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Improvement of the relationship between effort and fishing mortality quantifying and characterising the evolution of Fishing Power for the bottom-trawlers of South-Brittany targeting monkfish from 1983 to 1998

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Abstract

A method to quantify and explain the evolution of fishing power among a fleet targeting a species in a multi-fleet multi-species fishery is developed. Using generalised linear models, the analysis is carried out on CPUE data calculated with catches and fishing time reported in the logbooks for each fishing sequence and uses traditional explanatory variables such as year, month, area and more unusual one characterising the type of fishing activity. An annual index of abundance calculated from the CPUE of a referent boat catching the species as a by-catch, is used to separate the annual evolution of the fleet fishing power from the annual variation of abundance. Secondly, the observed differences in efficiency between individual vessels are explained with several technical vessel characteristics ranging from the gear to the captain's behaviour. An application of this method to the French bottom-trawlers targeting monkfish (*Lophius budegassa* and *Lophius pistacorius*) in the Bay of Biscay and in the Celtic Sea during the period 1983-1998, points out fishing gear (twin trawls) and engine power as the most discriminant variables for fishing power differences.

keywords: Fishing power, generalized linear models, twin trawls, catches per unit of effort, métier, index of abundance, fishing mortality.

Introduction

Catches and fishing effort (Gulland, 1956; Beverton and Holt, 1954) are basic input for assessment and management of marine resources. Catches per unit of effort computed with non standardised effort data used for tuning VPA may lead to errors in stock assessments, and management attempts to reduce fishing effort may not have the desired effect when efficiency is not taken into account. Particularly in mixed fisheries (multi-fleet, multi-species) distinguishing nominal fishing effort (Gulland, 1956), commonly quantified by the fishing time for trawlers, from effective fishing effort (Stocker and Fournier, 1981; Biseau, 1998), representative of fishing mortality by integrating a measure of efficiency, is fundamental. The variety of fishing strategies, the wide range of vessels characteristics and the continuous changes in both make it difficult to use catches divided by nominal effort as abundance indices (Beverton and Holt, 1954): the impact of a nominal effort by a vessel targeting a species will not be the same as an equivalent effort by a vessel by-catching the species. In the same way, nominal effort exerted in 1983 and 1998 would not have the same impact due to improvements in gear, changes of vessel characteristics, new equipment and improvement of skipper skills with time (Gulland, 1983). The effective effort is an indicator of fishing pressure whereas nominal effort is more a management quantity. To achieve reliable diagnostics on the state of stocks and to make sure that management measures meet conservation requirements, it is important to improve the relationship between fishing effort and fishing mortality by quantifying the fishing efficiency and its evolution (Sampson, 1993). This efficiency which is the ratio between effective effort and the nominal effort is an absolute measure not accessible. For these reasons, an estimation of relative efficiency also called fishing power is calculated comparing catches made in similar conditions (Gulland, 1956).

have been developed to quantify this relative efficiency. On one hand Beverton 1954 based their method on the ratio between the yield of each vessel or the whole fleet and the yield of a standard vessel. On the other hand, linear models are used to estimate fishing power taking into account the spatial-temporal heterogeneity. The multiplicative model to describe fishing power has its origin in the work of Gulland 1956 and Robson 1966. It is based on the assumption that for any vessel, the catches of a species are the product of a catchability term (depending on the efficiency and on the accessibility-vulnerability of the species), a nominal effort and the abundance of the species. The variations in the log-transformed CPUE are traditionally described using normal-linear model with temporal and spatial explanatory variables (Gavaris, 1980): Laurec 1975 proposed an application of this methodology to a single-species fishery (the Atlantic Japanese tuna longline fishery), whereas Kimura 1981 and Stocker 1981 applied it to mixed fishery (trawlers in British Columbia coast respectively targeting Pacific Ocean Perch and Rock Sole). Some variations were integrated using interactions between the explicative variables (Francis, 1974; Large, 1992) or environmental variables (Allen and Punsly, 1984; Gaertner et al., 1999). Other approaches close to economical models and based on production function can also be noted (Kirkley et al., 1995; Squires and Kirkley, 1999). Finally fishing power has been also studied with indirect methods using fishing mortalities estimated by cohort analysis (Paloheimo and Cheng, 1993; Gascuel et al., 1993; Pascoe and Robinson, 1996; Millisher et al., 1999). The drawback of these methods is the strong and commonly unverified hypothesis dealing with constant catchability, which underlies the models for fishing mortality estimation. Given the estimation of fishing power for each vessel of a fleet, detecting the influential factors of the efficiency is an important point for achievement of successful fishing management. A lot of authors focus on investigating various factors, for instance GPS and Plotter (Robins et al., 1998), vessel's tonnage (Goni et al., 1999), bird radar, fishing strategy and weather (Gaertner et al., 1999), economical variables (Squires and Kirkley, 1999) and vessel's length and engine power (Biseau et al., 1999, Salthaug and Godo, 2001).

