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Equlibrium Yield of Flemish Cap Cod From a General Stock and Recruitment Curve

by

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ABSTRACT

A bell shaped stock and recruitment curve was fitted to Flemish Cap cod data corresponding to the period 1959-1977 and the derived curves of surviving stock, residual stock, equilibrium CPUE and equilibrium yield were obtained permitting us to examine the effects of changing exploitation rates.

Two curves of sustainable catches were obtained, one of them corresponding to the stable equilibrium points and the other to the unstable ones. Both curves have an important discontinuity at fishing mortality F=0.45 and for larger values it is not possible to catch in equilibrium and a collapse can occur. The maximum sustainable yield is for F=0.35 .

SPECIAL SESSION ON RECRUITMENT

INTRODUCTION

The practical importance of the shape of a reproduction curve is best realized by analysing the equilibrium catch that it provides (Ricker,1975).

The yield curves permit us to examine the effects of changing exploitation rates upon the population parameters and the fishery itself. It is well known that the optimum fishing mortality or fishing effort can be obtained from these curves, whether for a maximum sustainable yield or a maximum economic yield (Anderson,1977).

The main problem to fit directly a production model, like those proposed by Schaefer (1957), Pella and Tomlinson (1969) or Fox (1970), to observed data of catch and effort is their inherent hypothesis of equilibrium, usually absent in fisheries, and the short interval of fishing mortalities or fishing effort data, making difficult their use since an equilibrium curve can be fitted to data representing a fishery operating out its equilibrium levels. To avoid these inconveniences the methods used by Ricker (1975) and Larrañeta (1981) to get a production curve from a stock and recruitment relationship are followed in this paper.

STOCK AND RECRUITMENT RELATIONSHIP

The time sequence of stock, recruitment and stock-recruitment data for Flemish Cap cod were calculated from the virtual population analysis (VPA) of Wells (1980) and are shown in figure 1. Though this VPA could have some inaccuracies, by comparing these data with other more recent VPA (Wells et al,1984) the same fluctuations of stock and recruitment were obtained in the coincident years (1972-1977), therefore the values of stock and recruitment calculated from the first mentioned VPA were used to fit the stock and recruitment models.

Two periods of different levels of stock are identified: the first one in 1959-1965 and the other in 1972-1977 when there was a significant reduction of stock abundance, like in figure 2, similar levels of catches (in numbers) for the two periods appear, but a substancial increase of fishing effort for the second period is shown (data from Gavaris,1981).

The following general model of stock and recruitment relationship is used (Gómez-Muñoz,1986), equivalent to the proposed by DeAngelis and Christensen (1980) but without its restrictions:

$$R= G(S)= \frac{ASexp(-BS)+ABCS^2exp(-BS)}{1+DS+AESexp(-BS)} \qquad (1)$$

where S is stock, R recruitment and the parameters A,B,C,D and E are related with natural coefficients as follows:

$$A= \alpha\, exp(-M_1 t_r)$$

$$B= k\, \alpha\, t_r$$

$$C = \frac{1}{M_1 t_r}$$

$$D = \frac{B + \alpha M_2 t_r}{M_1 t_r}$$

$$E = -\frac{M_2}{M_1}$$

and

M_1= Density independent mortality

M_2= Density dependent mortality

k= Stock dependent mortality

α = Mean fecundity

t_r= Recruitment age

This model contains the Ricker's model curves (for E=0) and the Beverton-Holt's model curves (for B=0).

The general model parameters fitted to Flemish Cap cod data, estimates of natural coefficients, the curve fitted and observed values are shown in figure 3, where a bell shaped curve is shown with a slope at the origin very low (parameter A of general model) and an inflection point between the origin and the maximum recruitment point. The last four years of these data are in that zone and it is possible to forecast a difficult recruitment recovery because of the low **slopes** there. The stock dependent mortality appears in figure 3 as the main cause of natural mortality in the early stages of these fishes.

The same figure 3 contains the usual fittings of a Ricker and Beverton-Holt curves from linear regressions of their respective models to these data. The sume of squares of deviations are included for each model for comparative purposes.

The most important consequence of a bell shaped stock and recruitment curve is that it will generate two equilibrium situations, one of them stable and the other one unstable and therefore inapplicable. These facts will be analysed in the next section.

