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Fitting a model of flexible multifleet–multispecies fisheries to Senegalese artisanal fishery data

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Abstract − Fisheries exploitation systems are characterized by reciprocal interactions between fisheries activity and the harvested resource. Variability and changes affecting 'natural' and 'socio-economic' environments generate non stationarity of the variables used to describe the fishing activity, the resource and the yields. This characteristic needs to be taken into account in describing the evolution of the relationships between those variables, and in describing fisheries adaptability and sustainability. We present a dynamical system model with an application to data from surveys on activity and results of the Senegalese artisanal fishery from 1974 to 1992. A fitting procedure is proposed, giving estimates of the parameters of the model. A simulation is then made with the fitted model in order to apraise possible impacts of various events of different kind.

dynamical system / multivariate time series / model fitting / fishing strategies / fishing tactics / fleet dynamics / population dynamics

Résumé − Ajustement d'un modèle de pêcherie adaptable multispécifique et multi-engin aux données de la pêche artisanale sénégalaise. Les systèmes d'exploitation halieutiques sont caractérisés par des impacts de l'activité de pêche sur les ressources halieutiques et, réciproquement, par l'influence des conditions de la pêche (biologiques, économiques) sur l'activité. Les changements et la variabilité des conditions d'environnement « naturel » ou « socio-économique » se traduisent par une non stationnarité des variables au moyen desquelles l'activité, la ressource et la production sont décrites. Il est important d'en tenir compte pour mieux décrire l'évolution des relations entre ces variables, les facteurs d'adaptation des pêcheries, et donc la viabilité et durabilité de tels systèmes d'exploitation d'une ressource naturelle par une activité humaine. Nous présentons un modèle de système dynamique avec une application à des données issues d'enquêtes sur l'activité et les résultats de la pêche artisanale sénégalaise entre 1974 et 1992. Une procédure d'ajustement est présentée, permettant d'estimer les paramètres du modèle. Une simulation est réalisée à partir du modèle ajusté pour évaluer les conséquences possibles d'évènements de natures différentes.

système dynamique / séries chronologiques multivariées / ajustement de modèle / stratégies de pêche / tactiques de pêche / dynamique des flottes de pêche / dynamique des populations

1. INTRODUCTION

Fisheries data analysis is useful for stock assessment purposes, for modelling harvested population dynamics and for fisheries management. From a technical point of view, data produced according to clear and balanced designs are very seldom available; the 'experimental design' is given by fishermen working to satisfy their own needs, not those of the scientists.

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Fishing activity partially depends on the state of the resource, and the state of the resource partially depends on the fishing activity. This means that knowledge is needed on each of those two components and on their interaction (Hilborn and Walters, 1992).

Frameworks for such dynamic systems have been proposed (for example Smith, 1969; Silvert and Dickie, 1982; Allen and Mac Glade, 1986; Laurec et al., 1991; Laloë and Samba, 1991; Hilborn and Walters, 1992; Bousquet et al., 1993; Le Fur, 1995). Because (at least) the environment of fishermen and fish (natural, economical, social) is fluctuating and changing, fisheries are dynamical systems that are not stationary. Moreover frameworks for such systems combine at least two points of view on the same real world. Therefore they constitute a complex representation that may be coherent with available knowledge and observations. But they do not have a unique solution and they provide no evidence of, and no clear distinction between, causes and effects (Legay, 1997).

This lack of evidence results in structural uncertainty on the nature of a fishery system. Reducing the level of structural uncertainty requires an "unknown level of research and statistical data analysis" (Charles, 1998). Models of fishery systems may thus be considered as defined by Röling (1994): "a system is a construct with arbitrarily defined boundaries for discourse about complex phenomena to emphasize wholeness, inter-relationships and emergent properties".

One of the problems is the availability of data that can be used with such models, and the construction of estimation procedures (Laurec et al., 1991). In this paper we propose such a procedure, with an application to the Senegalese artisanal fishery, using data on fishing activity and results at two landing places, per fortnight, from 1974 to 1992. This work is done using a general model that was initialy built in order to give a descriptive framework that takes into account characteristics of the fleet dynamics and interaction between components of the fishery system (Laloë and Samba, 1991).

The need for such a work has been identified because when going fishing at a given time, an artisanal fishing unit adopts one 'fishing tactic' among a set of available solutions (Laloë et al., 1981; Gérard and Greber, 1985; Pelletier and Ferraris, 2000). As the various available fishing tactics generate different impacts on the resource components, this situation has very important consequences, both on data analysis for stock assessment purposes and on the viability of the exploitation system.

We present the set of data, the principle of the model and the ad-hoc procedure used for parameter estimation according to a least square criterium. We then present some characteristics of the Senegalese artisanal fishery and a model with constraints on parameters that reduce their number. We then discuss some aspects of the results and indicate possible uses of those results, for example for management purposes.

2. MATERIALS AND METHODS

2.1. The data

Data are extracted from the CRODT (Centre de recherches océanographiques de Dakar-Thiaroye) data base (Ferraris et al., 1993). Those data are estimates from a consistent sampling design, implemented during the 1970s by the CRODT of the Institut sénégalais de recherche agricole (Isra). The purpose of the system was mainly to obtain fishing efforts and catch data to be used for stock assessment (Anonymous, 1982; Laloë, 1985; Samba, 1995).

The system is a stratified random sampling design combining landing place × gear × fortnight, with sub levels of observation for each of the considered strata. Fortnight is defined here as 'half a month', thus there are 24 fortnights in a year.

In this paper we analyse data collected in the two principal landing places of the north coast of the Senegal (the 'Grande Côte'): Saint-Louis and Kayar (*figure 1*). Fishing activities are defined as number of trips with a given gear and a given landing place per fortnight from 1974 to 1992. There are seven such time series. For each of the fishing time series, we consider the associated time series of fortnightly catch per trip for some species or group of species that may be caught with the given gear × landing place combination. Thirteen such species or group of species were defined. As some species or groups of species are not accessible for some gear × landing place combinations (e.g. *Sardinella* sp. cannot be harvested with hand lines), 36 time series of catch per trips are remaining for the study (see the combinations 'stratum-stock' on *figure 2* and definitions on *table I*).

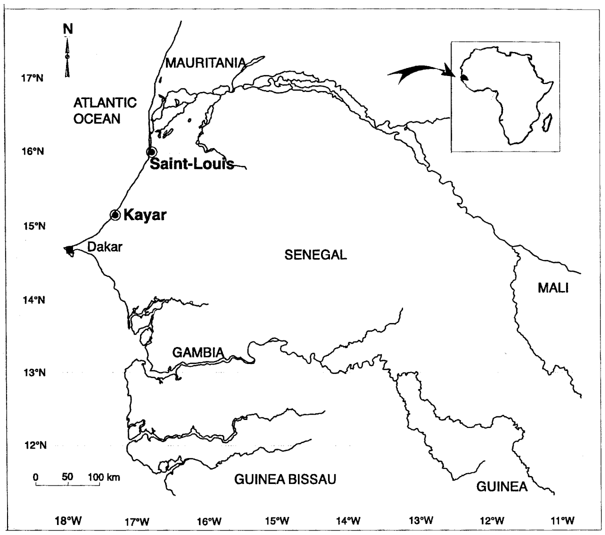

Figure 1. Geographical location of the study area.

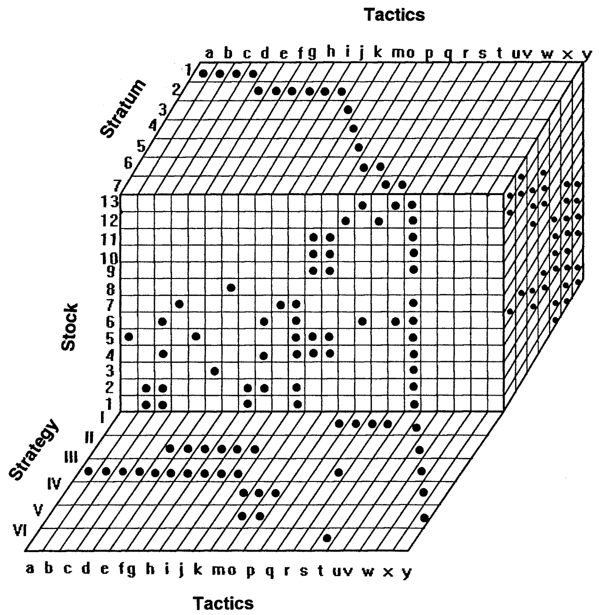

Figure 2. Relationships between stocks, strategies, tactics and strata (see definitions *table I*). 'Stock-stratum' combinations: a bullet indicates that the stock is catchable by at least one of the tactics belonging to the stratum of the sampling design. It indicates the existence of a corresponding *CPUE* time series. 'Tactic-stock' combinations: a bullet indicates that the stock is catchable by the tactic. 'Tactic-stratum' combinations: a bullet indicates that the tactic belongs to the stratum (note that one tactic may belong to at most one stratum). 'Tactic-strategy' combinations: a bullet indicates that the fishing having the strategy units may choose to use the corresponding tactic.

2.2. The model

The model (Laloë and Samba, 1991) provides a description of the fishery, based on relations among three components: a multispecific resource exploited by fishing units grouped according to fishing actions they are able to undertake. A typology, based on an equivalence relationship is constructed for each of the three components:
– the resource is made up of stocks: two elements of the resource (i.e. two biomass units) are equivalent (i.e. belong to the same stock) if they have equal probabilities of beeing caught and if they exhibit the same productivity;
– fishing actions are described using the concept of tactics: two fishing actions belong to a same tactic if they have, at each given moment, equal probabilities to catch any given part of the resource;
– fishing units are described using the concept of strategies: two fishing units belong to a same strategy if they have, at given moment, equal probabilities of using a fishing action belonging to a given tactic.

