

A PROPOSAL FOR STOCK ASSESSMENT AND MANAGEMENT IN MIXED STOCK FISHERIES : THE IN / OUT MODEL. APPLICATION TO WESTERN ENGLISH CHANNEL COD.

Clara ULRICH, Didier GASCUEL, Olivier MAURY

Laboratoire Halieutique, ENSAR, 65 rue de Saint Briec, 35 042 Rennes Cedex, France

P : (+33) (0)2 99 28 54 56, F : (+33) (0)2 99 28 75 35

Email : ulrich@roazhon.inra.fr ; dgascuel@roazhon.inra.fr ; maury@roazhon.inra.fr

Abstract : It may occur that a stock has to be considered for management purposes at a scale different from the one at which it is assessed. For the needs of an european project dealing with bioeconomic modelling of English Channel fisheries (ICES divisions VIIId-VIIe), we try to assess the local production functions of many species (i.e. Channel production vs. Channel fishing effort), whose stocks spatial limits lie well beyond the Channel boundaries (either in the Celtic Sea-Bay of Biscay or in the North Sea).

In order to solve this issue we propose here a model called IN / OUT Model. The Channel catches are considered to be made up of two components : a fraction α that comes from the global stock, whose distribution covers also areas outside of the Channel (OUT component), and a fraction $1-\alpha$ that comes from a stock considered as local (IN component). Each stock supports a fishing mortality, assessed by VPA. The model enables to explore the sensibility of the local production function to α .

The method is then applied to the western Channel cod. We show that for a large rank of values of α , the model leads to consistent local functions, fairly different from the ones calculated at the scale either local ($\alpha = 0$) or global ($\alpha = 1$). Means to assess α more precisely are discussed.

INTRODUCTION

A fish stock is defined as the fraction of a population that can be exploited. It is a management unit, or a portion of a fish species that is delineated for the purposes of management, whereas the population is assumed to be a genetic unit (Laurec & Le Guen, 1981). It is normally considered that the boundaries of the stock fit the boundaries of the population, and yet many fisheries are managed globally, on very large areas, assuming an homogeneous distribution of fishes and fleets. But considering one single stock for management when the truth would admit several sub-stocks may lead to large differences in long term dynamics and assessment (Waldman & Fabrizio, 1994), whose consequences may be irreversible (Selgeby, 1982 ; Cury & Anneville, 1997). The problem of non assessed sub-stocks has to be kept in mind when one wants to manage one given fleet or area, whose fishing effort doesn't cover the whole area of distribution of the assessed stock. Increasing this effort may not deplete significantly the stock at its whole scale, but the potential local stocks pooled into regional groups may suffer seriously from such a trend.

For the needs of an european project dealing with bioeconomic modelling of English Channel fisheries (ICES areas VIIId-VIIe), we try to assess the local production functions of all main species (i.e. Channel

production vs. Channel fishing effort). For some of them (especially the ones assessed by ICES working groups), stocks spatial limits lie well beyond the Channel boundaries (either in the Celtic Sea-Bay of Biscay or in the North Sea), and Channel fleets account for a small part of total catches. Yet, management policies on Channel fleets won't have any significant effect on stocks in their whole. But auxiliary studies, directed towards the delineation of fish stocks, showed that for some of these species, local sub-stocks may co-occur with the global stock within the Channel boundaries (Anon., 1993).

The purpose of this work is to present an investigation method in order to assess both local and global stock and to measure the effects of change in fishing effort on them, depending on a factor α , that represents the «degree of co-occurrence» of both stocks within the area to be managed.

I. METHOD

1.1. Different components of the stocks

We consider 2 areas, A and B. A represents the area to be managed, whose fishing effort will vary in the simulations, and B is all the rest of the stock distribution. Fishing effort in area B remains constant during all simulations.

Within this total distribution (A+B), fishes are divided into 2 sub-stocks, a global one (1), which covers the area B and a part of area A, and a local one (2), which occurs only within the area A. Catches in area A are considered to be made up of two components : a fraction α that comes from the stock 1 (OUT component), and a fraction $1-\alpha$ that comes from the stock 2 (IN component). Distribution of catches are shown schematically on figure 1.

