase in yield per recruit this would ensure that better estimates of yearclass strength were available before a yearclass was fished in big quantities and that the size of the spawning stock in most cases would be above the critical level were there is real danger for recruitment failure.

5. Control of fishing pattern by management

5.1 Separate quotas on young fish and minimum legal size regulations

Where young and older fish are separated in area or depth or are schooling separately the young fish fishery may be restricted through separate quotas on young fish and/or minimum legal size regulations (zero quota on fish below a certain size). Such regulations make it possible to directly control the fishing mortality on young and older fish separately and may therefore be regarded as the best way of regulating a fishery whenever practicable.

5.2 Mesh size regulations combined with a total allowable catch

Mesh size regulations increase the first age of capture and decrease the fishing mortality on the youngest age-groups in the catch. In assessing the effect of mesh size regulations the possibility that a change in mesh size will influence the fishing pattern is usually not taken into account. Such an influence will generally increase the effect of a change in mesh size. This is illustrated by the very simplified example given below.

Assume one are fishing on a stock where

(i) Weights at age are equal to those for Arcto-Norwegian cod (ANON. 1973)

(ii) Natural mortality (M)= 0.2

(iii) Age of first spawning = 8 years

(iv) All fish younger than 8 years old are in an area A and all fish 8 years old and older are in an area B (separate from area A).

In Fig. 1 are given the yield per recruit and spawning stock per recruit for three different mesh selection alternatives assuming the same fishing mortality in the two areas A and B. The three mesh selection alternatives are as follows (F_i= fishing mortality on age-group i):

Selection a): $F_{i<3}= 0$ $F_3= 0.3F$ $F_4= 0.6F$ $F_5= 0.9F$ $F_{i>5}= F$

Selection b): $F_{i<4}= 0$ $F_4= 0.3F$ $F_5= 0.6F$ $F_6= 0.9F$ $F_{i>6}= F$

Selection c): $F_{i<5}= 0$ $F_5= 0.3F$ $F_6= 0.6F$ $F_7= 0.9F$ $F_{i>7}= F$

The curves are also given for the situation where there is no fishing in area A.

If a total fishing effort E_T is applied on this stock, splitted on E_A in area A and E_B in area B, and the relationship

$$F= q\,E$$ (F= fishing mortality, q= catchability coefficient)

is assumed to be valid in both area A and area B separately, a high fishing mortality in area A will imply a low fishing mortality in area B, and vice versa. We have:

$$E_T = E_A + E_B = \frac{F_A}{q_A} + \frac{F_B}{q_B} \quad , \quad \text{i.e.}$$

$$F_B = q_B \, E_T - \frac{q_B}{q_A} \, F_A$$

The catch per unit of effort in the two areas is given by

$$(C/E)_A = \frac{q_A}{F_A} \, C_A$$

$$(C/E)_B = \frac{q_B}{F_B} \, C_B$$

In Fig. 2 are shown for the three different mesh selections the yield per recruit in area A, area B and the total area together with the catch per unit of effort (per recruit) when

$$q_A = q_B = 1.2 \quad \text{and} \quad E_T = 0.5 \; , \quad \text{i.e.}$$

$$F_B = 0.6 - F_A$$

In the calculations it was assumed that a certain combination of F_A and F_B had been applied for a period sufficiently long for establishing an equilibrium situation.

For mesh selection a) the catch per unit of effort is higher in area A than in area B when $F_A < 0.51$ (i.e. $F_B > 0.09$). When $F_A > 0.51$ (i.e. $F_B < 0.09$) the catch per unit of effort is higher in area B. If it is assumed that the effort will go to the area with the highest catch per unit of effort, this will tend to establish an equilibrium situation at the point where $(C/E)_A = (C/E)_B$, i.e. $F_A = 0.51$, $F_B = 0.09$. The yield per recruit would then be 0.94.

If the mesh size is changed to alternative b) the catch per unit of effort in area A will decrease relative to area B. The equilibrium point where $(C/E)_A = (C/E)_B$ would in this case be at $F_A = 0.26$, $F_B = 0.34$. If F_A and F_B did not change, an increase in mesh size from a) to b) would give an increase in yield per recruit from 0.94 to 1.05 only. If in addition the fishing pattern is changed to the situation where $F_A = 0.26$, $F_B = 0.34$ as a result of the change in mesh size, the yield per recruit would increase to 1.33.

If the mesh size is changed to alternative c) the catch per unit of effort will be higher in area B than in area A for all possible combinations of F_A and F_B, i.e. all the effort would tend to go to area B, resulting in $F_B = 0.6$, $F_A = 0$, and a yield per recruit value of 1.63. Again, if the change in fishing pattern resulting from an increase in mesh size from b) to c) had not been taken into account, the estimated effect of the mesh size change would be an increase in yield per recruit from 1.33 to 1.44.