The principle of the model may be summarized as it follows. At each step, each fishing unit uses a fishing action which belongs to a fishing tactic. Realizations of the fishing actions used by the fishing units will have an overall impact on the resource and, hence, on the future choices of fishing actions by fishing units. Those choices will depend on sets of available tactics, i.e. on strategies.

Table I. Definitions of the considered stocks, tactics, strategies and strata.

Stocks		Tactics		Strategies		Strata	
Code	Definition	Code	Definition	Code	Definition	Code	Definition
1	white grouper	a	line, bluefish, Saint–Louis	I	gill nets	1	hand lines at Saint-Louis
2	coastal seabreams	b	line, white grouper, Saint-Louis	II	lines of Kayar	2	hand lines at Kayar
3	deep seabreams	c	line, coastal seabreams, Saint–Louis	III	lines of Saint-Louis	3	hand lines with ice
4	false scad	d	line, octopus, Saint-Louis	IV	lines with ice / Seines	4	seines at Saint-Louis
5	bluefish	e	line, bluefish, Kayar	V	seines	5	seines at Kayar
6	gillnets fishes	f	line, deep seabreams, Kayar	VI	industrials	6	gill nets at Saint-Louis
7	octopus	g	line, sailfish, Kayar			7	gill nets at Kayar
8	sailfish	h	line, white grouper, Kayar				
9	round sardinella	i	line, coastal seabreams, Kayar				
10	flat sardinella	j	line, octopus, Kayar				
11	senegal jack	k	line, with ice Saint-Louis				
12	soles	m	seine, Saint-Louis				
13	sharks and rays	o	seine, Kayar				
		p	gill nets, soles, Saint-Louis				
		q	gill nets, Saint-Louis				
		r	gill nets, soles, Kayar				
		s	gill nets, Kayar				
		t	industrials				
		u	no fishing, strategy gill nets				
		v	no fishing, strategy lines of Kayar				
		w	no fishing, strategy lines of Saint-Louis				
		x	no fishing, strategy lines with ice - seines				
		y	no fishing, strategy seines				

Here we use the index k ($k = 1, ...K$) to characterise stocks, j ($j = 1, ...J$) for tactics and s ($s = 1, ...S$) for strategies. $(t_i)_{(i \in \mathbb{N})}$ will refer to time step. Each element of a typology is defined as a variable. Consequently, $(B_{k,t_i})_{(k,t_i) \in \{1,...K\} \times T \subset \mathbb{N}}$ will be the biomass of the K considered stocks, $(f_{j,t_i})_{(j,t_i) \in 1,...J \times T \subset \mathbb{N}}$ will be the allocation of fishing actions according to tactics, and $(N_{s,t_i})_{(s,t_i) \in \{1,...K\} \times T \subset \mathbb{N}}$ will be the allocation at step of time t_i of fishing units among strategies.

Previously defined variables may be expressed as consequences of characteristics process of the fishery. Three processes have been considered:

- the effort allocation process;
- the catch process;
- the stocks dynamics process (biomass process).

More than three processes could be considered in order to describe artisanal fishery activity, for example by adding a process relating evolutions of prices during landing operations. Hence, considering three processes is an arbitrary choice, representing a necessary compromise between a desirable parsimony and a convenient description of the fishery.

2.2.1. *Effort allocation process*

At each step of time t_i, each of the N_{s,t_i} fishing units belonging to the sth strategy chooses tactic j with probability p_{j,s,t_i}. Therefore, the total number of fishing units choosing this tactic will be:

$$f_{j,t_i} = \sum_{s=1}^{S} f_{j,s,t_i} = \sum_{s=1}^{S} N_{s,t_i}\, p_{j,s,t_i} \qquad (1)$$

N_{s,t_i} are given by equation:

$$N_{s,t} = N_{s,0} + (N_{s,\infty} - N_{s,0}) \frac{1}{1 + e^{4t_s p_s - 4p_s t}} \qquad (2)$$

with parameters $N_{s,0}$ (number at time $t = 0$), $N_{s,\infty}$ (number at $t = \infty$), t_s time at which the second derivative of $N_{s,t}$ is nil and $p_s \times (N_{s,\infty} - N_{s,0})$ is the slope a $t = t_s$.

p_{j,s,t_i} values depend on previous revenues obtained by the whole set of fishing units of the fishery (assuming a perfect information on those results). For a given strategy s, the set of available tactics is $\mathcal{J}(s)$ (ie $p_{j,s,t_i} = 0$ if $j \notin \mathcal{J}(s)$). The general principle of the model is to consider that if $j \in \mathcal{J}(s)$, p_{j,s,t_i} increases (decreases) if the expected revenues with tactic j is greater (lower) than the mean of expected revenues for tactics in $\mathcal{J}(s)$.

Let us note $(c_{j,k,t_i})_{k = 1,...K}$ the catches per trip on the K stocks obtained by fishing units using the jth tactic at time t_i. $R_{j,t_i} = \sum_k P_k\, c_{j,k,t_i} - C_j$ represents the revenue for one of those trips. Here P_k is the unit price for the stock k and C_j is the cost generated by the use of the tactic j. For example, the cost generated by the use of a seine is higher than the cost for hand line. A negative value for C_j may be introduced in order to express an opportunity cost for tactics that consists of a non fishing activity (agricultural activity, or use of a fishing tactic outside of the study area, during so-called migrations campaigns).

Let us note

$$\bar{R}_{j,t_{i+1}} = \frac{R_{j,t_i} + R_{j,t_i - \Delta_t}}{2} = \sum_{k=1}^{k} P_k \frac{C_{j,k,t_i} + C_{j,k,t_i - \Delta_t}}{2} - C_j \qquad (3)$$

$\bar{R}_{j,t_{i+1}}$ is an estimation of revenue at time t_{i+1} for tactic j, made with information available at end of time t_i. $\bar{R}_{j,t_{i+1}}$ is the average of R_{j,t_i} the last obtained revenue and $R_{j,t_i - \Delta_t}$ the revenue obtained with a Δ_t lag. This lag is introduced in order to take into account fishermen knowledge on annual periodicities, for example due to seasonal migrations of fish. In our context, the expected revenue is therefore expressed as the average of the last revenue and the revenue obtained a year ago (here $\Delta_t = 24 - 1 = 23$).

We consider a transformation of $\bar{R}_{j,t_{i+1}}$:

$$\tilde{R}_{j,t_{i+1}} = e^{\rho \bar{R}_{j,t_{i+1}}} \qquad (4)$$

Values of $(p_{j,s,t_i})_{j,s,t_i}$ are defined as it follows:

$$\begin{cases} \forall j \notin \mathcal{J}(s), \forall i, \; p_{j,s,t_i} = 0 \\ \forall j \in \mathcal{J}(s), \forall i, \; p_{j,s,t_{i+1}} = \mu_s\, p_{j,s,t_i} + (1 - \mu_s) \dfrac{\tilde{R}_{j,t_{i+1}}}{\sum_{j \in \mathcal{J}(s)} \tilde{R}_{j,t_{i+1}}} \end{cases} \qquad (5)$$

We use transformation (4) in order to deal with derivable functions for p_{j,s,t_i}.

The ρ parameter may be interpreted as giving more importance to the more lucrative tactics. The parameter μ_s refers here to the evolution of probabilities facing changes of expected revenues. By example if $\mu_s = 1$, the second term in equation (5) is nil and probabilities are constant, independent of results obtained by fishermen.

An empirical analysis of such an effort allocation process is given by Holland and Sutinen (1999). The effort allocation process could also be described at a lower level, with decisions taken in real time by fishermen (see for example Gaertner et al., 1999).

2.2.2. Catch process

The quantity of biomass of stock k caught during a fishing trip with tactic j is expressed as:

$$c_{j,k,t_i} = q_{j,k}(\overline{B_{k,t_i}} - \alpha_{j,k,m_{t_i}} B_{vk}) \tag{6}$$

$q_{j,k}$ is the catchability, i.e. the probability to catch one biomass unit of stock k during one trip with tactic j. $(\overline{B_{k,t_i}} - \alpha_{j,k,m_{t_i}} B_{vk})$ represents the quantity of biomass accessible to the fishing unit. This quantity is expressed as the difference between $\overline{B_{k,t_i}}$, the average biomass of stock k during time t_i and $\alpha_{j,k,m_{t_i}} B_{vk}$, an inaccessible biomass quantity of stock k. B_{vk} is the carrying capacity which refers to the maximal size the stock k can reach considering environmental capacity. $\alpha_{j,k,m_{t_i}}$ refers to an inaccessible proportion of the carrying capacity B_{vk}. This parameter depends on j, the tactic used during the fishing trip, on k the considered stock, and on m_{t_i}, the period of the year, expressed in fortnight, relative to time t_i. Usual catch process (Laurec and Le Guen, 1981) corresponds to a nil value of $\alpha_{j,k,m_{t_i}}$. Inaccessible biomass is introduced (Laloë, 1988) in order to take into account that fishing units cannot access the entire spreading area of the stock, due to their often short operating range or some other causes. Moreover, the distribution area of the stock may vary with time according to fish migrations and hydroclimatic changes. That is why $\alpha_{j,k,m_{t_i}}$ is m_{t_i} dependent.

