THE INFLUENCE OF ENVIRONMENT ON STOCK ASSESSMENT

An approach with surplus production models[1]

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ABSTRACT

Conventional global production models are not suitable for some stocks because fishing effort variations only explain only a small part of the total variability of annual catches. Often the residual variability originates from the influence of environmental phenomena, which affects either the abundance or the catchability of a stock from one year to the next. Therefore an additional environmental variable has been inserted into conventional models in order to improve their accuracy. These variables appear in simple formulae regarding either the stock abundance (surplus production), or the catchability coefficient, or both. The models are developed from the Schaefer's linear production model, the Fox's exponential model or the Pella and Tomlinson generalized model.

CLIMPROD is an experimental expert-system, using artificial intelligence, which provides a statistical and graphical description of the data set and helps the user to select the model corresponding to his case according to objective criteria. The software fits the model to the data set using a non-linear regression routine, assesses the fit with parametric and non-parametric tests, and provides a graphical representation of the results.

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[1] This communication is mainly based on two papers : Fréon (1983) and Fréon et al. (1989). See bibliography for more details.

Limitations of this kind of model are considered. The models can provide a fairly good interpretation of the fishery history, particularly when a stock collapses unexpectedly without any appreciable increase in the nominal fishing effort. These models can also provide a useful tool for efficient management of a fishery in those instances where climatic phenomena can be forecast, or when their influence is restricted to the year(s) preceding exploitation.

Model surplus produksi yang konvensional adalah tidak cocok untuk mengkaji sedian ikan tertentu, dimana hal ini disebabkan karena variasi upaya penangkapan hanya diterangkan oleh sebagian kecil dari variability total dari hasil tangkapan tahunan. Seringkali "residual variability" berasal dari pengaruh fenomena lingkungan, yang mempengaruhi kelimpahan maupun "catchability" suatu sediaan dari satu tahun ke tahun berikutnya. Oleh sebab itu tambahan variable lingkungan dimasukan kedalam model konvensional untuk meningkatkan ketepatan model tersebut. Variable-variable tersebut ditampilkan dalam suatu rumus yang sederhana sehubungan dengan kelimpahan sediaan ataupun koefisien "catchability" atau kedua-duanya. Model model tersebut dikembangkan dari model produksi linier Schaefer, model eksponensial Fox ataupun model umum dari Pella dan Tomlinson.

CLIMPROD adalah percobaan "expert - system", dengan mempergunakan "artificial intelegence" yang menyediakan diskripsi statistik dan grafik dari satu set data dan membantu pengguna untuk memilih model menurut kasus yang ada sesuai dengan kriteria-kriteria yang diinginkan. Piranti lunak yang dibuat menyesuaikan model terhadap suatu set data dengan mempergunakan rutin regresi non linier, pengkajian kesesuaian dilakukakan dengan uji parametrik dan non parametrik, dan menyediakan representasi grafik dari pada hasil-hasil yang diperoleh.

Keterbatasan dari model-model tersebut seyogianya dipertimbangkan. Model-model tersebut dapat memberikan interprestasi yang cukup baik dari evolusi suatu perikanan, tertutama bila sediaan merosot drastis tanpa adanya peningkatan upaya penangkapan nominal. Model-model ini juga menyediakan cara-cara yang berguna untuk pengelolaan perikanan yang eficien bila fenomena iklim dapat diduga sebelumnya, atau bila pengaruh-pengaruh tersebut terbatas pada tahun sebelum eksploitasi.

INTRODUCTION

Conventional surplus production models for stock assessment use only one input variable i.e. fishing effort. From the initial linear "Schaefer" model (Graham, 1935; Schaefer, 1954), two other global models have been developed and widely used : the exponential model (Garrod, 1969; Fox, 1970) and the generalized production model (Pella and Tomlinson, 1969). They have been further developed and adapted in order to improve the fit of models to observed data, particularly for non-equilibrium conditions of fishery or for time lags in stock response (Schaefer, 1957; Gulland, 1969; Uhler, 1980). In these models, variability not linked to the fishery is considered as random noise, and some stochastic models use a random variable (Doubleday, 1976).

Although the relationships between environment variations and stock abundance or availability have been described (e.g. Saville, 1980; Le Guen et Chevallier, 1983; Sharp and

Csirke, 1983; Csirke and Sharp, 1983), I am not aware of any deterministic model using both fishing **E** and an environmental variable **V**. Such an approach was suggested by Dickie (1973) but, as far as I know, only Griffin *et al.* (1976) used an empirical relationship between shrimp yield **Y** on the one hand, fishing effort **E** and river out-flow **V** on the other :

$$Y = aV^b (1-c^E)$$

where **a,b** and **c** are constant parameters.

This relationship is an increasing asymptotic function and is relevant only in a few special cases. However, theoretical bases for such models are available in various publications on terrestrial or aquatic ecology. Some authors have introduced hydro-climatic variables into structural production models (Nelson *et al., 1977* ; Loucks and Sutcliffe, 1978 ; Parrish and Mac Call, 1978), but they all require detailed data on the life history as some complex simulation models do (Laevastu and Larkins, 1981).

This paper gives a theoretical basis for production models using an environmental variable as an independent variable in addition to fishing effort. The influence of environmental factors has been considered at two levels : on stock abundance and on stock catchability. For each case, the linear and exponential models (and sometimes the generalized model) are considered. Then the case of an influence on both abundance and catchability is considered.

Limitations and applications of this kind of model in transitional states (non-equilibrium conditions) are then considered. Implications for fisheries management are indicated, especially for unstable stocks, and the method and criteria of fitting, as the choice of the appropriate model, are described. The CLIMPROD software allowing to perform all these tasks and to overcome part of them is then presented.

1. HOW AN ENVIRONMENTAL VARIABLE ACTS UPON SURPLUS MODELS

1.1 Definitions

Let **V** be an environmental variable representing any factor likely to modify the fisheries catches. Common examples are temperature, salinity, wind speed, turbidity, strength or direction of currents, river out-flow, etc.

The conventional notation, mainly from Ricker (1975), used in this paper is as follow :

- B : instantaneous stock biomass
- Bi : mean annual biomass
- B∞: environmentally limited maximum biomass or "carrying capacity" (K of terrestrial ecological models)

- k : constant of the rate of population increase (r of terrestrial ecological models)
- t : time, conventionally in years
- F : fishing mortality
- q : catchability coefficient
- Ei : annual fishing effort during year i, standardized to be proportional to F : Fi=qiEi
- Yi : annual yield
- Ui : annual mean catch per unit of effort (or CPUE)
- Be, Ee, Ye and Ue : correspond respectively to B,E,Y, and U under equilibrium conditions
- Ymax : maximal sustainable yield
- Umax : optimal CPUE corresponding to Ymax
- fmax : optimal effort corresponding to Ymax
- e : base of natural logarithms

1.2 Background

The background and the way of introducing an environmental variable into models are presented for the linear model only. More details on other models are presented in an other publication (Fréon, 1988). Surplus-yield models are based on the logistic equation expressed in terms of relative rate of stock increase :

$$\frac{dB1}{dtB} = \frac{k(B\infty - B)}{B\infty} = k\left(1 - \frac{B}{B\infty}\right) \qquad (1)$$

Various authors (synthesis in Mac Call (1984)), working on terrestrial ecology, studied the effects of habitat modification (in time or space) on this relationship. Habitat modification can theoretically be introduced into equation (1) in three different ways : effect on **B∞** only, effect on **k** only, or effect on both **B∞** and **k**. After analyzing all these cases, Mac Call (1984) concludes that the latter one is the most convenient, specially using the solution of a constant slope for equation (1):

$$\frac{dB1}{dtB} = k - hB \qquad (2)$$

where **k** keeps the same meaning and **h** is the slope of the relative rate of population increase. This means that : **h** = **k/B∞** = constant, and so far **h** corresponds to $\mathbf{k_1}$ from Schaefer (1954), who also considered it as a constant.