In Table 1 yield per recruit and spawning stock per recruit values are given for equilibrium situations estimated as above for four different sets of values of the parameters q_A, q_B and E_T. If $q_A = q_B = 1.2$ (as in Fig. 2) but $E_T = 1$, i.e.

$$F_B = 1.2 - F_A$$

all effort will be in area A for mesh selection a) creating a fishing mortality of 1.2. If mesh size is changed to alternative b) all effort still will be in area A, but there will be some increase in yield and spawning stock per recruit as a result of the mesh size change. If mesh size is increased to alternative c) some effort will be diverted to area B, but most of it will still be in area A. The situation must be characterized as highly unsatisfactory for all three mesh selection alternatives, and it illustrates a point made in an earlier section in this paper: In a "growth overfishing" situation created by too heavy fishing, effort inevitably will tend to concentrate on the younger yearclasses because of lack of old fish. In the case illustrated in the upper part of Table 1 ($E_T = 1$) the total fishing effort is so high that a moderate increase in mesh size from a) to b) will not increase the spawning stock size (the stock in area B) to the extent necessary to make the catch per unit of effort of mature fish higher than the catch per unit of effort in the young fish area, and all effort therefore still will concentrate on the recruiting yearclasses. If the total effort is cut down to half (E= 0.5) a change in mesh size from a) to b) will have a significant effect on the fishing pattern as illustrated in Fig. 2 and Table 1.

In the lower part of Table 1 the catchability coefficient in area A is assumed to be 0.6, i.e. half that assumed in the upper part of the table giving

$$F_B = 1.2 - 2\ F_A$$

and

$$F_B = 0.6 - 2\ F_A$$

for $E_T = 1$ and $E_T = 0.5$ respectively. The lower catchability coefficient in area A will have the effect of diverting more effort to area B. The mesh selection alternative b) will here be quite satisfactory even if total effort is set equal to 1 (it would of course be desirable to have a lower fishing mortality than 0.74 in area B, see Fig. 1). The table illustrates how a quite satisfactory situation may be turned to a highly unsatisfactory one if there is an increase in efficiency in the young fish fisheries. This could for instance be brought about by the introduction of pelagic trawls on off-bottom concentrations of young fish. A doubling in efficiency would mean to move from a situation in the lower part of the table to the parallell one in the upper part.

5.3. The effect on fishing patterns of greatly varying recruit-classes

The per recruit study illustrates how mesh size regulations and limitations on total effort (for example by a total quota) may change the fishing pattern. The main weakness with such studies is that changes in fishing pattern created by variations in yearclass strength are not taken into account. If a yearclass of many times "normal" strength recruits to the fishery, the fishing fleet will concentrate on this yearclass (if it is possible) as long as it is a dominating one. This may to some degree decrease the effects of mesh size regulations as illustrated in the following example:

Suppose a yearclass of 10 times normal strength recruits to the population used in the per recruit study and that $q_A = q_B = 1.2$ and $E_T = 0.5$ (as in Fig. 2). For selection a) the yearclass starts recruiting the fishery as 3 years old. There will then be a big increase in catch per unit of effort in area A which tends to draw all effort to this area, i.e. $F_A = 0.6$ and $F_B = 0$ (Fig. 3). For selection b) the same will happen at an age of four years old. For both selections all effort will be in area A until the yearclass is 8 years old. Then all effort, following the yearclass, is diverted to area B. In Fig. 4 the biomass in area A and area B is plotted against age of the strong yearclass. For selection a) so little is left of the yearclass at nine years of age that most of the effort will go back to area A. For selection b) no effort will go back to area A before the yearclass is 10 years old, and then only half of the effort will go back to that area. For both selections the fishing pattern will now gradually approach the equilibrium situation, i.e. $F_A = 0.51$, $F_B = 0.09$ for selection a) and $F_A = 0.26$, $F_B = 0.34$ for selection b). In Fig. 5 is plotted the catch and the accumulated catch from the year when the yearclass in 3 years old until it is 10 years old. In this period the accumulated catch is about 25 % higher for selection b) than for selection a) while in the equilibrium situation (yield per recruit) the difference would be about 41 %. The spawning stock (S_B in Fig. 4) at the time the yearclass becomes mature (8 years old) would be about 92 % higher for selection b) than for selection a).

In Fig. 6 is plotted the catch per unit of effort. Because effort is the same for the two alternatives the relative difference in catch per unit of effort will be equal to the difference in catch.