2.2.3. Biomass process

$B_{k,t_{i+1}}$ is the biomass of stock k at time t_{i+1}. This variable is supposed to be a function of both its value at time t_i and the fishing activity during the considered step of time. In continuous time, the evolution of $B_{k,t}$ is represented as:

$$\frac{dB_{k,t}}{dt} = r_k B_{k,t}\left(1 - \frac{B_{k,t}}{Bv_k} \right) - \sum_{j=1}^{J} f_{j,t}\, q_{j,k}(B_{k,t} - \alpha_{j,k,m_{t_i}} Bv_k) \tag{7}$$

Biomass differential is expressed as the difference between the biomass production and the catch caused by fishing units. The production term corresponds to the usual logistic model of common use in fisheries science (Graham, 1935; Schaefer, 1954), r_k and Bv_k are the growth rate and carrying capacity caracteristic of the species k. Assuming a constant fishing effort $(f_{j,t_i})_{j \in \{1,...J\}}$ during the step t_i, we can integrate equation (7), and express $B_{k,t_{i+1}}$ (at the end of the step t_i) as a function of B_{k,t_i} and $(f_{j,t_i})_{j \in \{1,...J\}}$ (see Jolivet, 1983). If for some combinations the value of $(B_{k,t} - \alpha_{j,k,m_{t_i}} B_{v_k})$ is negative, it is arbitrarily replaced by a zero value in equations (6) and (7).

We may now summarize our model as a simultaneous equations model (Gallant, 1987) with the following system of equations:

$$\begin{cases} c_{j,k,t_i} & = f(\overline{B_{k,t_i}}, \theta_f \subset \Theta) \\ B_{k,t_{i+1}} & = g\left(B_{k,t_i}, \sum_{j,s} f_{j,s,t_i}\, c_{j,k,t_i}, \theta_g \subset \Theta \right) \\ f_{j,s_{t_i}} & = h((c_{j,k,t_{i-1}}, c_{j,k,t_{i-\Delta t}})_{j,k}, \theta_h \subset \Theta) \end{cases} \tag{8}$$

System (8) is dependent of a set of parameters Θ relative to the resource (carrying capacities, growth rates), to the economy (fish prices, tactics costs), to the fishing actions (capturabilities, inaccessibilities rates) and to decisions rules used by fishermen (ρ and μ_s parameters).

2.3. Confrontation with available data

With a given set of values of the parameters and initial values B_{k,t_0} and p_{j,s,t_0} at an initial time t_0, we may run the model and obtain a data set with time series of catches, activity and biomass, which may be used for comparison with available data. Here, available data consist of the 7 time series of number of trips and 36 time series of mean catch per trip, from data collected through the sampling design from 1974 to 1992 (see data section). Note that the initial time t_0 does not necessarily correspond to the beginning of 1974. In the applications presented in this article, t_0 corresponds to the beginning of 1971.

We must hence notice that:

– Fishing effort and landings are estimations of corresponding unknown quantities.

– Some variables in the model are not directly observed (e.g. biomass).

– Available data structure may not correspond to the natural structure of the model. Fishing activity estimates consist in the number of trips by gear at a landing place. It is known (Laloë et al., 1981) that among fishing units using hand lines at Kayar, some anchor the pirogue in order to harvest demersal species such as *Epinephelus aenus* (white grouper), while others, e.g. those drifting over school of *Pomatomus saltatrix* (bluefish), do not anchor the pirogue. Hence, hand lines cover the use of (at least) two fishing tactics we want to take into account in order to properly reflect the dynamics of this artisanal fishery.

Modelled variables may hence be defined at lower levels than are the strata in the sampling design. We have therefore to agregate modeled variables in order to make them comparable with the sampled variables. Hereafter, we use the index g ($g = 1 ...G$) to characterise strata.

Let us note that $(\hat{f}_{g,t_i})_{(g,t_i) \in \{1,...G\} \times \mathbb{N}}$ represents the estimates of fishing effort per strata (g refers to the fishing type used, for example hand lines from Saint-Louis) and $(\hat{c}_{g,k,t_i})_{(g,k,t_i) \in \{1,...G\} \times \{1,...K\} \times \mathbb{N}}$ represents the estimates of catch per unit of effort per strata for each of the K considered stocks by help of the model. Let us write

$$\begin{cases} \hat{f}_{g,t_i} = \sum_{j \in \varepsilon(g)} \hat{f}_{j,t_i} \\ \hat{c}_{g,k,t_i} = \begin{cases} \frac{1}{\hat{f}_{g,t_i}} \sum_{j \in \varepsilon(g)} \hat{c}_{j,k,,t_i} \hat{f}_{j,t_i} & \text{if } \hat{f}_{g,t_i} \neq 0 \\ 0 & \text{if } \hat{f}_{g,t_i} = 0 \end{cases} \end{cases} \quad (9)$$

where $\varepsilon(g)$ refers to the set of tactics coming under stratum g. For example, if g refers to hand lines from Saint-Louis, $\varepsilon(g)$ refers to the set of the 4 tactics (a, b, c, and d) corresponding to the use of hand lines from Saint-Louis (see the combinations 'stratum-tactic' on *figure 2*).

In order to estimate parameter values with a maximum likelihood criterium, we should at least take into account the process variability and the sampling variability in order to identify the distribution of the time series obtained through the model. Even if attempts may be made to do it in this way (Pech, 1998), it seems extremely difficult to express theorical laws for $\hat{f}_{g,t_i}$ and $\hat{c}_{g,k}$.

For this reason we choose to compare fitted and available data by considering a least square criterium. All calculations have been done using routines written in C and the S-PLUS package (Statistical Sciences, 2000). Programs developped for this purpose have been linked in a package suitable for others applications. The last update of this package is available to the reader, together with the set of data and the set of parameters estimated values.

For a given time series, for example efforts $(f_{g,t_i})_{i=1,\ldots n}$, least squares criterium are expressed as:

$$\sum_{i=1}^{n} (f_{g,t_i} - \hat{f}_{g,t_i})^2 = \| f_g - \hat{f}_g \|^2 \quad (10)$$

As we deal with several time series (efforts and catch per unit of effort), we have as many sums of squares as estimated variables according to the sampling design. Dividing each of the sum of squares by a term proportional to the empirical variance make them comparable. Hence the following criterium can be considered:

$$\mathcal{L}(\Theta) = \sum_{g=1}^{G} \frac{\| f_g - \hat{f}_g \|^2}{\| f_g - \bar{f}_g \|^2} + \sum_{g=1,k=1}^{G,K} \frac{\| \ln(c_{g,k}+1) - \ln(\hat{c}_{g,k}+1) \|^2}{\| \ln(c_{g,k}+1) - \overline{\ln(c_{g,k}+1)} \|^2} \quad (11)$$

where $\bar{f}_g = \frac{1}{n} \sum_{i=1}^{n} f_{g,t_i}$, and Θ refers to the set of parameters of the model. Here, $\hat{f}_g$ and $\hat{c}_{g,k}$ refer to time series estimated by help of the model, f_g and $c_{g,k}$ are estimations from the sampling procedure. Based on empirical evidence of skewness, we transformed the catch data with a logarithmic function.

2.4. Identification of the model, identifiability of the parameters

The least squares criterium defined in (11) may be used to provide estimates of the parameters Θ. We have to solve two problems, dealing with the identification of the model (the three typologies of the resource, the fishing actions and the fishing units) and with the identifiability of the parameters for a given set of typologies.

The definition of our model implies characterizing each of the three components of the considered fishery. Hence, we need typologies of fishing actions (tactics), of the resource (stocks), and of fishing units (strategies). If such typologies are known, one model has to be considered. If we do not know those typologies, we have to deal with the problem of the model identification. We must hence choose a solution among a family of models. We can show (Laloë et al., 1998) that different models can lead to similar results with time series obtained from usual sampling design. This implies an initial building of the typologies, which must be done with parsimony and with an expert knowledge of the fishery.

Let us consider a model with dimension $\{K, S, J, G\}$. We may try to estimate parameters with the least square criterium: $\hat{\Theta} = \arg\min_{\Theta} \mathcal{L}(\Theta)$. This supposes the existence and uniqueness of the minimum, and the uniqueness of the set of parameters reaching this minimum. Such conditions usually do not hold. Consequently parameters of the model are not identified (Laloë et al., 1998). Similar difficulties have been underlined in the case of cohort analysis (Laurec, 1993).

2.4.1. Fitting procedure

The fitting procedure consists in an initial framework, built with expert knowledge on the fishery. In our case, $\{K, S, J, G\}$ equal $\{13, 6, 19, 7\}$ (see below). It appears not possible to find a solution directly using non linear algorithms of optimisation for the whole set of parameters Θ.

An alternative consists of searching iteratively for a solution by looking to a subset ($\theta \subset \Theta$) of parameters with a subset of series. That may be done with the partial criterium $\mathcal{L}_p(\theta)$ defined as:

$$\mathcal{L}_p(\theta) = \sum_{g=1}^{G} p_g \frac{\| f_g - \hat{f}_g \|^2}{\| f_g - \bar{f}_g \|^2} + \sum_{g=1,k=1}^{G,K} p_{g,k} \frac{\| \ln(c_{g,k}+1) - \ln(\hat{c}_{g,k}+1) \|^2}{\| \ln(c_{g,k}+1) - \overline{\ln(c_{g,k}+1)} \|^2} \quad (12)$$

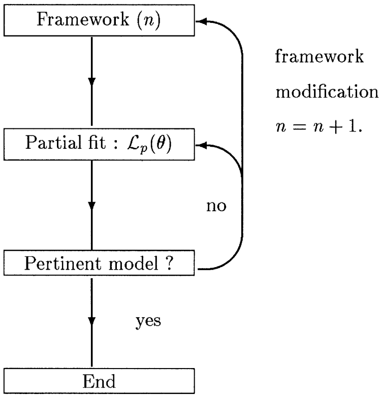

Figure 3. Fitting procedure.

$\mathcal{L}_p(\theta)$ is a weighted sum ($(p_g)_g$ and $(p_{g,k})_{g,k}$ being the weights) of the considered time series in $\mathcal{L}(\Theta)$ for a part $\theta \subset \Theta$.