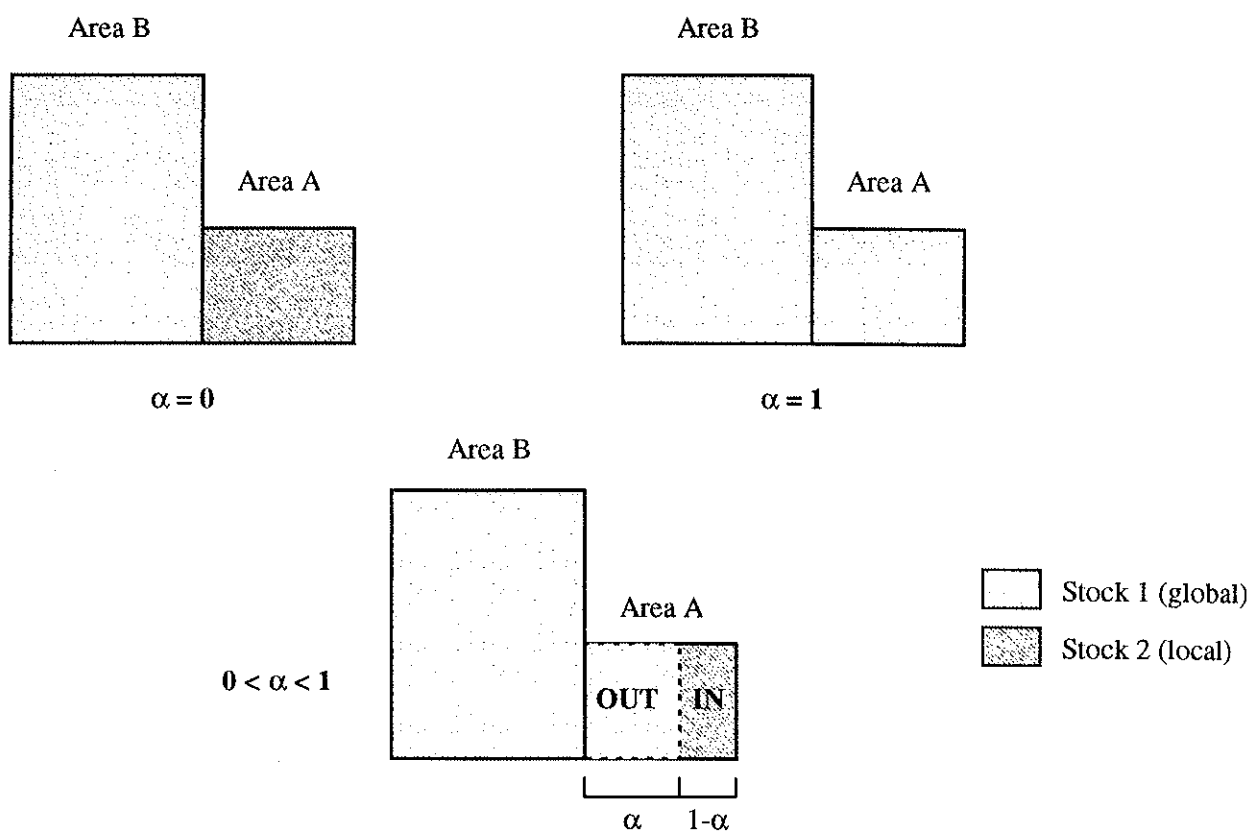


Figure 1. Origin of catches made in area A

NB : the figure 1 is a schematic representation of the model, but we have to keep in mind that α do not represent a varying spatial boundary between both stocks (as did Punt on South Cape hake - Punt *et al*, 1995 -), but only the probability for a fish caught within the area A to belong to the stock 1.

1.2. Equations of the model

The basic model used is a discrete model.

Catches in two areas are expressed as follows:

$$\begin{cases} C_{A,t} = C_{1A,t} + C_{2,t} \\ C_{B,t} = C_{1B,t} \end{cases} \quad (1)$$

and

$$\begin{cases} C_{1A,t} = \alpha \cdot C_{A,t} \\ C_{2,t} = (1 - \alpha) \cdot C_{A,t} \end{cases} \quad (2)$$

with $C_{A,t}$ and $C_{B,t}$, the total numbers of fishes caught in area A and B respectively during time step t (measurable inputs of the model), and $C_{1A,t}$, $C_{1B,t}$ and $C_{2,t}$, the numbers of fishes from the stock 1 caught in area A and B, and from the stock 2 in area A respectively during time step t .

