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De-seasonalizing of the abundance index of a species

Application to the albacore (*Thunnus alalunga.*) monthly catch per unit of effort (C. P. U. E.) by the Atlantic Japanese longline fishery *

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Summary

Two different statistical techniques of analysis have been worked out in order to analyse the components of available data of catch per unit of effort (C. P. U. E. by month), used as an abundance index, for the Atlantic Japanese tuna longline fishery harvesting north-southern stocks of albacore (*Thunnus alalunga*). These techniques have been developed in order to estimate different components of this abundance index, such as yearly trend, a seasonal component, fishing effort impact, and unknown residual component.

Both techniques combine these components either in an additive model or multiplicative one and allow to assign to the trend a continuous or discrete (stepwise) shape. The first technique is simple, it is called "moving average" and applies exclusively to complete sets of data without blank. The second technique is more powerful, it is a generalization of the first one, it uses the regressive methods and applies to complete or incomplete sets of data.

Applying these two techniques and their different options (model, trend, complete sets or not) to the data of longline fishery albacore, brings some new elements of knowledge on the real trends of abundance of the two stocks and their structure. The northern stock appears as a unit sustaining a unique longline fishery; on the opposite the southern stock appears to have a complex structure and to sustain two different longline fisheries with their own trends.

Resume

Disposant des captures par unité d'effort de la flottille palangrière thonière japonaise atlantique (CPUE mensuelles) pour les stocks nord et sud de germon *Thunnus alalunga*, deux techniques différentes d'analyse ont eté développées afin d'estimer les différentes composantes de cet indice d'abondance: tendance annuelle, composante saisonnière, incidence de l'effort de pêche, et composante résiduelle non

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identifiable.

Les deux techniques intègrent ces composantes soit dans un modèle additif, soit dans un modèle multiplicatif et permettent d'assigner à la dérive (tendance) une allure continue ou discontinue " en escalier ". La première technique simple dite des " moyennes mobiles " s'applique uniquement au cas d'une série complète sans lacune. La seconde technique, plus puissante, généralisation de la première fait appel aux méthodes régressives et permet de traiter une série incomplète présentant des lacunes.

L'application de ces deux techniques et des différentes options (modèle, dérive, série complète ou non) aux données de pêche palangrière du germon apporte quelques éléments nouveaux sur les tendances réelles de l'abondance des deux stocks et sur leur structure. Ainsi il apparaît que le stock nord est un stock unitaire supportant une seule pêcherie palangrière alors que le stock sud semble de structure plus complexe et supporter au moins deux pêcheries palangrières évoluant différemment.

Introduction

The estimation of the exploitation level concerning a stock or a population generally requires the calculation of an index of abundance. The use of the catch per unit of effort (C.P.U.E) as an index of abundance has often been discussed. The temporal evolution of the C.P.U.E is the resultant of many components, among which the following may be mentioned: the availability of the fish (owing to the seasonal or annual variations), the fishery effectiveness, in its broad sense, the real decrease in the fish abundance due to exploitation, the increasing or decreasing interest of a fishery for a species or for an area.

Some authors, (SHIOHAMA, 1970; HONMA, 1974), have more particularly considered the geographical or specific interest of the Japanese longline fishery in the Atlantic ocean. The purpose of this study, based on the same data, is to analyze the seasonal components of the catch per unit of effort in order to attempt to define a satisfactory monthly and annual index of abundance for those fisheries with a high seasonal variability. The application to the longline fishery of the albacore in the Atlantic ocean is intended to emphasize the real trends of the indices of abundance for this species, which is fished in the Northern Atlantic Ocean by the French-Spanish fishery and in the Central Atlantic Ocean by the Asian longline fisheries.

Data and treatment

The regular publishing, in number of individuals, month by month and for each 5-degree square, of the Japanese longline fishery catches from 1956 to 1972 (FISHERY AGENCY OF JAPAN, 1965–1974) has given rise to many studies. The nature of these rough data and their detailed treatment were described repeatedly (LE GALL, 1974).

Very succinctly, and regarding only the data used in this study, the " index of abundance" utilized is a weighted index of abundance (IAP) derived from the catch per unit of effort for 100 hooks and for each month, so that:

for a geographical area (n) including (m) squares for month (j) of year (k), (c) being the catch, in number, and (g) the effort in hooks:

$$IAP_{njk}=\frac{1}{m}\sum_{i=1}^{i=m}\frac{c_{ijk}}{g_{ijk}}$$

On the other hand, the division of the Northern Atlantic albacore populations into two North and South stocks is about unanimously accepted. Consequently, the treatment has been carried out similarly on both stocks and, inside each stock, on smaller geographical areas corresponding to various seasonal fisheries (Fig. 1).

Principle methods utilized

The objective aimed at is the identification of the three major variation sources determining the temporal evolution of a series of catches per unit of effort, i.e.: general trend, fluctuations of a seasonal origin and residual component. Recourse to the deliberately simplified theory of the temporal series makes it possible to develop the analysis implement adapted for objectives aimed at and likely to be utilized by users not specialized in the study of the stochastic processes.

The utilized elements of the temporal series theory (KENDALL, 1973 inter al.) are based upon the following fundamentals:

Model selection

—Additive model, multiplicative model and mixed model

Let x be the series under study, m the trend, s the seasonalizing factor and ε the unexplained residues; the additive model can be expressed:

$$x(t)=m(t)+s(t)+\varepsilon(t)$$

and the multiplicative model:

$$x(t)=m(t)\cdot s(t)\cdot\varepsilon(t)$$

When all the mentioned terms are positive the last model is expressed as an additive model through logarithmic transformation;

$$\log x(t)=\log m(t)+\log s(t)+\log\varepsilon(t)$$

Mixed models can be used:

$$x(t)=m(t)\cdot s(t)+\varepsilon(t)$$

—Continuous trend or stepwise trend

The trend may be a continuous function, or it may be assimilated to a stepwise function, constant within a year, for instance. In the second case, for instant t=month IM of the year IA,

$$x(t)=m(IA)+s(IM)+\varepsilon(t)$$

for the additive model. When the trend shows no significant variations within a year, the approximation of this trend by a stepwise function provides a simplicity of use without affecting the results significantly. This method has the advantage of providing an annual index directly.

—Model adjustment

Since the multiplicative models are expressed as additive models, only the adjustment of the latter type will be dealt with. Two adjustment techniques can be utilized: the moving averages (applicable only for complete series) and the regressive methods (suitable for complete and incomplete series). For each of these two techniques two types of approach are considered: either through continuous trend models, or stepwise models.

—Utilization of moving averages

This technique is limited to the analysis of the complete series (without any blank). This technique was developed by KENDALL (1973).

A) Continuous trend

In the additive model, $x(t)=m(t)+s(t)+\varepsilon(t)$

The first step consists in evaluating $m(t)$ by averaging $x(t)$ over 13 months distributed either side of the month considered, i.e. centered about t (the year is assumed to be divided into 12 months, generally it could be divided into intervals) and such that:

$$\bar{x}(t)=\frac{1}{12}\sum_{t-6}^{t+6} w(i)\cdot x(i)$$

where $w(t-6)=w(t+6)=0.5$

and $w(i)=1$ for $t-6<i<t+6$

to allow for the fact that terms $(t-6)$ and $(t+6)$ correspond to the same month and must have a weight of 0.5 instead of 1 in the weighted average.