Many studies among those cited above point out the existence of fishing power variations. For instance, Large 1992 showed the existence of interactions between the year variable and the vessel variable for the Western English Channel UK beam trawlers sole fishery and raised the possibility of studying trend in fishing power from these interactions. But most of these models mix up the evolution of fishing power with abundance fluctuation or make the assumption of a constant fishing power over the period, making it impossible to quantify the trend or change in fishing power over a period. In this context, analysing the variations in fishing mortalities estimated from a model of stock evaluation in an age-structured model, Pascoe 1996 proposed a quantification of change in efficiency against a referent year. Marchal 2001 have also analysed the temporal dynamics in fishing power by fleet for a Danish cod fisheries defining an index of fishing power (IFP). This index is a ratio of CPUE between vessels of the studied fleet and a subset of vessels from the fleet characterised by a very few variations in fishing power. Making the assumption that catchability can be decomposed into a component independent of abundance (the fishing power) and a component function of the abundance, the IFP should be free of temporal variations in abundance. The variations in the IFP allowed to quantify trend in the fishing power of the fleet. However the spatial heterogeneity of abundance was not taken into account in this model.

We propose a different method to quantify the change in time of fishing power for a fleet targeting a particular species at different levels. In the tradition of the models developed by Robson 1966 and then Gavaris 1980, this approach is based on an explicit distinguishing between CPUE variations due to stock abundance fluctuations and those due to change in efficiency. Contrary to Marchal 2001 the spatial and seasonal heterogeneity are taking into account, and this method allows to quantify individual fishing power to look forward the explanations of differences in individual efficiency. To distinguish the two sources of CPUE variations, we consider that a good approach is to use a vessel by-catching the species of interest as a referent boat. The CPUE of such a boat are supposed to be proportional to abundance over the period. First an index of variation in abundance is calculated using CPUE of this vessel. Using this index to remove the annual variation in abundance from the CPUE annual variations among the fleet, a generalised linear model to estimate the change in fishing power over the period can be assessed. Differences in individual efficiency of fishing power are then explained through explanatory variables connected to vessel equipment or crew (data from a face to face survey). This method is applied to the French bottom-trawlers targeting monkfish (*Lophius budegassa* and *L. piscatorius*) in the Bay of Biscay and in the Celtic Sea during the period 1983-1998.

Data

The data used to illustrate our methodology are coming from the bottom-trawlers off South-Brittany having harvested Anglerfish from 1983 to 1998. This fishery is particularly interesting for analysing fishing power: a new type of gear, the twin bottom-trawl, with same selectivity properties as single trawl, might be responsible for an increase in catches. Twin trawls appeared at the end of the 80's, but only started to be mentioned in fisheries statistics by 1996.

Classical data from logbooks

The study is carried out on anglerfish CPUE data calculated with landed catches and fishing time reported in the logbooks for each fishing sequence. Landed catches is mentioned to precise that discards (not available) are not integrated to catches. The fishing sequences (boat trip per statistical rectangle) selected for this analysis are characterised by at least 10% of Anglerfish in the reported landings for this sequence (in weight). This level of 10 % does not correspond only to a specialised Anglerfish strategy since several Nephrops boats meet this criteria too. This selection of fishing sequences allows to compare efficiency of boats that impact the Anglerfish significantly. The fleet associated to these fishing sequences is formed by 340 vessels. Among these 340 vessels, only those having fished every year within the period have been considered. Thus, the studied fleet is composed of 25 vessels regularly fishing Anglerfish, and 13775 fishing sequences are analysed. Figure 1 shows the distribution of the Anglerfish CPUE.

Explicative factors taken into account in the analysis are the vessel, its technical characteristics (engine power, age, length, tonnage), fishing area (ICES sub-division, statistical rectangle), fishing date (day, month and year of the sale), fishing gear (single trawl or twin trawls, only available from 1996) and targeting factor. This last variable is introduced in order to indicate the fishing strategy taking into account the multispecific sight of the fishery (Sampson, 1991; Marchal and Horwood, 1996; Biseau, 1998; Pelletier and Ferraris, 2000). The métier is defined according to the species or the set of species caught and has four categories B (Benthic), D (Demersal), N (Nephrops) and M (Mixed) defined by the followings levels of catches for each sequence:

- B if catches of benthic species (Anglerfish, rays, megrim) make at least the 20 % in weight of total catch,
- D if catches of demersal species (cod, whiting, haddock, ling) make at least the 40 % in weight of total catch,
- N if catches of Nephrops make at least the 10 % in weight of total catch,
- M: otherwise.
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The choices of the levels are the result of cluster analysis on standardised catches in weight or in value (Biseau, 1998, Maguer and Biseau 1999).

