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Estimation of the overall fishing power: A study of the dynamics and fishing strategies of Brittany's industrial fleets

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Abstract – The present paper suggests a method for estimating the fishing power of vessels and for analysing fleet dynamics. The approach is based on quantification of stocks catchability (q), derived from fishing mortality coefficients (F) as calculated by virtual population analysis. Catchabilities for each harvested stock are thus estimated relatively to the fishing effort (f_n) of each vessel, according to the equation: $q = (F/f_n)$. A linear model is then fitted to these catchabilities. The model allows the identification and quantification of trends in average mortality rates per fishing hour for each stock. Under some assumptions, trends are interpreted as variations in the overall fishing power of each fleet. The approach is applied to three industrial and semi-industrial fleets of Brittany (Lorient, Concarneau and Douarnenez) and to the main gadoid stocks they exploit off the west coast of Scotland (ICES area VIa), and in the Celtic Sea (ICES area VIIf,g,h) for Concarneau. Results show large variations in fishing power. Particularly, a marked increase trend in the fishing power exerted on saithe (*Pollachius virens*) is highlighted for the three fleets, over the period 1983–1989. These variations can be explained by the redirection of fishing strategies, which may occur on a large scale. Thus, we show how the collapse of saithe stock at first led the three fleets to intensify the harvesting of saithe, and from 1989 on, to adopt different strategies. The possible causes of the observed dynamics are discussed, as well as their consequences for fisheries management. In particular, the relevance of direct control of fishing effort as a regulatory tool is questioned.

Catchability / fishing power / fishing strategies / fishery management / fleet dynamics / linear model / *Pollachius virens* / north-east Atlantic

Résumé – Estimation des puissances globales de pêche : étude de la dynamique et des stratégies de pêche des flottilles industrielles de Bretagne sud. On propose ici une méthode d'estimation des puissances de pêche des navires et d'analyse de la dynamique des flottilles. L'approche s'appuie sur une quantification de la capturabilité (q) des stocks à partir des coefficients de mortalité par pêche (F) issus de l'analyse des cohortes. Les capturabilités de chaque stock exploité sont ainsi estimées relativement à l'effort de pêche (f_n) développé par chaque navire, selon la relation : $q = (F/f_n)$. Une modélisation linéaire des capturabilités est ensuite effectuée. Elle permet d'identifier et quantifier les tendances des mortalités moyennes par heure de pêche appliquées à chaque stock. Sous certaines hypothèses, ces tendances sont interprétées comme des variations de puissances de pêche développées par chacune des flottilles. La méthode est appliquée aux trois flottilles industrielles ou semi-industrielles de Bretagne sud (Lorient, Concarneau et Douarnenez) et aux principaux stocks qu'elles exploitent dans la zone nord-ouest d'Écosse (zone CIEM VIa), et en mer Celtique (zone CIEM VIIf,g,h) pour Concarneau. Les résultats montrent d'importantes variations des puissances de pêche. En particulier, un important accroissement de la puissance de pêche développée sur le lieu noir (*Pollachius virens*) est mis en évidence pour les trois flottilles, sur la période 1983–1989. Ces variations s'expliquent notamment par des modifications de stratégies de pêche, qui peuvent être de grande ampleur. On montre ainsi comment l'effondrement du stock de lieu noir a conduit d'abord à une stratégie d'intensification de son exploitation, puis, à partir de 1989, à des stratégies différentes pour chacune des trois flottilles. Les raisons susceptibles d'expliquer les dynamiques observées sont discutées, ainsi que leurs conséquences en terme de gestion des pêches. La pertinence d'une régulation directe de l'effort de pêche est notamment remise en question.

Capturabilité / puissance de pêche / stratégies de pêche / gestion des pêches / dynamique des flottilles / modèle linéaire / *Pollachius virens* / Atlantique nord-est

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1. INTRODUCTION

Factors which can lead to overfishing are obviously numerous. In the large majority of cases, however, the situation of overexploitation follows an intensification of fishing effort. This intensification can itself correspond to two different types. The first, most visible, and thus most foreseeable, could be described as 'quantitative'; it corresponds to an increase in the number of units of nominal fishing effort exerted. The second, much more difficult to recognise and thus to control, can be described as 'qualitative'; it corresponds to an increase in the efficiency of a unit of nominal effort.

This increase in fishing efficiency is related to the concepts of overall fishing power and effective effort, which aim to measure the real pressure exerted on stocks [16]. If the concepts seem relatively clear, their quantification however remains difficult [5, 13, 14, 24]. Indeed, the intensification of the effective effort, with constant nominal effort, has effects which are generally quantifiable, in particular in terms of fishing mortality. On the other hand, this intensification originates in basically qualitative phenomena (strategic choices, improvement in fishing technology, skill of the fishermen, organisation of work on board, etc.), which constitute the real process of intensification of vessel efficiency [1, 2, 8–10, 14]. This major difficulty in measuring increasing efficiency makes it particularly uncontrollable, and thus makes overexploitation of the stock more likely.

In the case of European fisheries, and particularly industrial ones, cases of overexploitation have been noted for a long time [3]. For a few years, measures of direct regulation of fishing effort were adopted, in particular within the framework of the Multi-annual Guidance Plans of the European Community, in addition to catch regulation policy based upon TAC (total allowable catch) and quotas. Periodically, the prospect for direct management of fishing time (quotas on fishing hours) is evoked. However, it is clear that the relevance of this type of regulation of nominal fishing effort strongly depends on the efficiency of each effort unit and on the capacity of fishermen to modify this efficiency.

Thus, the estimate of fishing power is a key-point, both for the analysis of exploitation dynamics and for the definition of relevant regulation means [10, 21, 22]. We propose here a method to quantify the fishing powers of the three main industrial fleets of southern Brittany (Lorient, Douarnenez and Concarneau) and to analyse their changes over the recent period.

2. MATERIALS AND METHODS

2.1. From catchability to overall fishing power

Overall fishing power measures the real efficiency of vessels, by taking into account all contributing factors related to the fishermen and to the vessel so that, for a given stock, a unit of nominal fishing effort results in catches [5]. In other words, for a stock of given accessibility, and for a nominal fishing effort expressed in fishing hours, the overall fishing power of a vessel measures the efficiency of each fishing hour, in terms of catches and mortality F generated (cf. notations *table I*). Thus, for constant nominal effort f_n, an increase trend over years of the fishing power Pg corresponds to an intensification of the effective effort f_e applied to the stock: $f_e = f_n \times Pg$.

Table I. Definition of notations used (unless specified within brackets, variables are without unit).

Indexes	
y	Index of year
s	Index of stock
n	Index of vessel
f	Index of fleet
Variables	
F	Fishing mortality rate
C	Catch in number (number of fish)
W	Yields in weight (tonnes)
q	Catchability ($q = a \times Pg$)
a	Accessibility
Pg	Overall fishing power
f_n	Nominal fishing effort (h)
f_e	Effective fishing effort (h)
φ	Yearly increase rate of overall fishing power
Model parameters	
Lq	Neperian log of catchability
N	Total number of years
S	Total number of stocks
α	Year effect
β	Stock effect
γ	Interaction effect
μ	Mean Y
LSM	Marginal means estimator
σ	Standard deviation of marginal means estimation
A	Estimation of accessibility index
Eg	Estimation of global fishing efficiency index
Es	Estimation of specific fishing efficiency index

In practice, the quantification of the global fishing powers of vessels is generally done using a direct approach. It is based upon estimating catches per unit of effort (CPUE) and upon the usual methods of standardisation of fishing effort [7, 14, 24]. The unit of fishing effort used in this case is defined in reference to a 'standard vessel', whose fishing power is supposed to be constant over time. This approach often faces a problem when we assume a trend in the fishing power of all vessels. Choosing a standard vessel appears impossible in this case.