EQUILIBRIUM YIELD

Assuming the stock-recruitment relationship (1), that is to say, the dependence of recruitment of the stock size is given by this expression, the equilibrium situation that recruitment and spawning stock sizes are constants, denoted here by R' and S' respectively, generates the following formulations:

For the recruitment age t_r, the first reproduction age t_R, the last age present in the fishery t_f and the total mortality coefficient $Z=F+M$ (with natural mortality M constant) the following expression is obtained:

$$S' = R' \exp(-Zt_d)\cdot(1+\exp(-Z)+\exp(-2Z)+\cdots\cdots+\exp(-Zt_p)) \qquad (2)$$

where $t_d=t_R-t_r$ and $t_p=t_f-t_R$

Putting $H(F)= \exp(-Zt_d)\cdot(1+\exp(-Z)+\exp(-2Z)+\cdots\cdots+\exp(-Zt_p))$

and using the expression (1) with the calculated parameters for Flemish Cap cod (figure 3), one obtains:

$$S' = G(S')\cdot H(F) \qquad (3)$$

Solving the expression (3) for S', the equilibrium stock size for each value of fishing mortality is obtained. The equilibrium recruitment size is $R' = G(S')$ and the equilibrium CPUE is proportional to R'/Z (Ricker, Op. cit.). The equilibrium yield is proportional to $R'F/Z$ (larrañeta, 1981).

For arbitrary values of stock S, the corresponding surviving stock at spawning time is $G(S)\cdot H(F)$, then the solutions S' of expression (3) are the intersections of the surviving stock curve and the diagonal line (figure 4a).

The surviving stock above this line is the residual stock, that is to say, values of stock that may be removed from the population without violating the equilibrium situation. From figure 4a one can also deduce that near the second equilibrium point the future values will shift to this point, therefore the larger equilibrium points are stable. On the contrary, the first equilibrium points are unstable because the fishery tends to the origin near this zone, therefore one could not apply the resulting curve in practice. These are only theoretical equilibrium points.

In figure 4b the residual stock curve for each value of stock are shown ($G(S)\cdot H(F) - S$), within the observed interval of stock for this fishery. Each curve corresponds to one fishing mortality and its two intersections with the horizontal axis, if one exists, are the equilibrium stock sizes. Figures 5, 6 and 7 are amplifications near the origin for several values of low fishing mortalities. Figure 5 shows that the minimum stock size in equilibrium without fishing is $S' = 0.6$ millions of fish, below this value the population would be decreased to extintion only with natural mortality. Figure 6 also shows the first equilibrium stock sizes for fishing mortality between 0.1 and 0.4 .

From figure 4 one deduces that the maximum permissive fishing mortality to maintain a stock in equilibrium is between 0.4 and 0.5 and figure 7 shows the corresponding residual stock curves for F= 0.4,0.41,0.42,...,0.49 and 0.5 where one finds that this fishing mortality is about 0.45 and for larger values the population would be graduatelly decreased. This situation is more clearly observed in figure 8, where the index of equilibrium CPUE and yield curves are shown respectively for values of fishing mortality between 0.0 and 0.5 . The upper curve in each graphic in this figure is generated for the larger equilibrium stock sizes. Below is that generated for the lower equilibrium points. These two equilibrium points can be easily observed in figure 7 where the corresponding curves of surviving stock and residual stock appear for each fishing mortality. For F=0.45 there are not equilibrium points, then an important discontinuity in the equilibrium CPUE and yield curves is generated (figure 8); for larger values of F than 0.45 there are not equilibrium points and therefore the stock will be led to collapse. The maximum sustainable yield corresponds to F=0.35.

The last theoretical consideration about this topic is that the upper equilibrium stock values produce an equilibrium yield curve like a Pella-Tomlinson curve for $m > 2$ (Pella and Tomlinson, Op. cit.) though the dotted line does not pertain to the yield curve derived from this method.

DISCUSSION

The method followed in this paper to obtain an index of equilibrium yield curve from a stock and recruitment fitting permits us to propose administrative regulations to maintain the fishing effort or the fishing mortality at a suitable level, whether to improve the fleet operation or to prevent a collapse.

Unfortunately it is not possible to deduce quotas in this way because of the equilibrium CPUE and yield curves obtained do not have their actual values and can be used only as index of equilibrium CPUE and yield respectively.