Figure 2 shows the variations in CPUE data depending on the five explanatory variables considered. The graph of the CPUE per year is very similar to the variations in abundance estimated by the working group of stock assessment, showing a clear decrease from 1983 to 1991. The graph of the CPUE per vessel shows important contrasts with large dispersions, which could be induced by the change in metier over the year or the period. Contrary to the little variations in the distribution of the CPUE per month suggesting a weak month effect, the spatial variability illustrated by the plot of the CPUE per sub-division appears to be very important with large dispersions of the catch rates and some important spatial differences in magnitude of CPUE. Following, the individual fishing seasonality would be estimated through the métier and the area variables, the different seasons corresponding to different areas fished and different target species.

Additional data from face to face survey

A face to face survey has been carried out with the skippers of the selected boats to verify and add informative data especially the purchased date of twin trawl. This survey was also aimed at the temporal evolution of technical characteristics (change in engine power, gear, electronic equipments). Since engine power possibly changes in time, the average over the period was chosen for modelling. Concerning the gear, the number of years using twin trawls among the period was chosen to explain differences. It's important to note that when twin trawls are acquired by a boat, they are systematically used for the following fishing sequences. The survey provided more details on the fishing strategy and allowed to be aware of change in captain. This explicative factor is introduced in the analyses as the number of years of the last captain within the period.

Table 1 summarizes the origin, the type of variable, and the dispersion of the technical factors considered in the analysis.

Concerning the referent boat

A referent boat has been chosen to deduce an annual abundance indices, requiring the analysis of 904 fishing sequences. This boat for which no technical improvement can be observed fishes in the same area as the understudied fleet (Figure 3) and is characterised by a fishing activity by-catching Anglerfish over the period (less than 10% of Anglerfish in catches). The reasons and the implications of such a choice are detailed in Discussion section.

Method

Modelling CPUE

Given the basic form of the catch equation (catches C proportional to fishing mortality F and average abundance N) and decomposing the fishing mortality as the product of the catchability coefficient q and the fishing nominal effort E, the following direct and simple equation holds:

$C/E = q\,N$ **(1)**

The catchability coefficient integrates both a component dealing with the vessel, called the fishing efficiency or fishing power, and a component due to the resource which is called accessibility/vulnerability (Gulland, 1956; Beverton and Holt, 1954). This model **(1)** assumes a linear relationship between CPUE and abundance, but several models which consider a more complex relationship such as a power curve have also been developed (Harley et al., 2001). In this study we have preferred the simpler one.

The CPUE series (catch divided by nominal effort) can not be considered as good index of abundance (Gavaris, 1980; Gillis and Peterman, 1998; Harley et al., 2001). Indeed improvement in efficiency with time, differences in efficiency between vessels into the fleet, spatial heterogeneousness of the density and the accessibility of the resource induce not comparative CPUE. Following, modelling the catchability coefficient describing these variations and standardizing the CPUE is necessary to make CPUE series valid. A more realistic model for CPUE is written:

$C/E = a\,Fp\,N$ **(2)**

where a denotes the coefficient of accessibility/vulnerability of the population targeted and Fp quantifies the fishing power of the vessel or the fleet catching the population. This model allows to analyse CPUE per vessel and per fishing sequence to estimate the relative fishing power of a vessel within the fleet and the change in efficiency over a period.

Fishing power analysis is traditionally investigated with linear models on log-transformed data. In this study, generalised linear models (McCullagh and Nelder, 1989) have been used to be as close as possible to the distribution of CPUE without any transformation. Such models allow to get rid of Laurent's correction factor (Laurent, 1963) necessary to unbiase the estimations obtained with a log-normal regression. The stochastic distribution which appears to be the more appropriate to describe CPUE of a targetted species, that is positive and continuous data, is a Gamma distribution rather than a normal distribution (Smith and Showell, 1996; Stefansson, 1996; Goni et al., 1999). This *a priori* choice is confirmed with the exploratory analysis (Figure 1). The Gamma distribution gives useful representations of many biological situations, mimicking closely a normal distribution while representing a positive random variable (Johnson et al., 1994).