Equations of survivorship and catches can then be written:

$$\begin{cases} N_{1,t+1} = N_{1,t} \cdot e^{-(F_{1A,t} + F_{1B,t} + M_{1,t})} \\ N_{2,t+1} = N_{2,t} \cdot e^{-(F_{2,t} + M_{2,t})} \\ C_{1A,t} = N_{1,t} \frac{F_{1A,t}}{F_{1A,t} + F_{1B,t} + M_{1,t}} \cdot (1 - e^{-(F_{1A,t} + F_{1B,t} + M_{1,t})}) \\ C_{1B,t} = N_{1,t} \frac{F_{1B,t}}{F_{1A,t} + F_{1B,t} + M_{1,t}} \cdot (1 - e^{-(F_{1A,t} + F_{1B,t} + M_{1,t})}) \\ C_{2,t} = N_{2,t} \frac{F_{2,t}}{F_{2,t} + M_{2,t}} \cdot (1 - e^{-(F_{2,t} + M_{2,t})}) \end{cases} \quad (3)$$

With $N_{1,t}$ and $N_{2,t}$, the fish numbers of stock 1 and 2 during time step t ; $F_{1A,t}$, $F_{1B,t}$ and $F_{2,t}$ the fishing mortality coefficients corresponding to effort in areas A and B for the stock 1, and in area A for the stock 2 respectively, during the time step t .

The model is based on the same fundamental assumptions as the VPA method : homogeneity of effort within each zone, and homogeneity of fish distribution within each stock boundaries. Without external information, natural mortality coefficients $M_{1,t}$ et $M_{2,t}$ are arbitrarily set as it is normally done in VPA.

By fixing α ($0 \leq \alpha \leq 1$), we can then calculate $C_{1A,t}$ and $C_{2,t}$, and estimate $N_{1,t}$, $N_{2,t}$, $F_{1A,t}$, $F_{1B,t}$ and $F_{2,t}$ by VPA. The model enables to explore the sensibility of the local production function to α .

- When $\alpha = 1$, $C_{2,t} = 0$. As fishing effort isn't zero, then $N_{2,t} = 0$. There isn't any local stock, fishes in the area A belong all to the stock 1 (*case of ICES working groups assessments*).
- When $\alpha = 0$, $F_{1A,t} = 0$. All catches in area A come from the local stock, which is then to be assessed and managed separately.

This model is rather different from the usual discrete spatial box models by the fact that most of them use a migration rate (Quinn II *et al*, 1990 ; Fahrig, 1993 ; Maury *et al*, 1997), implying that each stock strength depends of the other one. Here we make the assumption that there isn't any migration between the two stocks, and so each stock has its own dynamic.

1.3. Short term and long term predictions

The results obtained with this method can then be used into yield, yield per recruit and spawning stock biomass per recruit predictions, by stock and by area.

Yield per recruit and spawning stock biomass per recruit by stock are estimated with a Thompson and Bell model (1934), with the coefficients of natural mortality, maturity and weight-at-age used by ICES working groups:

$$(Y/R)_s = \sum_{i=1}^n \left(\left(\prod_{j=1}^i e^{-(F_{j,s}+M_{j,s})} \right) \frac{F_{i,s} W_{i,s}}{F_{i,s} + M_{i,s}} (1 - e^{-(F_{i,s}+M_{i,s})}) \right)$$

$$(SSB/R)_s = \sum_{i=1}^n \left(\left(\prod_{j=1}^i e^{-(F_{j,s}+M_{j,s})} \right) W_{i,s} \Phi_{i,s} \right)$$

with F the vector of fishing mortality (with $F_{i,s} = F_{i,s,A} + F_{i,s,B}$ for the stock 1 and $F_{i,s} = F_{i,s,A}$ for the stock 2 ; usually the mean fishing mortality on the last three available years is used), n the maximal number of age groups, i the index of the age group, M the natural mortality, W the weight-at-age (for the stock 1, W is a weighted mean of weight-at-age in both areas whenever they differ), and Φ the maturity rate.

Within the area A (the one which is to be managed), whose catches come from both stocks, the yield per recruit is a weighted mean of the ones of each stock. This is a similar approach as the one used in mixed-species yield per recruit model (Pikitch, 1987 ; Gribble & Dredge, 1994), but in our case, it deals with different stocks of the same species. It implies to assess a ratio of the two stocks recruitment : $r = R_2 / R_1$, which itself will depend of α and will be calculated in the simulation.