We use here an indirect approach, based on quantification of catchabilities from fishing mortalities, themselves estimated by cohort analysis. The catchability in this case is defined as the relation between the fishing mortality coefficient F and the corresponding nominal effort f_n. Consequently, it can be expressed as the product of fishing power Pg applied to the stock and of the accessibility[1] a of the stock:

$$q = \frac{F}{f_n} = \frac{a \times f_e}{f_n} = a \times Pg \qquad (1)$$

Theoretically, a change over time in the catchability of a stock can be due to vessels fishing power variations, stock accessibility variations, or, of course, to both of these at the same time. Nevertheless, under the assumption of constant accessibility, the interannual trend in catchability can be interpreted as an increase in fishing power. The method of estimation presented here is based on this principle. In effect, the starting point is the calculation of stocks catchabilities, which are converted to the scale of individual vessels to extract the 'accessibility' term on the one hand, which is constant over years but varies between stocks, and the 'fishing power of the fleet' term on the other hand, which varies between stocks and years.

2.2. Calculation of catchabilities

Cohort analysis (VPA) used by the ICES (International Council for the Exploration of the Sea) working groups provides a matrix of fishing mortality coefficients F, by age and year, for each stock studied. Summarised information for this matrix is given by the vector of annual average mortality rates for the most exploited ages [11, 12].

These average mortality rates measure the effect generated on one stock by the activity of all the fishermen harvesting the stock. They can be disaggregated by fleet, and on a finer scale, by vessel pertaining to these fleets. Thus, an average fishing mortality rate, termed 'mortality per vessel', which measures the effect generated on stock by the activity of a single vessel, can be defined.

Mortality rate per vessel (average on the most exploited ages), per year y, stock s and vessel n, is calculated from the total average mortality, per year and stock, and by evaluating the proportion of the total number of fish caught by each vessel:

$$F_{y,s,n} = F_{y,s} \times (C_{y,s,n} / C_{y,s}) \qquad (2)$$

As $C_{y,s,n}$ terms (catch numbers per vessel) are not generally available, we approximate the ratio of catch in number by the ratio of catch in weight $W_{y,s,n}/W_{y,s}$:

$$F_{y,s,n} = F_{y,s} \times (W_{y,s,n} / W_{y,s}) \qquad (3)$$

Knowing the individual annual fishing efforts in area z corresponding to the distribution area of the vessels fishing effort, in which stock s is present, catchabilities per stock, year and vessel are deduced from the calculation of mortality rate per vessel as follows:

$$q_{y,s,n} = F_{y,s,n} / fn_{y,z,n} \qquad (4)$$

We only take into account fishing hours which potentially lead to catches. Effort concentrated on areas where the stock is theoretically not present is regarded as not directed at this stock and does not enter in the definition of overall fishing power developed on the stock. On the contrary, fishing effort directed on other stocks wholly or partly present in the same areas is included. This is a rough but easily available estimate of effort, comparable to nominal effort.

The estimated catchability can be interpreted as the probability (for a given year and a given stock) a fish has of being captured by a unit of fishing effort of the vessel considered, given that it is fishing within the stock's distribution area. For convenience, we will term this 'catchability per vessel'. If the boat does not fish in the stock's distribution area, this catchability is not null but undefined.

2.3. Preliminary study

A preliminary study of the catchabilities per vessel is carried out, consisting in a simple analysis of variance, aiming at two objectives. First, we wish to test the existence of an annual component in the observations, which would indicate a trend in the catchabilities over the period. Second, we wish to measure the influence of the fleet factor on catchability values. This influence, if it exists, indicates a significant difference in average fishing efficiency between fleets, and thus justifies the estimate of the overall fishing power of fleets, which is our main purpose.

An analysis of catchabilities is undertaken stock by stock. The asymmetrical distribution of the studied variables requires a logarithmic transformation of the catchabilities. Furthermore, this transformation is in line with the multiplicative nature of the relationship between variables of the studied system.

We write:

Lq, the dependent variable, is the logarithmic transformation of stock catchability, $Lq_{y,s,f,n}$, the nth observation (for the nth vessel) of Lq corresponding to stock s, fleet f, year y, $q_{y,s,f,n}$ is the catchability of stock s, year y, relating to vessel n pertaining to fleet f and:

$$Lq_{y,s,f,n} = \ln (q_{y,s,f,n} \times 10^7 + 1) \qquad (5)$$

As the values of catchability are always very close to zero, about 10^{-6} to 10^{-8}, we use a multiplier 10^7 to minimise the influence of the one added.

The model of analysis of variance used can be written as follows for each stock s:

$$Lq_{y,s,f,n} = E_y + E_f + E_{y,f} \qquad (6)$$

[1] The French scientific community, in contrast to the English one, makes a distinction between the terms 'disponibility', 'accessibility' and 'vulnerability', where accessibility and vulnerability are the two components of disponibility. Thus, the English term 'accessibility' used here refers to the generic French term 'disponibility'.

where E_y, E_f, $E_{y,f}$ are the statistical effects corresponding respectively to factors *Year, Fleet*, and to interaction term *Year*Fleet*. For each stock, the analysis of variance makes it possible to quantify the share of the total variability of Y explained by each of the two simple effects *Year* and *Fleet*, and the effect of the interaction term.

2.4. Estimate of global fishing powers

Assuming that differences between fleets exist, as shown in the preliminary study done stock by stock, we now estimate the overall fishing powers of each fleet. For this purpose, a linear model of catchabilities is adjusted fleet by fleet. The catchabilities used are those calculated previously (4); each vessel n belonging to a single fleet f, an index referring to the fleet is added. For each fleet, the effects *Year, Stock*, and the interaction term *Year*Stock* are tested. The share of each effect in total variability and its significance are quantified by variance analysis. The cellular and marginal averages, used for the variance analysis, are estimated according to the criterion of unbalanced least squares [20, 26].

The model of analysis of variance is specified for each fleet f:

$$Lq_{y,s,f,n} = E_y + E_s + E_{y,s}$$

where E_y, E_s, $E_{y,s}$ are the statistical effects corresponding respectively to the factors *Year, Stock* and to interaction term *Year*Stock*.

The fitting of this model leads to estimate for each fleet f an average log-catchability of stock s, for year y:

$$E(Lq_{y,s,f,n}) = \hat{\mu}_{y,s} = \mu + \alpha_y + \beta_s + \gamma_{y,s} \qquad (7)$$

where: $\hat{\mu}_{y,s}$ is the log-catchability mean of stock s, the year y, μ is the average term, α_y and β_s the terms relating to the single factors *Year* and *Stock*, $\gamma_{y,s}$ the interaction term.

For each fleet considered, the statistical effect *Year* is interpreted as an index of global fishing efficiency (noted *Eg*), for all the species taken into account, variable over the period considered. This global efficiency measures the average efficiency of fishermen effort, on all the stocks considered; it is thus reliable to a 'technical' efficiency of the fishing activity of a fleet, as it refers to the ability to fish in one area, whatever the stock considered. The *Stock* effect is interpreted as an index of accessibility (noted *A*), constant over the period for each stock. The *Year*Stock* effect measures the changes in catchability between stocks. It is interpreted as an index of specific efficiency (noted *Es*), varying from one stock to another and from one year to the next. This specific efficiency measures the efficiency of fishermen's nominal effort (applied on all stocks) to fish one single stock; it is thus the consequence of strategic choices of fishermen, and is reliable to a 'strategic' efficiency.

The model of catchability on which these interpretations are based can be formalised in the following way:

$$q_{y,s,f} = A_{s,f} \times Eg_{y,f} \times Es_{y,s,f} \qquad (8)$$

where $q_{y,s,f}$ is the average catchability for year y, stock s, and relative to fleet f, $A_{s,f}$ the accessibility index for stock s, relative to the fleet f, $Eg_{y,f}$ the global fishing efficiency index of fleet f, for year y, $Es_{y,s,f}$ the specific efficiency of fleet f, on stock s, for year y.

This model corresponds to a model of global fishing power Pg with two factors:

$$Pg_{y,s,f} = Eg_{y,f} \times Es_{y,s,f} \qquad (9)$$

This representation of the overall fishing power of vessels is characterised by the division of the causes of its variations: on the one hand, the membership of a particular fleet, which is more or less efficient in a global way compared to the other fleets, and on the other hand, the identity of the stock on which this fishing power is exerted, within the same fleet. In other words, the fishing power of a vessel is represented here as the result of a global fishing efficiency *Eg* ('technical efficiency') and of a strategy of use of this efficiency on available stocks *Es* ('strategic efficiency').