The main drawback of this modelling approach is the mixture of temporal variations in the Fp (equation (**2**)), abundance variations in the resource and efficiency variations in the fleet. To undergo this difficulty we decide to construct an annual indices of abundance with the CPUE of a referent vessel.

obtaining an index of abundance from the analysis of CPUE variations in the referent vessel (model 1)

The following model is fitted on the CPUE of the only fishing sequences of the referent boat:

CPUE(fishing sequence) ~ year+month+area + (ε ~ Gamma) **(model 1)**

The error is supposed to be gamma distributed and in order to consider multiplicative effects on the response scale, the logarithm link function is chosen. The choice of the type of contrast allows to test the significant differences between estimated year coefficient. Given the assumption that the CPUE of the referent vessel are proportional to the abundance of the species of interest, the estimations of the year effects are the value for each year of the relative index of abundance, *coef(year)*. From this fitted model, confidence interval of each estimation can be constructed. Let us denote *ystart* the first year of the study, *N(y)* the abundance of the year *y* and *coef(y)* the multiplicative coefficient which allows to calculate the abundance of the year *y* from *N(ystart): N(y) = coef(y) N(ystart)*. This coefficient is a relative index of abundance taking *ystart* as the referent year.

If we consider that variations in abundance are annual and using equation **(2)**, for each fishing sequence of the year *y*, the ridded CPUE of abundance is of form:

$$\frac{C(fishing\,sequence)}{coef(y)E(fishing\,sequence)} = a\ Fp\ N(ystart) \qquad \textbf{(3)}$$

Later on, we note CPUE_C the CPUE of the fleet cleaned from annual variations in abundance:

CPUE_C = CPUE (fishing sequence) / coef (year)

quantifying heterogeneity of individual fishing power within the fleet and its evolution over the period (model 2)

To quantify the evolution in fishing power of each vessel over the period within the fleet, the following generalized linear model has been considered:

*$CPUE_C$ (fishing sequence) ~ vessel*year*mois*metier*area + (ε ~ Gamma)* (**model 2**)

*(the notation * means that interactions between variables have been tested to select the best model according to the criteria of Akaike (AIC)).*

As for **model 1**, the error is supposed to be distributed according to a gamma distribution and a logarithm link function has been chosen. The model considers two kinds of temporal variables: in the case of no significant interaction, the year takes into account the annual variations in fishing power of the fleet over the period and the month characterizes the seasonal variation in harvesting (Laurec and Le Gall, 1975). The vessel effect quantifies the vessel fishing power during the whole period. The métier variable describes the fishing strategy of the vessel during a fishing sequence characterised by different levels of targeting the species understudied (Stocker and Fournier, 1981; Marchal et al., 2001; Biseau, 1998; Biseau et al., 1999). The strategy may change with the season and implies a particular choice of fishing area. Thus, if the métier variable is well defined, we can assume that the month and the area effects are free of variation in efficiency. Area effects then describe spatial variations in abundance and catchability and the metier effect quantifies the impact of efficiency due to fishing strategy.

Regarding to fishing power evolution, a selected model without any interaction express a global change in fishing power of the whole fleet but no individual particular course. If interactions between year and vessel are significant, fishing efficiencies of vessels do not change in the same direction and the fishing efficiency of a given *vessel* for a given *year* is estimated by (*year effect* + *vessel effect* + *vessel*year effect*). According to statistical results on allowable comparisons between estimated coefficients when interactions Philippeau, 1989, the evolution of fishing power inside the fleet can be studied vessel per vessel and comparisons between vessels can only be made at a given year.

In our study-case, no interaction are significant and the estimation of each vessel effect has been used to explain the differences in efficiency with technical factors.

explain the differences in efficiency with technical characteristics (model 3)

To evaluate and explain the differences in efficiency among the fleet, the following approach has been followed:

1. each estimated vessel fishing power, i.e. all vessel coefficients except the first one fixed by the chosen contrasts to make them independent, are extracted from the fitted **model 2**;
2. considering this set of values as observations, and then for each explanatory variable (date of change in gear, average of engine power on the period, date of installation of GPS, change in captain, length of headline, kind of ground rope) a traditional linear model is fitted on these values of individual fishing power:

   vessel coef ~ variable (ε ~ Normal) **(model 3)**

In **model 3**, each variable is treated individually because strong correlations between variables (except for change in skipper) are expected.

Results

All the analysis have been performed using the software S+ 2000 for PC. To fit the generalized linear models, usual contrasts (called treatments in S+) have been chosen. Thus, the first modality of each variable is supposed to be the referent modality (equal to 0), making each estimation directly interpretable.

Estimation of an index of abundance (model 1)

The fitted **model 1** on the CPUE of the referent vessel allows to obtain an index of abundance derived from the year effect estimation. The part of explicated deviance around 52% (all the factors being significant, cf. Table 2) and the quality of the fit according to the residuals express that the model explained well the variability of the referent vessel's CPUE. Figure 4 shows the value of the resulting index for each year of the period with a 95% confidence interval. We note a global decrease of Anglerfish abundance during the period 1983-98. The trend can be separated into three parts showing a similar decrease slope of abundance from 1984 to 1987, from 1988 to 1993 and from 1994 to 1998. The highest abundance is observed at the beginning of the period in 1983-1984 and the lowest in the middle and the end of the period, respectively in 1992-1993 and in 1997-1998.