And then:

$$(Y/R)_A = \frac{\sum_{i=1}^n \left(\left(\prod_{j=1}^i e^{-(F_{1,j}+M_{1,j})} \right) \frac{F_{1A,i} W_{1A,i}}{F_{1A,i} + M_{1A,i}} (1 - e^{-(F_{1A,i}+M_{1A,i})}) \right) + r \sum_{i=1}^n \left(\left(\prod_{j=1}^i e^{-(F_{2,j}+M_{2,j})} \right) \frac{F_{2,i} W_{2,i}}{F_{2,i} + M_{2,i}} (1 - e^{-(F_{2,i}+M_{2,i})}) \right)}{\alpha + r(1 - \alpha)} \quad (4)$$

The coefficient r varies each year, depending on relative recruitment within each stock. In order to make long term predictions, we decide not to use the geometric mean of r on past years, but to calculate a ratio that gives the observed last year yield with the last year exploitation pattern in the dataset.

1.4. Application of the method

This method has been applied to the western English Channel cod (*Gadus morhua* L., ICES division VIIe), for the year 1988 to 1995. This period may seem quite short to have good information on the history of exploitation, but before 1988 there wasn't any reliable catch-at-age data in this area.

It's only in 1994 that ICES Southern Shelf working group decided to assess western Channel cod together with the Celtic Sea cod (ICES divisions VIIefgh), although studies based on biological considerations did not indicate useful regrouping of divisional stocks » (Anon., 1993 ; Anon, 1996).

Distribution of cod densities in the English Channel and in adjacent waters is shown on figure 2.

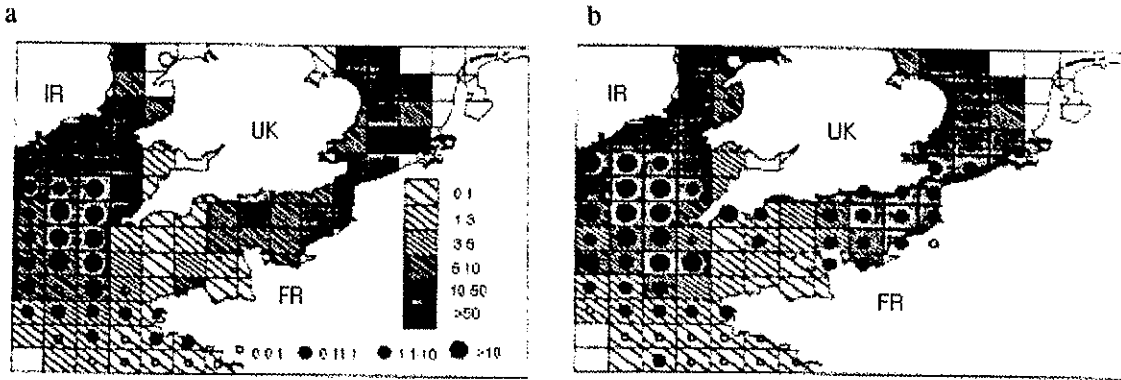


figure 2 : quarterly distribution of CPUE (kg/hr) of cod in the English Channel and adjacent areas in 1989. Surveys CPUE are figured by circles. a : quarter 2 ; b : quarter 4. (Anon., 1993)

II. RESULTS

II.1. Actual exploitation pattern and ICES assessment

In the Celtic Sea, the cod is mainly exploited by south Brittany french offshore trawlers (around 80% of landings) and by irish and english trawlers also. In the western Channel, it is exploited for one half by offshore trawlers coming from Channel ports (which may spend also a part of their time outside of the Channel), and for one half by inshore gears (Tétard *et al*, 1995). Except for some Channel offshore boats, we can consider that fleets are strongly linked to one single area.

Total landings decreased from around 19 000 t in 1989 (due to an abundant 1986 year class) to 10 000t in 1995, and Western Channel catches decreased as well, accounting for 17% of total catches in 1988 and for only 8% in 1995 (Anon., 1996). No individual TACs is set for divisions VIIefgh, only a precautionary TAC covers all of sub-areas VII to X, except VIIa (20 000 t in 1996). Total landings are presented in the table I.

According to ACFM advises, the stock is considered to be close to safe biological limits, with a high fishing mortality and a fluctuating SSB (close to MBAL) and recruitment. ICES recommends that the total fishing mortality should be reduced by 20%.