The various indexes are calculated using estimators (noted *LSM*, for 'least square means') of marginal averages, corresponding to single effects, and of the cellular averages, corresponding to cross effect. These estimators are calculated in the following way [26]. From model (7), we write:

$$\begin{cases} LSM(\alpha_y) = \sum_{s=1}^{S} \frac{\hat{\mu}_{y,s}}{S} = \sum_{s=1}^{S} \frac{\overline{Lq_{y,s}}}{S} \\ LSM(\beta_s) = \sum_{y=1}^{N} \frac{\hat{\mu}_{y,s}}{N} = \sum_{y=1}^{N} \frac{\overline{Lq_{y,s}}}{N} \\ LSM(\gamma_{y,s}) = \hat{\mu}_{y,s} = \overline{Lq_{y,s}} \end{cases} \qquad (10)$$

where N is the total number of years taken into account (whatever the fleet, $N = 12$), and S the total number of stocks taken into account for each fleet.

A correction factor [7, 19] is applied in reversing the logarithmic transformation, in order to return to gross amounts. Thus, the estimated indexes are expressed as follows, for each fleet *f*:

$$\begin{cases} Eg_{y,f} = \exp\left(LSM(\alpha_y) + \frac{\sigma_y^2}{2}\right) - 1 \\ A_{s,f} = \exp\left(LSM(\beta_s) + \frac{\sigma_s^2}{2}\right) - 1 \\ Es_{y,s,f} = \frac{\exp\left(LSM(\gamma_{y,s}) + \frac{\sigma_{y,s}^2}{2}\right) - 1}{A_{s,f} \times Eg_{y,f}} \end{cases} \quad (11)$$

where $LSM(\alpha_y)$, $LSM(\beta_s)$, $LSM(\gamma_{y,s})$ are the estimators of marginal averages, respectively relative to *Year*, *Stock* and *Year*Stock* effects, σ_y, σ_s, $\sigma_{y,s}$ the associated standard deviation of estimates.

The estimated fishing power $Pg_{y,s,f}$, developed by fleet *f*, on stock *s*, for year *y*, is expressed as follows:

$$Pg_{y,s,f} = \frac{\exp\left(LSM(\gamma_{y,s}) + \frac{\sigma_{y,s}^2}{2}\right) - 1}{\exp\left(LSM(\beta_s) + \frac{\sigma_s^2}{2}\right) - 1} \quad (12)$$

Lastly, average rates of interannual increases in fishing power are calculated from an exponential regression between fishing power and year. The rate of increase φ is calculated from the parameter *k* in regression:

$$Pg_{y+i,s,f} = Pg_{y,s,f} \times \exp(k_{s,f} \times i)$$

$$\varphi = \exp(k_{s,f}) - 1$$

It is then possible to express the average interannual change in fishing power, as follows:

$$Pg_{y+1,s,f} = Pg_{y,s,f} \times (1 + \varphi) \quad (13)$$

These rates of interannual increase allow a quantification of the order of magnitude of drifts in overall fishing powers.

2.5. Application to the industrial fleets of southern Brittany

The preliminary study and the estimation of overall fishing powers are carried out using the GLM (general linear model) procedure of the SAS software [25]. They use catches per vessel data for three southern Brittany harbours: Lorient, Douarnenez and Concarneau. The fleets are made up exclusively of off-shore trawlers, so-called 'industrial' for Lorient, 'industrial and semi-industrial' for Concarneau and Douarnenez. As this study focuses on the west coast of Scotland fishery, only the vessels which frequent this area at least part of the time have been retained. This is why the 'semi-industrial' from Lorient (gadoids trawlers in the Celtic Sea) have been excluded from this study.

Each one of these fleets is relatively homogeneous in term of vessel design features, target species and fishing areas. On the other hand, a great technological disparity exists between fleets (*table II*). The fleet of Lorient consists of very powerful vessels (1 400 kW on average), being on average 630 tons, for a length of 54 m. This is an old fleet, the average age of vessel being 20-year-old in 1994. The fleets of Douarnenez and Concarneau are made up of vessels of much lower fishing capacities, with lengths and respective average powers of 38 m for 1 030 kW, and 34 m for 665 kW, respectively. For Concarneau, vessels appear much younger than in Lorient, with a 12-years average age per vessel in 1994.

The vessels exploit the west coast of Scotland and north Ireland fishing areas (ICES area VIa), as well as the Celtic Sea (ICES area VIIf,g,h) for Concarneau. However, a disparity also exists between the sub-areas exploited preferentially by the fleets within area VIa. Thus, the greatest part of the applied fishing effort in this area concentrates mainly in the north of Scotland for Lorient vessels, whereas Concarneau and Douarnenez fleets mainly exploit a closer sub-zone, to the west of Scotland. The Concarneau fleet spread its fishing effort from the Celtic Sea towards the west of Scotland in 1990 (*figure 1*).

The main stocks targeted by these fleets (*table III*) are gadoids: saithe (*Pollachius virens*), cod (*Gadus morhua*), whiting (*Merlangius merlangus*) and haddock (*Melanogrammus aeglefinus*). To a lesser extent, blue ling (*Molva dypterygia*), ling (*Molva molva*) and, since 1989, deep-sea species like roundnose grenadier (*Coryphaenoides rupestris*) are also targeted. Secondary species, such as hake (*Merluccius merluccius*) or anglerfish (*Lophius budegassa* and *Lophius piscatorius*) for Concarneau, are not considered in the results, but are taken into account in the estimates.

Data on nominal fishing effort, as reported in the vessels log-book, and catches per area and species for each vessel are available in Ifremer's database at Lorient, based upon the information collected by the

Table II. Mean technical specifications of the fleets of Lorient, Concarneau and Douarnenez, for 1994.

Fleet	Fleet size (No. of vessels)	Tonnage (TJB)	Horse-power (kW)	Vessel size (m)	Age (years)
Lorient	13	632	1 438	54	20
Concarneau	35	232	665	34	12
Douarnenez	4	273	1 030	38	18

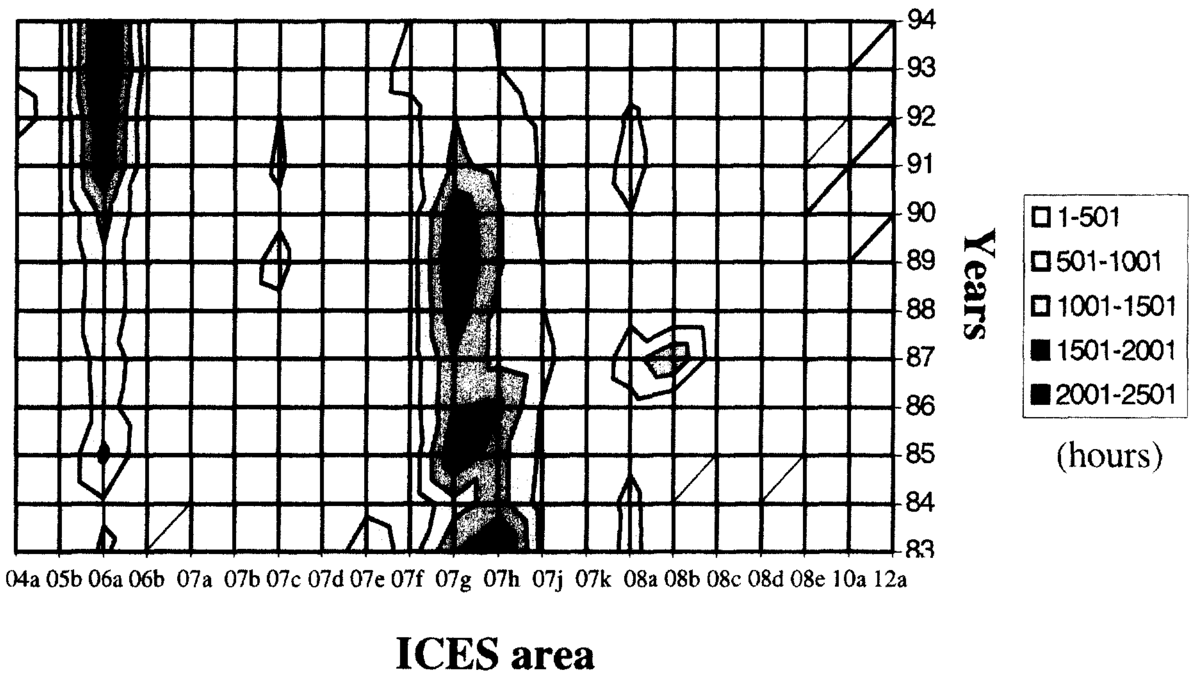

Figure 1. Mean fishing time on area by vessel (h) for the Concarneau fleet.