Change in efficiency of the whole fleet (model 2)

Using the indices of abundance calculated above, the **model 2** is fitted with the 13775 $CPUE_c$ associated to the fishing sequences of the 25 vessels of the fleet. The output of final model selected for its explanatory ability and its quality of fit is described in Table 3. The part of explained deviance is roughly equal to 60% (Table 3) and the standardised residuals verify the hypothesis of normality (Figure 5). Despite a weak trend in the residuals (Figure 5), the model fits well the data. All the simple effect tested in the model with the Wald-test is significant (Table 3) whereas none of the interactions between variables are significant. This latter result implies that inside the fleet, each boat has a similar evolution of efficiency over the period.

- The vessel variable quantifies the relative average efficiency of each vessel over the period as said in Method paragraph. Figure 6 plotting the estimations of the vessel coefficients in **model 2** shows large differences in fishing power. The 72% of the vessels has a fishing power close to the mean. The most efficient vessel of the fleet (the 13th in Figure 6) is the one which develops the strongest engine power (442 kW). This boat has been using twin trawls since 1988 and has a typical benthic fishing strategy. The least efficient vessel of the fleet (the 3rd in Figure 6) is the one, which develops the lowest engine power (211 kW). Most of time, this boat is targeting Nephrops in South of Ireland and has been using twin trawls since 1994.

- The metier variable is describing the global efficiency of the fleet per fishing strategy. Every métiers Demersal, Nephrops and Mixed are, as expected, less efficient on Anglerfish than the main metier Benthic targeting this species (Figure 7).

- The month and the sub-division variables respectively estimate the seasonal variations in accessibility over the whole studied area, and the spatial variation in the distribution of the species over the period. Figure 8 shows a lower accessibility during the months of spring and summer which corresponds to a transfer of fishing effort on Nephrops. Figure 9 shows some higher estimations for the sub-division in the Bay of Biscay and the south of the Celtic Sea which correspond to a better habitat for Anglerfish coupled with an easier accessibility for trawling.

- The year effect quantifies the annual change in efficiency of the whole fleet over the period. The estimations of each modality of the year variable from the fitted **model 2** are illustrated in Figure 10. We observe two principal trends in the evolution of the mean fishing efficiency of the fleet: a period with global decrease from 1983 to 1991 and then a period of increase from 1992 to 1997, with a new decrease for year 1998. The decrease between 1984 and 1991 (from 0 to -0.5, with the confidence intervals drawing in Figure 10) is only partially balanced by the increase from 1992 to 1997 arriving at level -0.2. This unexpected decrease is analysed in the Discussion Section.

Explanations of the efficiency differences by technical characteristics (model 3)

The results from the analyses performed with **model 2** indicate a large disparity in efficiency. A subset of reasons to explain these differences has been considered. The first one, traditional issue, is the engine power (REF). The second comes under a radical change in the fishing method and deals with the acquisition of a new gear (twin trawls) which is suspected at first sight to be nearly 30% or 40% more efficient than the traditional gear (single trawl). Engine power and kind of fishing gear are expected to be strongly correlated, but Figure 11 shows no relation between engine power and fishing gear and the lowest value of engine power of the fleet corresponds to a boat using twin trawls.

Other sources of explanation considered lies to technical characteristics of the trawl, the kind of Ground rop and the area trawled characterised by the length of the headline. The set of navigation equipment such as the GPS which may be responsible (Robins et al., 1998) of an increase in fishing efficiency. Finally the human aspect in differences in efficiency is analysed with the change in captain for each vessel during the studied period, considering that a vessel without any change in captain would be more efficient over the period than a vessel changing captain with a certain time of adjustment. Moreover, since the great majority of vessels of the fleet are artisan, the skipper is also the owner of the boat and a change in skipper can lead to a change in fishing strategy.

Table 4 reports the results of the influence of each technical factor on fishing efficiency of the fleet. The most influent variables are, by order of importance, the engine power (result to take with caution because of the frequency of cheating concerning engine power declaration) of the vessel, the kind of gear (twin trawls or single trawl) and the length of headline of the gear.

These results match well the fishermen answers to the point of justifying an increase of efficiency over this period. First the most common answers were the fishing gear and it explains 29.8% of the variance of vessel efficiency. Second, Electronic equipment (GPS, computers…) said to improve above all both comfort and safety of their work rather than fishing efficiency only explains 0.04% of the variance of the vessels coefficients.