Thus, writing down $\bar{m}(t), \bar{s}(t), \bar{\varepsilon}(t)$ for the weighted averages

$$\bar{x}(t)=\bar{m}(t)+\bar{s}(t)+\bar{\varepsilon}(t)$$

the over all influence of the seasonal factors over the whole year must be zero, hence $\bar{s}(t)=0$, $\bar{x}(t)=\bar{m}(t)+\bar{\varepsilon}(t)$

since the "residues" series $\varepsilon(t)$ is assumed to be free of any low frequency constituting phenomenon (corresponding here to a slow evolution) the sum of the residues should be approximately zero. Thus, it remains that:

$$\bar{x}(t)\doteqdot\bar{m}(t)$$

and, if the evolutive trend is regular:

$$\bar{m}(t)\doteqdot m(t)$$

The evaluation of $m(t)$ by means of $\bar{x}(t)$ is therefore justified if the following three hypotheses are complied with:

(1) $\bar{s}(t)=0$, which is included in the definition of a seasonal component.

(2) residues $\varepsilon(t)$ are sufficiently jumpy for their influence accumulated over the year to be zero.

(3) the trend is regular enough to prevent its being appreciably modified by the

smoothing due to a weighted factor.

Under the preceding three hypotheses, and in a first phase, $m(t)$ is evaluated by $\bar{x}(t)$. A series without trend is then developed:

$$z(t)=x(t)-\bar{x}(t)\doteqdot s(t)+\varepsilon(t)$$

The second step consists in evaluating $s(t)$

This evaluation is obtained by averaging the corresponding $z(t)$'s, $(t, t+12, t+24, t+36...)$ for each month. Actually, the evaluations thus obtained do not necessarily comply with the condition:

$$\sum_{t=1}^{12} s(t)=0$$

If Sm is the average, the evaluation will be obtained by subtracting this average from the first evaluation of $s(t)$ and by adding this constant to the first evaluation of the trend (KENDALL, 1973).

B) Stepwise trend

The constant value of the trend within a year is merely evaluated by the average of the $x(t)$ values for the various months of that year. The isolation of the seasonal factor and residues is carried out later on, as in the case of a continuous trend.

—Regressive methods

This technique, which has a greater flexibility of use, is almost a generalization of the preceding one and makes it possible to deal with incomplete series.

If the trend can be expressed in the form

$$m(t)=\sum_{j=1}^{J} d_j f_j(t)$$

where the d_j's are J coefficients and the $f_j(t)$'s are as many functions given at the start, the evaluation of $m(t)$ and $s(t)$ boils down to a multiple regressive problem. In the case of an additive model this regression becomes multilinear, but with a special feature. If the year is divided into K intervals (12 months or 4 quarters), $k(t)$ an interval, in model:

$$x(t)=m(t)+s(t)+\varepsilon(t)=\sum_{j=1}^{J} d_j f_j(t)+S_{k(t)}+\varepsilon(t)$$

where $k(t)$ is the interval containing instant t.

$$S_{k(t)}=s(t)$$

$$\sum_{j=1}^{J} d_j f_j(t)=m(t)$$

The following additional condition must be added:

$$\sum_{k=1}^{K} S_k=0$$

which means, as explained above, that the influence of the seasonal factor accumulated over a year is equal to zero.

We are now going to explain functions $f_j(t)$ and, as done previously, to consider the case of a continuous trend and a stepwise trend, in succession.

A) Continuous trend

The simplest hypothesis consists in assuming that trend $m(t)$ is a polynomial in t with a degree ND. Functions f_j are then monomials $i, t, t^2, \ldots t^{D}$ and $ND = j-1$.

The model is therefore written thus:

$$x(t) = \sum_{j=1}^{J} d_j \cdot t^{j-1} + S_{k(t)} + \varepsilon(t)$$

with

$$\sum_{k=1}^{K} S_k = 0$$

without this condition, the model would have an infinity of solutions. It could be possible to add any constant to the S_k's, provided that this constant is subtracted from d_1.

To develop the calculations it is useful, at this level, to insert series $w(t)$.

$w(t)=1$ if $x(t)$ is known

$w(t)=0$ if $x(t)$ is unknown

Adjustment by the method of least squares, then, consists in minimizing:

$$\sum_t w(t)\left[x(t) - \sum_{j=1}^{J} d_j t^{j-1} - S_{k(t)}\right]^2 = P(d_1, \ldots d_J, S_1 \ldots S_K)$$

The current method, then, consists in having the following equal to zero:

$$\frac{\partial P}{\partial d_j} \qquad j=1, J$$

$$\frac{\partial P}{\partial S_k} \qquad k=1, K$$

in order to form the system called I. It is then ascertained that the system thus obtained is "degenerate", or has an infinity of solutions. One of the equations of system I will be replaced by the additional equation.

$$\sum_K S_k = 0$$

Generally, this system will have one and only one solution and will make it possible to obtain the evaluation aimed at for the d_j's and S_k's.

Assuming a residual series, $\varepsilon(t)$, forming a white noise it would be possible to engage in statistical inferences about the estimators thus obtained. The development of the calculations is shown in Appendix A.

B) Stepwise trend

The interval notations K, $k(t)$, are maintained, L corresponds to the number of years considered, $l(t)$ to a particular year.

$$x(t) = M_{l(t)} + S_{k(t)} + \varepsilon(t)$$

$$M_{l(t)} = m(t)$$

where $S_{k(t)} = s(t)$

with condition $\sum_{k=1}^{K} S_k = 0$

The model is determined by the $K+L$ parameters $M_l, l=1 \ldots L$; S_k, $k=1, \ldots K$.

As previously, series $w(t)=0$ or 1, according as $x(t)$ is known or not, is introduced and the adjustment by the method of least squares consists in minimizing:

$$\sum_{t} w(t)\left(x(t)-M_{l(t)}-S_{k(t)}\right)^2$$

with the additional linear condition

$$\sum_{k=1}^{K} S_k=0$$

The details of the calculations are shown in Appendix B.

Particular features about the application to the data concerning the catch per unit of effort (C. P. U. E.)

The C. P. U. E. concerning a species depends upon the density (true abundance of the stock: N) showing relatively slow variations, upon the catchability, q, which is most often related to seasonal fluctuations, and upon the fishing effort really developed.

The combining of these three factors conduce to retain the multiplicative model as being the more realistic. In addition, the logarithmic transformation of the C. P. U. E. ensures that the variations of the trend (i. e. of the stock density logarithm), within the year, are low.

When the model selection is completed, the meaning of the multiplicative model parameters, in the specific case of the application to a catch per unit of effort, it still to be accurately defined. The correspondence between the stock density, $N(t)$, and the trend value, $m(t)$, is clearly established as well as between the seasonalizing factor value, $s(t)$, and the catchability, q. The influence of the fishing effort on the C. P. U. E. reliability can be introduced, when using the regressive methods (in continuous trend or stepwise), through a modulation of series $w(t)$. As stated previously in the discussion of the principles, series $w(t)$ accepted only two values, 0 or 1, according as value $x(t)$ of series w was known or not. This particular case would be perfectly applicable for the description of the data series $x(t)$ obtained from only one observation. In the more general case, in which series $x(t)$ is obtained from several observations (i. e. from several data collector ships having operated for several days), and in which the reliability of $x(t)$ is, to some extent, proportional to the data collecting effort, the weighting of series $w(t)$ according to the instantaneous values of the effort is to be preferred. In the present case of a C. P. U. E. series we can introduce into series $w(t)$ the values of the efforts developed, $f(t)$. The values of the efforts developed monthly for each data series are indicated on additional tables, just after the rough data (C. P. U. E.) for each geographical area concerned.