Table III. ICES area and target species of the fleets of Lorient, Concarneau, and Douarnenez.

Fleet	ICES area	Target species	
Lorient	VIa	*Pollachius virens*	Saithe
		Gadus morhua	Cod
		Merlangius merlangus	Whiting
		Melanogrammus aeglefinus	Haddock
Concarneau	VIa	*Pollachius virens*	Saithe
		Gadus morhua	Cod
		Merlangius merlangus	Whiting
		Melanogrammus aeglefinus	Haddock
	VIIf,g,h	*Gadus morhua*	Cod
		Merlangius merlangus	Whiting
Douarnenez	VIa	*Pollachius virens*	Saithe
		Gadus morhua	Cod
		Merlangius merlangus	Whiting
		Melanogrammus aeglefinus	Haddock

Regional Centre of Statistical Processing (CRTS) of the French administration of Maritime Affairs. This information is formatted so as to obtain catches by stock and year, and total nominal fishing effort per area and year for each vessel. The period examined runs from 1983 to 1994.

In addition, ICES working groups provide fishing mortality matrices for the main stocks affected by these fisheries. However, some important species, such as grenadier and ling, are not yet subject to any stock evaluation. Consequently, they could not be taken into account here.

3. RESULTS

3.1. Preliminary study

For each of the studied stocks, the fitting of the model (equation (6)) is highly significant, at the 99.9 % confidence level (*table IV*). Depending upon the stock, the model explains between 48.7 and 64.5 % of the total variance in catchabilities per vessel. The various effects taken into account are all highly significant at the 99.9 % confidence level, with the exception of the interaction effect for whiting stock of the Celtic Sea, which is significant at the 95.0 % confidence level. The variability explained by the model is distributed differently according to the stock considered: the *Fleet* effect constitutes between 2.7 and 94.3 % of the variance explained by the model, while the share of the *Year* effect varies between 3.2 and 87.4 %. The interaction effect explains a share of variability ranging between 2.5 and 14.0 %.

A clear difference appears here between stocks of Celtic Sea (VIIf,g,h area), and those of the VIa area. Indeed, the catchability of Celtic Sea cod and whiting stocks presents a very strong *Fleet* component (86.1 % for cod and 94.3 % for whiting), and a weak annual component (respectively 4.2 and 3.2 %). This is a consequence of the fact that the Celtic Sea constitutes only one very secondary fishing area for the considered vessels from Lorient and Douarnenez. Thus, the membership of a particular fleet (among the three studied here) largely explains the fishing efficiency in this area. Moreover, the weakness of the annual component

Table IV. Goodness-of-fit parameters for the analysis of variance model of catchability per ship fitted for each stock: *n*, total number of observations; *df*, degrees of freedom; **, $P < 0.001$; *, $P < 0.05$; VIa, west of Scotland ICES area; VIIf,g,h, Celtic Sea ICES area. Explained variance rates are provided: relative to the global variance for complete model; compared to the variance explained by the model, for each model factor (*Fleet* effect, *Year* effect and cross effect).

ICES area	Stocks	Tested effect	*df*	% of explained variability	*P* level
VIa	Cod (*Gadus morhua*)	Model	35	48.7	**
		Fleet effect	2	43.1	**
		Year effect	11	42.9	**
	n = 706	Cross effect	22	14.0	**
	Whiting (*Merlangius merlangus*)	Model	35	59.9	**
		Fleet effect	2	2.7	**
		Year effect	11	87.4	**
	n = 706	Cross effect	22	9.9	**
	Haddock (*Melanogrammus aeglefinus*)	Model	35	63.1	**
		Fleet effect	2	21.7	**
		Year effect	11	73.2	**
	n = 706	Cross effect	22	5.1	**
	Saithe (*Pollachius virens*)	Model	35	63.5	**
		Fleet effect	2	73.9	**
		Year effect	11	19.0	**
	n = 778	Cross effect	22	7.1	**
VIIf, g, h	Cod (*Gadus morhua*)	Model	35	56.6	**
		Fleet effect	2	86.1	**
		Year effect	11	4.2	**
	n = 852	Cross effect	22	9.7	**
	Whiting (*Merlangius merlangus*)	Model	35	64.5	**
		Fleet effect	2	94.3	**
		Year effect	11	3.2	**
	n = 852	Cross effect	22	2.5	*

seems to indicate a very weak temporal variability of catchability relative to these stocks.

Conversely, stocks in the west of the Scotland area have a marked annual component (19 % for saithe, 42.9 % for cod), which is especially so for whiting (87.4 %) and haddock (73.2 %). This seems to indicate a strong temporal variability in catchabilities for these stocks. Moreover, *Fleet* effect explains a significant part of variance of catchability: 73.9 % for saithe, 43.1 % for cod, 21.7 % for haddock. These results translate strong differences in fishing efficiency between fleets for these stocks, notably for saithe. Concerning the whiting stock, catchability depends to a far lesser extent (2.7 %) on the *Fleet* effect, so it seems that the three fleets fishing efficiency for this stock are similar.

Despite the interaction between *Year* and *Fleet* (interaction effect is highly significant), these results seem to indicate a strong heterogeneity between fleets for most of the studied stocks. It is assumed in the following section that this heterogeneity can be mostly explained by differences between the global fishing powers developed by these fleets.

3.2. Estimate of fishing powers

3.2.1. Goodness-of-fit of the model

For each of the studied fleets, the fitting of the model (equation (7)) is highly significant, at the 99.9 % confidence level (*table V*). Depending upon the fleet considered, the model explains between 74.9 and 93.3 % of the total variance in catchabilities. The various effects, including the interaction effect, are highly significant, at the 99.9 % confidence level. In the three cases, the *Stock* effect predominates, explaining between 83.0 and 90.3 % of the total variability explained by the model. The interaction effect also explains a significant part of variability (between 4.6 and 15.5 %).

Table V. Goodness-of-fit parameters of the analysis of variance model fitted for each fleet: *n*, total number of observations; *df*, degrees of freedom; **, $P < 0.001$. Explained variance rates are provided: relative to the global variance for complete model; compared to the variance explained by the model, for each model factor (*Stock* effect, *Year* effect and cross effect).

Fleets	Tested effect	*df*	% of explained variability	*P* level
Lorient	Model	59	90.9	**
	Stock effect	4	90.3	**
	Year effect	11	5.1	**
n = 1 204	Cross effect	44	4.6	**
Concarneau	Model	143	74.9	**
	Stock effect	11	87.8	**
	Year effect	11	1.7	**
n = 4 293	Cross effect	121	10.5	**
Douarnenez	Model	59	93.3	**
	Stock effect	4	83.0	**
	Year effect	11	1.4	**
n = 472	Cross effect	44	15.5	**

These results highlight two elements. First, the predominance of the *Stock* effect indicates that levels of mean accessibility differ between stocks: for a given fleet, a difference between two observations of catchability per vessel is explained initially by the identity of stocks to which they refer, i.e. by the difference in average accessibility of stocks. Second, once this *Stock* effect is separated out, the remainder of catchabilities' variance explained by the model is differently distributed according to the fleet. For Lorient, this share of explained variance is distributed between the *Year* effect and the interaction effect. For Concarneau and Douarnenez, the temporal variability in fishing efficiency seems much less marked, since the share of variance explained by the *Year* effect is only 1.7 and 1.4 %, respectively. The differences between estimated catchabilities, for an equivalent level of accessibility, seem to be explained primarily by changes of fishing strategies. Thus, these results imply a separation of two fleet behaviours.

3.2.2. Indexes estimated by the model

Examination of *A*, *Eg* and *Es* indexes, estimated from equation (11) for the fleets of Lorient, Douarnenez and Concarneau, allows several points to be highlighted (*figure 2*).