Discussion

The classical studies based on a multiplicative model to evaluate and characterize fishing power did not deal with trend in fishing power: the year effect describing the annual change in catch rates not only quantifies the change in efficiency but also the change in abundance. The method based on the IFP (Marchal et al, 2001) estimates the change in fishing power of a whole fleet but not of individual vessels. It also makes the assumption of an homogeneous distribution of the species over the fishing area. Our modelling approach of the fishing power using a multiplicative model on $CPUE_c$ data consists in: first, quantify the change in fishing power over a certain period for a fleet targeting a particular species, and second explain the individual differences of fishing power with technical characteristics. Spatial heterogeneity of the species and the annual variation of abundance are also taken into account.

Its application to bottom-trawlers of South-Brittany targeting Anglerfish pointed out an unexpected decrease in fishing power. Between years 1983 and 1988, no technical improvement or no tactical change which can have significanty changed the trend in fishing power of the fleet was reported in the fishery. Over this period, assuming constant accessibility, invariability of the mean fleet fishing power value or even a regular increase attributed to fisherman skill was expected. But Figure 10 shows during this period a global decrease in fishing efficiency. Two explanations could be considered: (i) the referent boat chosen wasn't suitable to obtain good abundance indices, and our process to clean CPUE from annual variations of abundance did not perfectly worked; (ii) fundamental hypothesis of separability (equation **2**) is too strong and fishing power may be correlated to fish accessibility. It is still difficult to choose between the two. Despite the four first points which could raised the problem, Figure 10 shows a period of adjustment to new equipment till year 1991 followed by an increase in fishing efficiency due to technical improvement. Indeed, twin trawls have started to be used at the end of the 80's (Table 5) and change in gear explains 30 % of the fishing power variability (Table 4). Between 1991 and 1997, the fleet fishing

efficiency on Anglerfish was described by a slot equal to 10% (Figure 9), whereas Anglerfish abundance index was equal to –0.75 in 1991 and to –1.25 in 1997 (Figure 3). The acquisition of twin trawls by the fleet was very staggered for the period (Table 4). Few vessels, very specialised in benthic species have used twin trawls very early. The vessels which got lately twin trawls harvest both Nephrops and fishes. Several reasons could explain such a delay: problem of investment, catching efficiency sufficient with a single bottom trawl,.…
Even if engine power appears to be the most explicative variable (Table 6), these results must be taken with great caution because of the frequency of cheating concerning engine power declaration. It should also be noted that the roughly definition of the gear induced by a very large disparity of its characteristics implies differences in efficiency.

Most of the hypotheses underlying our model are those of the traditional method based on a multiplicative model of fishing power (Robson, 1966; Laurec and Le Gall, 1975), that is separability of the abundance and the catchability, homogeneity of the catch rates at the spatial and time scale chosen in the model. Regarding to the results discussed at the beginning of the Discussion section, the assumption of separability of fishing power and accessibility could be discussed especially for vessels targeted the species. Other assumptions are made when defining the métiers and building the index of abundance.

The temporal dimension in the model is seen at several scales: the month scale for seasonal variation within the year for fishing power, fishing strategy, accessibility and migration of the resource and an annual scale for global variation in abundance during the period. This choice of the month scale has been conducted by the data available, which allows to look to a seasonal modelling without any daily variation (*Gillis, 1999*).

Concerning the spatial scale of the modelisation, we had the choice between the ICES sub-division and the statistical rectangle. The latter, smaller than the former, was only available since 1986 and presented the statistical drawback in modelling of an immoderate increase of number of degrees of freedom. The quality of fitting of a **model 2** with ICES sub-division and a **model 2** with statistical rectangle as spatial effect from 1986 to 1998 are compared using the Akaike Information Criterion (AIC). The AIC value is 9445.5 using the statistical rectangle and 10189.7 using the ICES sub-division. Given the small differences in quality between the two models, we decided to make the analysis on the whole period (from 1983 to 1998) using the sub-division as spatial scale instead of removing three years for modelling the variations in catch rates at a smaller scale. Furthermore even the statistical rectangle is too large to take into account the real local heterogeneity (variation in deep, temperature, substrate, etc.).

Face to the difficulty and maybe the clumsiness of fitting a model with too many degrees of freedom (according to software aspect but also to statistical aspect making significant every tested effects), we did not introduce any interaction between the year and exploited area assuming similar evolution of abundance over the period at the selected spatial scale. However, it does not prevent from spatial differences of abundance (habitat effect) or spatial variation in efficiency due to variation in accessibility to the resource.