Applications

Treatment of a complete series by means of the moving averages technique

Two complete series (i.e. without any blank) have been selected. The first one corresponds to the monthly C.P.U.E. for 100 hooks, (IPA_{njk}), of the Japanese longline fishery on the Northern stock of albacore (areas $N1+N2$—Fig. 1; tables 1.1 and 1.2). The second one is the homologous series concerning the Southern stock (areas S1+S2 —Fig. 1; tables 2.1 and 2.2). In order to test the impact of the model selection, the two treatments i.e. according to the additive or multiplicative models, have been carried out on the only case of a continuous (polynomial) annual trend.

The three series: rough data, smoothed data (=annual trend) and predicted data (trend+seasonal component) are shown graphically on the same figure, so as to facilitate the comparison according to the following references:

AREAS	OPTIONS 1. Method 2. Model 3. Trend	TABLES (Nos)	CONTENTS	FIGURES
NORTHERN STOCK ($N1+N2$)	1. moving averages	1.1 1.2	Rough data Efforts/month	Fig. 2 and 3
	2. Additive 3. Continuous		Annual trend Trend+season	Fig. 2
	2. Multiplicative 3. Continuous		Annual trend Trend+season	Fig. 3
SOUTHERN STOCK ($S1+S2$)	1. Moving averages	2.1 2.2	Rough data Efforts/month	Fig. 4 and 5
	2. Additive 3. Continuous		Annual trend Trend+season	Fig. 4
	2. Multiplicative 3. Continuous		Annual trend Trend+season	Fig. 5

Treatment of a complete or incomplete series by means of the regressive technique

—Continuous trend and complete series

In order to test the efficiency of this technique the preceding two complete series (Northern stock and Southern stock) have been, in a first step, dealt with again through the regression method by using, this time, the efforts developed (in number of hooks) as a weighting series, $w(t)$. As previously, the results are represented graphically according to the references given below:

AREAS	OPTIONS 1. Method 2. Model 3. Trend	TABLES (Nos)	CONTENTS	FIGURES
NORTHERN STOCK $N1+N2$	1. Regressive 2. Multiplicative 3. Continuous		Annual trend Trend+season	Fig. 6
SOUTHERN STOCK $S1+S2$	1. Regressive 2. Multiplicative 3. Continuous		Annual trend Trend+season	Fig. 7

—Continuous trend and incomplete series

Within the limits of each Northern or Southern area, such as they are defined above, a smaller area has been retained, i.e. area $N2$ for the Northern stock and the BRAZIL area for the Southern stock (Fig. 1). The first area ($N2$) corresponds approximately to the longline fishery in the North Atlantic Ocean during the winter and provides a series with break of indices of abundance, owing to its seasonal characteristics (Tables 3.1 and 3.2).

The second area (BRAZIL) is the oldest summer albacore fishery area in the South Atlantic Ocean and is located on the concentration areas of the mature adults (Tables 4.1 and 4.2). As seen above, the three series: rough data, smoothed data (annual trend) and predicted data (trend and seasonal component) are shown graphically on the same figure and in the form of annexed tables with figured data according to the following references.

AREAS	OPTIONS 1. Method 2. Model 3. Trend	TABLES (Nos)	CONTENTS	FIGURES
$N2$ Northern winter fishery	1. Regressive 2. Multiplicative 3. Continuous	3.1 3.2	Rough data Efforts/month Annual trend Trend+season	Fig. 8
BRAZIL Southern summer fishery	1. Regressive 2. Multiplicative 3. Continuons	4.1 4.2	Rough data Efforts/month Annual trend Trend+season	Fig. 9

—Stepwise trend and incomplete series

The regressive technique, associated to a stepwise annual trend, has been applied only to the two previously defined series: $N2$ and BRAZIL. The rough data, smoothed data and predicted data are given, as previously in the form of figures according to the following references:

AREAS	OPTIONS 1. Method 2. Model 3. Trend	TABLES (Nos)	CONTENTS	FIGURES
N2 Northern winter fishery	1. Regressive 2. Multiplicative 3. Stepwise		Annual trend Trend+season	Fig. 10
BRAZIL Southern summer fishery	1. Regressive 2. Multiplicative 3. Stepwise		Annual trend Trend+season	Fig. 11

Results

Acquisitions in the technological field

It appears of interest to estimate the impact of the model selection the technique utilized (moving averages or regressive method) and of the type of trend (continuous or stepwise). On the other hand, it is of importance to compare the stock evolution determined from the treatment of the complete series collected on the whole distribution area and from the treatment of an incomplete series collected over only a selection of the distribution area.

—Impact of the treatment options (model, method, type of trend)

In the present case of the treatment of a C.P.U.E. series, the first conclusion conduces to retain the multiplicative model. In effect, the non-adequacy of the additive model is emphasized by the following phenomenon: the incidence of the seasonal factor on the predicted values series (trend+seasonal component) is excessive during the years when the true C.P.U.E. is low, and inadequate when the C.P.U.E. is high (Fig. 4). Conversely, the adequacy of the multiplicative model will be better when the influence of the seasonal factor is multiplied, in absolute value, by the trend.

The second option concerns the type of trend (continuous or stepwise). In theory, the continuous trends seem preferable, however, the stepwise series provide a certain simplicity and conduce directly to the evaluation of annual indices, without introducing significant distortions in the results.

At the level of the selection of the model adjustment method, it can be noticed that the trends provided by the simple method of the moving averages sometimes exhibit unexplainable jumps which should be further smoothed. The adjustment through the regressive method seems therefore preferable. When the polynomial trends are considered the degree selection sets no problems in the examples dealt with (cf. appendix A).

The weighting by means of the fishing efforts, whose selection could not be theoretically justified, provides an additional improvement in the treatment of a C.P.U.E. series.

Finally, a more detailed analysis of the residues would show the pre-eminence of the multiplicative models, the usefulness of the selected weighting and the non-independence of the residues concerning two consecutive months. This last characteristic makes it possible, for this particular problem, to rule out the sophisticated statistical tests based upon the assumption of the residues independence at various instants.

—Comparison of the results obtained from a complete series and from an incomplete series.

Since the continuous trend multiplicative model adjusted by means of the regressive method is recognized to be the most adequate for the example discussed, it therefore remains to compare the trends deduced from a complete series of data and from an incomplete series. This comparison is carried out in succession for the Northern stock: complete series (area $N1+N2$, Fig. 6), and incomplete series (area $N2$, Fig. 8) and, then, for the Southern stock: complete series (area $S1+S2$, Fig. 7) and incomplete series (BRAZIL area, Fig. 9).

It can be noticed that, in the case of the Northern stock, the annual trend has the same aspect, in complete series and incomplete series with, however, a constant deviation of about 1 to 1.5 units for 100 hooks (catch for 100 hooks), which confirms that the fishing efficiencies in area $N2$ are always definitely higher than those obtained on the whole Northern stock.

On the contrary, in the case of the Southern stock, the aspect of the annual trend is very different according as we observe the complete series (total stock) or the incomplete series (BRAZIL). In the BRAZIL series the efficiencies drop rapidly during the first years and settle later on. Conversely, on the whole area of the Southern stock the reduction of the efficiencies appeared only during the last years when the Japanese fishery lost interest in the albacore species. In this case, (Southern stock) it seems, therefore, that no conclusions can be drawn about the whole south stock from the data concerning the summer fishery in the South Atlantic Ocean in spite of its old existence.

Conclusions about the fisheries and the apparent abundance

—Comparison between the Northern and Southern stocks

To begin with, and taking as only basis the results of the Japanese fishery, we can see that the efficiencies obtained on both stocks are relatively close to each other if we consider the present trend. The evolution is fairly similar for both stocks and, more particularly, shows a reduction of the efficiencies, starting from 1969, even before the disinterest shown by the Japanese fishery for this species (1972 and 1973).