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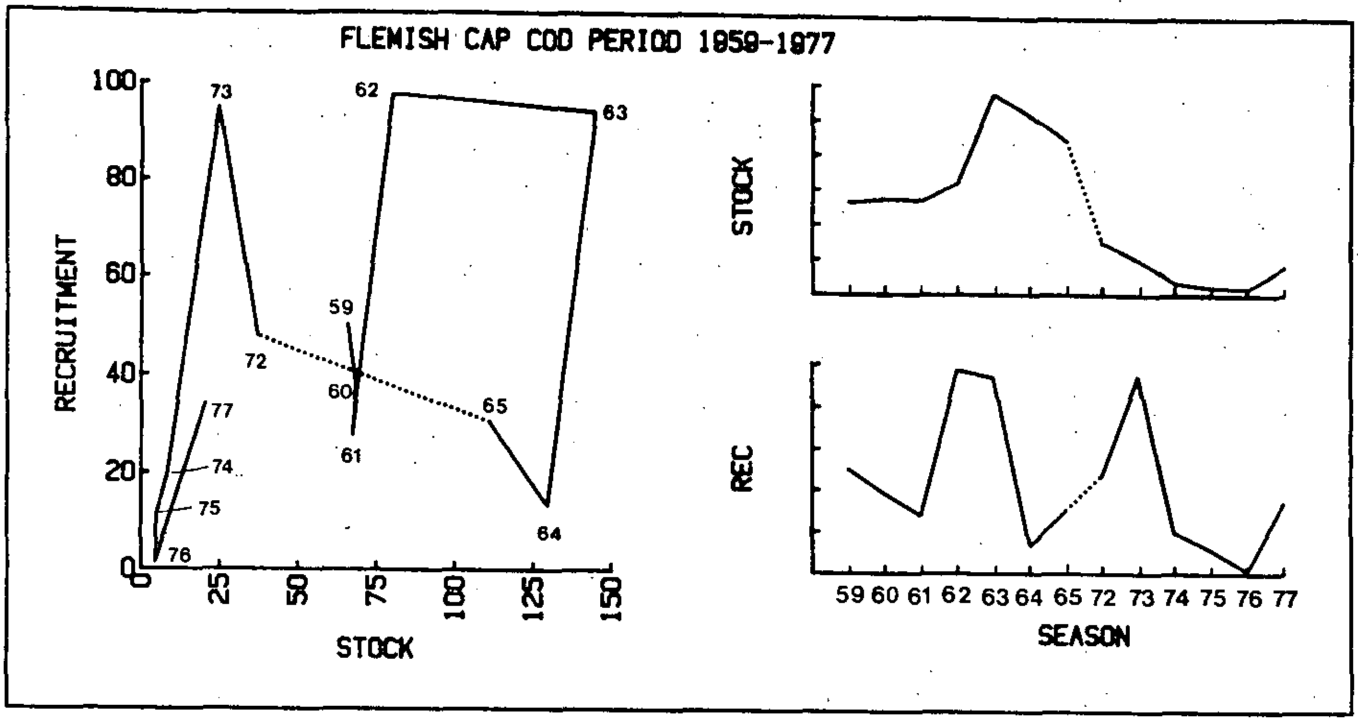

Figure 1. Time sequence on stock, recruitment and stock-recruitment data of Flemish Cap cod calculated from VPA of Wells (1980).