Making the assumption that a vessel not targeting a species is less efficient than a vessel targeting the species (certainly truer when the resource becomes scarce), we performed our analysis on the part of fleet harvesting significantly the species (Anglerfish) to have a realistic measure of fishing power (Salthaug 2001). The definition of the 10% threshold allowing to characterize the fishing strategy (level of targeting in a multi-species fishery) is discussed in several papers (Biseau, 1998; Biseau and Kettab, 1999) and was confirmed by the face to face survey.

Concerning the observation data used in the analysis, the CPUE are available by fishing sequence and are assigned to a particular metier. But a fishing sequence is composed with several fishing operations, which can be directed to different species in different manner. Given that a more precise information (ie by haul) is not yet accessible in the French fishing statistical database, we have made the assumption that the fishing strategy remained the same during a fishing sequence.

To distinguish the annual variations in abundance from the trend in fishing power, we have transformed the CPUE data according to an annual index of abundance. This index should be independent of CPUE data used by the ICES Working Group on the Assessment of the Southern Shelf Demersal Stocks. As done by Harley 2001, we could have used a research survey abundance estimates from a vessel with no trend in fishing efficiency and having a spatial and temporal cover adapted to the analysis. Because of few Anglerfish in catches, radical changes in the spatial cover and several years without any survey, we decided not to use the French trawl surveys EVHOE, a priori the most appropriate survey to our study. This has lead us to consider a referent vessel whom CPUE time series can be used as those from a scientific vessel. This referent or standard vessel must have the following (Salthaug and Godo, 2001): no change in efficiency, a spatial and temporal cover identical to one of the fishery. Thus, to be close to the assumption of constancy of fishing power, the referent boat must have kept the same engine power and used a single bottom trawl during the studied period 1983-98 (since change in gear and engine power are the most discriminant factors for fishing efficiency). To minimize the chances of increase in efficiency to catch Anglerfish due to skill, we decided to choose a vessel by-catching the species throughout the whole period making the assumption that a possible increase in efficiency for its metier does not induced an increase in efficiency in by-catch.

The vessel chosen as a referent boat to obtain abundance indices is a vessel with no technical changes over the period and an important activity in Celtic Sea and Bay of Biscay (904 fishing sequences during the period). Its fishing strategy is constant and fixed by the fitter-out, privileging demersal species -mainly Gadidés- exploitation. This boat is not targeting Anglerfish (Anglerfish represents less than 10% in weight of the total catch of the 80% of the fishing sequences) but it is able to catch this species when it's present on the fishing area. Since the middle of the 90's, a few fishing sequences have been oriented forward deep species exploitation. These fishing sequences are realised on different area and have been moved over from the analysis.

To compare the annual fishing power estimations of the whole fleet obtained with $CPUE_c$ and those obtained with the CPUE, we fitted a model defined as **model 2** for the explicative factors but on the CPUE data instead of $CPUE_c$ data (cf. Table 6). Figure 11 shows the year effect with confidence interval at level 95% estimated with this model (whom fitting quality is similar to model 2 one). Regarding to the trend of year effect in Figure 11 and Figure 10, standard vessel has an impact in the estimation of the annual variations in abundance in **model 2**. Besides the estimation of abundance from the scientific survey EVHOE (with all the precaution that should be taken with this index) meets the estimation from the referent vessel. All these remarks make us confident in the issue of cleaning the CPUE from variations in abundance.

Most papers dealing with explanation of differences in efficiency with technical characteristics directly introduced the explanatory variable in the global model (Gulland, 1956; Beverton and Holt, 1954; Robson, 1966; Stocker and Fournier, 1981; **Hilborn and Walters, 1992**; Pascoe and Robinson, 1996; Gaertner et al., 1996; Robins et al., 1998; Gaertner et al., 1999; Gillis, 1999; Rijnsdorp et al., 2000; Marchal et al., 2001; Salthaug and Godo, 2001).). We discuss below the reasons of our two-steps approach (**model 2** and **model 3**). First, the variations in the CPUE data are very complex. The decomposition of the modelling allows first to clean the CPUE from spatio-temporal and strategic variations in catch rates to concentrate on variations due to technical differences in fishing power. Second, we want to quantify the change in fishing power of each vessel of the fleet. Following, we need an identifier vessel in the global **model 2** to answer this question. We could have considered in the global **model 2** some technical variables in addition to the vessel variable, but the high correlation between the resulting explanatory variables would have induced a complicated and even impossible fit of the model. Integrating a technical variable instead of the vessel variable in **model 2** allows to quantify the fishing power associated to a fleet characterised by the technical variable. But in the context of a multi-species fishery, fishing power can not be reduce to a single technical variable.