Expressing absolute rate of the exploited stock increase as a function of environmental capacity and fishing mortality rate **qE** leads to the conventional equation of the Schaefer's model :

$$\frac{dB}{dt} = kB - hB^2 - qEB = hB\,(B\infty - B) - qEB \qquad (3)$$

1.3 Introducing an environmental variable

Using this formulation environmental factors may interact at only two levels : with **q** if catchability changes or with the pair of variables **k-B∞** (the ratio of these two variables being constant) if natural variations of abundance are considered. In the latter case, to make the presentation easier, I chose only formulae in which **B∞** and **h** appear and allowed **B∞** to change according to the environment. However, it should be noted that any variation of **B** corresponds to a symmetrical variation in **k**. Moreover, **B∞**, in production model mathematical formulations, cannot simply be interpreted as the carrying capacity for the recruited stock. Growing evidences (i.e. Sharp, 1980) indicate that the temporal and spatial processes affecting the eggs and larvae dispersal may well dominate the density-dependent energetic/trophic processes in the limitation of the cohort biomass before recruitment. In such cases adult stocks will not necessary fill the carrying capacity of their environment.

Let **g(V)** and **y(V)** be the functions representing fluctuations of respectively **B∞** due to environmental factors, and **q**. Schaefer's model assumes that, under equilibrium conditions, the rate of population increase is zero, which can be obtained from (3) if :

$$Be = B\infty - qE/h = g(V) - y(V)\,E/h \qquad (4)$$

such that :

$$Ue = qBe = qB\infty - q^2\,E/h = y(V)\,g(V) - y^2(V)\,E/h \qquad (5)$$

$$Ye = EUe = qB\infty\,E - q^2\,E^2/h = y(V)\,g(V)E - y^2(V)\,E^2/h \qquad (6)$$

E_{max} will be the value of **E** obtained by cancelling out the derivative of equation (6) such that:

$$E_{max} = B\infty\,h/2q = g(V)h\,/\,2y(V) \qquad (7)$$

1.4 Functions g(V) and y(V)

The real mathematical functions **g(V)** or **y(V),** linking a climatic variable with respectively **B∞** or **q**, are generally unknown. So far a very flexible function has been used such as :

$$g(V) \text{ or } y(V) = a+bV^{c} \qquad (8)$$

which will be used only as a general tool leading to the four particular cases where :

$\alpha = 0;\ \beta = 0$ and $\lambda = 1$ or: βV (8.I)

$\alpha = 0;\ \beta = 1;\ \lambda = 0$ and $\lambda = 1$ or: V^{λ} (8.II)

$\alpha = 0;\ \beta = 0$ and $\lambda = 1$ or: $\alpha + \beta V$ (8.III)

$\alpha = 0;\ \beta = 0$ and $\lambda = 1$ or: βV^{λ} (8.IV)

Functions (8.I) and (8.II) are justified in particular cases where a constant is fortunately not required. The last function (8.IV) is still very flexible : if we are just interested in situations where **g(V)** or **(V)** are positive and monotonic functions it covers a large number of situations. Mac Call (*in* : Fox, 1974) used it to describe the relationship between **q** and **B∞**.

In the case where **g(V)** is non-monotone but is a shaped function, other equations must be used as for example the parabolic one used in this work :

$$g(V) \text{ or } y(V) = aV - bV^{2} \qquad (9)$$

The value of parameters α, β and λ (or the value of global parameters **a**, **b**, **c**, or **d** obtained after restructuring the equations) will be estimated by fitting the model to the data using a regression technique. Models with more than four parameters will not be retained because they could reduce the degrees of freedom too much, owing to the usually short length of the data series.

1.5 Final models

Following the line presented above for linear or exponential model leads to several equations corresponding to the case of an environment influence on the stock abundance (fig. 1), catchability (fig. 2) or both (fig. 3 and 4, Appendix 1).

Numerous hypothesized examples about an environmental influence or abundance, through recruitment and/or population growth, can be found in the literature, such as : influence of upwelling strength, relationship between stock production and rivers discharges, influence of temperature during a critical stage, etc. (tab. I). Schematically four periods or critical stages have been identified :

- Before spawning by influencing the fecundity of the parent stock;
- During early life stages by influencing the fecundation and/or the natural mortality of eggs and larvae;

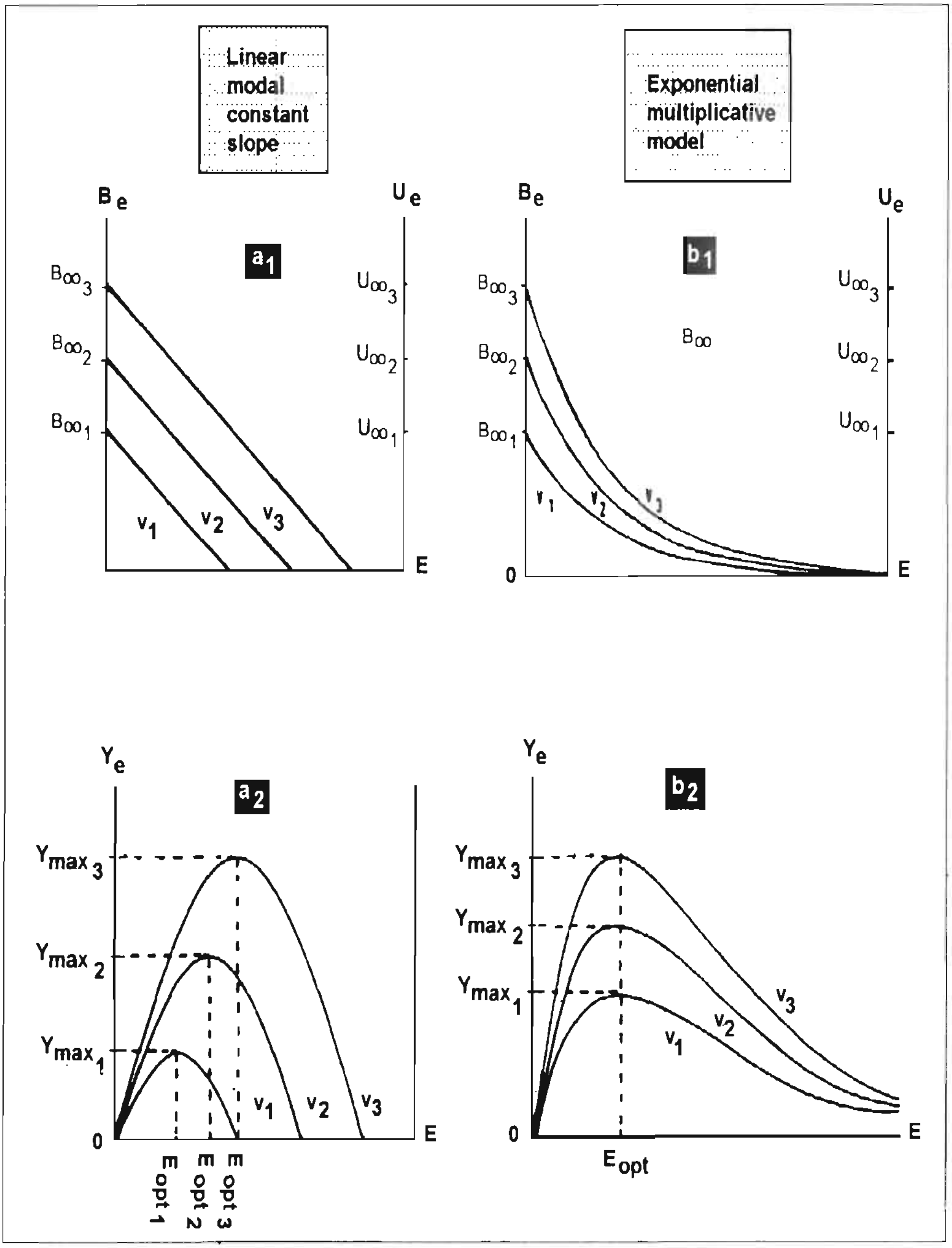

Figure 1

Linear production model (fig. a1, a2) and exponential multiplicative model (fig. b1, b2) where an environmental variable V influences the abundance ($B\infty = g(V)$) according to three different values (V_1, V_2, V_3)