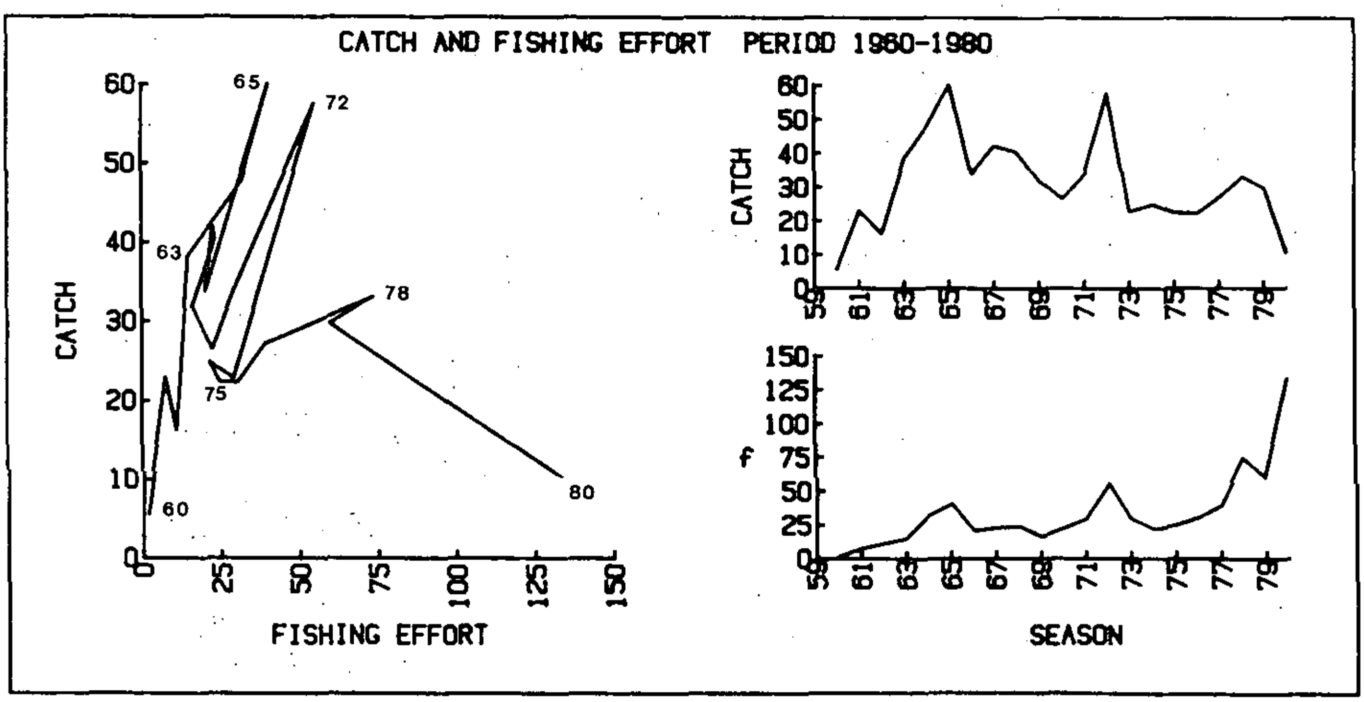

Figure 2. Time sequence on catch (t), standardized fishing effort (hr) and catch-fishing effort of Flemish Cap cod data from Gavaris (1981).