First of all, marked differences between accessibility indexes of stocks appear clearly in the three cases. In particular, whiting and haddock stocks in the west of Scotland area have a very low mean accessibility compared to saithe and cod stocks. Saithe accessibility is somewhat higher than cod for the west of Scotland area in the case of Lorient, but is lower than the one for Concarneau and Douarnenez. These variations can be explained by the disparity in fishing sub-areas exploited by the fleets within the area VIa, mentioned previously.

Examination of the *Eg* index shows a decreasing trend in global fishing efficiency over the period. However, this is most marked for Lorient, where the index *Eg* loses 60 % over the period, and 75 % between 1984 and 1994. The fall is about 15 to 20 % for Concarneau and Douarnenez. These results confirm the disparity of behaviours between the fleets.

Lastly, the *Es* index makes it possible to follow the changes over time in the specific efficiency for each fleet which reflects the strategic choices of the fishermen (see Materials and Methods, 2.4.). A strong strategic redirection towards saithe is apparent for the three fleets over the period, while whiting and haddock stocks are forsaken. Saithe in turn seems to have been somewhat forsaken since 1990–1991 by the Lorient and Douarnenez fleets.

For the fleet of Concarneau in the Celtic Sea, the specific efficiency for cod shows a clear increase of 70 % over the period, while it remains constant overall for whiting. A relative strategic transfer from whiting to cod seems to have occurred since 1990.

3.2.3. Changes in overall fishing power

The overall fishing powers of fleets are estimated from equation (12), and correspond to the product of the global fishing efficiency *Eg* and the specific fishing efficiency *Es* of each fleet, as shown in equation (9). Two types of fishing power variations are identified for stocks in the west of Scotland area (*figure 3*). The fishing powers exerted on haddock, whiting and, to a lesser extent, cod show a strong decrease trend over the period 1983–1994. For haddock, this decrease is about –17.9 % per year for Concarneau, –17.5 % per year for Lorient, and –10.4 % per year for Douarnenez. For whiting, the decrease of fishing power is even more marked, reaching –30 % per year for Concarneau, –22 % per year for Douarnenez, and –19 % per year for Lorient (*table VI*). The case of Concarneau however is quite different, since its fishing power exerted on whiting remained practically constant between 1983 and 1988, and then strongly decreased between 1988 and 1989.

Conversely, the fishing powers exerted on saithe present an increase trend over the period. This is about +19 % per year for Douarnenez, and +8 % per year for Concarneau. The fleet of Lorient shows two different trends, with an increase of +16.5 % per year between 1983 and 1989, followed by a strong decrease, of about –18 % per year between 1989 and 1994. Thus, the fishing power of Lorient is by far the most important exerted on saithe during the period 1983–1989, and then, because of its collapse, becomes the lowest at the end of the period.

The fishing power developed by the fleet of Concarneau on the Celtic Sea cod stock shows a regular increase trend (about +12 % per year) over the period (*figure 4*), whereas no significant trend is apparent for the whiting stock. However, a clear fall in fishing power exerted on whiting (about –22.2 % per year) between 1990 and 1993 can be noted.

4. DISCUSSION

4.1. Link between fishing mortality estimates and effort

Fishing mortality rates used to calculate catchabilities were estimated by the ICES working groups using eXtended Survivors Analysis (XSA) tuning method. In this process, catch-at-age and effort data from various fleets are used to tune the analysis, with the assumption that no trend affects the catchability for all the fleets. Fishing mortality estimate is thus somewhat dependent on fishing effort [4]. In contrast, using the results of such analysis to estimate catchabilities and study their changes over time is probably not totally accurate. Fishing mortalities estimated from commercial independent data (i.e. survey) would allow a more accurate estimate. However, the convergence property of cohort analysis makes realistic the estimate of catchabilities used here, except for the last years.

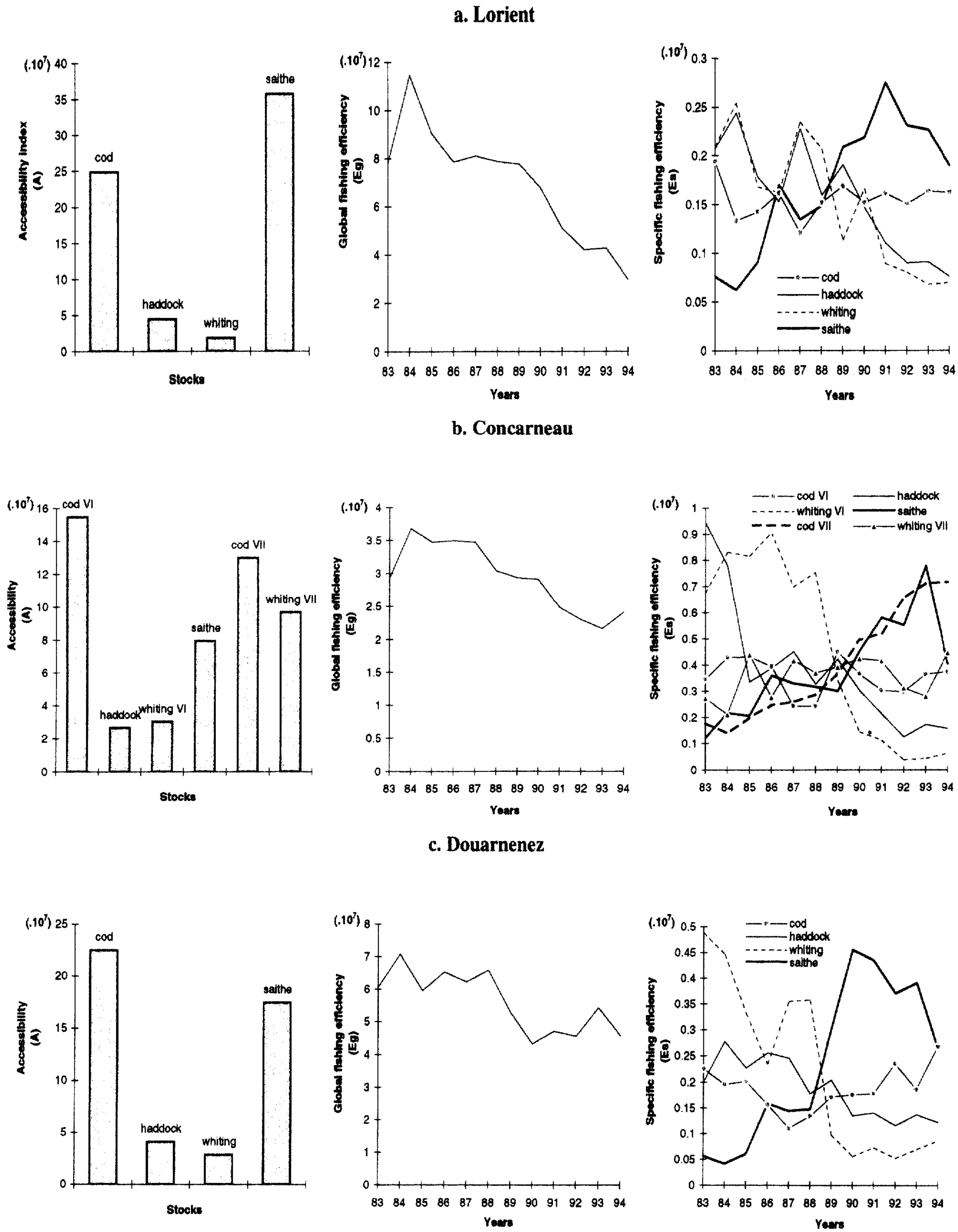

Figure 2. Estimated indexes, given by the model fitted on catchability's data of the fleets of Lorient (a), Concarneau (b), Douarnenez (c).