This disinterest explains the collapse of the efficiencies in 1972, and artificially indicates this real trend to a decrease of the efficiencies which goes back to 1969.

—Structure of the stocks

The Northern stock appears as forming a single one, simply constituted, and the trends appearing over a seasonal fishery seem to correctly reflect the general trend of the stock. Conversely, the Southern stock seems to be of a complex nature, and to sustain two longline fisheries whose trends are rather independent from each other: ancient fishery off Brazil (definitely on the wane) and winter fishery in the South Atlantic Ocean, which succeeded to the first type as far back as 1964. The handling of the Southern stock must allow for this apparent heterogeneity.

Conclusions

The selection of the treatment options: type of model (additive or multiplicative), aspect of the trend (continuous or stepwise) and of the method of calculation (moving averages or regression) is essentially determined by the nature of the data. In the present case of a C.P.U.E. series the multiplicative model is imperative, as well as the use of the regressive technique, which makes it possible to get rid of the obstacle of the incomplete feature of the indices of abundance series and, to some extent, to integrate the incidence of the fishing effort through weighting. Finally, the adoption of a continuous, or stepwise, trend depends upon the result aimed at: an annual average index, or all the intermediate punctual values.

The particular application to the C.P.U.E. data concerning the Northern and Southern stocks of Atlantic albacore provides some new elements concerning the evolution of these two stocks. Regarding the Northern stock of albacore first, the general aspect of the trend, evaluated from the collection of the C.P.U.E.'s over the whole distribution area of the stock, is in agreement with the estimated trend of only one section of its distribution area (Northern area). This common trend indicates a small reduction of the efficiencies, as far back as 1969, before the disinterest shown by the Japanese fishery for this species (1972 and 1973).

On the other hand, regarding the Southern stock the aspect of the trend estimated over the summer fishery off Brazil is essentially different from that evaluated from the whole distribution area of the Southern stock. The general trend is fairly similar to that of the Northern stock in the whole and drops a hint of a reduction for 1970, even before the disinterest shown by the Japanese fishery for the albacore species in the Atlantic Ocean, in general.

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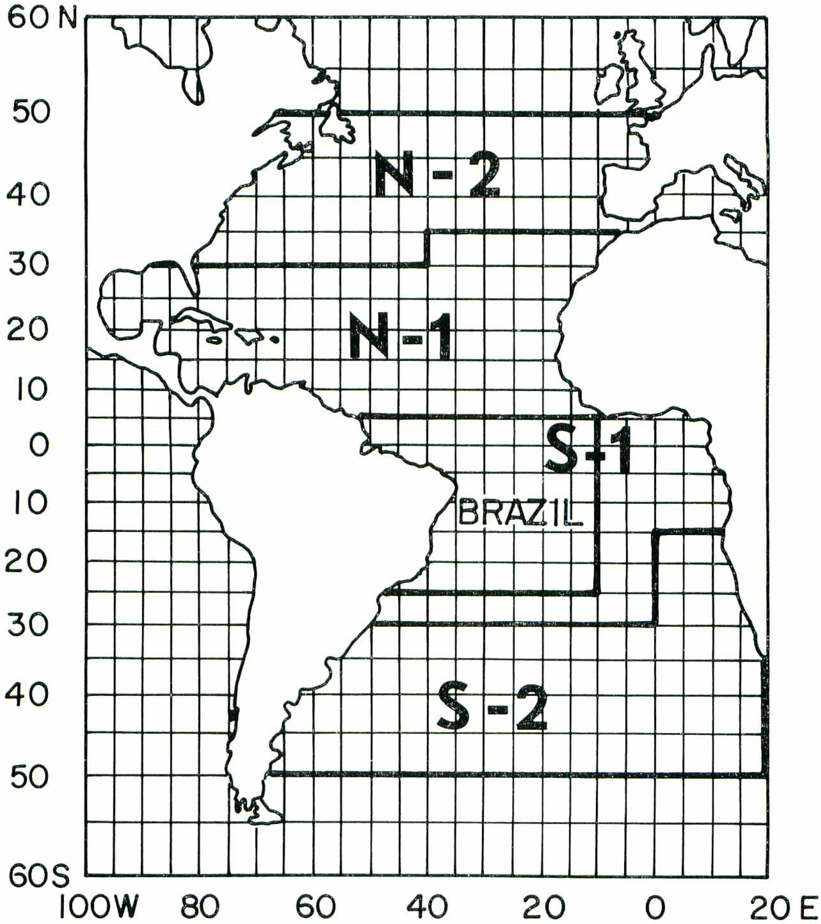

Fig. 1. Delimitation of the geographical areas for the Northern stock ($N1+N2$) and Southern stock ($S1+S2$) from SHIOHAMA (1973). and BRAZIL area.

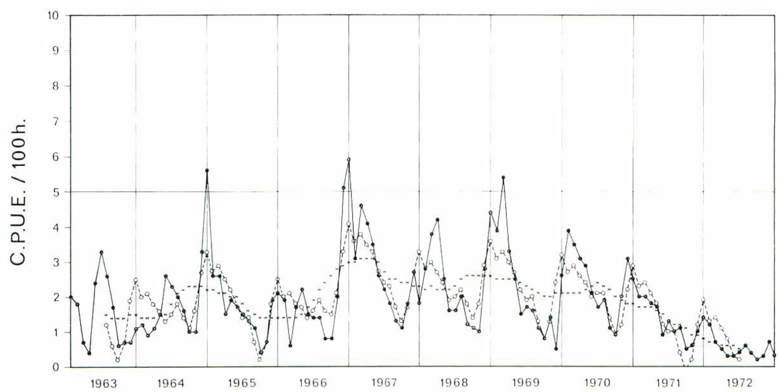

Fig. 2. Evolution of the true data, predicted data (trend+seasonal component) and annual trend for the Northern stock, ($N1+N2$), according to the technique of moving averages in continuous trend and additive model. (•—• : black dots for true data; ∘—∘ : Circles for predicted data; ××× : Crosses for annual trend)

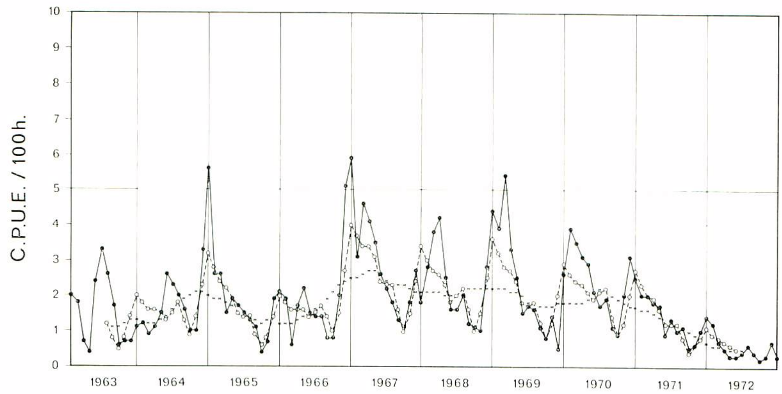

Fig. 3. Same arrangement as for figure 2 : moving averages, continuous trend, multiplicative model.