We can then propose an identification and a fitting ad-hoc procedure of the model. Such a procedure (*figure 3*) consists in the definition of tactics, strategies, stocks, accessible stocks for each tactic, available tactics for each of the strategy. Next, we try to fit the data using the $\mathcal{L}_p$ criterium. For this we have to choose the values of the weights $(p_g)_g$ and $(p_{g,k})$, to fix the values of some parameters and to fit on the remaining parameters. Note that if estimations obtained this way correspond to a lower value of $\mathcal{L}_p(\theta)$, this is not necessarily true for $\mathcal{L}(\Theta)$.

We can, in order to appraise estimations we have obtained, look at some variables of the model (biomass, incomes, dispatching of the efforts by tactics) for which we have no observation but we may know some piece of information. We can also look at the appropriateness of estimated values of the parameters with some range of variation known or supposed.

The procedure is iterated, defining new weights and changing or not the set of parameters θ to be estimated. Such choices are arbitrary, and we have no definitive rule to help us. At the end of the procedure, some parameters may have never been considered in θ subsets and remain fixed to their initial values.

The model may be changed in this structure, for example if we do not diminish the $\mathcal{L}(\Theta)$ criterium in a convenient way. Changes may be operated, for example, by adding a new tactic or changing the definition (the set of available tactics) of one strategy. Then a new fitting step is performed until the next modification of the model or until the end, if the obtained fit is considered as correct.

2.5. Fitting the model to the Senegalese artisanal fishery data

2.5.1. Characteristics of the Senegalese artisanal fishery

The existence of fishing tactics has been pointed out by several authors from the analysis of individual trips obtained particularly during oversampling operations (Laloë et al., 1981; Gérard et Greber, 1985; Pelletier and Ferraris, 2000).

The ability to choose among different tactics has two main consequences:

– First, if more than one tactic may be present in the same stratum of the sampling design, the mean catch per trip from this stratum cannot be considered as a function of abundance of resource, since it is a weighted mean of such functions, with weights 'decided' by the fishermen. It means that the use of the mean catch per trip may be misleading for stock assessment purposes.

– Second, this characteristic may ensure that at each given time an available tactic permits positive revenues. This solution is of great interest for fishing units that have short operating range, in a context of large seasonal variation in spatial distribution of the various components of the resource.

Changes in the conditions of exploitation may also occur on a interannual scale. They may concern prices (for example CFA devaluation in 1994 has generated price increases for exported species), costs of material, or environmental (natural, social, economical, political) conditions. They may sometimes be generated by the fishermen themselves, for example when adopting new fishing techniques as purse seine during the 1970s (Laloë and Samba, 1989), long-lines at the end of the 1980s (Samba and Fontana, 1989) or more recently the trammelnet (Charles-Dominique and Diallo, 1996).

Causes of such changes may be known or not. For example, several plausible hypotheses have been put forward to explain the collapse of catches of *Pomatomus saltatrix* (bluefish) at the beginning of the 1980s (Samba and Laloë, 1991). The cause of this collapse may lie in a collapse of the stock, or a change in its migration patterns, or a change in fishing technology and socio-economical conditions that make this species less attractive (or other species more attractive). Most probably it is a result of a combination of a number of causes.

2.5.2. Applying the fitting procedure

2.5.2.1. Initial model

We first consider a 'simple' model, taking into account expert knowledge of the dynamics of the fishery. Specially, we try to account for relationships between the two landing places. For example, fishing units of Saint-Louis may migrate to Kayar, but fishing units of Kayar always fish at Kayar. Moreover, we cannot disregard relationships between the set 'Saint-Louis-Kayar' and external components of the system.

We also take into account migrations of fishing units outside of our study area, as well as the impact of exploitation carried out by industrial vessels.

This initial model distinguishes 6 strategies and 19 tactics. For example, the strategy 'hand liners of Kayar' is characterized by 6 hand line tactics used at Kayar, where the principal targeted stocks are bluefish, deep seabreams, sailfish, white grouper, coastal seabreams and octopus.

The strategy 'hand liners of Saint-Louis' may use the whole set of tactics accessible to the strategy 'hand liners of Kayar' plus four tactics with use of hand lines at Saint-Louis. This strategy represents fishermen of Saint-Louis whose units may migrate, particularly to Kayar.

We do not specifically study the industrial fishery here. However, industrial and artisanal fishing units may harvest from the same components of the resource. Hence, we consider an 'industrial' strategy with a virtual industrial vessel, the catches of which reflect those made by 'real' industrial vessels. We account for possible changes in catchability of industrial tactic for each stock with the following equation:

$$q_k(t) = q_{k_0} + (q_{k_\infty} - q_{k_0}) \frac{1}{1 + e^{4t_k p_k - 4p_k t}} \quad (13)$$

See comments given with equation (2) for an explanation of parameters t_k and p_k.

Occasionaly, we may change characteristics of this virtual vessel in order to explore possible consequences of management decisions (see below).

Except for the 'industrial' strategy, we add to each strategy a tactic called 'activity other than fishing on north coast'. The aim of such a tactic is to represent a non-fishing activity (rest, agricultural activity) or a fishing activity outside of our study area.

2.5.2.2. Final model

After about 100 'partial fits' (see *figure 3*), the model dimension is changed, removing 2 of the tactics and adding 6 new tactics.

Some of the new tactics concern non fishing operations and were needed in order to better represent opportunity costs. The latter may be seasonal with the following equations.

$$C(t) = a + b \sin(\pi \Delta_t t) + c \cos(\pi \Delta_t t) + d \sin(2\pi \Delta_t t) + e \cos(2\pi \Delta_t t)$$

with

$$\Delta_t = \frac{1}{24} \quad (14)$$

The final dimension {K, S, J, G} equals {13, 6, 23, 7}. Definitions of stocks, strategies, tactics and strata are given on *table I* and the diagram presented on *figure 2* provides the basic aspects of the various combinations between classes.

2.5.2.3. Number of the parameters

The total number of parameters is huge. With the dimension ({K, S, J, G}={13, 6, 23, 7}), the total number of parameters is greater than 6000. This number may be reduced with some constraints and submodels.

The list of the accessible stocks for each tactic (see combinations 'stock–tactic' on *figure 2*) defines a set of constraints on the catchability values (non capturable stocks have a nil catchability). Accounting for those constraints reduced the parameter numbers to 1402, 1224 of them dealing with $\alpha_{j,k,m}$ values.

Since m varies from 1 to 24, there are 24 $\alpha_{j,k,m}$ parameters for a given stock and tactic combination. Those parameters may be expressed as an harmonical function depending on 5 parameters, $u_{j,k,i}$, $i = 0...4$.

$$\alpha_{j,k,m} = \frac{1}{1 + e^{-u_{j,k,0} - \sum_{i=1}^{4} u_{j,k,i} h_i(m)}}, \quad m = 1...24 \quad (15)$$

where $h_i(t)$, $i = 0...4$ are sine and cosine functions of period 24 and 12, except for bluefish, which is available for seines only 2 or 3 fortnights a year (Laloë and Samba, 1991). For these two cases (bluefish with seines at Kayar and Saint-Louis) α values are estimated using sine and cosine functions of period 24, 12 and 8. For some 'stock–tactic' combinations involving hand lines with ice and industrial, we assume that α values are constant because of long operating ranges.

Provided those constraints, the dimension of Θ was reduced to 389, which remains however a high value justifying the ad-hoc procedure described in previous section.

2.5.2.4. Accounting for changes

Main changes are accounted for, either by modification on some definitions in set of available tactics for some strategy, or by introduction or estimation of a change in some parameters. The list of those modifications is given in *table II*, with a short explaination of each of them.

2.5.2.5. Initial values of the parameters

We fixed initial values of parameters from expert knowledge and various available information. This work (Pech, 1998) is not described in details here, but it required quite a substantial amount of time and multidisciplinary communication. As such, it is part of the process of the framework construction.

3. RESULTS

The final value of $\mathcal{L}(\Theta)$ is equal to 29.55. This value may be compared to 43, that would correspond, for each of the 43 time series, to fitted values equal to its mean.

Table II. Fitting the model for two landing places of the Grande Côte of Senegal: list of selected changes.

Year	Fortnight	Modification	Origin	Source
1974	1	No tactic, line with ice		
		No tactic, seines		
		Gillnets are not available at Kayar	Prohibited use	Laloë and Samba, 1989
1977	1	Tactic line with ice becomes accessible at Saint-Louis	Technological innovation	Laloë and Samba, 1989
1979	1	Tactics seines becomes available at Kayar	Technological innovation	Laloë and Samba, 1989
1981	1	Tactics seines becomes available at Saint-Louis	Technological innovation	Samba and Laloë, 1991
		Catchability of tactics 'line, bluefish' is divided by 2 (fixed parameter)	Several possible reeasons	Laloë and Samba, 1989
1983	1	Increased price of deep seabreams (421 CFA francs) (estimated parameter)	Commercial opportunity	Chaboud, personal communication
1985	1	Tactic gill nets to sole becomes available at Kayar	Pressure of units from Saint-Louis	Laloë and Samba, 1989, Le Fur, 1995
1986	8	Catchability of line with ice for white grouper is multiplied by 1.1 (estimated parameter)	Use of long lines	Samba and Fontana, 1989
1989	1	Biomass of octopus is multiplied by 100 000	Apparition of the species	Caverivière, 1990
		Tactic 'line, octopus, Kayar' is accessible	Technological innovation	Samba, unpublished data
		Tactic line with ice is inaccessible	No more access to the Mauritanian waters	Samba, 1995
1990	10	Tactic line with ice is accessible	Possible access to Mauritania	Samba, unpublished data
1992	1	Tactic octopus is accessible at Saint-Louis	Technological innovation	Samba, unpublished data

Estimated values of parameters are shown in *tables III–VII* and *figure 4*. As noted above, the complete set is available from the authors.