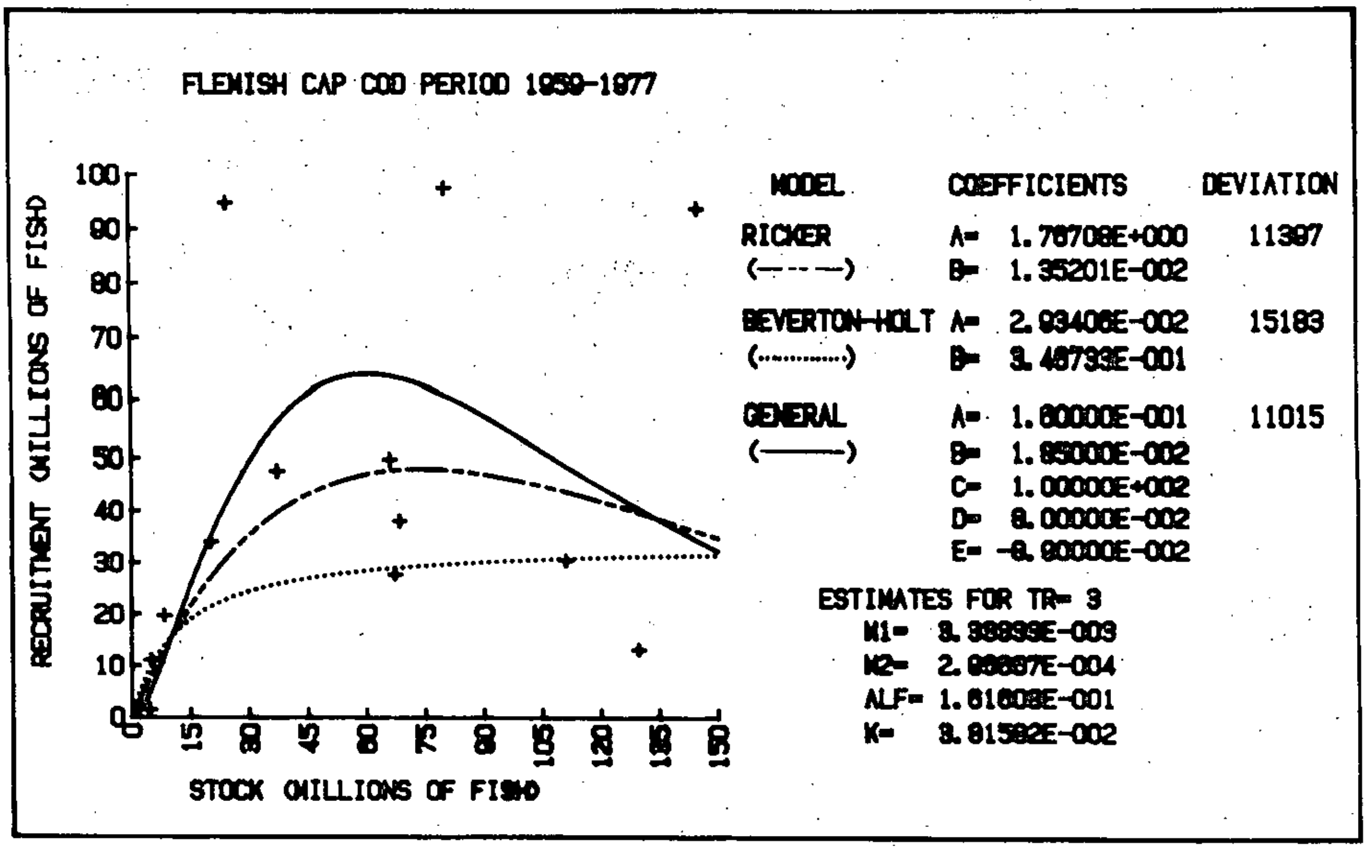

Figure 3. Stock-recruitment curves and their parameters fitted on Flemish Cap cod data calculated from VPA of Wells (1980). General model: (——), Ricker's model: (—--) and Beverton-Holt's model: (...).

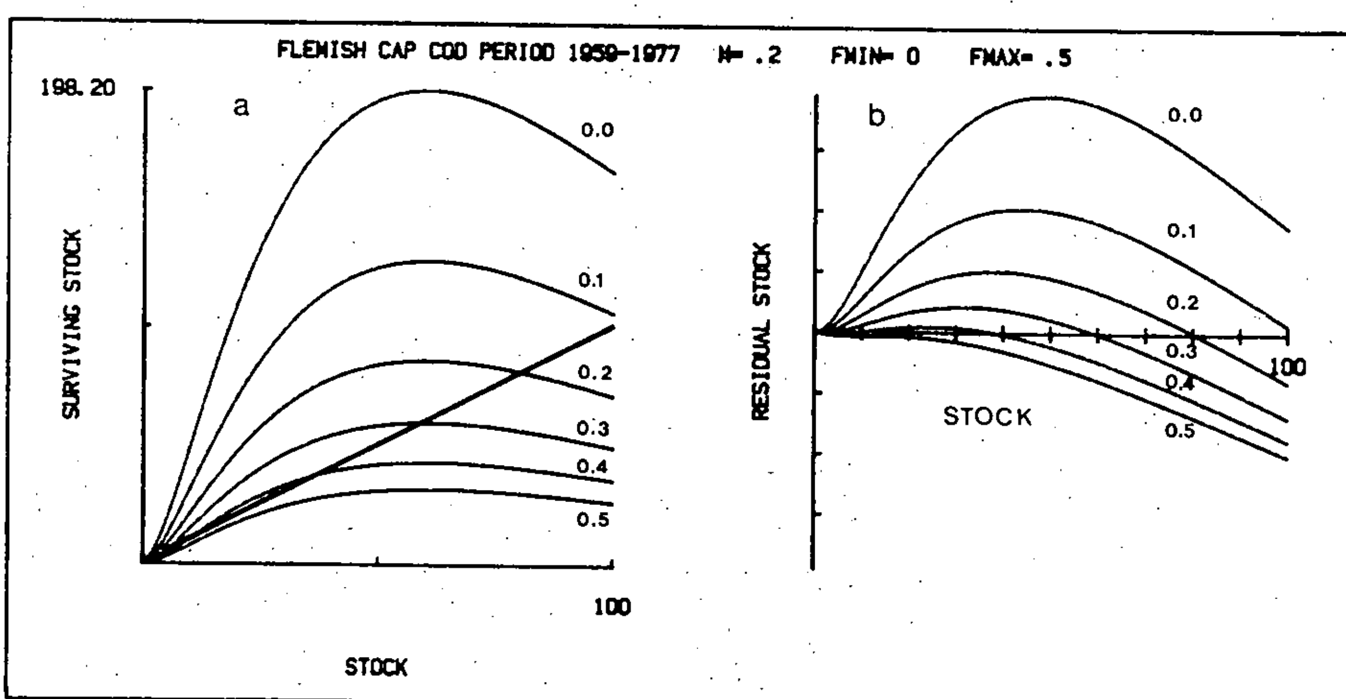

Figure 4. Surviving and residual stock for different levels of fishing mortality.