In Fig. 3 - 6 are also illustrated two alternative strategies having mesh selection b). In alternative I it is assumed that by separate quotas in areas A and B the fishing mortalities are all the time kept at the equilibrium point, i.e. $F_A = 0.26$ and $F_B = 0.34$. If it is not possible for practical reasons to have separate quotas in the two areas, one solution could be to set the total quotas so low that F_A is kept well below 0.6 the years when all effort will be diverted to area A, but allow an $F_B = 0.6$ when the yearclass has recruited the spawning stock. This is illustrated as alternative II in Fig. 3 - 6, assuming a total quota equal to the catch corresponding to $F_A = 0.26$ during the years when the strong yearclass is 4 - 7 years old. This implies no fishing on 8 years old and older fish during those years. Both these strategies gives a little higher accumulated catch (Fig. 5) over the period than fishing with the same mesh size but with no additional regulations. In addition the stock size at the end of the period is higher (Fig. 4) wich means higher catches also in the first coming years. Alternative II gives the highest catch per unit of effort of all strategies studied as would be expected when reducing the effort for some years.

The strategy giving maximum long term yield (in weight) would be not to fish in area A at all.

It should again be stressed that the example given above is very simplified. Especially the factors determining distribution of effort will be more complex in real situations. The example illustrates, however, that a mesh size which in an equilibrium situation protects young fish to a satisfactory extent will not necessarely do so when an outstanding yearclass is recruited and the fishing pattern changes with the relative abundance of young and old fish. It should be noted that a similar change in fishing effort from old to young fish as illustrated above also would take place if the stock of old fish for some reason has become exceptional low and yearclasses of normal strength recruit to the stock of young fish. In situations where mesh size regulations do not have the desired effect, relevant additional regulatory measures would be to set separate quotas on young and old fish or, if this is not possible for practical reasons, to set the total quota low enough to ensure that even if all the quota is taken as young fish the fishing mortality on this component will be kept at a relative low level. The temporary decrease in yield by such a strategy may then be more than counterbalanced by increased yield in future years.

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Table 1. Equilibrium situations for different combinations of catchability coefficients, total effort and mesh selection pattern

C_{max} = maximum sustainable catch when all effort is in area B. S= spawning biomass per recruit

S_v = spawning biomass per recruit in unexploited stock. For further explanation see text

q_A	q_B	E_T	Selection	E_A	E_B	F_A	F_B	C_A 1)	C_B 1)	C_T 1)	$(C/E)_A$ 1)	$(C/E)_B$ 1)	C_T/C_{max} 1)	S/S_v 1)
			a	1	0	1.2	0	0.79	0	0.79	0.79	0.22	0.482	0.010
		1	b	1	0	1.2	0	0.95	0	0.95	0.95	0.75	0.579	0.035
1.2	1.2		c	0.775	0.225	0.93	0.27	0.96(1.03)	0.28(0)	1.24(1.03)	1.24(1.03)	1.24(2.49)	0.756 (0.628)	0.065(0.115)
			a	0.425	0.075	0.51	0.09	0.80	0.14	0.94	1.87	1.87	0.573	0.090
		0.5	b	0.217	0.283	0.26	0.34	0.58(0.82)	0.75(0.23	1.33(1.05)	2.67(1.92)	2.67(3.12)	0.811(0.640)	0.144(0.148)
			c	0	0.5	0	0.6	0 (0.73)	1.63(0.39	1.63(1.12)	2.68(1.71)	3.26(5.20)	1.0 (0.683)	0.199(0.251)
			a	0.708	0.292	0.425	0.35	0.76	0.31	1.07	1.07	1.07	0.652	0.058
		1	b	0.383	0.617	0.23	0.74	0.54(0.76)	0.85(0.48)	1.39(1.24)	1.39(1.08)	1.39(1.65)	0.848(0.756)	0.089(0.090)
0.6	1.2		c	0	1	0	1.2	0 (0.65)	1.64(0.73)	1.64(1.38)	1.34(0.92)	1.64(2.50)	1.0 (0.841)	0.127(0.136)
			a	0	0.5	0	0.6	0	1.63	1.63	2.42	3.26	1.0	0.199
		0.5	b	0	0.5	0	0.6	0	1.63	1.63	1.94	3.26	1.0	0.199
			c	0	0.5	0	0.6	0	1.63	1.63	1.34	3.26	1.0	0.199

1) Figures in bracket refer to a situation where fishing pattern does not change when selection in changed from a) to b) or c) i.e. E_A and E_B for selection b) and c) are equal to E_A and E_B for selection a).