Results are graphically presented on *figures 5* to *11*. It can be seen that fitted values account for main seasonal patterns and for main interannual changes. However, the global fit is far from 'perfection'. Among poorly fitted series, 2 cases can be distinguished. First, some series have no clear seasonal pattern, such as *CPUE* for hand lines with ice (*figure 7*), *CPUE* of flat sardinella for seines, and of round sardinella for seines at Kayar (*figures 8* and *9*). Second, series whose pattern we were not able to represent, e.g. series of efforts for gillnets at Saint-Louis and Kayar.

Usual residual analysis confirms the existence of autocorrelations for most of the time series of residuals. We could not assume here the validity of the usual hypothesis needed for statistical tests or confidence interval building.

The utility of this modellisation may lie also in the analysis of some events that appear at certain points of the overall result. For example, the seasonal trend of deep seabream CPUE with hand lines at Kayar (*figure*

Table III. Fitting the model for two landing places of the Grande Côte of Senegal.

Stocks	Parameters			
	B_0 (1974, tons)	B_v (tons)	Growth rate (r)	Price (FCFA)
1. white grouper	*13 713*	*28 919*	*0.62*	*634*
2. coastal seabreams	*16 664*	*41 103*	*0.98*	*299*
3. deep seabreams	*6 133*	*15 505*	*0.80*	*215*
4. false scad	*84 194*	*201 096*	*1.0*	*218*
5. bluefish	*31 695*	*66 324*	*0.62*	*275*
6. gill nets fishes	*11 896*	*14 683*	*0.82*	*26*
7. octopus	0.25	0.5	10	*447*
8. sailfish	*47 517*	*51 808*	*0.38*	*238*
9. round sardinella	*116 603*	*116 984*	*2.0*	70
10. flat sardinella	*47 745*	*47 841*	*2.02*	*43*
11. senegal jack	*21 596*	*23 905*	*0.84*	*69*
12. soles	*1 728*	*2 654*	*1.16*	*531*
13. sharks and rays	*4 244*	*29 989*	*0.60*	*31*

Initial biomass (1974), carrying capacity, growth rates by stock for the selected model. Estimated values in italic.

Table IV. Fitting the model for two landing places of the Grande Côte of Senegal.

Strategies	Parameters				
	N_0	N_∞	t_s	p_s	μ_s
Gillnets	*81*	*211*	*430*	*0.01*	*0.26*
Line at Kayar	*169*	*169*	–	–	*0.41*
Line at Saint-Louis	*1 311*	*1 410*	*184*	*0.01*	*0.53*
Line with ice / Seines	*30*	*66*	*374*	*0.01*	*0.45*
Seines	*28*	*56*	*264*	*0.1*	*0.61*
Industrials	100	100	–	–	–

Parameters values of the logistic function describing number of fishing units per strategy. Parameters μ_s (see equation (5)). Estimated values in italic.

Table V. Fitting the model for two landing places of the Grande Côte of Senegal: catchabilities (×10[6]) for the selected model.

	Stocks												
Tactics	1	2	3	4	5	6	7	8	9	10	11	12	13
a	0	0	0	0	*2.65*	0	0	0	0	0	0	0	0
b	*2.5*	*0.59*	0	0	0	0	0	0	0	0	0	0	0
c	*0.53*	*2.4*	0	*0.82*	0	*3.5*	0	0	0	0	0	0	0
d	0	0	0	0	0	0	_0.75*_	0	0	0	0	0	0
e	0	0	0	0	*2.9*	0	0	0	0	0	0	0	0
f	0	0	*8.4*	0	0	0	0	0	0	0	0	0	0
g	0	0	0	0	0	0	0	*7.6*	0	0	0	0	0
h	*1.8*	*1.4*	0	0	0	0	0	0	0	0	0	0	0
i	0	*1.5*	0	*1.5*	0	*2.2*	0	0	0	0	0	0	0
j	0	0	0	0	0	0	_0.58**_	0	0	0	0	0	0
k	*8.0*	*1.7*	0	*0.016*	*0.04*	*1.3*	*0.0005*	0	0	0	0	0	0
m	0	0	0	*0.6*	*3.3*	0	0	0	*1.28*	*3.2*	*3.5*	0	0
o	0	0	0	*3.9*	*2.5*	0	0	0	*1.0*	*2.3*	*3.7*	0	0
p	0	0	0	0	0	0	0	0	0	0	0	*8.6*	0
q	0	0	0	0	0	*8.3*	0	0	0	0	0	0	*11.4*
r	0	0	0	0	0	0	0	0	0	0	0	*22.1*	0
s	0	0	0	0	0	*10.5*	0	0	0	0	0	0	*4.7*
t	–	–	–	–	–	–	–	0	–	–	–	–	–
u	0	0	0	0	0	0	0	0	0	0	0	0	0
v	0	0	0	0	0	0	0	0	0	0	0	0	0
w	0	0	0	0	0	0	0	0	0	0	0	0	0
x	0	0	0	0	0	0	0	0	0	0	0	0	0
y	0	0	0	0	0	0	0	0	0	0	0	0	0

Estimated values in italic. For tactic *t* (industrials), see *table VI*. * $q_{4,7} = 0$ until 1991. ** $q_{10,7} = 0$ until 1988.

6) shows one peak a year until 1982 and two peaks a year after 1982. The fitted values account for this change. According to expert knowledge, this change is mainly due to an increase of price of seabream that occurred in 1983. The occurrence of such an increase is introduced in the model (*table II*). The estimated values for price of seabream are 215 CFA francs until

Table VI. Fitting the model for two landing places of the Grande Côte of Senegal.

	Parameters			
Stock	$q_{\infty 0}(\times 10^6)$	$q_{k\infty}(\times 10^5)$	t_k	p_k
1. white grouper	*12.3*	*13.9*	*104*	*0.006*
2. coastal seabreams	*28.6*	*41.6*	*477*	*0.0004*
3. deep seabreams	*25*	*25*	–	–
4. false scad	*27.3*	*27.3*	–	–
5. bluefish	*12.8*	*12.8*	–	–
6. gill nets fish	*1.8*	*11.8*	*169*	*0.05*
7. octopus	10	10	–	–
8. sailfish	–	–	–	–
9. round sardinella	*0.031*	*0.031*	–	–
10. flat sardinella	0	0	–	–
11. senegal jack	0	0	–	–
12. soles	*1.7*	*1.7*	–	–
13. sharks and rays	*6.3*	*6.3*	–	–

Parameters of the function (equation 13) describing the evolution of industrial catchabilities for the selected model. In italic estimated values.

Table VII. Fitting the model for two landing places of the 'Grande Côte' of Senegal.

	Parameters				
Tactics	a	b	c	d	e
a	*10 046*				
b	*2 597*				
c	*1 911*				
d	*11 059*				
e	*10 997*				
f	*10 842*				
g	*6 687*				
h	*356*				
i	*6 290*				
j	*6 469*				
k	_30 560*_				
m	*5 882*				
o	*18 717*				
p	*1 987*				
q	*653*				
r	*21 240*				
s	*6 316*				
t	0				
u	*– 3 647*				
v	*– 12 853*				
w	*– 24 073*				
x	*– 39 022*	*– 5 008*	*1 400*	*– 4 967*	*300*
y	*– 6 584*	*2 188*	*– 100*	*4 565*	*100*

Values are cost parameters (a, b, c, d, e, see equation 14) for the selected model. Estimated values in italic. * cost valid from 1977 to 1988 and from 1990 (fortnight 20) to the end.

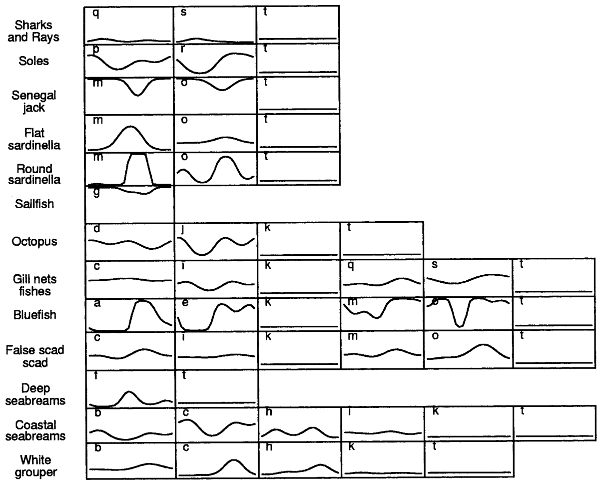

Figure 4. Fitting the model for two landing places of the Grande Côte of Senegal: estimated profiles of inaccessibilities for stocks and tactics (a to t, see *table I*) combinations.

1982 and 421 CFA francs after 1982. Hence, changes in seasonal patterns may be due to events that do not lie in the biological or ecological domain.

3.1. Discussion

Having fitted the model, we may address the question of its use, especially in some predictive sense. Usual models consider the resource dynamics for a given time series of the impact of fishing activity. Therefore they can be used to answer questions on future catches and results with a given fishing activity, or on the nature of the fishing activity that could lead to some desirable result. With a dynamical system such as the one considered in this paper, we may address questions of changes in future catches and in fishing activity that would result from changes in some part of the system.

This may be illustrated by using the fitted model for a simulation of the fishery after 1992, the last year considered in our fit. We introduce three events of different nature in this simulation:

– The first change concerns possible changes resulting from the devaluation of the CFA franc in 1994 (year $n + 2$ with $n = 1992$). Prices of exported species are multiplied by 1.5, the others remaining unchanged. This change results from an external decision in the global economical environment.

– The second change concerns a possible event in the 'natural environment' in year $n = 6$, with a reduction by three of the carrying capacity for octopus.

– The last change concerns a possible decision of management occurring in year $n = 8$, with a multiplication by three of the catchability of our 'virtual industrial vessels' on white grouper and on false scad. This could come about, for example, from new licences issued for two types of vessels targeting one of those species, or from an increase in fishing power of such vessels.