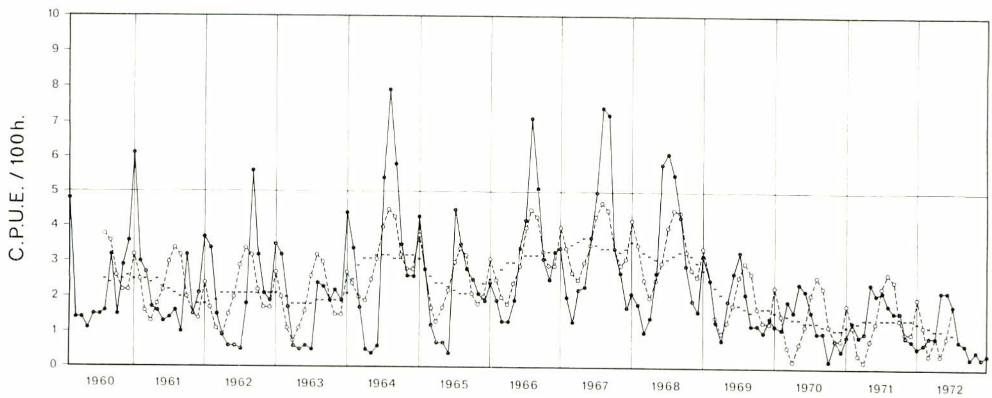

Fig. 4. Same arrangement as for figure 2 : Southern stock ($S1+S2$), moving averages, continuous trend, additive model.

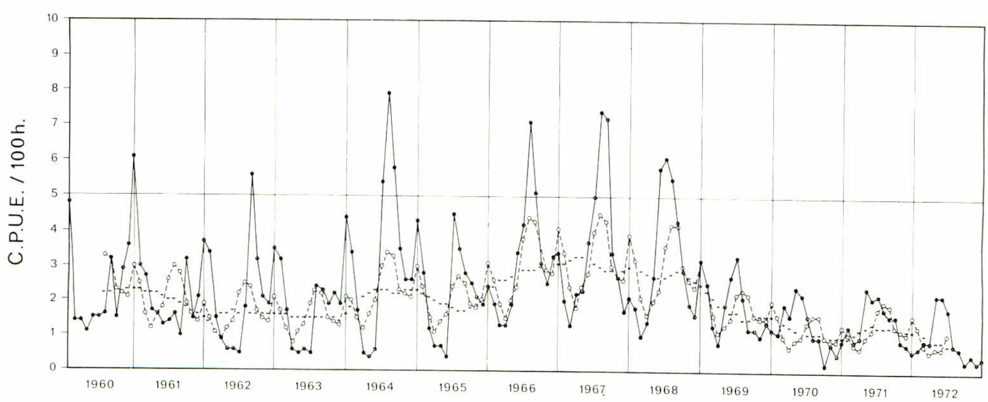

Fig. 5. Same arrangement as for figure 2 : Southern stock ($S1+S2$), moving averages, continuous trend, multiplicative model.

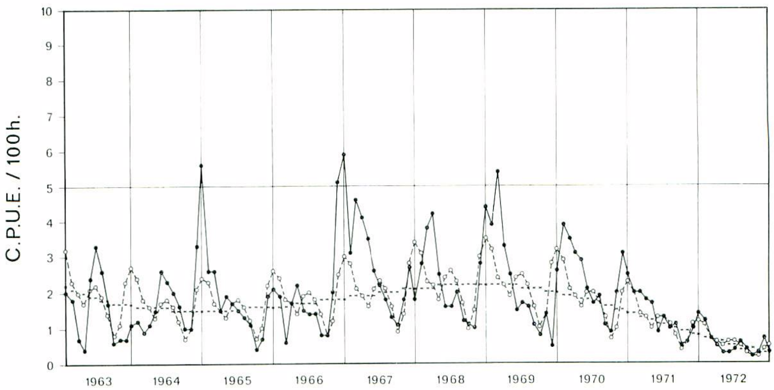

Fig. 6. Same arrangement as for figure 2 : Northern stock ($N1+N2$) regressive method, multiplicative model, continuous trend.

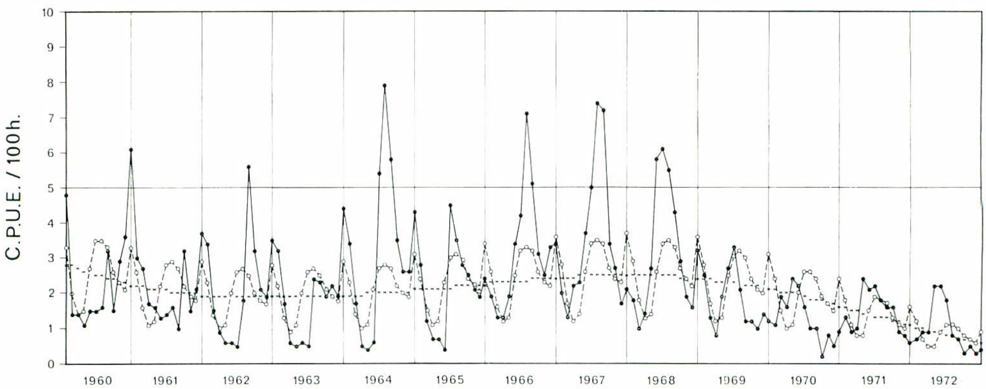

Fig. 7. Same arrangement as for figure 2 : Southern stock ($S1+S2$), regressive method, multiplicative model, continuous trend.

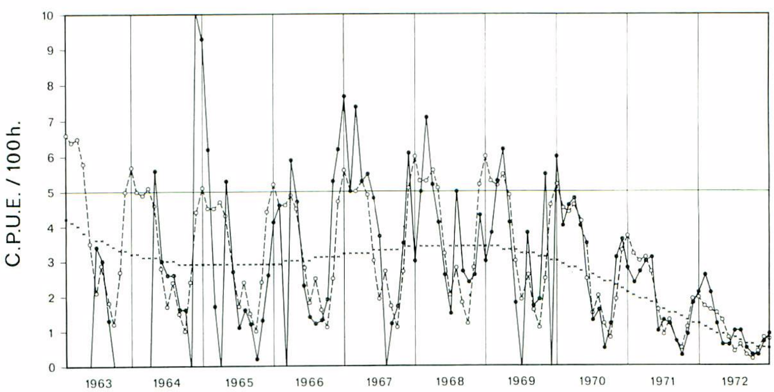

Fig. 8. Same arrangement as for figure 2 : incomplete series on Northern stock ($N2$), multiplicative model, continuous trend.

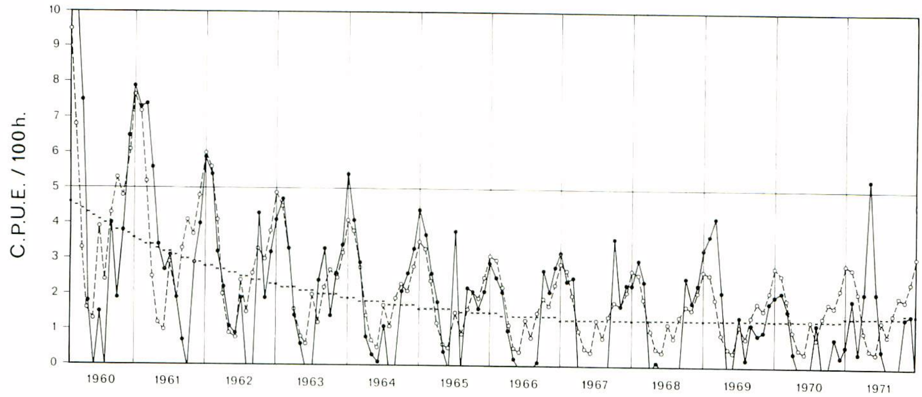

Fig. 9. Same arrangement as for figure 2 : incomplete series on Southern stock (BRAZIL), multiplicative model, continuous trend.