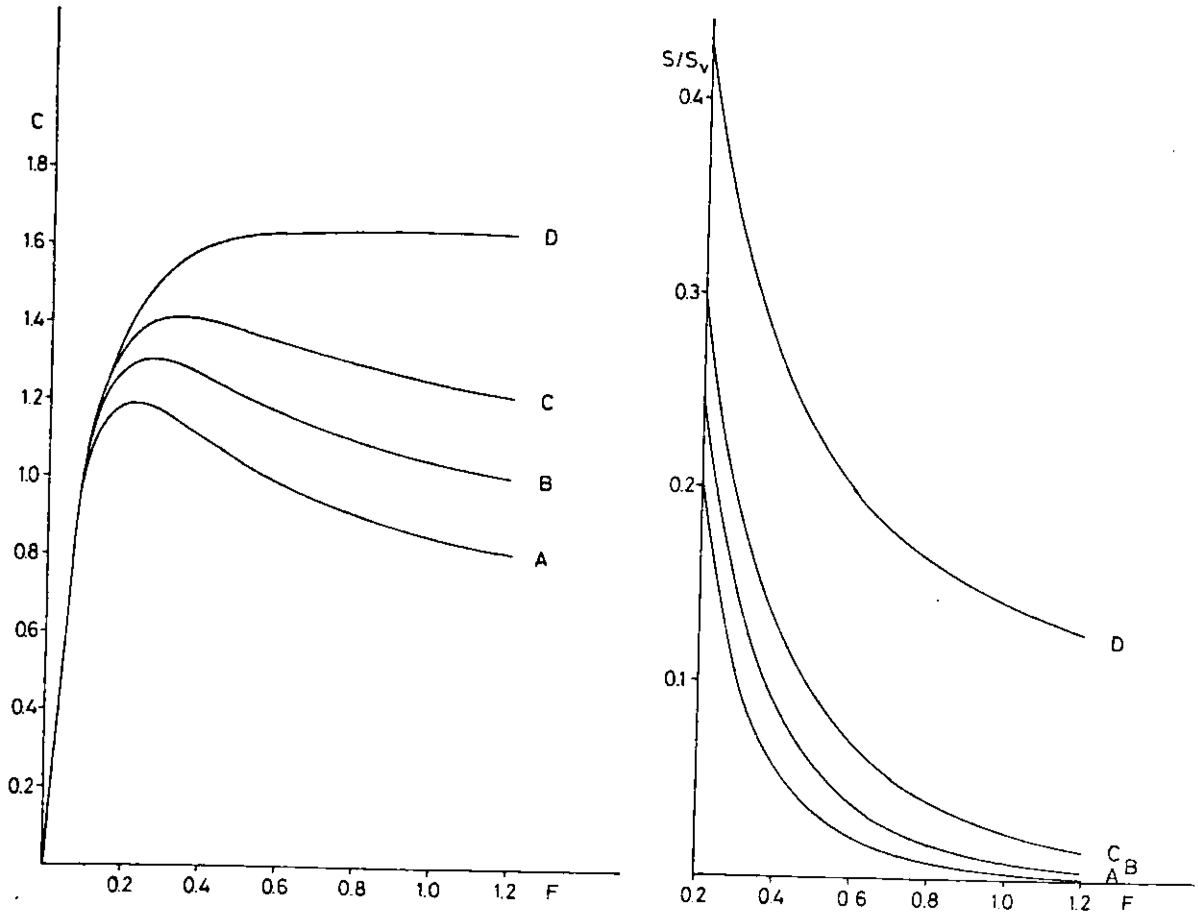

Fig. 1. Yield per recruit (C) and spawning stock per recruit (S/S_v where S_v = spawning stock per recruit in unexploited stock) against fishing mortality (F).

A: Mesh selection a)
B: Mesh selection b)
C: Mesh selection c)
D: No fishing in area A

For further explanation see text.