Table I : total landings (tons) of Celtic Sea and western Channel cod as used by the working group in 1996 (Anon., 1996)

Year	Divisions VIIefgh	Division VIIe	Total
1988	13619	2750	16369
1989	16674	2201	18875
1990	10093	1279	11372
1991	6883	755	7638
1992	7605	698	8303
1993	8971	587	9558
1994	8790	620	9410
1995	9143	818	9961

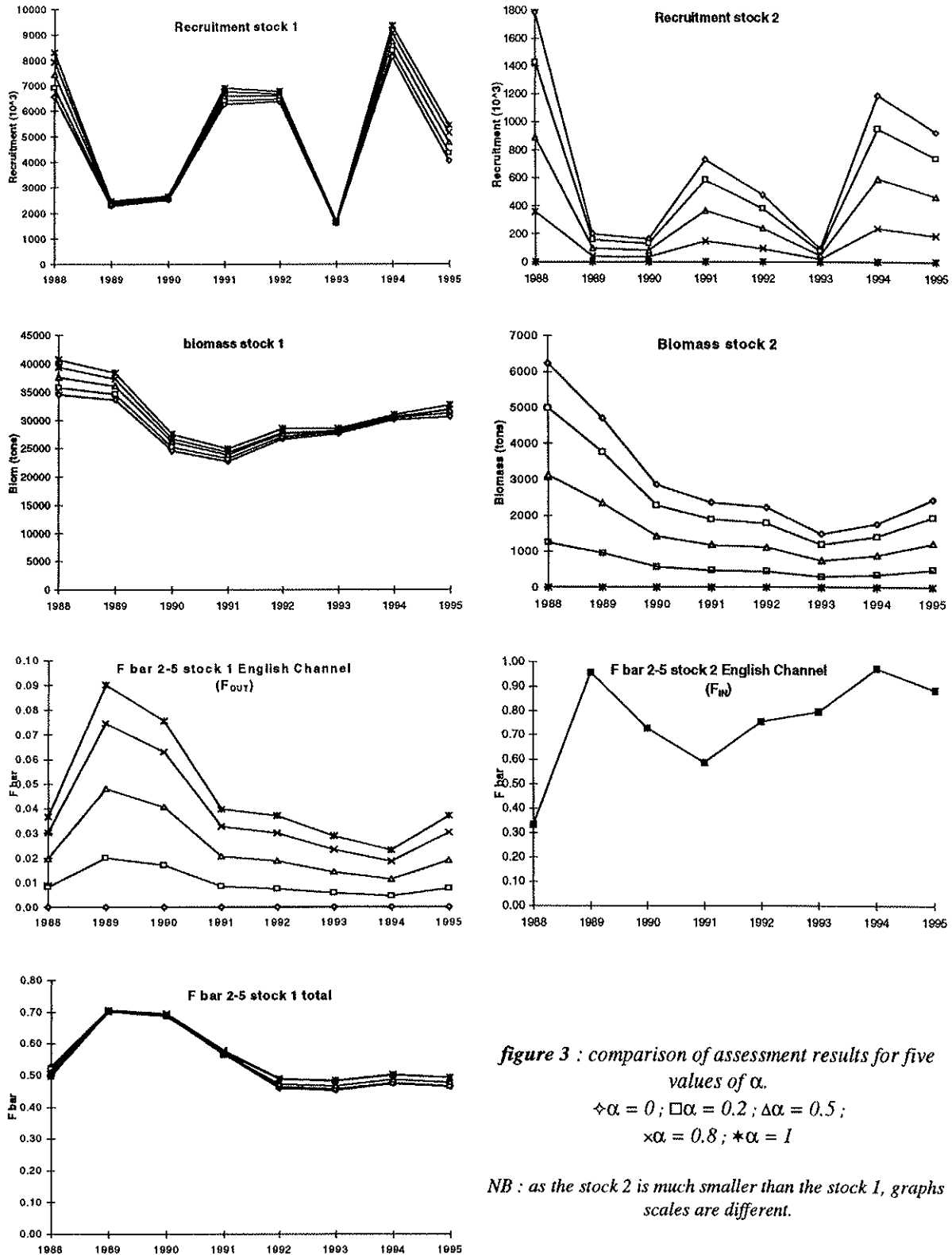
II.2. Comparison of assessed R and F for different values of α

The model has been run for 5 values of α ($\alpha = 0$; $\alpha = 0.2$; $\alpha = 0.5$; $\alpha = 0.8$; $\alpha = 1$). At each run, catch-at-age for each stock in each area have been calculated, then fish numbers and fishing mortality coefficients have been estimated.