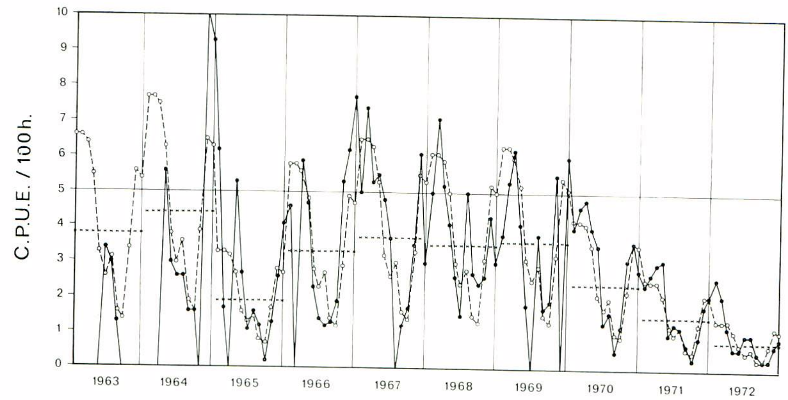

Fig. 10. Same arrangement as for figure 2 : incomplete series on Northern stock (*N*2), multiplicative model, stepwise trend.

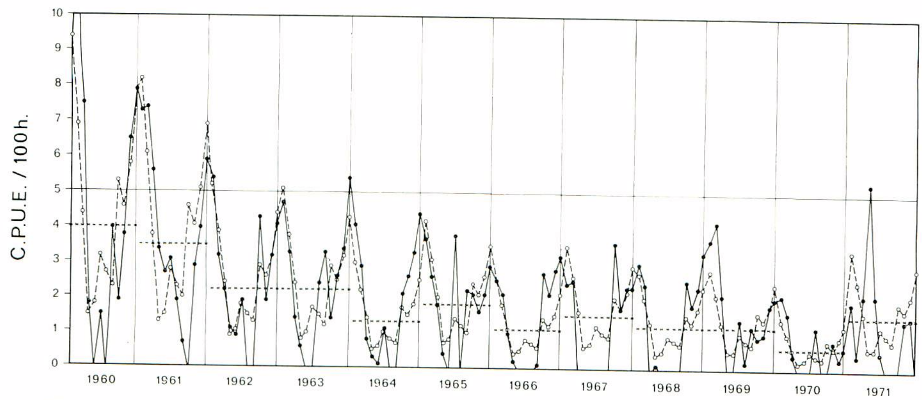

Fig. 11. Same arrangement as for figure 2 : incomplete series on Southern stock (BRAZIL), multiplicative model, stepwise trend.

Table 1. 1. Raw data (CPUE/100 h.) for Noath Atlantic : Area $N1+N2$ (Albacore)

year \ month	1	2	3	4	5	6	7	8	9	10	11	12	Annual mean
1963	1.963	1.775	0.667	0.394	2.413	3.297	2.633	1.686	0.624	0.715	0.722	1.055	1.495
1964	1.238	0.856	1.061	1.454	2.558	2.309	2.031	1.577	0.988	1.030	3.280	5.607	1.999
1965	2.559	2.612	1.529	1.921	1.748	1.526	1.343	1.073	0.392	0.650	1.926	2.110	1.616
1966	1.877	0.615	1.663	2.151	1.510	1.412	1.401	0.830	0.849	1.964	5.093	5.945	2.109
1967	3.082	4.639	4.061	3.533	2.564	2.164	1.845	1.287	1.054	1.815	2.696	1.753	2.541
1968	2.810	3.760	4.162	2.451	1.569	1.644	2.047	1.232	1.056	1.005	2.772	4.368	2.406
1969	3.902	5.368	3.333	2.506	1.455	1.676	1.643	1.113	0.776	1.415	0.474	2.585	2.187
1970	3.858	3.513	3.116	2.887	2.100	1.737	1.945	1.133	0.861	1.968	3.064	2.489	2.389
1971	2.008	1.951	1.787	1.667	0.949	1.325	1.014	1.066	0.544	0.594	1.010	1.449	1.280
1972	1.162	0.710	0.474	0.252	0.268	0.415	0.588	0.372	0.220	0.308	0.678	0.312	0.480

Table 1. 2. Set of monthly efforts ($\times 100$ hooks) for North Atlantic : Area $N1+N2$ (Albacore)

year \ month	1	2	3	4	5	6	7	8	9	10	11	12
1963	371	1 082	884	27 802	54 903	48 449	37 045	24 944	21 497	19 997	11 819	8 740
1964	7 026	11 046	29 653	23 701	72 714	71 109	43 015	63 362	47 081	23 310	19 738	12 034
1965	14 620	9 973	39 531	40 423	63 778	56 164	43 690	50 748	38 773	30 103	11 995	14 489
1966	7 684	9 774	18 434	17 295	24 949	27 331	21 357	22 193	21 376	16 065	7 151	4 543
1967	5 298	6 300	8 231	10 722	17 538	12 678	14 624	15 381	14 622	12 412	8 355	4 323
1968	4 451	2 538	4 419	8 804	12 522	14 782	12 906	17 729	13 137	7 760	2 766	680
1969	2 093	2 830	5 754	8 603	16 855	10 845	17 952	16 751	9 782	5 602	2 419	1 596
1970	3 623	4 137	6 417	9 801	15 455	18 524	19 682	18 345	16 278	14 324	13 490	9 538
1971	14 999	15 861	23 469	26 358	35 474	36 010	33 954	27 894	34 748	41 193	26 535	21 554
1972	36 932	35 830	32 871	23 997	17 895	10 458	8 647	12 547	13 200	9 472	6 493	8 862

Table 2. 1. Raw data (CPUE/100 h.) for South Atlantic : Area $S1+S2$ (Albacore)

year \ month	1	2	3	4	5	6	7	8	9	10	11	12	Annual mean
1960	4.821	1.417	1.421	1.066	1.479	1.494	1.581	3.203	1.512	2.910	3.569	6.080	2.546
1961	3.005	2.706	1.669	1.610	1.271	1.413	1.628	1.018	3.246	1.482	2.090	3.657	2.066
1962	3.378	1.539	0.896	0.551	0.600	0.489	1.759	5.552	3.151	2.071	1.905	3.488	2.115
1963	3.212	1.715	0.559	0.527	0.556	0.523	2.447	2.304	1.950	2.172	1.876	4.359	1.850
1964	3.420	1.697	0.521	0.393	0.569	5.364	7.890	5.828	3.493	2.600	2.634	4.279	3.224
1965	2.802	1.151	0.741	0.708	0.426	4.482	3.490	2.789	2.527	2.144	1.907	2.449	2.135
1966	1.914	1.332	1.326	1.929	3.433	4.188	7.119	5.052	3.131	2.467	3.300	3.375	3.214
1967	1.977	1.312	2.159	2.319	3.719	5.003	7.389	7.246	3.430	2.685	1.748	2.112	3.425
1968	1.814	0.970	1.421	2.743	5.819	6.126	5.509	4.257	2.935	1.872	1.568	3.205	3.186
1969	2.541	1.348	0.796	1.919	2.729	3.324	2.075	1.212	1.165	0.962	1.356	1.151	1.715
1970	1.074	1.927	1.603	2.414	2.179	1.646	0.997	0.993	0.185	0.788	0.521	0.909	1.270
1971	1.261	0.894	0.996	2.408	2.149	2.192	1.751	1.583	1.624	0.940	0.752	0.588	1.428
1972	0.685	0.857	0.930	2.190	2.204	1.838	0.818	0.690	0.339	0.486	0.326	0.353	0.976