Model produksi linier (gambar a1 dan a2) dan model eksponensial multiplikatif (gambar b1 dan b2) dimana peubah lingkungan V mempengaruhi kelimpahan ($B\infty = g(V)$ berdasarkan tiga nilai yang berbeda (V_1, V_2, V_3)

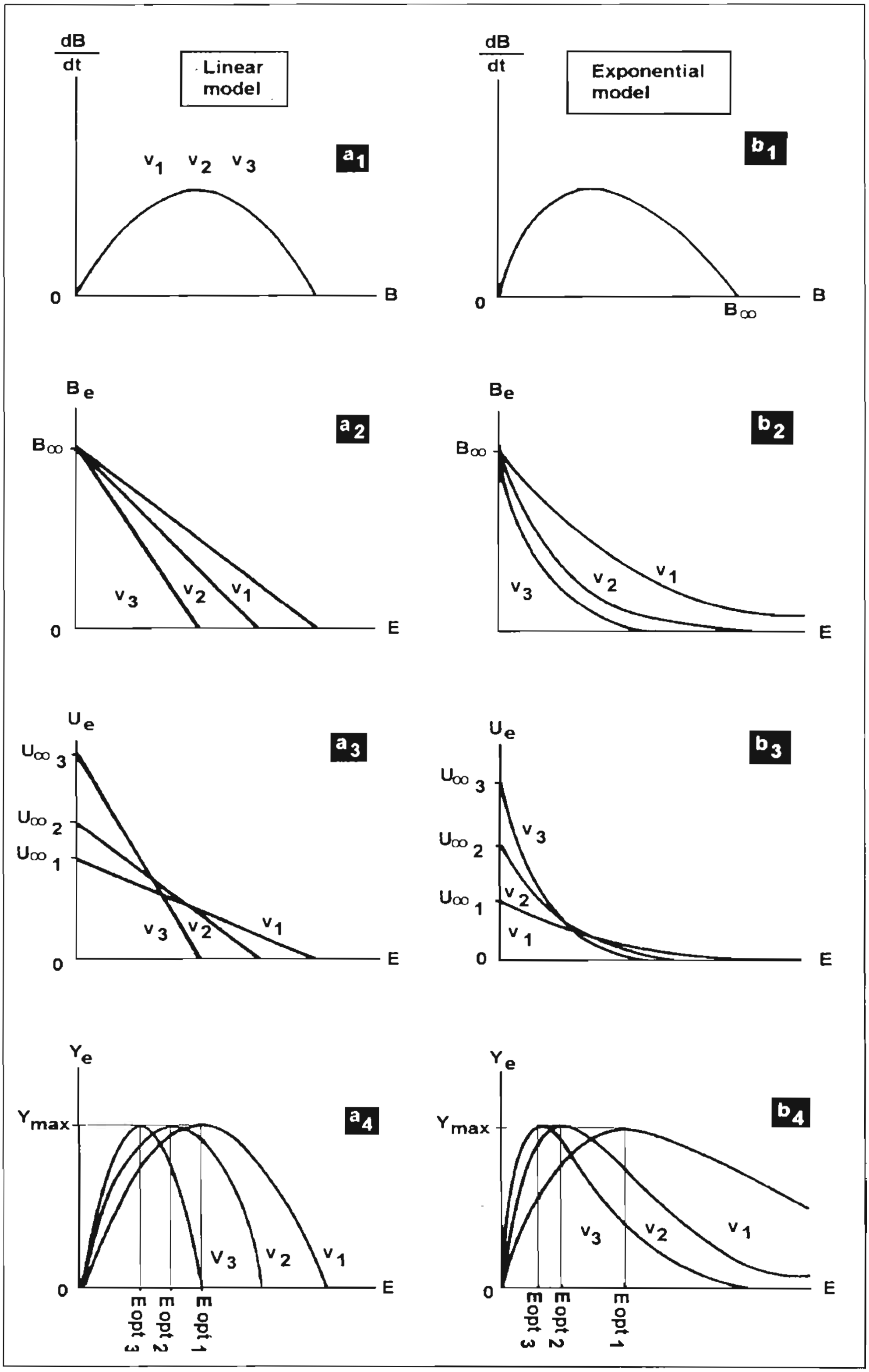
Linear model
Exponential model
dB/dt
a1
b1
v1 v2 v3
0
B
B∞
Be
a2
b2
B∞
v3 v2 v1
E
Ue
a3
b3
U∞ 3
U∞ 2
U∞ 1
Ye
a4
b4
Ymax
Eopt 3
Eopt 2
Eopt 1

Figure 2 *(left page)*

Linear production model (fig. a1,...a4) and exponential production model (fig. b1, ...b4) where an environmental variable V influences the catchability according to three different values (V_1, V_2, V_3)

Model produksi lineer (gambar a1 ..... a4) dan model eksponensial (gambar b1 .... b4) dimana peubah lingkungan V mempengaruhi catchability berdasarkan tiga nilai yang berbeda (V_1, V_2, V_3)