Note that, although a devaluation of the CFA franc really occurred in 1994, the consequences in terms of price changes are here arbitrarily stated. The two other changes are examples that do not correspond to known

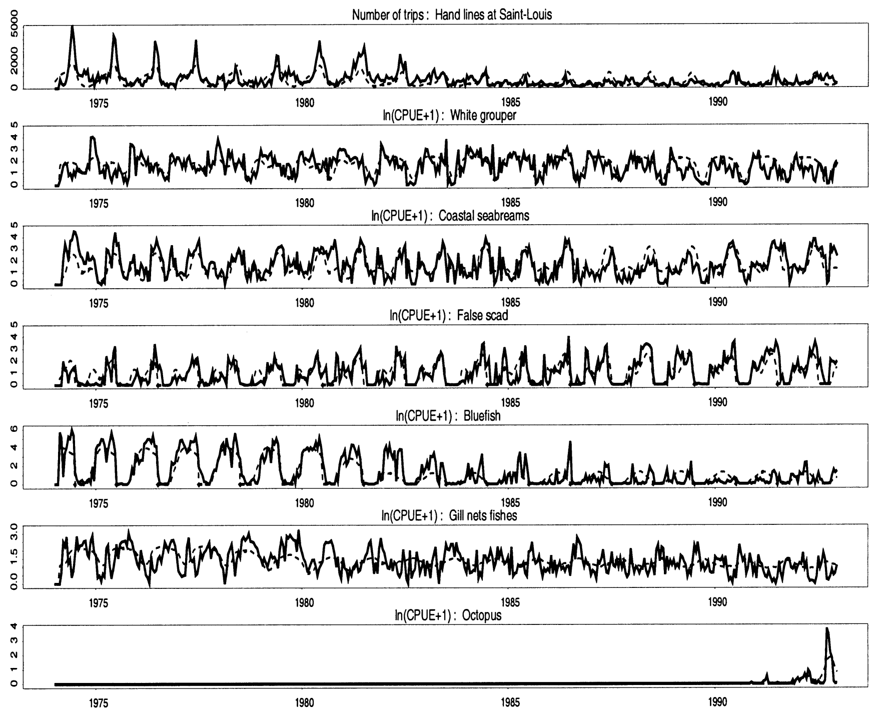

Figure 5. Fitting the model for two landing places of the Grande Côte of Senegal: lines at Saint-Louis. Continuous line corresponds to observed values and dashed lines to fitted values. From top to bottom: efforts (number of landings per fortnight) and ln (*CPUE*+1) for catchable stocks.

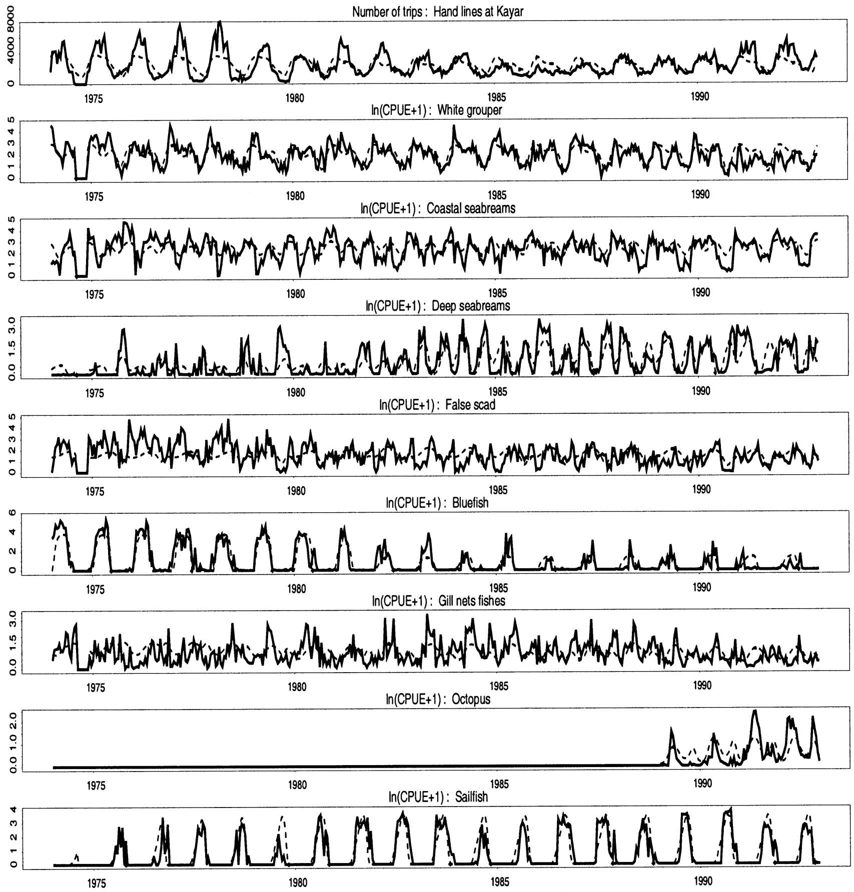

Figure 6. Fitting the model for two landing places of the Grande Côte of Senegal: lines at Kayar. Continuous line corresponds to observed values and dashed lines to fitted values. From top to bottom: efforts (number of landings per fortnight) and ln (*CPUE*+1) for catchable stocks.

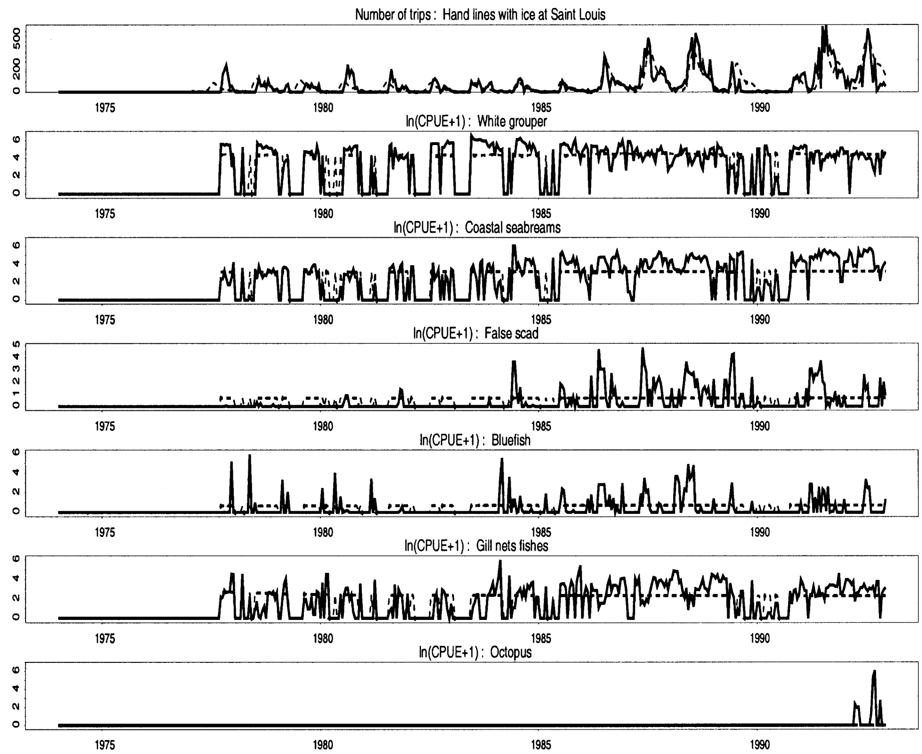

Figure 7. Fitting the model for two landing places of the Grande Côte of Senegal: lines with ice at Saint-Louis. Continuous line corresponds to observed values and dashed lines to fitted values. From top to bottom: efforts (number of landings per fortnight) and ln (*CPUE*+1) for catchable stocks.

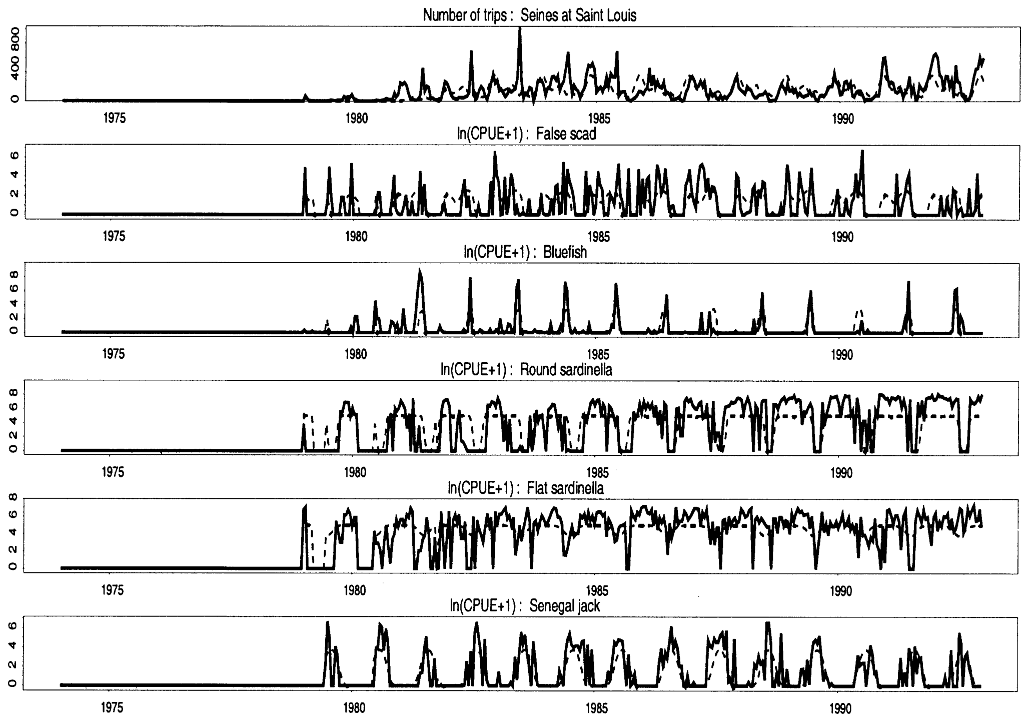

Figure 8. Fitting the model for two landing places of the Grande Côte of Senegal: purse seines at Saint-Louis. Continuous line corresponds to observed values and dashed lines to fitted values. From top to bottom: efforts (number of landings per fortnight) and ln (*CPUE*+1) for catchable stocks.