Table 2. 2. Set of monthly efforts ($\times 100$ hooks) for South Atlantic : Area $S1+S2$ (Albacore)

year \ month	1	2	3	4	5	6	7	8	9	10	11	12
1960	10 610	12 536	11 535	14 488	7 562	3 510	1 263	107	1 101	7 337	18 819	232 32
1961	19 087	21 678	20 299	20 414	16 390	11 244	16 145	9 199	1 404	13 721	20 808	24 831
1962	39 334	34 116	39 331	35 047	9 140	12 101	10 047	8 734	12 626	21 741	42 544	60 162
1963	58 072	48 036	56 679	45 715	5 794	308	3 778	10 893	10 420	13 254	14 105	13 286
1964	49 206	46 349	32 128	37 226	3 610	3 623	7 833	15 998	26 719	62 998	53 226	50 598
1965	66 795	73 443	59 454	48 674	4 117	33 198	46 177	36 568	29 394	37 601	42 979	34 182
1966	56 083	46 165	40 767	36 233	24 474	24 296	18 571	16 328	10 223	11 392	14 026	18 914
1967	20 134	23 570	21 782	17 485	5 551	4 001	4 068	5 175	10 798	19 272	17 890	15 948
1968	24 218	12 039	20 674	13 374	14 614	15 909	14 807	13 353	15 248	18 060	11 894	10 153
1969	8 337	15 381	24 279	20 308	17 152	16 021	17 947	13 566	11 595	8 725	12 177	12 147
1970	28 653	42 682	40 398	27 347	23 567	21 671	14 091	6 561	5 285	6 090	11 378	6 671
1971	9 142	14 861	20 570	32 806	25 190	10 446	10 083	6 874	11 410	9 526	9 030	4 082
1972	17 922	24 462	31 007	16 524	10 987	10 438	5 991	8 471	8 659	13 094	18 941	11 042

Table 3. 1. Raw data (CPUE/100 h.) for North Atlantic : Area *N*2 (Albacore)

year \ month	1	2	3	4	5	6	7	8	9	10	11	12	Annual mean
1963	0.000	0.000	0.000	0.000	0.000	3.400	2.983	1.271	0.000	0.000	0.000	0.000	2.551
1964	0.000	0.000	0.000	5.589	3.032	2.630	2.593	1.634	1.615	0.000	11.355	9.266	4.714
1965	6.212	1.730	0.000	5.277	2.734	1.066	1.566	1.205	0.170	1.345	2.613	4.079	2.545
1966	4.572	0.000	5.884	4.746	2.335	1.410	1.236	1.267	1.878	5.304	6.228	7.690	3.868
1967	5.041	7.370	5.308	5.491	4.756	3.677	0.000	1.173	1.657	3.459	6.115	3.005	4.277
1968	5.029	7.116	5.228	4.115	2.581	1.537	4.963	2.727	2.427	2.610	4.281	2.987	3.800
1969	3.842	5.320	6.202	4.102	1.752	0.000	3.836	1.737	1.935	5.539	0.000	5.951	4.022
1970	3.982	4.576	4.803	4.042	3.542	1.293	1.559	0.454	1.207	3.133	3.632	2.770	2.916
1971	2.439	2.698	2.958	3.125	1.014	1.340	1.200	0.721	0.340	0.395	1.806	2.132	1.726
1972	2.609	2.082	1.227	0.583	0.619	1.022	1.007	0.466	0.271	0.303	0.743	0.946	0.990

Table 3. 2. Set of monthly efforts (×100 hooks) for North Atlantic : Area *N*2 (Albacore)

year \ month	1	2	3	4	5	6	7	8	9	10	11	12
1963	0.000	0.000	0.000	0.000	0.000	25	6 259	2 978	0.000	0.000	0.000	0.000
1964	0.000	0.000	0.000	1 030	477	9 336	2 893	3 243	1 142	0	927	5 068
1965	6 948	1 035	0	5 041	22 032	17 107	5 113	3 130	1 726	4 456	5 779	4 750
1966	769	0	434	5 918	7 813	6 342	1 385	1 020	3 139	5 993	5 951	3 520
1967	1 229	2 553	2 874	4 222	3 775	691	0	449	2 620	2 989	2 831	1 425
1968	1 947	559	1 121	3 336	2 505	1 679	1 879	2 709	1 164	2 155	1 487	366
1969	893	979	871	2 868	207	0	942	1 334	1 518	567	0	595
1970	2 878	1 467	1 127	3 496	2 760	785	1 672	1 694	4 213	8 167	11 101	9 011
1971	11 313	6 155	5 972	2 126	2 326	10 795	18 107	16 284	19 707	28 977	22 856	8 355
1972	3 596	1 827	22	1 389	1 156	1 422	4 621	7 736	9 881	9 472	6 293	2 247

Table 4. 1. Raw data (CPUE/100 h.) for South Atlantic : Area BRAZIL (Albacore)

year \ month	1	2	3	4	5	6	7	8	9	10	11	12	Annual mean
1960	10.710	10.340	7.550	1.826	0.000	1.488	0.000	4.050	1.949	3.835	6.540	7.926	5.621
1961	7.310	7.414	5.640	3.432	2.743	3.031	1.911	0.653	0.000	2.900	3.935	5.851	4.084
1962	5.403	3.188	2.230	1.061	0.945	1.922	0.000	0.000	4.337	1.920	3.194	4.064	2.827
1963	4.684	3.317	1.412	0.590	0.000	0.000	2.405	3.337	1.424	2.553	3.337	5.351	2.846
1964	4.116	2.895	0.807	0.318	0.100	1.100	0.000	0.000	2.102	2.572	3.266	4.370	2.165
1965	3.684	2.627	1.846	0.384	0.000	3.761	0.000	2.224	2.074	1.643	2.063	2.948	2.326
1966	2.527	2.056	1.028	0.238	0.000	0.000	0.000	0.107	2.671	2.057	2.842	3.183	1.857
1967	2.429	2.522	0.000	0.000	0.000	0.000	0.000	0.000	3.650	1.720	2.295	2.293	2.485
1968	3.037	2.351	0.000	0.078	0.000	0.000	0.000	0.000	2.506	1.817	2.263	3.305	2.195
1969	3.723	4.244	2.074	0.000	0.000	1.440	0.202	1.182	0.931	1.037	1.814	1.996	1.864
1970	2.053	1.563	0.442	0.000	0.000	0.000	1.186	0.000	0.000	0.849	0.331	0.553	0.997
1971	1.924	0.446	2.102	5.294	2.114	0.500	0.000	0.000	0.000	1.379	1.506	0.000	1.908

Table 4. 2. Set of monthly efforts (×100 hooks) for South Atlantic : Area BRAZIL (Albacore).

year \ month	1	2	3	4	5	6	7	8	9	10	11	12
1960	5 307	1 889	580	506	0	616	0	40	106	1 325	12 339	17 788
1961	7 431	3 447	3 307	1 852	1 920	3 461	2 669	49	0	1 429	6 917	18 865
1962	30 748	10 532	4 323	3 320	73	154	0	0	157	8 154	32 049	55 432
1963	47 933	17 348	4 257	8 729	0	0	69	138	800	1 771	5 864	12 386
1964	42 253	16 567	10 436	2 402	1 668	342	0	0	1 999	25 821	40 834	38 119
1965	33 234	12 420	3 841	1 546	0	800	0	830	2 979	3 379	14 103	18 861
1966	39 425	25 018	4 040	21	0	0	0	65	503	3 866	9 517	15 268
1967	14 984	1 689	0	0	0	0	0	0	60	2 224	3 144	7 459
1968	4 605	1 689	0	38	0	0	0	0	1 849	2 637	5 491	8 113
1969	2 241	331	256	0	0	122	80	389	132	1 750	2 921	3 343
1970	8 527	2 985	118	0	0	0	43	0	0	71	301	1 021
1971	395	482	1 101	1 020	562	58	0	0	0	291	566	0