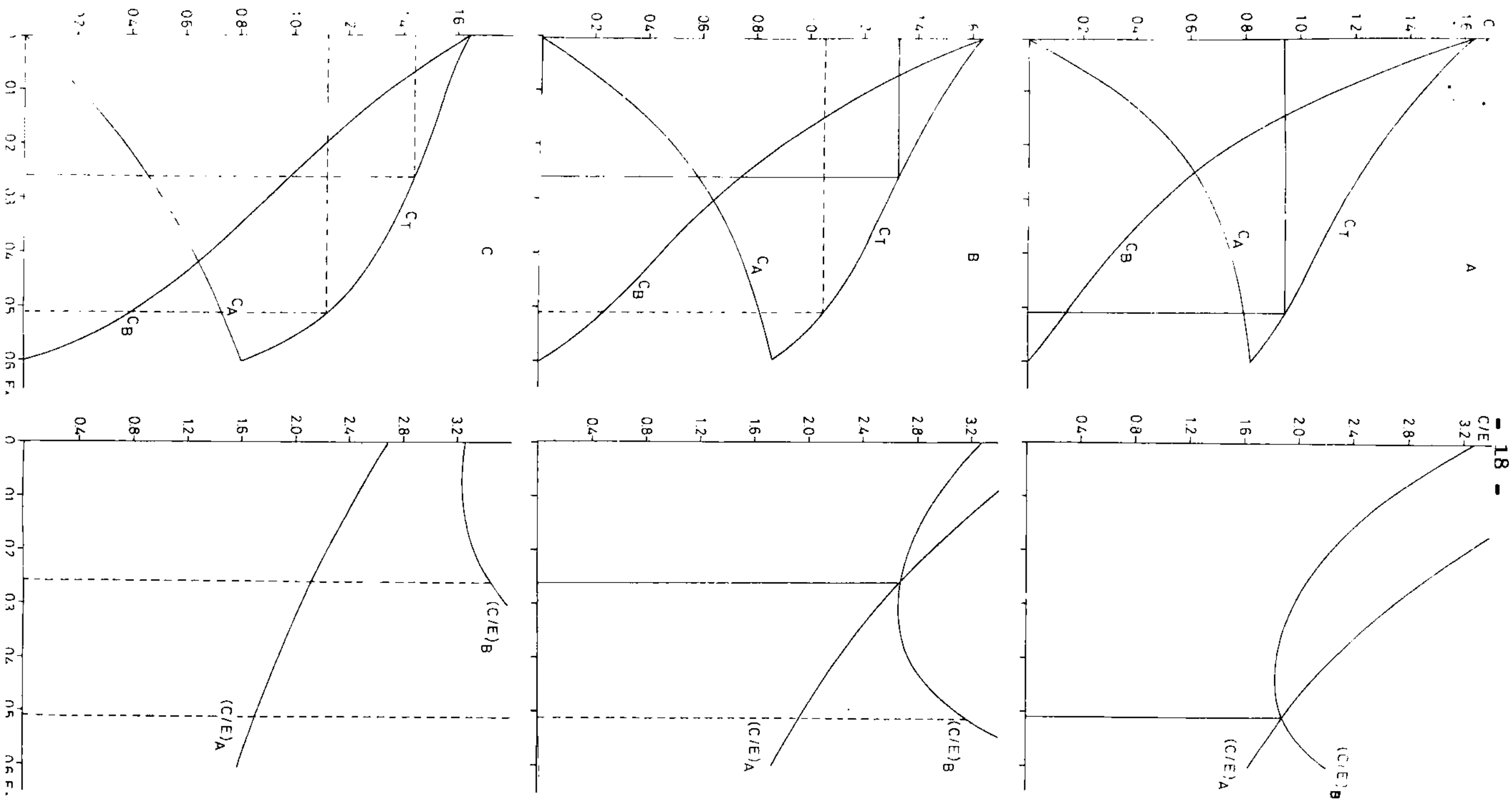

Fig. 2. Yield per recruit and catch per unit of effort (per recruit) for different combinations of fishing mortalities in area A (F_A) and area B (F_B) for mesh selection a (A), b (B) and c (C) when $F_A + F_B = 0.6$.
C_A, C_B and C_T: The yield in area A, area B and the total area respectively.
$(C/E)_A$ and $(C/E)_B$: The catch per unit of effort in area A and area B. For further explanation see text.