To tune the VPA, we decided to iterate the model until

$$\begin{cases} F_{last_age,y} = (F_{last_age,y} + F_{last_age-1,y}) / 2 \\ F_{last_year,a} = (F_{last_year,a} + F_{last_year-1,a} + F_{last_year-2,a}) / 3 \end{cases}$$

Results of assessments are shown on figure 3.



We see that the value of α doesn't affect significantly the results of assessment for the stock 1 (global stock). This is not surprising if we consider that less than 20% of total catches occur in the western English Channel (12% of landed weight on average for the whole period 1988-1995). The fishing mortality in this area is very low, compared to the total mortality ($F_{OUT} < 0.1$). Assessing this stock with or without these catches lead to close diagnostics, especially for last years, when Channel catches decreased down to 8% of total landings. The biomass is stable, although the recruitment and the SSB are highly variable around the mean ; the fishing mortality is high. Whatever α is, we find same results as ICES working group.

On the other hand, the local Channel stock estimated recruitment is strongly dependant of α . The closer from 0 α is, the higher the recruitment is. The exploitation pattern itself is not affected by α , because catches are homothetic. The structure of the stock doesn't change, but only the total abundance. The fishing mortality is very high ($F_{IN} = 0.88$ in 1995). Fluctuations of the recruitment follow the ones of the global stock recruitment, and the total recruitment, as estimated by ICES working group, do not depend of α (table II). The decrease of catches associated with an increase of the fishing mortality, as well as the decrease of the total biomass, indicate a situation of heavy overexploitation, especially serious when the stock is considered to be important (α is close to 0). Not taking into account this stock when it is thought to exist may lead to a real underestimation of the fishing pressure on it.

Table II. Mean values of recruitment in the two stocks for different values of α

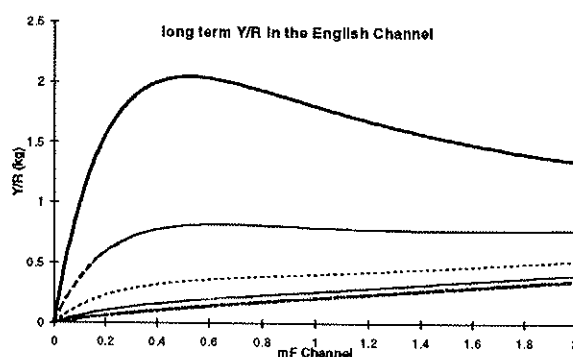
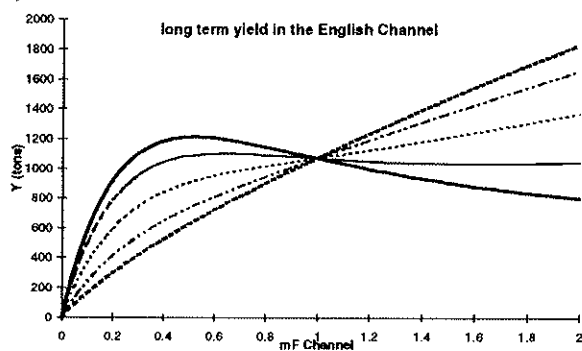
	Geom. mean 88-93 (10^3)			Arithm. mean 88-93 (10^3)			r (cf. I.3)
	N1	N2	N2/N1	N1	N2	N2/N1	
$\alpha = 0$	3660	352	0.10	4265	574	0.13	0.13
$\alpha = 0.2$	3741	281	0.08	4378	459	0.10	0.1
$\alpha = 0.5$	3851	176	0.05	4537	287	0.06	0.06
$\alpha = 0.8$	3942	70	0.02	4676	115	0.02	0.03
$\alpha = 1$	4029	0	0	4799	0	0	0.01

II.3. Short term and long term simulations.

We show here only the results of long term (figure 4) and short term (figure 5) simulations for 1) the whole western English Channel area (with a mix of both stocks) and 2) the only local stock (stock 2). The multiplier of effort mF which is used is a multiplier for the whole Channel effort, i.e. it is the same for F_{IN} and F_{OUT} .

The total effort support by the stock 1 becomes then : $F_1 = (mF * F_{1A}) + F_{1B}$; and for the stock 2, $mF * F_2$.