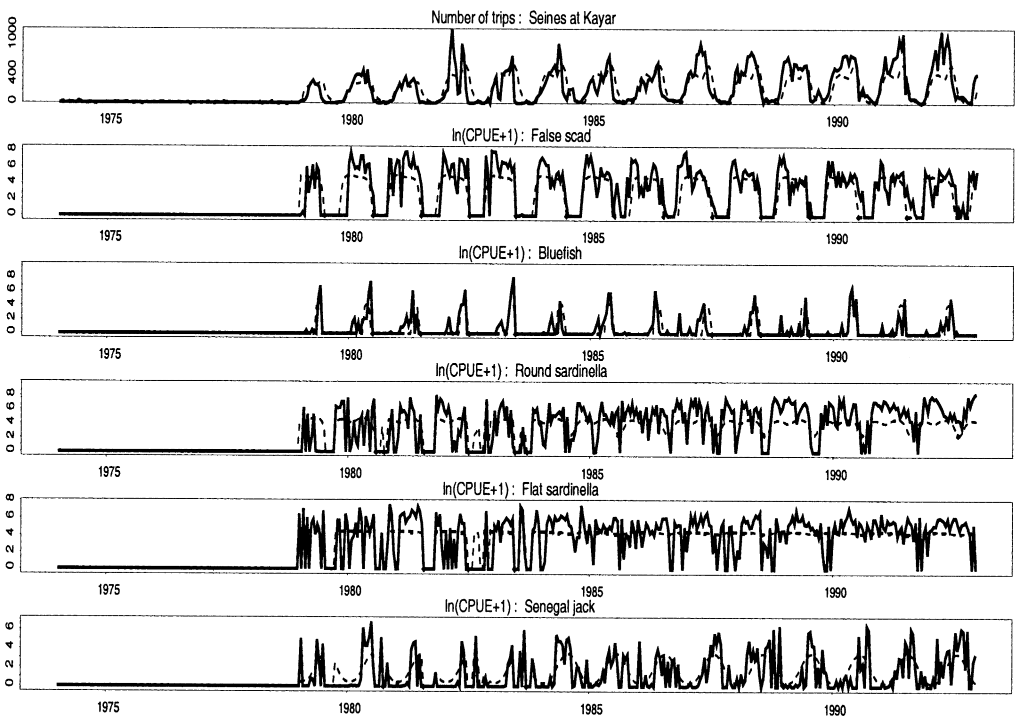

Figure 9. Fitting the model for two landing places of the Grande Côte of Senegal: purse seines at Kayar. Continuous line corresponds to observed values and dashed lines to fitted values. From top to bottom: efforts (number of landings per fortnight) and ln (*CPUE*+1) for catchable stocks.

and quantified events. The following results are therefore shown only as illustrations of potential use of the model.

We can observe the nature of the consequences of the introduced modifications by looking at the results of the simulation. We present here the evolution of a

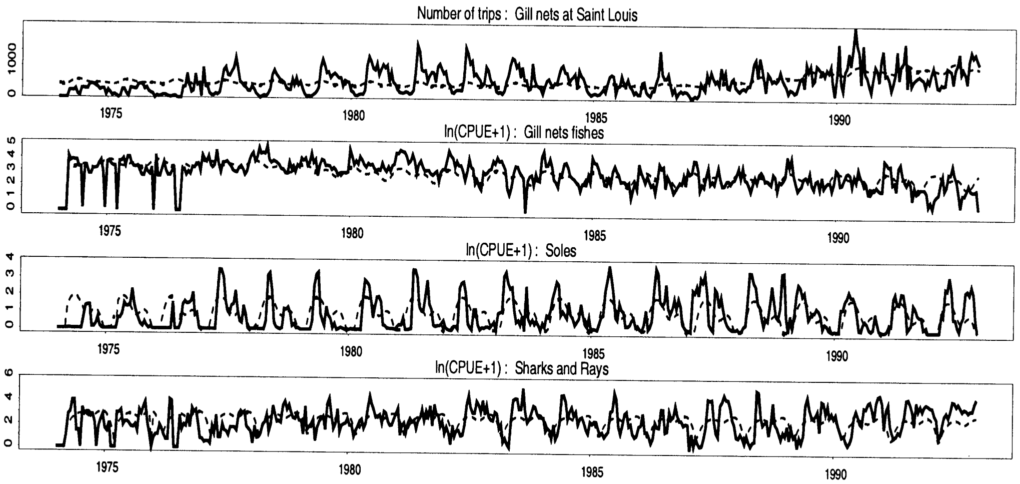

Figure 10. Fitting the model for two landing places of the Grande Côte of Senegal: gill nets at Saint-Louis. Continuous line corresponds to observed values and dashed lines to fitted values. From top to bottom: efforts (number of landings per fortnight) and ln(*CPUE*+1) for catchable stocks.

number of trips and results for handlines at Kayar (*figure 11*). Similar results are obtained with the six other 'gear-landing places'.

The impact of price changes in 1994 leads to an increase of the number of trips, which corresponds to an increasing use of tactics targeting exported species (such as white grouper). Immediate consequences are a small increase in catch per trips for those species, and a decrease in catch per trip for species that are not exported (e.g. bluefish). We then observe a small decrease in white grouper catch per trip due to a lower abundance of that species.

The reduction (two thirds) of carrying capacity of octopus leads to a much more important reduction of catch per trip for that species.

Finally the increase of industrial fishing activity on white grouper and on false scad leads to a collapse of catches on the second species and a high decrease of catch per trip for white grouper. We observe a decrease in activity with hand lines at Kayar, and an increase of catch per trip for bluefish and deep seabreams.

Those impacts of changes depend on estimated values of the parameters of the fitted model. As there is no unique solution, the observed impacts are themselves a solution among many others possible.

For example the increase of catchability of industrial vessels on false scad in year 2000 leads to a collapse of *CPUE* of hand lines at Kayar on this stock (*figure 12*). This is because the biomass is reduced below the level of biomass of false scad inaccessible to hand lines. If we impose an arbitrarily lower level of inaccessible biomass (for this we increase in equation (15) the value of $u_{9,4,0}$ from 0.68 to 2), we may

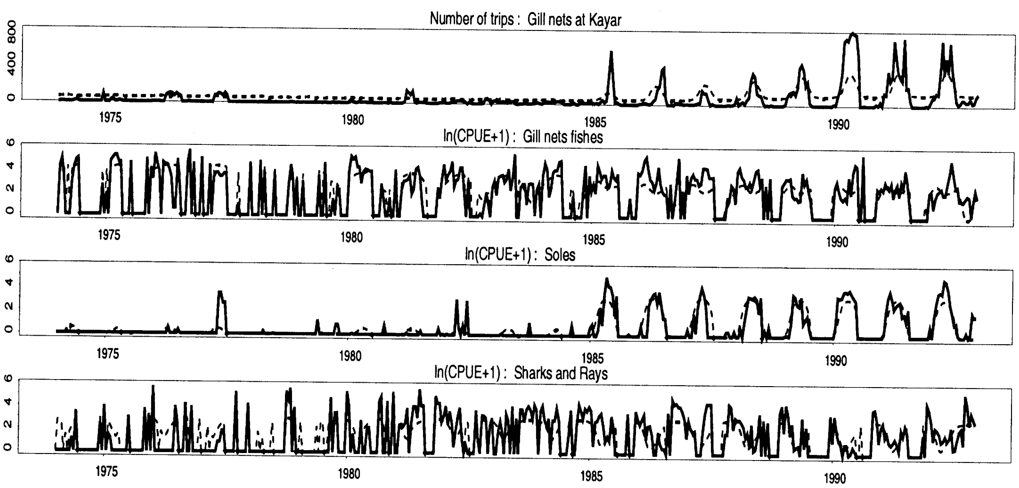

Figure 11. Fitting the model for two landing places of the Grande Côte of Senegal: gill nets at Kayar. Continuous line corresponds to observed values and dashed lines to fitted values. From top to bottom: efforts (number of landings per fortnight) and ln (*CPUE*+1) for catchable stocks.