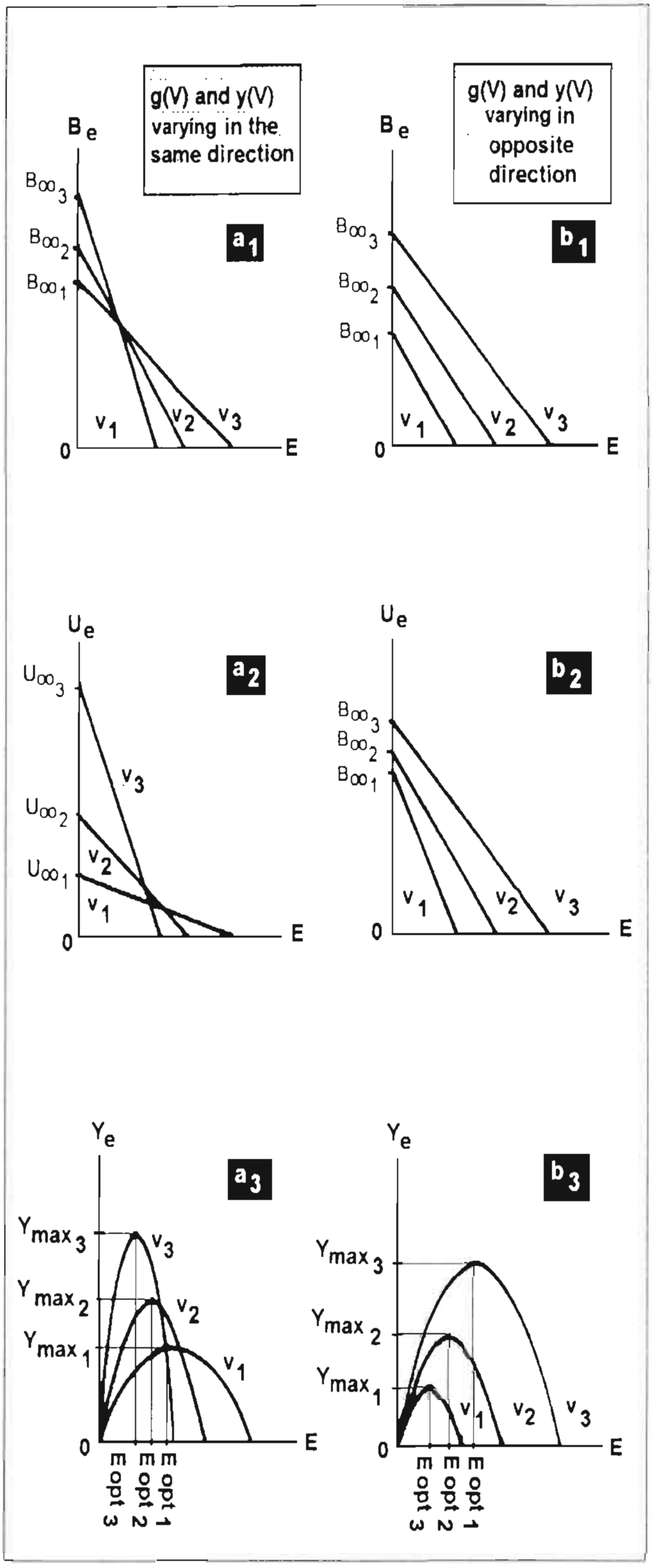

Figure 3

Linear production model for three values (V_1, V_2, V_3) of an environmental variable V influencing both the stock abundance (B∞ = g(V)) and the catchability (q = y(V)), when g(V) and y(V) vary in the same direction (fig. a1, a2, a3) or in opposite directions (fig. b1, b2, b3)

Model produksi lineer untuk tiga nilai (V_1, V_2, V_3) dari peubah lingkungan V yang mempengaruhi kelimpahan sediaan (B∞ = g(V) dan catchability (q = y(V)), bila g(V) dan y(V) berfaruasi dalam arah yang sama (gambar a1, a2 dan a3) atau dalam arah yang berlawanan (gambar b1, b2 dan b3)

Table 1

Environmental effects on production models; key variables, biological mechanism involved, time window of the effect, lag on production, type of effect and its sign

Pengaruh lingkungan pada model produksi; variable kunci; mekanisme biologi skala, waktu perbedaan produksi, jenis pengaran dan tandanya

ENVIRONMENTAL MECHANISM	VARIABLE	BIOLOGICAL MECHANISM	TIME WINDOW	LAG PROD.	EFFECT	EFF. SIGN
Increase of primary production by upwelling	Wind speed or Ekman transport or SST	Fecundity	Season	Years	Abundance	+
"	“	Natural mortality (any stage)	Season or year	Years	Abundance	+
"	“	Growth	Season or year	Years	Abundance	+
"	“	Migration pattern	Season	Month	Catchability	+
"	“	Aggregation level	Season	No lag or days	Catchability	+ or -
Current increase (upwelling or other)	Ekman transport or current data	Larval advection	Month	Years	Abundance	-
Water column turbulency	Wind speed^3	Difficulty of larval alimentation	Month	Years	Abundance	-
Sea temperature anomalies (not linked to upwelling)	SST or water column T or thermocline depth	Physical effect on eggs and larvae survival	Month	Years	Abundance	+ or -
"	“	Change in biotope	Year	Years	Abundance	+ or -
"	“	Change in vertical distribution or aggregation	Season or year	No lag or days	Catchability	+ or -
Increase of primary production by rivers discharge	River flow or level near mouth or plume extension (satellite obs.) or rainfall	Fecundity (any stage)	Season or year	Years	Abundance	+
"	"	Natural mortality (any stage)	Season or year	Years	Abundance	+
"	"	Growth	Season or year	Years	Abundance	+
Physical water mass changes in relation to rivers discharge	" or salinity or turbidity	Spatial distribution or aggregation level	Season or year	No lag or days	Catchability	+ or -

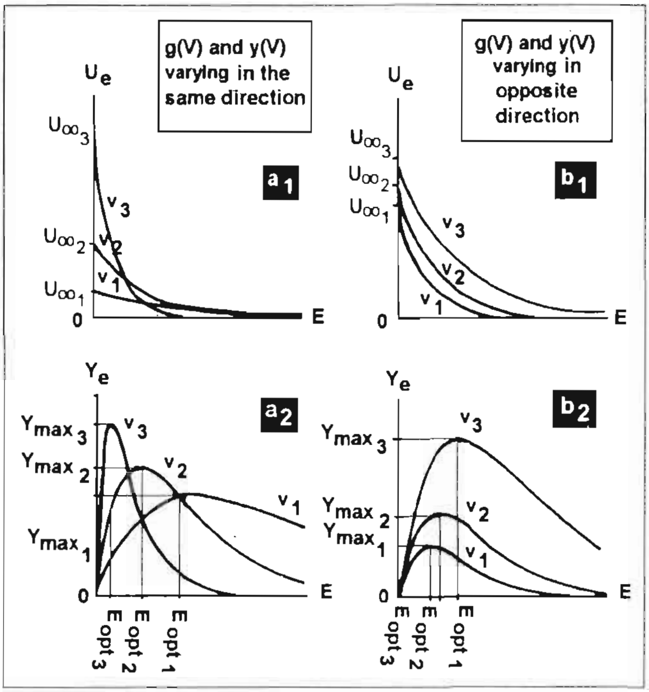

Figure 4

Linear production model for three values (V_1, V_2, V_3) of an environmental variable V influencing both the stock abundance ($B\infty$ = g(V)) and the catchability (q = y(V)), when g(V) and y(V) vary in the same direction (fig. a1, a2) or in opposite directions (fig. b1, b2)

Model produksi linier untuk tiga nilai (V_1, V_2, V_3) dari peubah lingkungan V yang mempengaruhi kelimpahan sediaan ($B\infty$ = g(V) dan catchability (q = y(V)), bila g(V) dan y(V) berfariasi dalam arah yang sama (gambar a1, a2) atau dalam arah yang berlawanan (gambar b1, b2)

- During the period of high growth rate (usually corresponding to the pre-recruitment stage) when the environment influences the individual growth and/or the natural mortality;
- During the post-recruitment, if the natural mortality and/or condition factor (and secondarily the growth rate) are concerned at this stage.

These four cases are not mutually exclusive, of course, and in some cases it is difficult to identify at which stage the environmental influence is the greatest. Nevertheless, stages 1 to 3 (especially stage 2) are usually known as the most important ones in terms of natural abundance variability, meanwhile stage 4 is generally concerned with fishing mortality variation in relation with environmental changes.

The catchability coefficient **q** may be linked to the environmental conditions through any of its two components : accessibility or vulnerability. For instance, water mass movements can modify the migrations pattern and are therefore linked to the accessibility especially in the case of short-range fleets. Water turbidity can increase either the vulnerability of the fish to some type of gear (gill-nets, trawls) or decrease it (light fishing). The case where **q** changes according to stock abundance has been already investigated by Fox (1974).

In some cases, it is reasonable to postulate that the environment influences both stock abundance and catchability. In such cases **q** and **B∞** will be replaced by functions of **V** (Appendix 1; fig. 3 and 4). I have examined only the simple case where both **g(V)** and **y(V)** are described by the function (8.IV), in order to limit the number of parameters. This is acceptable because this function is very flexible but theoretically nothing allows us to suppose that **g(V)** and **y(V)** would be identical. Moreover, the past-effort-averaging approach used for estimating model parameters in the case of transitional state allows to use these models only in particular cases (see below).