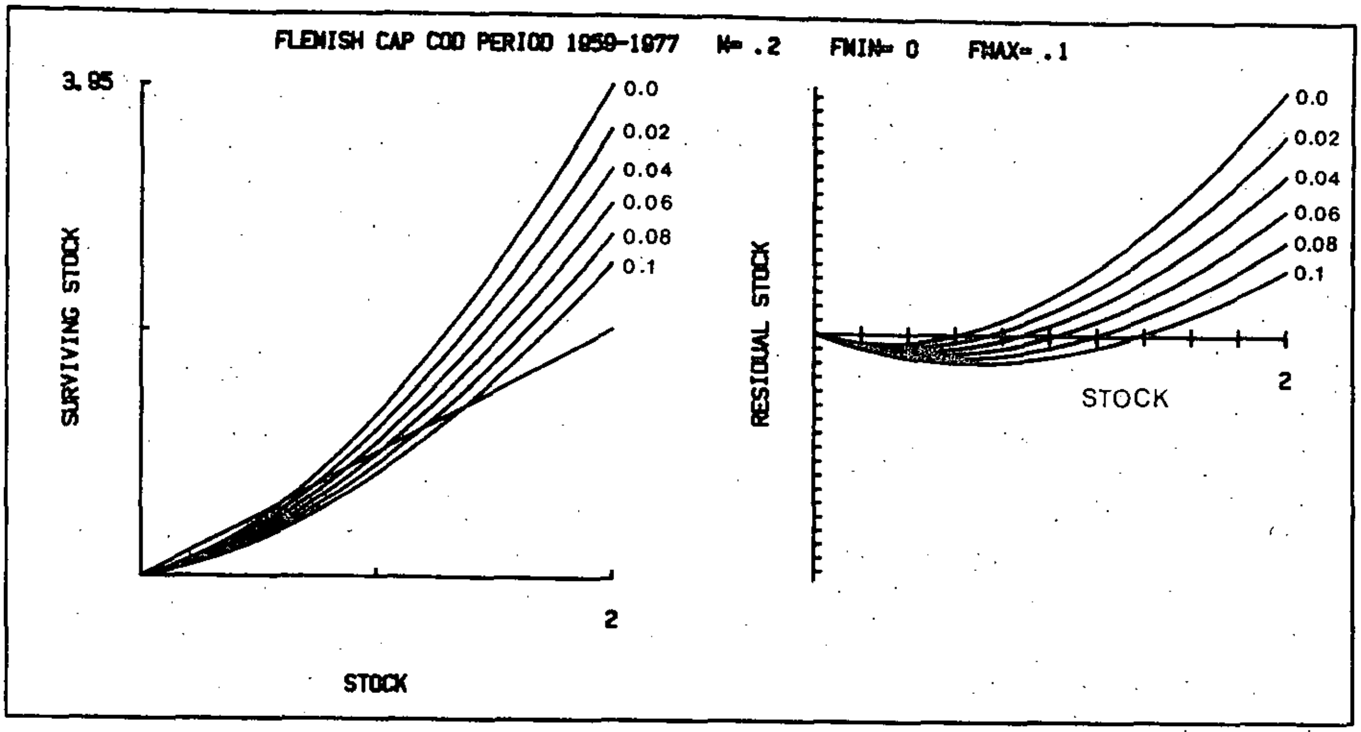

Figure 5. Surviving and residual stock near the origin for low levels of fishing mortality. The lower equilibrium stock sizes are shown.