Appendix A

Adjustment in the meaning of the least squares of a model with polynomial trend, selection of the polynomial degree

I—Adjustment for a given degree

As indicated in the text, and keeping the same notations, the following should be minimized:

$$\sum_t w(t)\left(x(t)-\sum_{j=1}^{J} d_j t^{j-1} - S_{k(t)}\right)^2$$

with the supplementary equation

$$\sum_{k=1}^{K} S_k = 0$$

Deriving the function to be minimized with respect to d_{j0} the following equation is obtained:

$$-2\sum_t w(t) t^{j_0-1}\left(x(t)-\sum_{j=1}^{J} d_j t^{j-1} - S_{k(t)}\right)=0$$

or $\sum_t w(t)\left(\sum_{j=1}^{J} t^{j+j_0-2} d_j + t^{j_0-1} S_{k(t)}\right) = \sum_t x(t) w(t) t^{j_0-1}$

this for $j_0=1,\ldots J$

Similarly, by deriving with respect to Sk_0, we obtain:

$$\sum_t w(t)\delta k_0,\ k(t)\left(\sum_{j=1}^{J} t^{j-1} d_j + S_{k(t)}\right) = \sum_t x(t) w(t) \delta k_0,\ k(t)$$

for $k_0=1,\ldots K$, δ corresponding to the Kronecker symbol.

$\delta k_0, k(t)=0$ if $k_0 \neq k(t)$

$\delta k_0, k(t)=1$ if $k_0 = k(t)$

By grouping the equations obtained by derivation we obtain a degenerate system including an infinity of solutions. We can suppress one of the equations and replace it by condition

$$\sum_{k=1}^{K} S_k = 0$$

This results in a conventional linear system.

II—Degree selection

This selection, which most often will be somewhat arbitrary, is likely to be guided by principles originated from the variance analysis. To this end, we calculate the variance, called "a priori", of the $x(t)$, then that of residues $x(t)-m(t)-s(t)$ —under various assumptions concerning degree ND of m. It is obvious that the greater ND the lower the variance of the residues. However, should a model with a polynomial trend be truly satisfactory, it will appear that the decrease of the residual variance, with ND increasing rapidly first, will stabilize beyond a value of ND which will therefore be retained.

Appendix B

Adjustment in the meaning of the least squares of a model with a stepwise trend

The following should be minimized:

$$\sum_t w(t)\Big(x(t)-M_{l(t)}-S_{k(t)}\Big)^2$$

with condition:

$$\sum_{k=1}^{K} S_k=0$$

Then, the derivation conduces easily to a first system.

$$\sum_t w(t)\delta l_0,\ l(t)\Big(M_{l(t)}+S_{k(t)}\Big)=\sum_t w(t)\delta l_0,\ l(t)x(t)$$

$l_0=1, \ldots K$, δ corresponding to the Kronecker symbol.

$$\sum_t w(t)\delta k_0,\ k(t)\Big(M_{1(t)}+S_{k(t)}\Big)=\sum_t w(t)\delta k_0,\ k(t)x(t)$$

$k_0=1, \ldots K$

The system also is degenerate and the final system will, in fact, be obtained by replacing any equation of this first system by

$$\sum_{k=1}^{K} S_k=0$$

The linear system that is then formed can be resolved by the current methods.

Some properties of the solution should be emhasized:

—within each year the sum of residues $x(t)-m(t)-s(t)$ is zero for instant t when x is known.

—For each interval of the year, say every month, the sum of the residues obtained for the various years is zero.

When the $x(t)$ series is without any break, including a whole number of years, the adjustment by means of the least squares method gives exactly the same solutions as procedure using the averages. Consequently, it is a generalization of this method.

Appendix C

Remarks about the least squares adjustment procedure

This method is very widely used. However, it is important to know that it is optimal (in the sense that it conduces to the maximum likelihood estimator) only under a triple assumption.

Assumption 1—Normality of the residues

This assumption is rarely complied with in practice. However, inasmuch as the residues do not have a very particular distribution (in particular when the probability density flattens quickly when one departs from expectation) non-adherence to this assumption is not very important.

Assumption 2—Independence of the residues

This assumption implies that $\varepsilon(t)$ and $\varepsilon(t')$ are stochastically independent if t is different from t'. It can be examined " a posteriori " from the residues obtained after adjustment of the model and, particularly, through the calculation of their autocorrelation function, and of their spectrums. Non-adherence to this assumption may more seriously alter the optimality of the least squares adjustment procedures. More sophisticated procedures can then be proposed, but this would complicate this study which we want to be limited and simplified.

Assumption 3—Constant variance of the residues

The variance of $\varepsilon(t)$ is assumed to be constant, and more exactly independent from t. In practice, it may occur that certain values of series $x(t)$ of the C. P. U. E's appear as less reliable, for instance because, without being zero, the effort at instant t was very small. Here again, the simple adjustment by means of the least squares method is no longer optimal but this can easily be corrected. Series $w(t)$, which was introduced previously, took only two values : 0 or 1. In fact, other positive values can be given to $w(t)$, the resolving being carried out with the same formulas. A weighted regression (in theory $w(t)=1/v(t), v(t)$ being the variance of $\varepsilon(t)$, infinite variance if $x(t)$ is not known) is then performed, generalizing the previously mentioned regression, where the only weights authorized were 0 or 1. It is, therefore, easy to return to the case where assumption 3 is adhered to.

In practice, non-adherence to these assumptions, and particularly to assumption (2) will first prevent the statistical interferences (a priori it would be possible to calculate the variance of the estimators) and then be detrimental to the optimality of the estimators obtained. This being said, they will most often remain good estimators (un-biased ones, particularly), even if they are no longer optimal. The preceding statement is an adaptation of the conventional methods of regression set forth particularly by DRAPER and SMITH (1973).

季節変動の影響を除く資源量指数の取扱い 日本の大西洋はえなわ漁業におけるビンナガ（*Thunnus alalunga*）の月別単位努力量当り漁獲量（C. P. U. E.）への適用

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要　約

大西洋における日本のはえなわ漁業の対象となるビンナガ（*Thunnus alalunga*）の南北両ストックの豊度指数として用いられる月別単位努力当漁獲量（C. P. U. E.）を，２通りの異なった統計的手法によって解析し，この指数を長年変動傾向，季節変動，漁獲努力の影響，未知の残差成分などの諸成分に分解しこれらを推定する方法を発展させた。

これら２種の統計的手法では，ともに上記諸成分が加算的モデル又は乗算的モデルとして組合わされ，これらは，それぞれ連続的長年傾向又は段階的傾向の２種の傾向線にあてはめられた。第１の手法は簡単な移動平均法であり，これは欠測のない完全なデータでなくては適用されないのに対し，第２の手法は回帰線を用いるもので，これは第１のものより有力で，より一般的であり，完全なデータにも欠測のあるデータにも適用される。

加算的モデル，乗算的モデル，長年傾向が連続的な場合，段階的な場合，欠測のある場合，ない場合等，色々の場合に応じて上記の２つの手法を，はえなわによるビンナガのデータに適用した結果，２つのストックの構造や豊度の実際の傾向等について新知見が得られた。すなわち，北部ストックはそれ自身，１つのはえなわ漁業を維持している単一単位であり，これに対し南部ストックの構造は複雑で，それぞれ独自の傾向をもった２つのはえなわ漁業を維持しているように想定された。