2. USING THE MODELS WITH TRANSITIONAL STATE DATA

2.1 General presentation

The preceding equations are based upon a stock in equilibrium state at various stable levels of fishing effort and environmental conditions. The "transition prediction approach" was adopted for a model to fit the observed data. It consists in adjusting the data of fishing effort and environment so as to estimate an equilibrium state. Fox (1974) modified it by using a weighted average of the effort series instead of the simple average initially proposed by Gulland (1969). The same approach can be used for the environmental variable (see Fréon, 1988 for further details).

This approach is easy to use but the problem of the artifact caused by the non-independence of the data series concerning fishing effort and CPUE is to be faced (Roff and Fairbairn, 1980). This approach is neither precise when **g(V)** and/or **y(V)** are linear functions nor acceptable in the case of non-monotonic functions when the inter-annual variation of **V** is large and when, for certain years, the mean value of **V** results from values located on each side of the optimum value. Nevertheless, I propose to adapt it to the environmental production models for pragmatic reasons. It is recognized that the transition prediction approach can lead to some bias or errors about the parameter estimations, as emphasized by Walter (1975), Schnute (1977), Uhler (1980) and Hilborn and Walters (1992). However, Uhler (1980) shows that the best statistical estimations of the parameters do not necessarily provide the best estimations of **Ymax** and **fmax** which are the main objectives of the global production models.

2.2 Transitional states and environmental influence

Concerning the environmental variable, the use of the transition prediction approach assumes that the life stage during which the environment acts upon the stock is already known. The shorter the life span is (or at least the fishable life span) the better the transition prediction approach will be. In such cases it is easier to determine and to quantify the environmental effect on catchability or on abundance. In the latter case, the most favorable situations are provided by a rapid action of the environment on a life stage or by slow fluctuations of environment (auto-correlated data series). In order to make the presentation easier the inter-annual environment fluctuations may be considered as cyclic with a "period" **T**. However, in most cases, the reality is no more than an alternation between positive and negative climatic anomalies, not necessarily of same duration. In the special cases where the environmental fluctuations would be truly periodical, the resonant frequencies of the ecosystem could be observed as noted by Silvert (1983).

If the fishery data series have a negligible duration compared to **T** (century scale for example) it will be difficult to quantify an eventual environmental influence such as suggested by the results of Soutar and Isaacs (1974). Stochastic production models using a periodical function can also be used in such a case (Steele and Henderson, 1984). When the extent of the fishery data series is shorter than **T** but greater than **T/4** a model can be attempted if, by chance, the whole data series is located on a single side (increasing or decreasing) of the "periodical function T". But in this limited case, any extrapolation of the result would be hazardous.

If the duration of the critical stage **p** is greater than or equal to **T**, it will be very difficult to identify the environmental effects because they will be smoothed for each cohort. The most favorable conditions for using these models occur when **p** is shorter than **T**, and especially when shorter than **T/2**, and when the fishable life span **n** is also shorter than **T/2**. In such cases, the mixture of various cohorts in annual catches will produce a minimal smoothing of global yields.

3. IMPLICATIONS FOR FISHERIES MANAGEMENT

3.1 Influence of the environment on abundance

We have seen that, in some cases, the environmental effect on stock abundance is more than "white noise" and therefore it is possible to modulate the fishing effort according to abundance predictions.

In situations where the forecasting of abundance is reliable (delay of climatic influence or remote connections) the difficulty of management will result from its dual objective : on one hand, optimization of the yield by increasing effort when the abundance increases, on the other hand, protection of the stock against a collapse by quickly

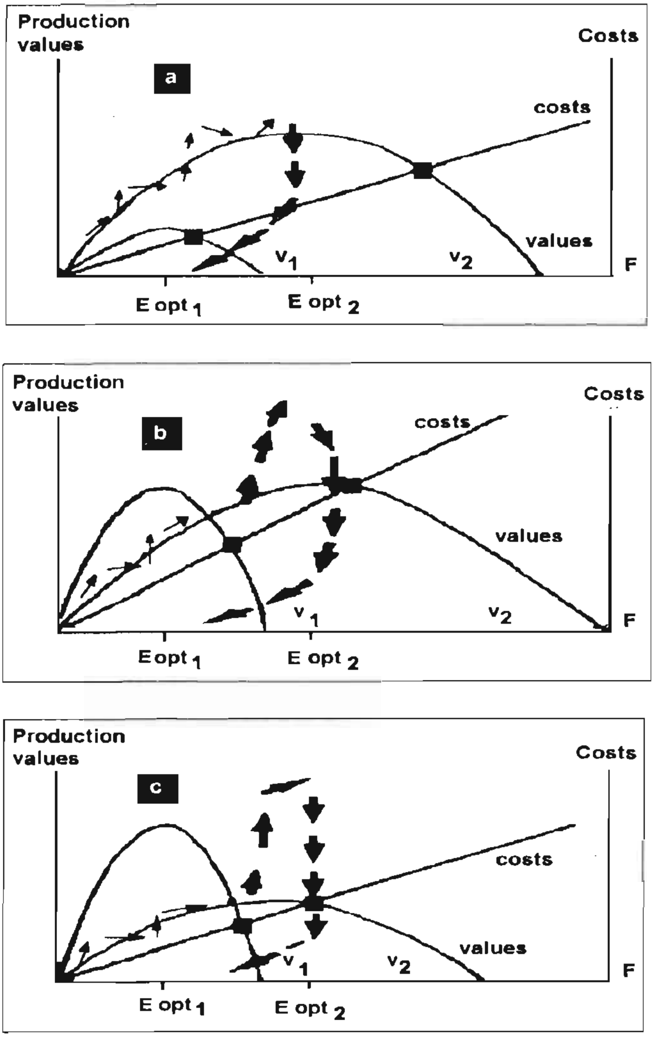

Figure 5

Bio-economical production models and theoretical examples of stock collapses when the environment influences the stock abundance (fig. a), the catchability (fig. b) or both those two factors in the same direction (fig. c) according to two values (V_1 and V_2) of the environmental variable V

Model produksi bio-ekonomi dan contoh teoritis dari sediaan yang menurun drastis bila lingkungan mempengaruhi kelimpahan sediaan (gambar a), catchability (gambar b) atau kedua faktor tersebut dalam arah yang sama (gambar c), menurut dua nilai (V_1 dan V_2) dari peubah lingkungan V

——— *theoretical curves (V_1 and V_2)*
— — — → *observed values under V_2*
▬ ▬ ▬ ➡ *observed values under V_1*
■ *threshold of probability*

reducing the fishing effort when the environmental factors are unfavorable. Such a collapse can, in fact, happen rapidly without any increase of effort if an "optimal" effort is maintained, which no longer corresponds to the actual climatic situation (fig. 5a). The collapse will occur more rapidly when there are few exploited cohorts acting as a buffer and when the critical life stage lasts less than a year (Fréon, 1983 and 1984). This permanent adjustment of the fishing effort is not easy to apply because of a delay between profits and investments. An analysis of this problem is available (Csirke and Sharp, 1983). Fishery management can be based on variable yearly quotas or on variable maximum allowable efforts.

3.2 Influence of the environment on catchability

Here the main risk of collapse occurs when from unfavorable climatic conditions to favorable ones. Following the usual bio-economic model (Troadec, 1982) the first situation will lead after a few years to an increase of the fishing effort providing catches closed to **Ymax** (fig. 5b). When catchability then suddenly increases the yields may increase too and the non-equilibrium state of the fishery will result in its collapse. In such a case the proper management decision is to fix a single quota, generally easier to determine and to control than variable effort limitations.

3.3 Influence of environment on both abundance and catchability

Depending on whether the environment influences **B∞** and **q** in the same direction or in opposite directions the resulting figures will be completely different (fig. 3a and 3b). Only two extreme cases will be analyzed here, but there are numerous intermediate situations.