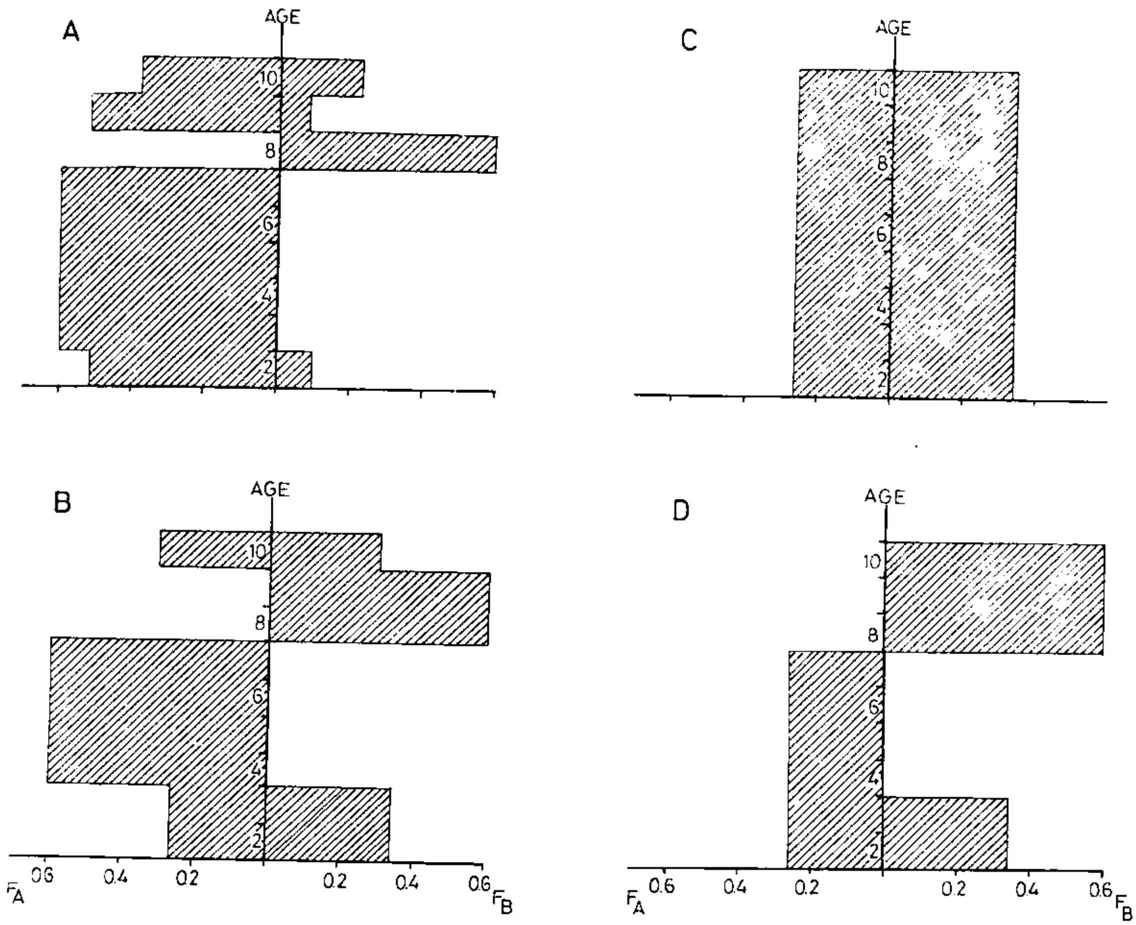

Fig. 3. Fishing mortality in area A (F_A) and area B (F_B) at different ages of strong yearclass.

A and B: Mesh selection a) and b) respectively, $F_A + F_B = 0.6$ and fishing effort goes to the area with highest catch per unit of effort.

C and D: Alternative strategies I and II respectively. For further explanation see text.