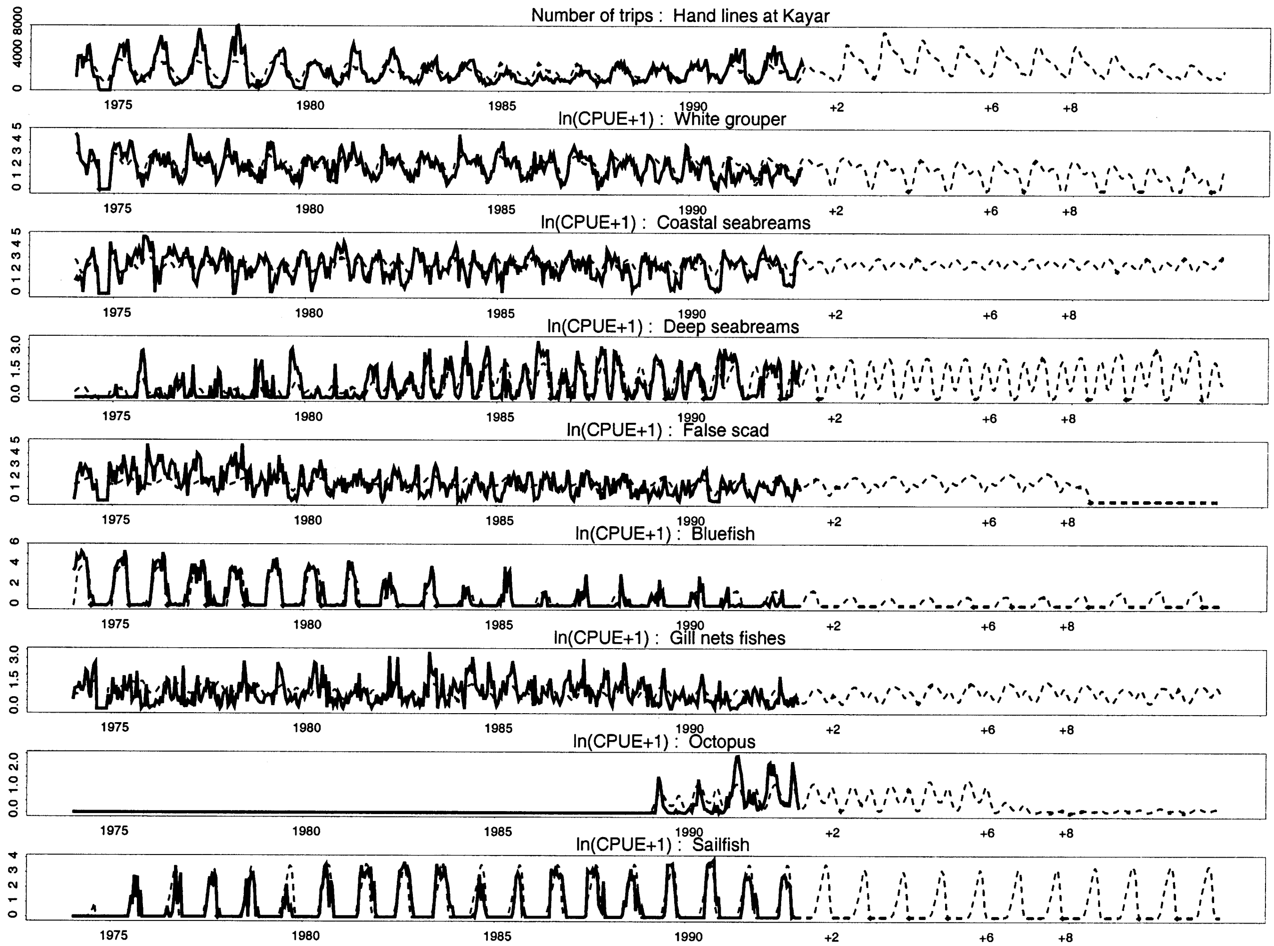

Figure 12. Fitting the model for two landing places of the Grande Côte of Senegal: lines at Kayar. Continuous line corresponds to observed values and dashed lines to fitted values prolonged 11 years introducing three events (see text).

estimate the values of $q_{9,4}$ and $u_{9,4,i}$, $i = 1...4$. We obtain a least square criterium value of 29.63. Results are again presented for hand lines at Kayar (*figure 13*). We observe that false scad CPUE sharply decreases, but there is no other collapse. Other results remain quite unchanged.

Because of a decrease of the number of fishing trips, the white grouper and false scad *CPUE* decrease seems a logical result but, again, we need expert knowledge in order to be able to choose between different solutions.

4. CONCLUSION

The results obtained by the selected model using our ‘ad-hoc’ fitting procedure may appear as qualitatively correct. However, we are not so confident in such results. First we are not sure of the proposed structure of our model, nor of the quality of the parameter estimates. Secondly, even if our model is somewhat comprehensive, it remains reductive. Such results underline the problematic use of data obtained from such a fishery survey system, due to the complex interaction among biological dynamics and adaptative fleet dynamics, in the context of a variable environment.

This kind of work combines basic research with statistical data analysis, the need of which is stated by Charles (1998). Moreover, statistical data analysis appears clearly as one of the essential components of this research. Evidence of the existence of fishing tactics — and of related problems in such a context for use of data on fishing activity and results — was obtained with statistical data analysis. The general model, the fitting procedure, and the criticism of the results are largely based on a number of statistical tools and concepts. The improvement of the fitting procedure would need additional basic research, in statistical field too.

We did not find a unique solution for the parameter values. The proposed solution is based on choices of

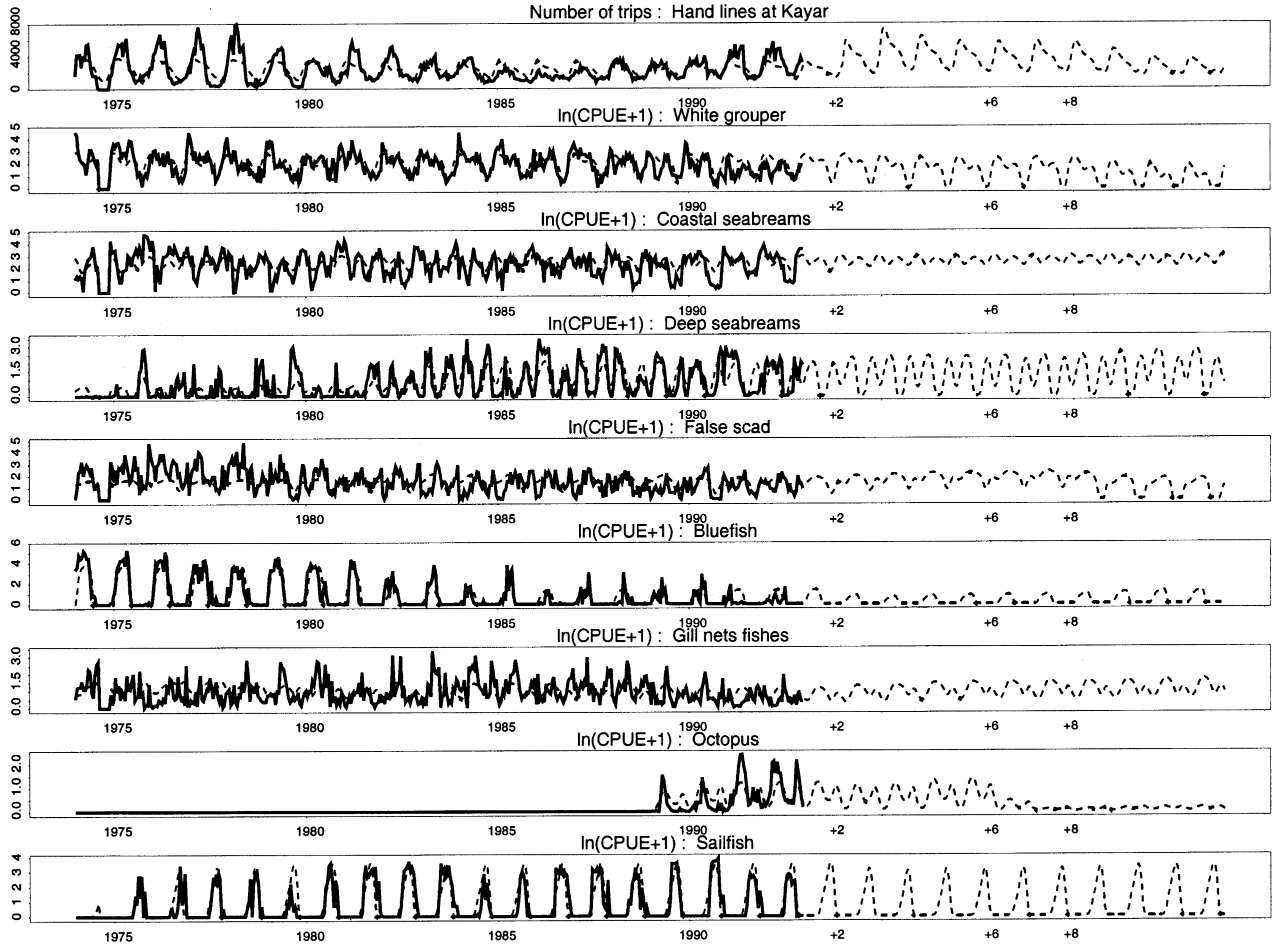

Figure 13. As for *figure 12,* results obtained with a lower quantity of biomass of false scad inaccessible to hand lines. From top to bottom: efforts (number of landings per fortnight) and ln (*CPUE*+1) for catchable stocks.

some plausible hypotheses. With a simulation study, we showed (Laloë et al., 1998) that catch and effort data, such as those used in the present study, may be quite perfectly fitted with {2,2,1,1} and {2,1,1,1} models with very different conclusions on the dynamics of the resource: those conclusions highly depend on (often implicit) asumptions about the fleet dynamics structure. One benefit of constructing such systems of 'fish and fishermen' dynamics may be to highlight the existence of such problems.

If, as we have shown, normally available data are not adequate to distinguish between solutions, one may wonder what kind of new data and what tools would lead to make a better distinction (Morand and Ferraris, 1998). In this study, we were quite confident of the existence of identified tactics. Hence, the process of model building and data collection is a dynamic one. We must recognize, however, that this work cannot be done only within the scope of statistics. We noted at many places of this paper the need of 'expert knowledge' for choosing between solutions, knowledge which is one of the products of interdisciplinary collaborations and communications in the context of research conducted at the CRODT.

Such work should be considered as part of what Stephenson and Lane (1995) call 'fisheries management science', which 'provides the framework and methodologies for defining multiple objectives and constraints, modelling alternative management scenarios and assessing and managing risks'. Hence, validity of such frameworks does not imply certitude on the structure of the 'real fisheries system'. They must be coherent with available knowledge (from different disciplinary points of view) and with available data, and their validity also lies in their capacity to give some answer to relevant management questions (Charles, 1998), and to help the identification of such questions in a context of structural uncertainty. In that sense, the framework considered here is coherent with the definition of a system given by Röling (1994).

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