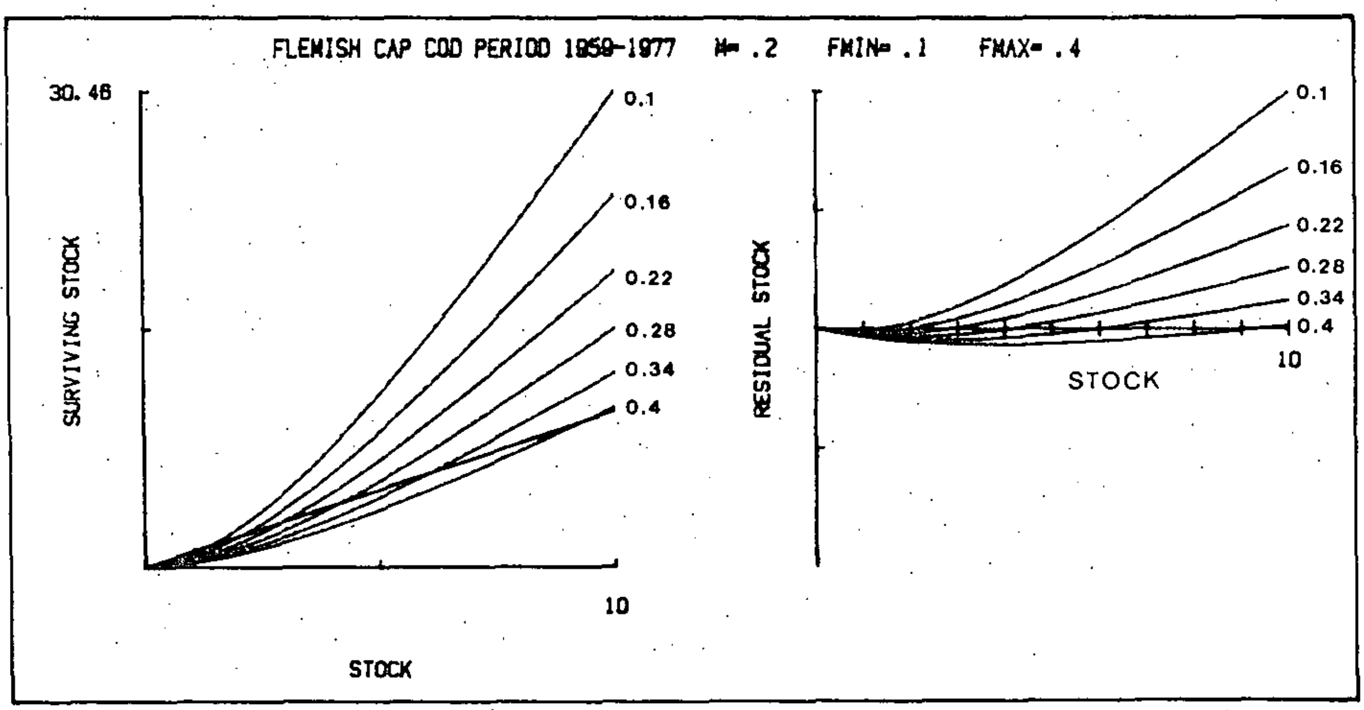

Figure 6. Surviving and residual stock sizes for fishing mortality F between 0.1 and 0.4 . All curves intersect the lines and the lower stock in equilibrium still exit.