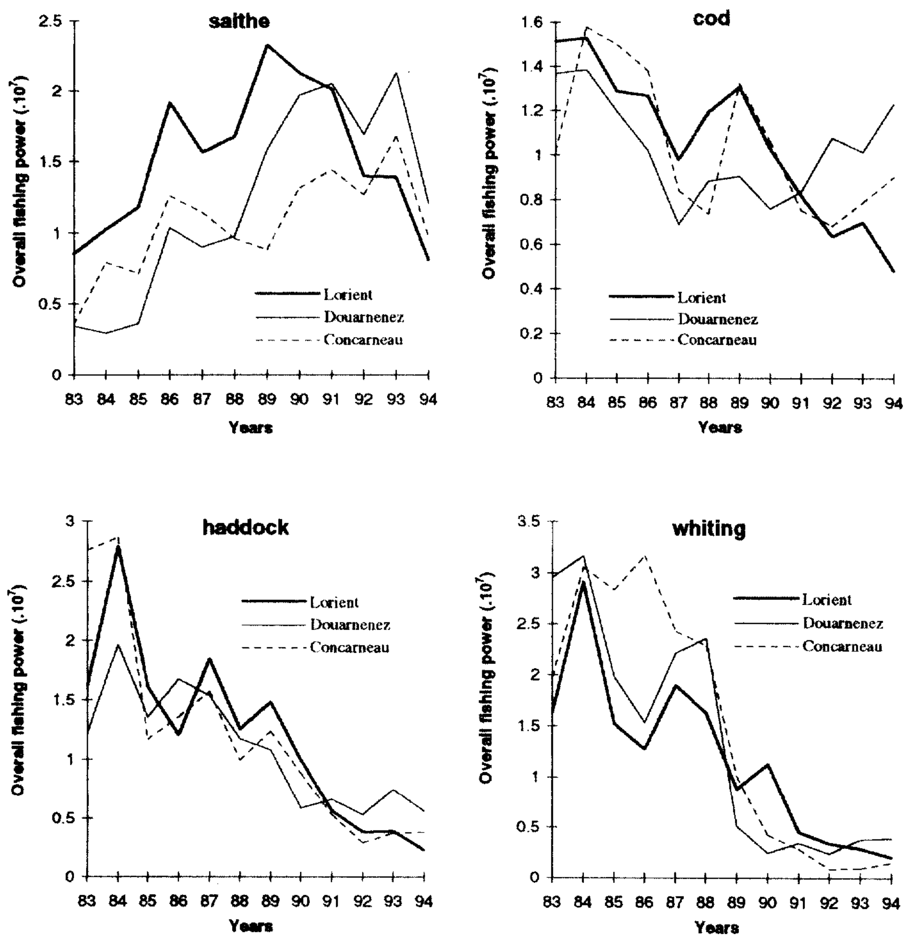

Figure 3. Mean overall fishing power exerted by the fleets of Lorient, Douarnenez and Concarneau on saithe (*Pollachius virens*), cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and whiting (*Merlangius merlangus*) in the west of Scotland area (ICES sub-area VIa), over the period 1983–1994.

Table VI. Yearly increase rates of individual fishing power by stock and by fleet. Non-significant increases are provided within brackets. These rates are estimated from an exponential regression on the period 1983–1994, unless specified in bold.

Fleets	West of Scotland area				Celtic sea area	
	Saithe	Cod	Haddock	Whiting	Cod	Whiting
Lorient	**1983–89**: +16.5 % **1989–94**: –18.0 %	–8.9 %	–17.5 %	–19.0 %	–	–
Concarneau	+8.0 %	(–5.0 %)	–17.9 %	–30.0 %	+12.0 %	(–1.5 %)
Douarnenez	+19 %	**1983–87**: –15.5 % **1987–94**: +6.6 %	–10.4 %	–22.0 %	–	–

One must also keep in mind that the relationship between fishing mortality and effort can be affected by possible spatial aggregation of fish, and changes in the size of aggregations together with changes in the distance between them, when total abundance of a stock decreases. However, the spatial distribution of fish is not taken into account when stocks are assessed with classical tools, and the assumption of evenly distributed stocks is kept in the present study.

4.2. Calculation of catchabilities 'per vessel'

The current analysis is largely based upon the calculation of catchabilities per vessel. Equation (3) used for this calculation needs two assumptions. On the one hand, we assume that age structure of catches for a given stock and a given year is the same for all vessels, and equivalent to the age structure of catches for all the fleets. Thus, we assume that the fishing pattern is the same for each vessel, equal to the 'average' fishing pattern for all the fleets fishing the stock under consideration (equation (2)).

In addition, it is assumed that for each year, the average weight by age of catches is the same for all the vessels, and equal to the average weight by age of catches for all the fleets (approximation of equation (2) in equation (3)).

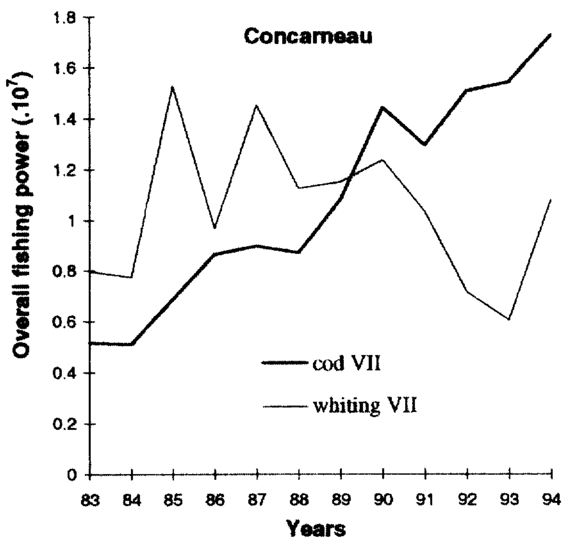

Figure 4. Mean overall fishing power exerted by the fleet of Concarneau on cod (*Gadus morhua*) and whiting (*Merlangius merlangus*) in the Celtic Sea area (ICES sub-area VIIf,g,h) over the period 1983–1994.

Although the second assumption seems plausible within a given year, the first appears more restrictive, because of the diversity of the fleets involved. Thus, for example, gadoid stocks in the Celtic Sea (cod, whiting, ling) are not only harvested by trawlers (French, British, Irish, Spanish and Belgian), but also by some long-liners and gill netters [23]. Various fishing patterns and various demographic structures can correspond to these various types of fishing gears [18]. Furthermore, differences between vessels in the demographic structure of catches can exist within the same fleet. Obviously, these differences introduce some uncertainty into the calculation of average catchability per vessel. In the present case, the ideal situation would be to work on catches by age disaggregated at least by fleet and gear [6]. This would make it possible to calculate mortalities with the real proportion of numerical catches for each age group.

However, trawling by industrial vessels constitutes the dominant fishing practice. In particular, this is the case for stocks in the west of Scotland area. Moreover, the statistical results obtained show that inter-fleet or inter-annual variability remains highly significant. Thus, the use of yields for the calculation of mortalities per vessel seems to constitute a valid approximation in this case.

4.3. Choice of studied stocks

Since the analysis presented here relies on fishing mortality rates, only stocks which are currently assessed can be studied. This is why the interpretation of the decreasing trends of *Eg* for all fleets but especially Lorient must be done with caution. One must keep in mind that this index is related to the studied stocks only. The somewhat dramatic decrease of apparent efficiency for that fleet, which might be partly true, must be tempered by the fact that since 1990, a large part of the total catch is made up of deep-sea fish.

4.4. Choice of nominal effort

The calculation of catchabilities per vessel uses individual fishing effort data, entered for each ICES area. For a given stock, this calculation takes into account a share of the vessel fishing effort directed towards other stocks present in the same area: catchability per vessel corresponds to the fishing efficiency of the total effort applied by the vessel on the area, whatever the depth. Therefore, the estimated fishing power includes both technical and strategic aspects of the efficiency within a delimited area, instead of focusing only on the technical ability of fishermen to fish a given stock.

The use of estimated directed efforts on specific stocks, calculated from thresholds of specific catches [4], would allow a more accurate estimation of this technical efficiency. In the case of recorded fishing areas in which depths vary widely (such as many ICES squares on the edge of the shelf), the species caught are the only indication of the depth fished. Thus, identifying changes in target species may allow to determine whether or not an hour spent fishing in a given area would provide effective catch of the studied stock. More generally, taking into account the fishing effort that can lead to effective catch of the species (because the vessels fish in the right area and depth) would lead to an estimate of fishing power restricted to its technical efficiency component.

However, an important interest in the method outlined here resides in allowing an estimate of fishing powers to be made from sufficiently simple, easily calculable, nominal effort data, as it is used by fishery management. Thus, the estimate of overall fishing power provided here constitutes a link between a simple nominal effort easily usable for management processes, and the effective effort, i.e. the real pressure, applied on stocks by fishing activity.