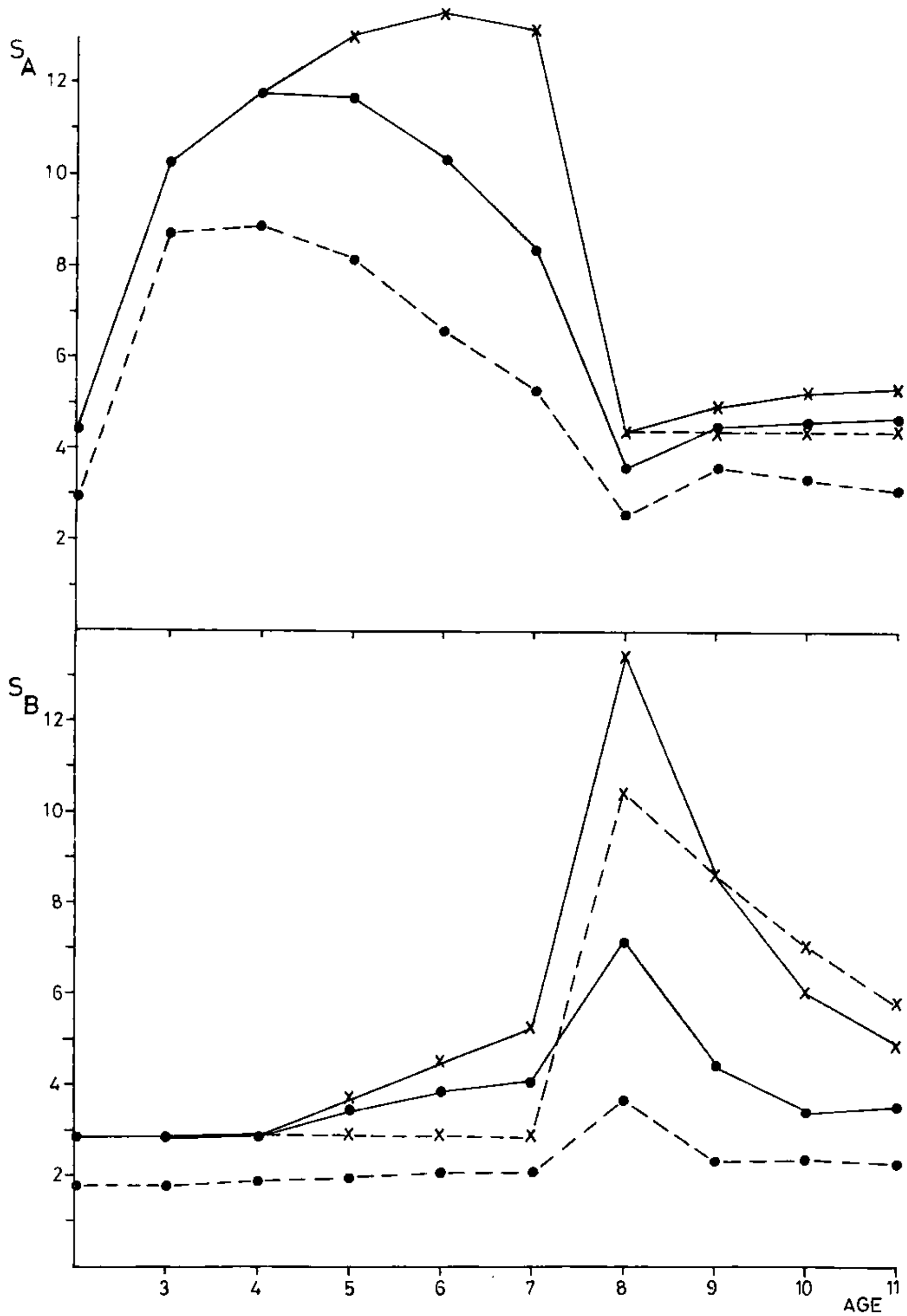

Fig. 4. Stock biomass in area A (3 to 7 years old fish) and area B

●– – ●– – ● and ●——●——● Mesh selection a) and b) respectively, $F_A + F_B = 0.6$ and fishing effort goes to the area with the highest catch per effort.

x– – x– – x Alternative strategy I

x——x——x Alternative strategy II

For further explanation see text.