In the first case, where **g(V)** and **y(V)** have the same sign of variation, a sudden occurrence of an unfavorable environment relative to abundance is not dangerous because the catchability would then be low. On the other hand, when the environmental conditions are both favorable to abundance and to catchability, and if there is no regulation mechanism provided by a market saturation or by a price adjustment, the fishing effort will tend to exceed **Emax** (fig. 5c). A strong limitation is then necessary.

In the second case, when a high abundance is associated with a low catchability, the main risk of collapse occurs when bad climatic conditions follow good ones. This situation is comparable to the one described above in the case of an influence of the environment on the abundance only (fig. 5a).

4. METHOD AND CRITERIA OF FITTING

Most of these models require non-linear regressions for fitting as, for example, those based on Marquardt's (1963) algorithm, on Gauss-Newton's modified method (Dixon and Brown, 1979) or on Simplex method (Nelder and Mead, 1965). These methods are iterative and used the least-square criterion. Fitting can be done by using formulae of CPUE (**Ui**) or catches (**Yi**). This last solution makes the fit more difficult but theoretically avoids the bias on regression coefficients due to non-independence of **Ei** and **Ui** (provided that **fi** and **Yi** have been estimated independently).

Some modifications of the procedure can be made by weighting the residuals. Fox (1971) analyzed this problem and retained the solution considering the error proportional to the estimated catches **Yi**, leading to a minimization of function **S** :

$$S = \sum_{i=1}^{n} [(Yi-Yi) / Yi]^2 \qquad (9)$$

All the algorithms need estimated starting values of the parameters for initializing the iterative process. In order to avoid convergencies toward local minima or toward irrational solutions from a biological point of view, those starting values must be carefully estimated . This can be done by using the initial model formulation where **$B\infty$** or **$U\infty$** appear. Their values can be estimated by doubling the maximum catch (or CPUE) observed in the data series. Exponents of **g(V)** and **y(V)** function can be initialized as 1 or zero.

A non-parametric estimation of the fit can be obtained using jackknife or cross-validation methods (Ducan, 1978; Efron and Gong, 1983). These methods show the stability of the model when one year observation is removed from the data series. It is interesting to notice that, in some cases, all the parameter values change while the fitting remains more or less the same inside the range of observed data but the curves are divergent outside this range. This indicates the risk in using such models outside the range of observed data on fishing effort and environmental factors. On some occasions it seems preferable to fix a "reasonable" value to one of the parameters, as already mentioned by Pella and Tomlinson (1969) in their generalized model.

5. CHOICE OF THE APPROPRIATE MODEL

Owing to the generally low number of yearly observations and to the relatively high number of parameters to estimate, the models present few degrees of freedom. Consequently the choice of the appropriate model among the numerous presented here must not be reasonably based on the criterion of the best fit. Additional information independent from the catch and effort statistical series must be taken into account in order to avoid spurious correlations.

Two categories of objective criteria can be identified and are briefly presented here. First, it must be decided if environment influences stock abundance or catchability. The choice of models where both phenomena are considered must be supported by some observations instead of being an opportunist choice. Time-series analysis, using a short time interval, may allow to distinguish between a contemporaneous effect of environment on catchability, and a delayed one on abundance (in this last case the lag can be estimated). In order to remove the seasonal effects and to determine the critical stage, transfer functions between CPUE and environment can be performed. Fishermen interview may also be useful in those instances where large inter-annual variations of environment allow to detect a long term effect despite a seasonal one.

The second step is then to decide whether a linear or an exponential model must be used. If the stock has never been over-exploited when considering any "maximal fishing efforts", the three kinds of models provide similar fits. However, the curves are divergent over those maximal efforts and it is preferable to give a representative trend, though any model should not be used for predicting situations outside the range of observed data.

An additional information on the stock structure may help to choose between a pessimistic linear model and an exponential one which allows a slow decline toward the stock collapse. Qualitative data on the stock history can directly provide a decisive information when collapses have already been reported. Linear models are suitable for short-lived species when all year-classes are exploited. Subdivision into sub-stocks, natural reserves where fishing is impossible or high gear selectivity on adults would incite to use exponential models. The expert-system CLIMPROD optimizes the choice according to such information.

6. CLIMPROD SOFTWARE

6.1 General presentation

CLIMPROD is based on an experience in artificial intelligence for choosing the best adapted model to each situation and for assessing the fit according to the data series and to the background on the stock. It is designed as an expert-system. Its conception was aided by FAO grants.

The software is written for PC/XT/AT compatible micro-computers using MS-DOS version 3.0 (at least). It is fully interactive and has two main objectives : first a normal data management function, whose statistical and graphical utilities use TURBO C language; second a guided selection of the appropriate model showing the information path. This part of the model uses an inference engine written in TURBO PROLOG. It applies about one hundred rules which are interactive with the informations provided by :

- Questions to the user on the stock, independently from the set of data (for example : the species life span)
- Statistics on the set of data (for example : the ratio of effort range on minimum effort value)
- Graphic deduction from the set of data (for example : does this time series look unstable ? Is there a decreasing relationship on this plot ?)
- Answering "I don't know" is allowed. The program is structured and does not necessarily use the whole set of questions. An example of order in the application of the rules is presented in figure 6.

From the main menu, the user is allowed to open or select a data file, to update it with a full screen editor, to search for the most suitable model, or to choose one directly, to validate the model (assess the fit), to plot the model function, predicted values and residuals, to see the path of the expert decisions and finally to use the model for prediction.

It should be noted that in order to choose among 30 multivariate models (see appendix 1), the program first performs a regression using the CPUE as the dependent variable and the effort (or the environment in some cases) as the independent variable. From the graphic display of the residuals of this regression versus the environmental variable the user may determine which kind of relationships will link environment and CPUE in the final multivariate model. This procedure provides an easy interpretation and visualization of the process to choose the model and allows an interactive dialogue with the user who can make use of additional information. Nevertheless, recent statistical techniques of optimal transformation for multiple regression (Breiman and Friedman, 1985; Cury and Roy, 1989) could be more powerful and optimal for choosing the model from a strictly statistical point of view. As this technique only uses the multi-variate time series (which is often too short for its optimal use) it should be a useful complementary help in the model selection.

6.2 Data entry and update

The basic data set used by CLIMPROD includes time series of catch (**Y**), fishing effort (**E**), CPUE (**U=Y/E**) and an environmental variable (**V**). A full screen editor allows for data entry, correction and updating.

6.3 Monovariate statistics and graphs of raw data

The following statistics are computed for each variable : sample size, average, variance, standard deviation, coefficient of variation, coefficient of skewness and kurtosis, minimum and maximum values, range, median. The data distribution is shown on a frequency histogram allowing eventual outlier values to be detected. Although no fishery data could be used if normality was strictly required for modeling, this results may give an idea of the data-structure. CLIMPROD stops the analysis and/or displays advice or warnings, according to the distribution of the values in the different variables, or if the range/minimum ratio of the effort values is lower than 40%.

6.4 Examination of time-series

Each variable is plotted against time (years) in order to detect any strong instability in the series which would sometimes hinder the interpretation of the results. In the case of strong instability of **E** or **V** for instance, if the retained model requires an averaging one of these variables over several years to approximate an equilibrium state, the results will be of little value.

6.5 Bivariate graphics

The following relations are plotted : **Y** versus **E**, **Y** versus **V**, **U versus E**, **U** versus **V** and **V** versus **E**. These graphs reveal any outlier points which can structure the data-set or any strong relationship (linear or not) between the two independent variables **E** and **V**. It must be underlined that at present the program does consider potential lag-effects between variables at this graphical stage.