4.5. Link between variables

Most of the analysis presented here show significant interaction terms (*Fleet*Year* or *Stock*Year*). It is well known that in this case, the interpretation of each single effect may be difficult since part of these effects are confounded in the interaction term. This is why the discussion on single effects was just given as an illustration. However, the main result of this study, i.e. changes in global fishing power, takes into account the interaction between factors since this coefficient is calculated as the product of a single effect and the interaction term.

4.6. Stock accessibility

The modelling of catchabilities, from which we estimate the fishing powers of the fleets, is based on the assumption that accessibilities vary without trend over time. This is a strong assumption, difficult to validate, but also to invalidate. Actually, the accessibility of the stocks considered here has not been studied specifically. Thus, this assumption remains the main limitation of the method proposed here.

Examination of the estimated fishing powers clearly underlines differences of fishing efficiency between fleets, in particular for saithe. At first glance, the big differences in technical specifications or strategic behaviour between the three studied fleets could explain the differences in the fishing power of the fleets. On the contrary, to attribute these differences to accessibility would mean that, for a given stock, the differences of efficiency between fleets are only explained by the differences of variation of the accessibility according to the fleet considered. As the changes of efficiency are of high magnitude, and occurred in relatively short time periods, it seems more reasonable to consider the measured variations as being due to increasing trends in fishing power, not in accessibility.

4.7. Fishing power and strategy

As shown in the results, the period 1983–1990 was characterised by a marked intensification of fishing power exerted on saithe in the west of Scotland area. This intensification seems to be due to a strategic redirection towards saithe, whereas haddock and whiting stocks are progressively forsaken. This 'saithe' strategy was supplemented, for the Douarnenez fleet, by an intensification of fishing power exerted on cod from 1987. The vessels from Concarneau were characterised by progressive specialisation in their activity, towards saithe, and to a lesser extent cod, in the west of Scotland area on the one hand, and Celtic Sea cod on the other hand. These changes in fishing powers are to be associated with the modifications in the catches and size of each fleet, and with the variations of abundance of each stock (*Appendix*) which allow the proposal of some hypotheses to explain the dynamics of the considered fleets. The changes highlighted for Lorient and Douarnenez fleets thus appear partly similar, especially as they are characterised by a three-step sequence.

4.7.1. Lorient - Douarnenez

During the period 1983–1986, there were marked falls in cod, whiting and haddock abundance in the west of Scotland area. The vessels then seem to have started a strategic re-allocation of fishing efficiency towards saithe, in response to these abundance falls.

In 1986, saithe abundance started to drop. The fleets then accentuated the strategic redirection to saithe, with an almost complete abandoning of haddock and whiting stocks in the west of Scotland area. This redirection results in a marked increase – associated with the increased fishing powers exerted on saithe – of total landings of saithe. Fleet size remained approximately constant over these two periods, around 23 vessels for Lorient, and eleven for Douarnenez. However, this marked increase in the exerted fishing power on saithe seems to have had a significant impact on saithe abundance, which was almost halved between 1986 and 1989.

Since 1989, the fishing power exerted on saithe decreased for Lorient, and seems to have somewhat stabilised for Douarnenez, if we disregard the last year (the results presented depend closely on cohort analysis outputs, which exhibit divergence problems for the last years; thus, it is advisable to carefully consider the 1994 drop in fishing power exerted on saithe observed for the three fleets). For the same period, saithe abundance was stabilised at a very low level (approximately 55 000 tons, compared to 140 000 tons at the beginning of the period [11]). At the same time, saithe landings fell markedly, falling to one third for Douarnenez, and to one quarter of their previous level between 1988 and 1994 for Lorient. Moreover, fleet size fell markedly, to thirteen vessels for Lorient, and four vessels for Douarnenez in 1994.

Thus, the 1989–1994 period seems to correspond to a selection of the most efficient vessels, with the others being forced to stop their activity. Lorient developed in parallel the exploitation of deep-sea fish (mainly grenadier, black scabbard fish), which can explain the fall in fishing power allocated to the saithe stock in the last years. So, in this latter period, the Lorient fleet seems to have supplemented its 'saithe' strategy by an increasing search for deep-sea fish. By contrast, the Douarnenez fleet remained specialised in saithe, and, to a lesser extent, cod. However, the lack of evaluation of grenadier and ling, which represent a significant part of the catches of Lorient over the period, prevents quantification of the effective share, in terms of fishing powers and strategic allocation, of these stocks.

4.7.2. Concarneau

Since 1990, the fleet of Concarneau shows a marked redirection of fishing effort from the Celtic Sea to the west of Scotland area (*figure 1*). Fishing effort in the Celtic Sea has decreased by a factor of two between 1990 and 1994, and doubled in the west of Scotland area during the same period, while the overall fishing effort has slightly decreased. During the period 1990–1994, saithe landings doubled, which confirms the fleet's strategic redirection towards saithe, indicated by the increasing fishing power exerted on saithe. Despite an increasing average fishing power exerted on Celtic Sea cod by this fleet, landings of this stock has decreased since 1990, the big 1986 year class being progressively exhausted [12]. Both fishing power and landings of Celtic Sea whiting have dramatically decreased in the 1983–1993 period. However, contrary to what was seen for cod, the decrease of stock abundance (due to low recruitment in the end of the

1980s) did not lead to an increase in fishing power but to a progressive abandoning of Celtic Sea whiting as a target species. It is as if the effort and strategic redirection from Celtic Sea to the west of Scotland was mainly caused by vessels strategically oriented towards whiting, whereas vessels oriented towards cod remained in the same area. These strategic changes and diversity of approach could be one explanation for the relative stability of the Concarneau fleet, whose size remained between 38 and 45 vessels over the period, in contrast to the two preceding fleets.

4.8. Consequences on cohort analysis tuning

One very important consequence of this study is related to the assumptions of the catchability model – therefore the fishing power model – which support the tuning methods of cohort analysis. The Laurec and Shepherd method [17] assumes catchability by age and fleet to be constant over the years; the 'hybrid' methods are based on an exponential or a linear model of catchability increase; the integrated method XSA also assumes a constant catchability by age [15]. The various evolutions by fleet presented here seem to show the very strong restriction imposed by these assumptions.

In a very general way, the catchability trend is regarded as a simple disturbance phenomenon. If valid in many cases, the present study shows that this trend can also constitute an essential factor in the history of fisheries.

5. CONCLUSION: RETURN ON FISHERY MANAGEMENT TOOLS

These results highlight the very marked variability in fishing powers exerted by a fleet. Thus, strategic choices can quickly change, as the case of the Lorient fleet testifies, involving important fishing power drift phenomenon. As these transfers of strategy can lead to an important increase in overall fishing power, they constitute a real risk in terms of stock overfishing: the case of saithe in the west of Scotland area appears to demonstrate this quite explicitly.

They also question the relevance of fishing effort management, which recommends a limitation of nominal fishing effort to prevent overfishing situations. This type of management would ignore the important variations in fishing efficiency, which may occur in a fishery. Thus, to have limited the nominal effort applied in the west of Scotland area by the industrial fleets of Southern Brittany between 1983 and 1989 apparently would not have modified the catastrophic downward trend in saithe abundance. The prospect for management of fishing activity by effort limitation must be carefully considered. Fishing power increases can constitute, not only simple 'drifts', but a very important phenomenon, that needs to be taken into account to determine and control the causes of overfishing.

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REFERENCES

[1] Abrahams M.V., Healey M.C., Variation in the competitive abilities of fishermen and its influence on the spatial distribution of the British Columbia salmon troll fleet, Can. J. Fish. Aquat. Sci. 47 (1990) 1116–1121.

[2] Allen P.M., McGlade J., Dynamics of discovery and exploitation: the case of the Scotian shelf groundfish fisheries, Can. J. Fish. Aquat. Sci. 43 (1986) 1187–1200.

[3] Biais G., La gestion des pêches par contingentement des captures dans le Nord-Ouest de l'Europe, in: Gascuel D., Durand J.L., Fonteneau A. (Eds.), 1er Forum Halieumétrique, Colloques et séminaires, Orstom ed., 1995, pp. 309–319.

[4] Biseau A., Definition of a directed fishing effort, and its impact on CPUE trends: the case of the French demersal fishery off the west coast of Scotland, Aquat. Living Resour. 11 (1998) 119–136.