1)



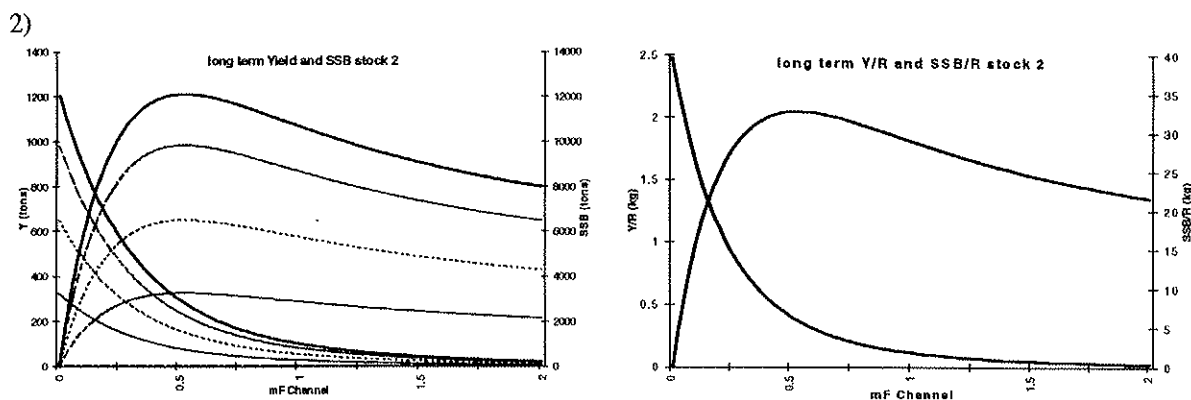


figure 4 : comparison of long term prediction for five values of α .
 — $\alpha = 0$; - - - $\alpha = 0.2$; $\alpha = 0.5$; $\alpha = 0.8$; ■ ■ $\alpha = 1$

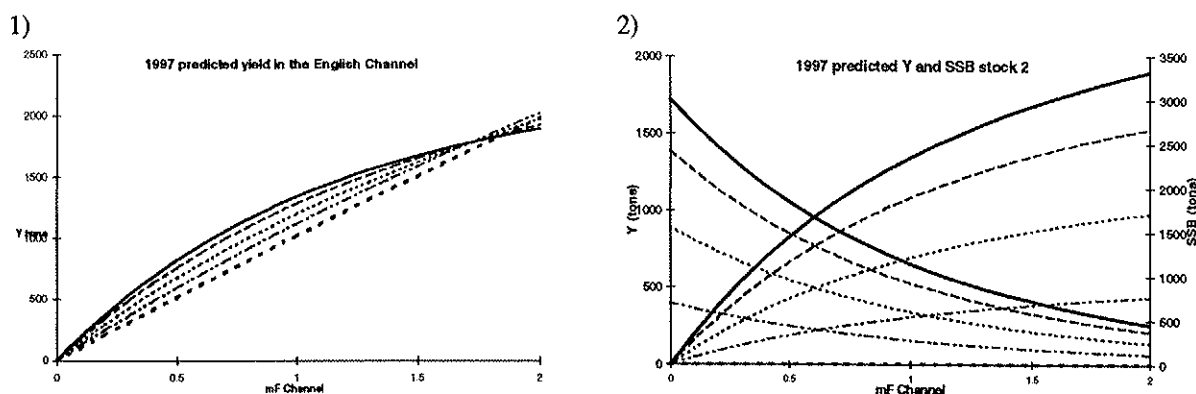


figure 5 : comparison of short term prediction for five values of α .
 — $\alpha = 0$; - - - $\alpha = 0.2$; $\alpha = 0.5$; $\alpha = 0.8$; ■ ■ $\alpha = 1$

As for assessment results, short term and long term simulations show large differences when α changes. ICES method ($\alpha = 1$) lead to optimistic predictions : given the low proportion of Channel catches in total catches, increasing the fishing effort in this area would produce higher yield, without jeopardising the resource sustainability. On the other hand, considering an important local stock in the English Channel ($\alpha = 0$) confirms the diagnostic of overexploitation made at §II.2. The fishing mortality should be reduced of more than 30% in order to maximise catches ($mF_{max} = 0.52$, $mF_{0.1}$ is close to 0.37) and to increase the SSB above the MBAL. It would lead to reduced catches in the short term (- 20% in 1997) but to a 10% higher yield at the equilibrium.