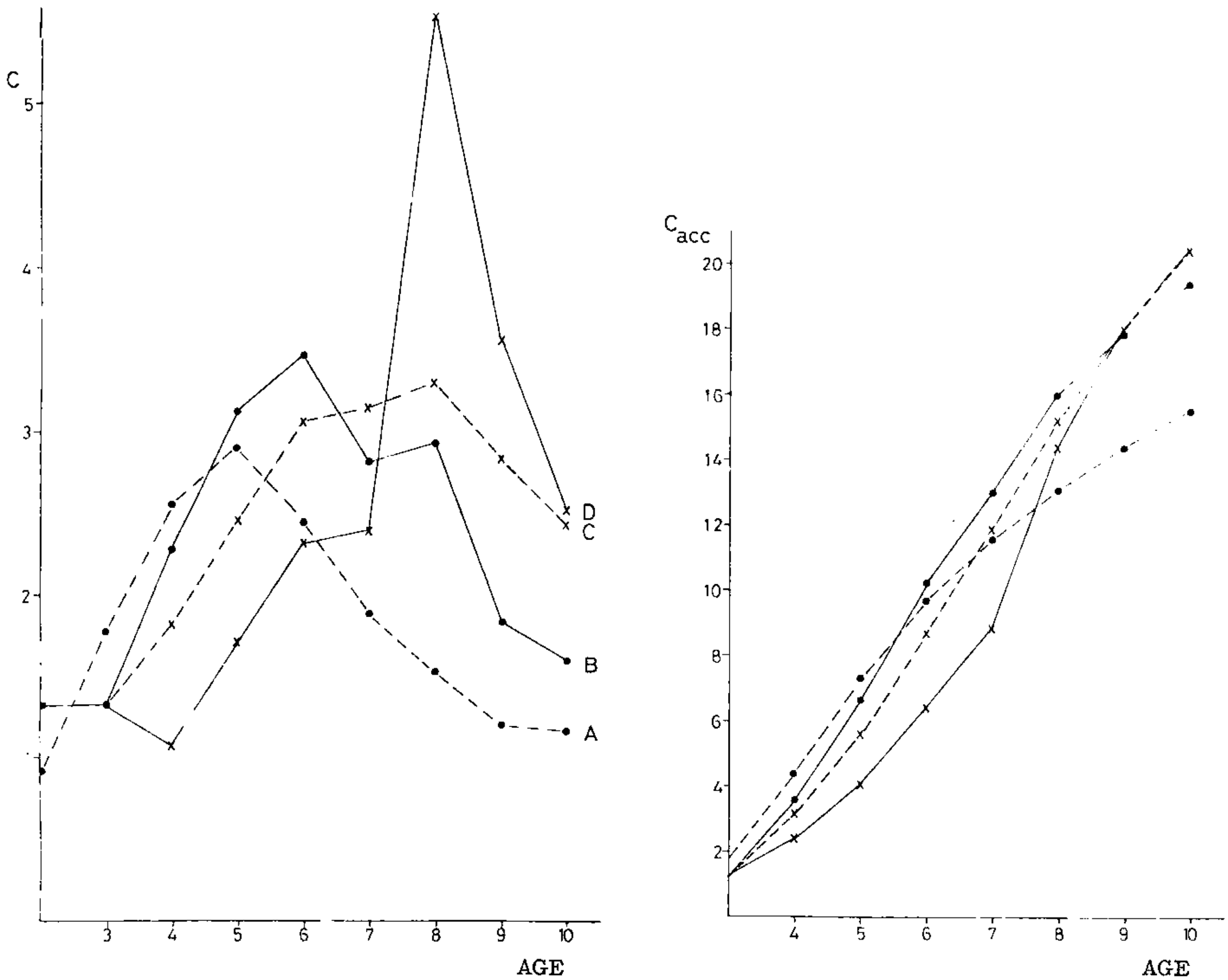

Fig. 5. Total catches (C) and accumulated total catches (C_{acc}) against age of strong yearclass. Symbols as in Fig. 4.

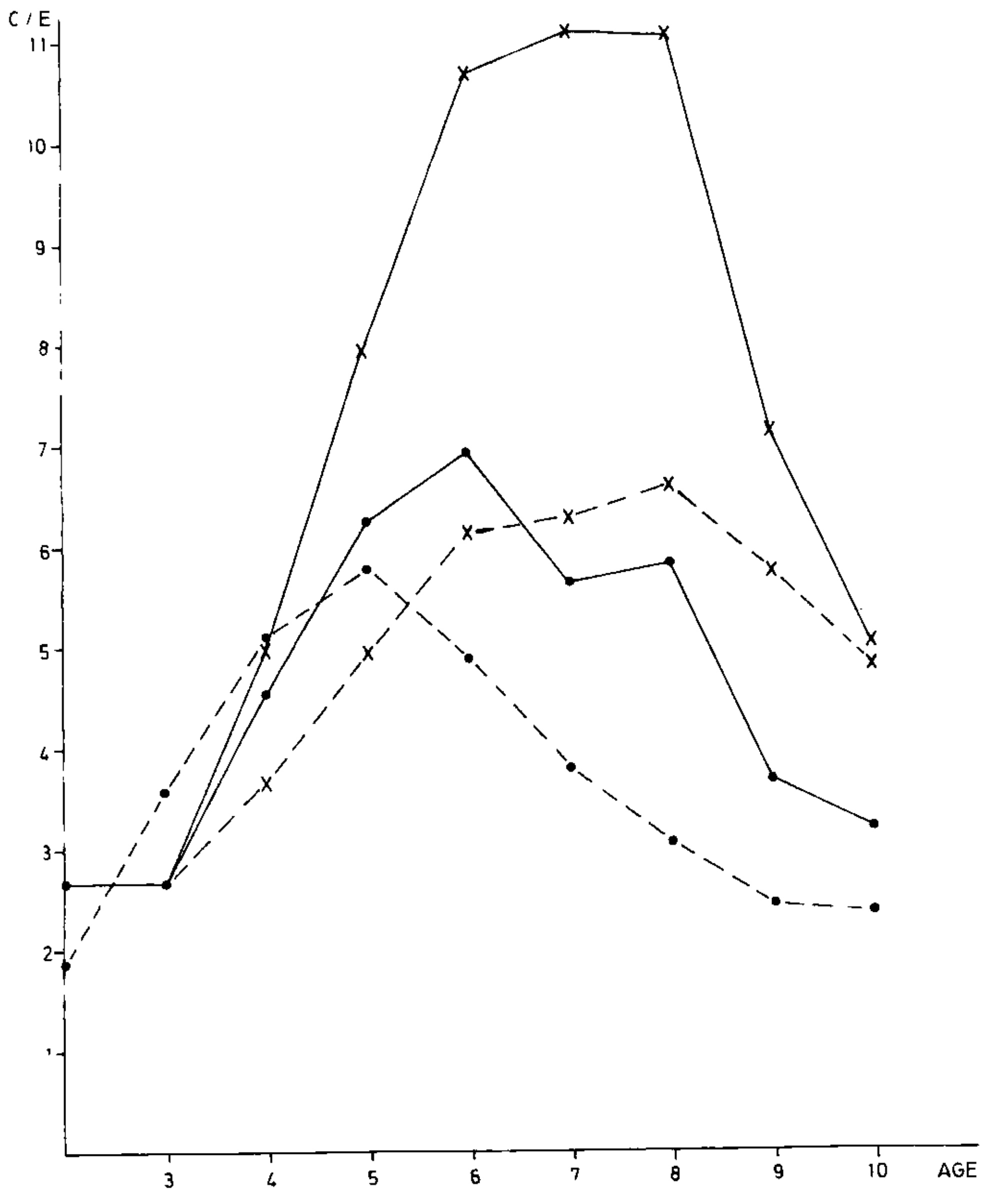

Fig. 6. Catch per unit of effort against age of strong yearclass. Symbols as in Fig. 4.