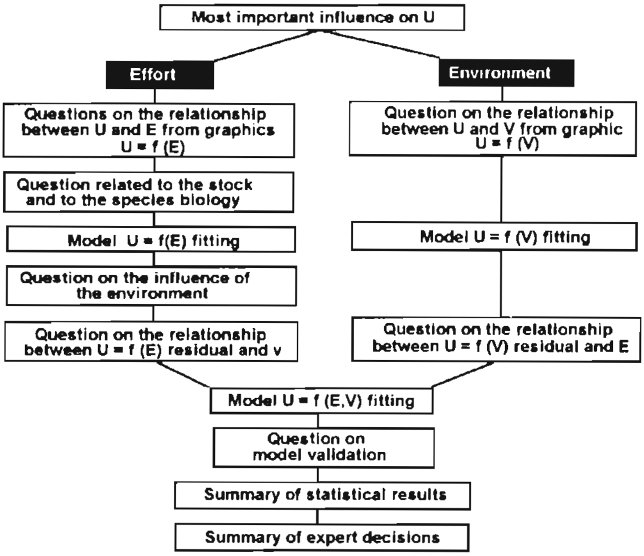

Figure 6

PARTIAL AND SIMPLIFIED FLOW DIAGRAM OF CLIMPROD, WHERE U IS THE CPUE, E THE FISHING EFFORT AND V AN ENVIRONMENTAL VARIABLE

SKHEMA CLIMPROD YANG DISEDERHANAKAN, DIMANA U ADALAH UPAYA PER UNIT PENANGKAPAN, E UPAYA PENANGKAPAN DAN V PEUBAH LINGKUNGAN

6.6 Questions guiding the choice of model

Four questions on basic assumptions of surplus production models are systematically asked, and the program is stopped if these assumptions are not met. The following questions are also systematically asked :

- Do you think that the effort influence on CPUE is more important than the environmental one (if unknown, yes is assumed) ? The answer, guided by statistical and graphical help, first orients the program either to **U=f(E)** or to **U=f(V)** models;
- Does the environment influence the abundance, the catchability or both ? At this moment the program does not provide any help for answering this question. It is supposed that the user knows the mechanism of action of the environment on the stock.

Between these two questions, the program will ask one or several questions in order to determine which relationship is more suitable between **U** and **E** (Schaefer's linear model, Fox and Garrod's exponential model or Pella and Tomlinson's generalized model), and between **U** and **V** (linear, exponential, general or quadratic).

6.7 Model fitting

In case of non-equilibrium conditions (transitional cases) a weighted average of **E** and/or **V** is computed. In case of delayed influence of the environment on abundance a lag is inserted between the weighted average of **V** and **U** (see Fréon, 1988, for further details). The Marquardt's algorithm is used for least-square estimation of non linear parameters. According to the model the initial values of the parameter are 1,0 or computed from the original data set before running the algorithm. As first result, the percentage of variation explained by the model (**R^2**) is given. The following steps depend on the quality of the fit, that is :

- After the step of bivariate model estimation, if **R^2**<40%, the program stops or invites the user to give new answers to the previously unanswered questions. If **R^2**>90% a validation of the bivariate model can be tried. If 40<**R^2**<90%, the program will try to find a multivariate **U=f(E,V)** model providing a better correlation than the bivariate one;
- After a multivariate model estimation, a validation attempt is possible if **R^2**>70%.

6.8 Statistical test of robustness (validation)

The fit assessment is mainly based on a jackknife estimation of the parameters and of **R^2**. It also takes into account the residual analysis and the data set characteristics. From the graphical presentation of the predicted values of the model and of its residuals, the user's own opinion is finally required.

6.9 Summary of expert decision

At the end of every step of the main menu the user may display the path followed by the program at each level of decision with the corresponding rule number.

7. EXAMPLE

An example of application is presented in figures 7 and 8 which corresponds to the Senegalese sardine fishery (Fréon, 1983; 1988). A tentative new abundance index has been used, i.e., the mean annual weight per set when a single successful set is performed per trip (Fréon, 1989). The environmental variable influencing the stock abundance is the mean wind speed during the upwelling season.

According to stock and species knowledge, CLIMPROD first chooses to fit the exponential model for the function **U=f(E)** and find **R^2**= 86%. The relationship between the residuals of this model and **V** is linear (fig. 7). Therefore the linear-exponential model is fitted and provides an **R^2** value equal to 95% (fig. 8) The jack-knife validation indicates that all parameters are significant at a 5% level and that no single year contributes to more than 35% of any coefficient estimation which is relatively satisfactory. The residuals of the model are not auto-correlated.

8. DISCUSSION

Although the results obtained on the Senegalese stock seem satisfactory, further studies are necessary before accepting the catch per set as a representative index of abundance. Therefore this particular example -given only as an illustration of the program capabilities- will not be further discussed here. Of greatest interest is the discussion on improvements, limitations and risks brought by the expert-system approach.

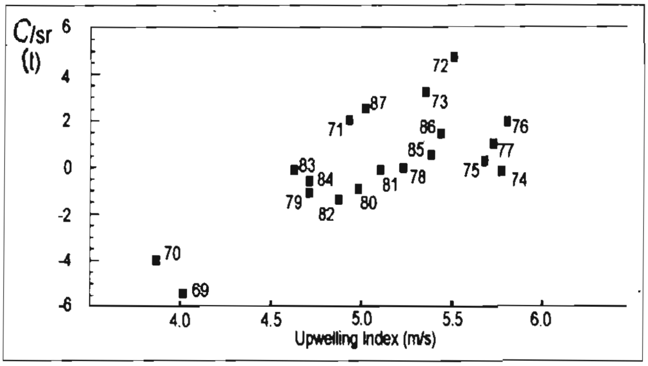

Figure 7

Coded scatterplot between upwelling index (two years weighted average of wind speed during the up welling season) and the catch per set residuals (C/sr from a conventional surplus production model; see text); numbers represent years

Diagram pencar antara indeks upwelling (rata-rata tertimbang kecepatan angin selama musim upwelling selama dua tahun) dan hasil tangkapan setiap "set residuals" (C/sr dari model produksi konvensional, lihat teks) ; nomor adalah tahun

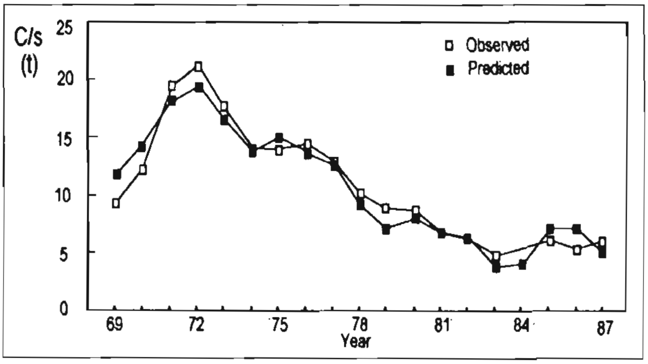

Figure 8

Predicted and observed catches per set (C/s) when introducing an environmental variable in surplus production model

Hasil tangkapan berdasarkan pengamatan dan dugaan setiap set dengan memasukan peubah lingkungan kedalam model surplus produksi

The introduction of an environmental variable into global production models increases in the number of parameters in the final formulation and consequently there are four main difficulties:

- Although fitting is easier, confidence limits of the parameters are often high and the fitting procedure may be unstable.
- It is sometimes difficult to estimate the real contribution of each variable (**E** and **V**) in the models, owing to their interaction and/or colinearity.
- The problem of transitional states becomes more difficult to solve, especially when the environmental influence is described by a shaped function (in such cases CLIMPROD does not provide a satisfactory solution).
- By increasing the number of explanatory variables one also increases the probability of getting randomly good correlations independently of any real biological phenomena (Ricker, 1975). The literature provides many examples of good historical fits which breakdown as soon as the model is used for forecasting.