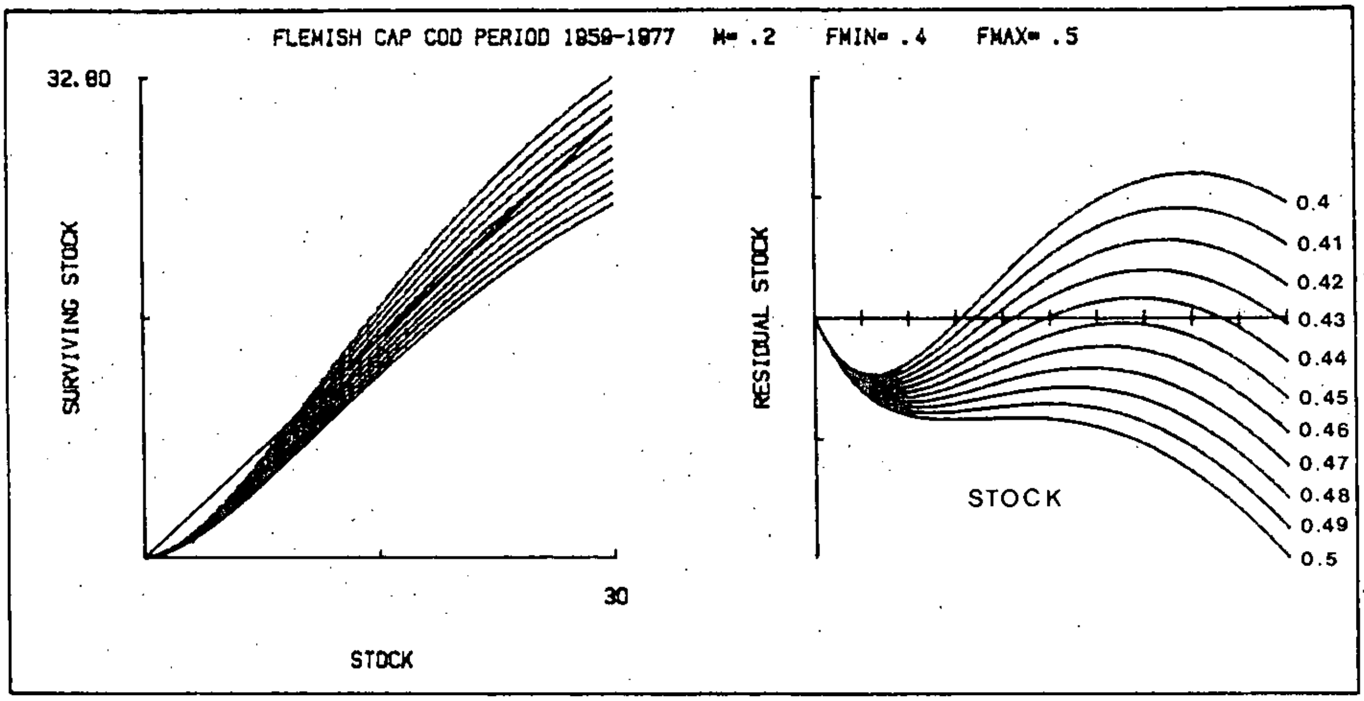

Figure 7. Surviving and residual stock for fishing mortality between F=0.4 and F=0.5 . The corresponding curves for F=0.45 do not intersect the lines and the equilibrium stock do not exist for this F and greater values.

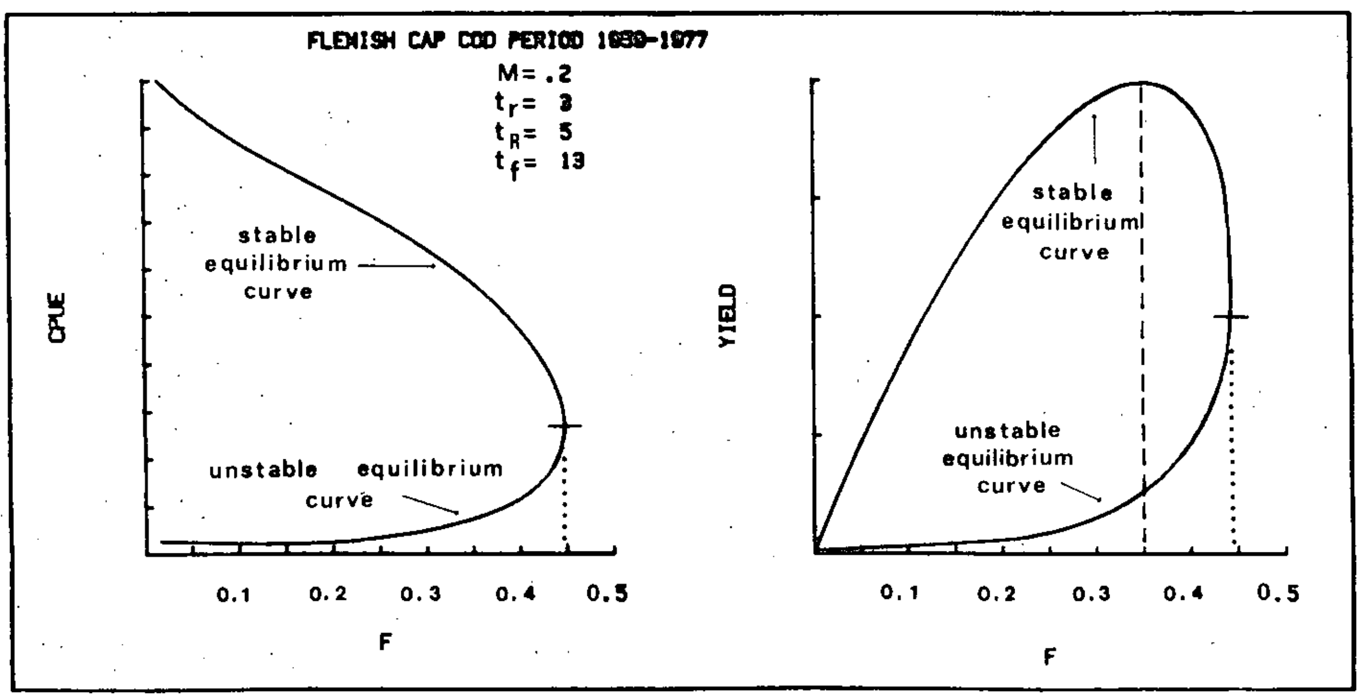

Figure 8. Equilibrium CPUE and yield curves in arbitrary units. The upper curve in each graphic is generated for the larger equilibrium stock sizes which are stables. Below is that generated for the lower and unstable equilibrium stock sizes.