Intermediary values of α lead to diagnostics bounded between these optimistic and pessimistic hypotheses. The local stock is truly overexploited, but it is not important enough within the English Channel to justify a drastic reduction of the fishing effort. It is very important, for management purposes, to consider yield per recruit curves for the whole Channel area (fig. 4.1), and not for the single local stock (fig. 4.2), because this stock may be too small to deserve a real conservation policy.

NB : the yield per recruit curves don't cross at the value $mF = 1$, because the equilibrium recruitment within the Channel is a function of α : $R_e = \alpha \cdot R_1 + (1 - \alpha) \cdot R_2$. Then the same yield will be obtained with different values of yield per recruit when α varies.

III. DISCUSSION AND CONCLUSION

III.1. How to assess α ?

The previous figures showed us how different results of assessment and predictions could be, when considering the existence of local stocks or not, and which consequences it may have to forget them. It leads to opposite management policies, a pessimistic one asking for Channel fleet effort reduction, and an optimistic one, recommending the status-quo, or even a possible increase. The problem is then to estimate the relative importance of these local stocks, and the proportion of total catches they give. In this purpose, many authors used morphometric characteristics and length distribution, estimated in isolated sub-stocks, to assess catch proportion in mixed stock fisheries (Pella & Robertson, 1979 ; Fournier *et al.*, 1984 ; Hanson, 1995). These methods can't be used in the case of the western Channel cod, because this local stock has never been really bounded and sampled. But the study conducted in order to record all existing works helping to identify stocks of all main species in the English Channel (Anon., 1993) concluded that cods in the western Channel were probably isolated from adjacent eastern and western stocks : eggs and immatures have been found ; tagging data, although limited, show that juveniles do not migrate to the Irish Sea, and that Celtic Sea adults do not mix with western Channel ones ; and english fishermen state that cods migrate only from inshore to offshore waters in the Channel. Further works should be conducted to improve thoroughly the knowledge about this stock, such as genetic studies and better migration data through tagging programs ; but with actual information we can already affirm that this local stock seems to exist and to be important enough to be taken into account into assessments.

It is hard to quantify exactly how much it participates into total catches, because information is mostly qualitative, so we propose here an empirical value for α . We suggest that α may be under 0.4. We saw that the value of α didn't affect the diagnostic made on the local stock itself in terms of fishing mortality and long term yield per recruit, but that it had an influence on the total expected long term yield within the western English Channel area. The value we propose here leads to a proposal for management measures recommending the status-quo or a slight reduction of effort in that area, but certainly not an increase as could be interpreted in a global assessment.

III.2. Interest and limits of the method

This simple method is interesting to investigate the consequences, in terms of assessment and management, of considering the existence of local sub-stocks, located on the edges of the stock distribution. It is easy to use, for that it uses only one single coefficient, α , which represent the probability for a fish caught in the area of interest to belong to the large and global stock. In a larger meaning, α is inversely proportional to the importance of the local stock that may exist within this area. The major problem is then to estimate the best value possible of α . Unless having already identified and sampled this local stock and having own morphometric and meristic characteristics, which allow a good separation of catches in mixed stock fisheries and thus, a good estimation of α , an empirical value has to be set. It can be approached by gathering all existing information (qualitative and quantitative) about reproduction areas, migration and other biological studies. Yet it is necessary to explore the sensibility of the model to α .

A limit of this method comes also from the fact that all calculations depend of α only, which is equal for each age and each year. And if a local stock exists independently of the global one, both recruitments may have different trends and variations, and α may vary every year. Further investigations should be conducted in order to estimate a variable α . But as we said, this method is mostly useful to explore

different hypotheses, and to give some general management trends advises. It can't give absolute results, because α is subjectively assessed.

III.3. Consequences for management

We saw that for the western English Channel cod, for which a local stock is thought to exist (Anon., 1993), the estimated local production functions (i.e. Channel production vs. Channel effort) are highly dependant of α . The diagnostic is opposite for extreme values of α , and then the assessment can be bounded by an optimistic hypothesis ($\alpha = 1$) and a pessimistic one ($\alpha = 0$). But within these two hypotheses, we saw also that a slight change in the value of α would not affect significantly the results of simulations. We decided to propose a value of α being under 0.4, and we showed that a value between 0.2 and 0.4 would lead to close assessments. An uncertainty on the true value of α is not a too severe problem in terms of expected performance from management policies.

Yet we see that gathering different stocks into one single regional assessment and one single management unit may have dangerous consequences for some local edge stocks. Their importance in the general dynamic is often underestimated. They should be assessed separately to avoid possible irreversible troubles.

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