These difficulties common for any multi-regression can be overcome by an objective choice of variables (supported by biological observations as far as possible). As underlined by Bakun and Parrish (1980) the selection of the environmental variable to be introduced into the model must, as far as possible, be *a priori* and not only empirical (they present a list of likely variables).

In addition, those models still have the usual limitations of conventional surplus production models, linked to their basic assumptions, as discussed by Fox (1974). Even after their modification they remain an empirical procedure for assessing fish stock responses (in terms of biomass and yield) to changes in the fishing rate and environmental conditions. Therefore they represent a blind approach for investigating recruitment variability.

When causal environmental factors and/or processes cannot be forecasted and have a short term effect, the proposed approach can only be used for assessing the range of environment-induced fluctuations and for comparing it to that of fishing effects. This would already be useful for it could improve management strategy particularly when stocks are at the upper and lower ranges of their biomass and/or catchability.

Simple surplus production models have been criticized because they suffer from lack of biological realism. Nevertheless, in many instances more sophisticated age-structured models, as proposed by Deriso (1980), do not better perform owing to difficulties in the estimation of additional parameters (Ludwig and Walters, 1985). CLIMPROD only uses one additional variable and zero to three (but often one) additional parameters to the conventional surplus production models. Moreover, the artificial intelligence allows for using additional quantitative or qualitative data which are not included in the model as variables but help the user to choose the best model equation according to the stock characteristics and not only to the criterion of the best fit. This last criteria has been demonstrated to not necessarily provide a more realistic policy prescription (Uhler, 1980). The present approach can provide better assessment and management of the stock by taking into account the user's knowledge of stock biology or structure and the expert's experience with other stocks.

Some negative aspects of CLIMPROD must also be pointed out. This tool will be made available to fishery biologists or fishery managers and can be used to fit any model without special knowledge of population dynamics. The program asks the user to respond to various questions regarding the basic assumptions underlying the model and it stops in case of insufficient knowledge. Nevertheless, the user remains free and is responsible for other errors. Moreover, the objective choice of an environmental variable (including its spatio-temporal window and its lag on production) is often the key factor to avoid spurious correlations. In general, even in the case of surplus production models, a minimum knowledge of the stock and of the species biology is required.

CONCLUSION

Few studies on the relationships between the marine species and their environment allow an estimation of combined effect of the environment and the fishing effort on the stock in term of actual production and MSY.

The models here outlined allow to take into account the effect of environment on yields and therefore to overcome the difficulties caused by two underlying requirements of the conventional surplus production models, namely : the data set must concern a period when the environmental factors influencing the stock abundance were stable (or fluctuated randomly over a long enough period of observation) and the catchability must also be independent from the environment. This advantage allows an increase of the usable data series but requires more parameters to be estimated. The decision whether to use the traditional models or their modified versions here proposed will result from the balance between such considerations.

As these models are still global they retain the limitations of such models and require the other usual basic assumptions. Despite such constraints these models are often a more acceptable solution than the traditional ones, especially in tropical areas where environmental factors are the predominant influence on production of short lived species. In such areas fish ageing is often difficult and requires expensive intensive sampling owing to the high variability of the fish length within the cohorts associated with a special type of aggregation in the case of small pelagic species (Fréon, 1985). Under such circumstances the usual analytic methods are hardly usable. Although environmental production models do not need quantitative biological data, it is necessary to possess a minimum knowledge of the species ecology for their proper use. One of the aim of CLIMPROD expert-system is to force the user to take into account this knowledge for selecting and fitting an appropriate model.

This experience in artificial intelligence, through the necessary dialogue between computer and biology sciences, leads to the formulation of modeling rules which are often empirical and crude. Such a simplification of the biologist's way of thinking is not devoid of interest. It allows for the exchange of ideas between the experts. Moreover, the software itself could be an interesting pedagogical tool either when used with real data sets or with simulated ones.

The utilization of these models for predictions is not risk-free. It requires a forecast of fishing effort and in some cases a forecast of one environmental factor (when there is not enough lag between this factor and its effect on the fishery). This latter forecast is often imprecise, as underlined by Walters (1978). Moreover, the confidence limits of the parameters are sometimes so high that the predictions within the observed range of the variables would be hazardous and of course it would be even worse to forecast using input values outside the observed range.

Nevertheless, the MSY concept, despite its epitaph (Larkin, 1977), can still be used but in a plural sense with the present models which can be considered as a final development. They provide different MSYs for each state of the environmental variable, or at least a different **fmax** when only the catchability is modified. Application examples were presented in upwelling areas (Fréon, 1988; Fréon *et al.*, 1992) showing that CLIMPROD models can provide a fairly good interpretation of fishery history. They can explain how some large fluctuations of the catches (and sometimes collapses) may occur, without any increase of the nominal effort, as a result of environmental changes. Such an eventuality has already been catered in stochastic models (Laurec *et al.*, 1980) but only in a statistical way. A deterministic tool is proposed here for the use of fishery managers. Despite imprecise catch predictions it allows to understand, and sometimes to forecast, the fishery tendencies. In this last case, the goal is not only to preserve the resource, but also to optimize the surplus production provided by favorable environmental situations.

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APPENDIX 1 : CLIMPROD AVAILABLE MODELS

U=f(E) models

U=a.exp(b.E)	(exponential)
U=a+b.E	(linear)
U=(a+b.E)^(1/(c-1))	(generalized)

U=f(V) models

U=a+b.V	(linear)
U=a.V^b.	(exponential)
U=a+b.V^c	(general)
U=a.V+b.V^2+c	(quadratic)

U=f(E,V) models;influence of V on abundance

U=a.V+b.E	(linear-linear)
U=a+b.V+c.E	(linear-linear)
U=a.V^b+c.E	(linear-exponential)
U=a.V+b.V^2+c.E	(linear-quadratic)
U=(a+b.V).exp(c.E)	(exponential-linear)
U=a.V.exp(b.E)	(exponential-linear)
U=a.exp(b.E)+c.V+d	(exponential-linear)
U=a.V^b.exp(c.E)	(exponential-exponential)
U=a.V^b.exp((c.V^d.E) without constraints	(exponential-exponential)
U=(a.V+b.V^2).exp(c.E)	(exponential-quadratic)
U=((a.V^b)+c.E)^(1/(d-1))	(generalized-exponential)
U=((a+b.V^2)^(d-1)+c.E)^(1/d-1)	(generalized-quadratic)

U=f(E,V) models;influence of V on catchability

U=a.V+b.V^2.E	(linear-linear)
U=a+b.V-c.(a+b.V)^2.E	(linear-linear)
U=a.V^b+c.V^(2.b).E	(linear-exponential)
U=a.V.exp(b.V.E)	(exponential-linear)
U=(a+b.V).exp(-c.(a+b.V).E)	(exponential-linear)
U=a.V^b.exp(c.E.V^b)	(exponential-exponential)
U=a.V.(b-c.V)-d.V^ 2.(b-c.V)^2.E	(linear-quadratic)
U=a.V.(1+b.V).exp(c.V.(1+b.V).E)	(exponential-quadratic)

U=f(E,V) models;influence of V on both abundance and catchability

U=a.V^(b+c)+d.V^(2.b).E	(linear-exponential-exp.)
U=a.V^(1+b)+c.V^(2+b)+d.V^(2.b).E	(linear-quadratic-exp.)
U=a.V^b.exp(E.c.V^d)	with sign constraint (exp.-exp.-exp.)
U=(a.V^(1+b)+c.V^(2+b)).exp(d.V^b.E)	(exp.-quadratic-exp.)