[5] Gascuel D., Efforts et puissances de pêche : redéfinition des concepts et exemple d'application, in: Gascuel D., Durand J.L., Fonteneau A. (Eds.), 1er Forum Halieumétrique, Colloques et séminaires, Orstom ed., 1995, pp. 159–181.

[6] Gascuel D., Fonteneau A., Foucher E., Analyse de l'évolution des puissances de pêche par l'analyse des cohortes : application aux senneurs exploitant l'albacore (*Thunus albacares*) dans l'Atlantique Est, Aquat. Living Resour. 6 (1993) 15–30.

[7] Gavaris S., Use of a multiplicative model to estimate catch rate and effort from commercial data, Can. J. Fish. Aquat. Sci. 37 (1980) 2272–2275.

[8] Gillis D.M., Peterman R.M., Implications of interference among fishing vessels and the ideal free distribution to the interpretation of CPUE, Can. J. Fish. Aquat. Sci. 55 (1998) 37–46.

[9] Hilborn R., Ledbetter M., Determinants of catching power in the British Columbia salmon purse seine fleet, Can. J. Fish. Aquat. Sci. 42 (1985) 51–56.
[10] Hilborn R., Walters C.J., Quantitative Fisheries Stock Assessment, 2nd ed., Chapman and Hall, London, 1992, 570 p.
[11] ICES, Report of the working Group on the assesment of the northern shelf demersal stock, ICES, Doc. CM, 1996, Assess:1.
[12] ICES, Report of the working Group on the assesment of the southern shelf demersal stock, ICES, Doc. CM 1996, Assess:5.
[13] Laloë F., Efforts effectifs - efforts nominaux, quelques questions de traduction, in: Gascuel D., Durand J.L., Fonteneau A. (Eds.), 1er Forum Halieumétrique, Colloques et séminaires, Orstom ed., 1995, pp. 189–201.
[14] Laurec A., Analyse et estimations des puissances de pêche, J. Cons. Int. Explor. Mer 37 (1977) 173–185.
[15] Laurec A., Étalonnage de l'analyse des cohortes en halieutique, in: Lebreton J.D., Asselain B. (Eds.), Biométrie et environnement, Masson, Paris, 1993, pp. 205–239.
[16] Laurec A., Le Guen J.C., Dynamique des populations marines exploitées. Tome 1 : concepts et modèles, Rapp. Scient. Techn. 45, Publ. CNEXO, Brest, 1981, 118 p.
[17] Laurec A., Shepherd J., On the analysis of catch and effort data, J. Cons. Int. Explor. Mer 41 (1983) 81–84.
[18] Laurec A., Biseau A., Charuau A., Modelling technical interactions, ICES Mar. Sci. Symp. 193 (1991) 225–236.
[19] Laurent A.G., Lognormal distribution and the translation method: description and estimations problems, J. Am. Stat. Assoc. 58 (1963) 231–235.
[20] Littel R.C., Freund R.J., Spector P.C., SAS System for Linear Models, 3rd ed., SAS Institute Inc., Cary NC, 1991, 329 p.
[21] Ludwig D., Hilborn R., Walters C., Uncertainty, resource exploitation, and conservation: lessons from history, Science 260 (1993) 17–36.
[22] McGlade J., Integrated fisheries management models: understanding the limits to marine resource exploitation, Am. Fish. Soc. Symp. 6 (1989) 139–165.
[23] Ould el Kettab M., La pêcherie des Gadidés de mer Celtique : description, analyse de l'exploitation et évaluation des stocks. Tentative de gestion par un modèle bio-économique, Ph.D. thesis, Univ. Bretagne Occidentale, Brest, 1993, 207 p.
[24] Robson D.S., Estimation of the relative fishing power of individual ships, ICNAF Res. Bull. 3 (1966) 5–15.
[25] SAS Institute Inc., SAS/STAT Guide for Personal Computers, Version 6, SAS Institute Inc., Cary NC, 1987, 1028 p.
[26] Searle S.R., Speed F.M., Milliken G.A., Population marginal means in the linear model: an alternative to least squares means, Am. Stat. 34 (1980) 216–221.

Appendix. Fleet size, fishing effort and landings (tonnes) of the industrial fleets of Lorient, Douarnenez and Concarneau over the period 1983-1994.

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Lorient												
Fleet size (number of ships)	28	21	22	24	23	23	20	20	20	16	14	13
Fishing time (10^3 h)	90	70	74	77	82	84	74	72	68	61	51	38
Landings (tonnes)												
Saithe (*Pollachius virens*)	14 604	10 208	14 851	19 589	14 855	15 378	10 499	9 049	6 424	4 039	5 310	3 454
Cod (*Gadus morhua*)	5 744	4 087	3 111	2 472	2 736	4 138	3 223	2 309	1 219	726	1 210	637
Whiting (*Merlangius merlangus*)	508	560	223	187	371	248	91	235	84	48	51	24
Haddock (*Melanogrammus aeglefinus*)	2 838	3 533	2 440	1 878	2 553	1 437	1 001	668	423	313	401	176
Grenadier (*Coryphaenoides rupestris*)	0	0	0	0	0	0	1 839	3 035	3 435	4 334	3 859	3 059
Douarnenez												
Fleet size (number of vessels)	11	11	11	9	11	11	10	10	9	7	4	4
Fishing time (10^3 h)	29	34	42	37	44	43	40	35	34	21	15	12
Landings (tonnes)												
Saithe (*Pollachius virens*)	1 362	1 117	1 840	3 033	3 130	3 215	3 129	2 022	1 159	784	1 284	903
Cod (*Gadus morhua*)	2 120	1 924	1 553	796	867	1 373	1 119	557	337	311	379	335
Whiting (*Merlangius merlangus*)	651	501	253	141	347	290	39	16	18	14	29	21
Haddock (*Melanogrammus aeglefinus*)	910	1 286	1 079	1 060	990	612	299	129	144	122	214	107
Grenadier (*Coryphaenoides rupestris*)	0	0	0	0	0	0	411	306	150	143	53	174
Concarneau												
Fleet size (number of ships)	46	40	37	38	41	42	45	40	36	36	36	35
Fishing time (10^3 h)	178	93	168	173	182	188	201	179	168	157	157	140
Landings (tonnes)												
Area VIa												
Saithe (*Pollachius virens*)	302	749	1 806	1 905	2 018	2 152	1 547	1 698	2 262	1 833	3 569	2 896
Cod (*Gadus morhua*)	552	779	1 426	687	751	1 076	1 197	1 187	885	857	1 457	1 482
Whiting (*Merlangius merlangus*)	503	254	363	284	250	279	90	54	63	42	61	145
Haddock (*Melanogrammus aeglefinus*)	726	656	754	562	583	429	349	335	306	307	517	454
Grenadier (*Coryphaenoides rupestris*)	0	0	0	0	0	0	150	510	1 420	1 226	1 528	2 269
Area VIIf,g,h												
Cod (*Gadus morhua*)	1 082	526	1 432	1 855	1 589	2 912	3 602	2 006	978	1 001	996	804
Whiting (*Merlangius merlangus*)	1 179	409	1 474	1 057	1 505	1 975	2 697	1 844	1 018	536	732	759

Total biomass (tonnes) [11, 12]	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
Area VIa												
Saithe (*Pollachius virens*)	138 112	137 868	138 773	136 802	108 014	104 436	78 290	64 540	56 085	52 719	56 090	60 195
Cod (*Gadus morhua*)	46 833	48 567	35 508	31 963	43 012	40 540	35 485	26 332	23 051	23 348	23 177	22 975
Whiting (*Merlangius merlangus*)	47 249	44 390	35 963	30 421	35 565	26 036	24 659	27 920	31 880	40 158	36 560	28 230
Haddock (*Melanogrammus aeglefinus*)	127 190	130 407	106 620	98 411	100 822	66 613	52 326	49 547	69 182	80 771	88 016	78 224
Area VIIf,g,h												
Cod (*Gadus morhua*)	13 039	10 897	15 203	14 915	18 255	25 819	26 451	17 636	12 401	13 544	14 942	17 289
Whiting (*Merlangius merlangus*)	17 586	18 064	19 219	20 612	31 037	34 259	31 790	22 752	23 024	28 546	38 212	29 187