More precise results when applying this method to the studied fishery, would be reached improving the quality of the input data. For instance, the length of headline is only available for the last gear used by each vessel. Then its introduction into the analysis (**model** 3) supposed its constancy over the whole period even if a change in gear occurred. It would have been better to use a mean weighted by the number of years using each gear. The length of headline is a proxy of the area trawled by a boat. It would also be interesting to consider the volume trawled, which depends on the speed of trawling and on the rigidity of the mesh (kind of material used). Another technical characteristic of the gear, the kind of rig, not available for our study, should be interesting to take into account. Indeed fishermen point out that an appropriate rig can compensate a lack of engine power. Concerning the quality of the data we got during face to face survey, dates of acquisition of new equipment were answered from memory and the level of precision of the reply is the year only. This could also be an aspect to improve.

The approach developed in this paper allows to characterize the differences of efficiency inside the fleet and to observe annual variations in mean fishing power for the whole fleet. Technical variables tested in model 3 give information about the influence of technical factors on mean fishing efficiency of the whole fleet. The same process could have been applied to each boat taken individually. This approach would be particularly interesting if vessel-year interactions are significant. Then **model 2** (without the variable vessel) can be fitted to each boat data set. Comparing annual variations in fishing power (year effect of the model) of a boat with its annual variations in technical or human factors could be the way to achieve the impact of such variables on the fishing efficiency.

One of the most important interest of this study is to have annual values of fishing power of the fleet. These annual values must be seen as conversion factors between nominal effort (main parameter for fisheries management) and effective effort, representative of fishing mortality. Such a conversion factor could be the link between stock assessment and fisheries management. Most of the assessment models use fishing effort or CPUE data either directly (surplus Model) or to tune the analysis (XSA). Using nominal effort in this purpose could lead to misleading signal in abundance variations since an increase in efficiency could be seen as an increase in abundance.

Figures

Figure 1. Density histogram of the Anglerfish CPUE.

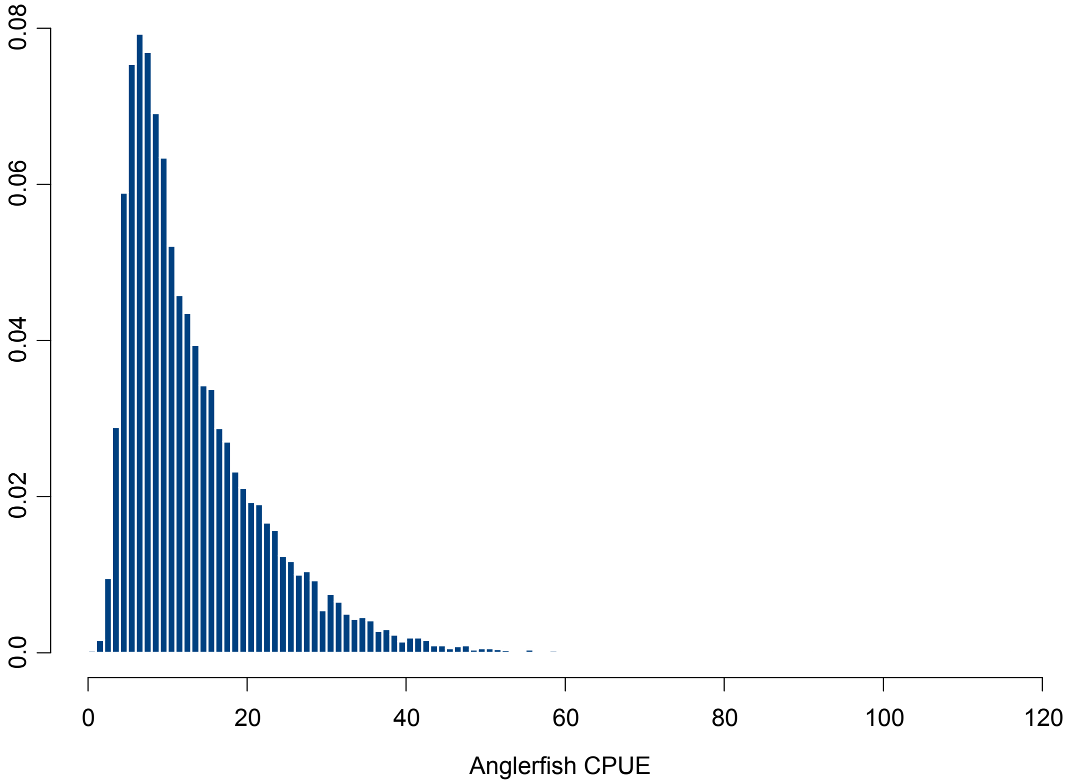


Figure 2. Anglerfish CPUE of the studied fleet depending on several variables: from up to down and right to left, respectively year, vessel, sub-division, month, and métier.

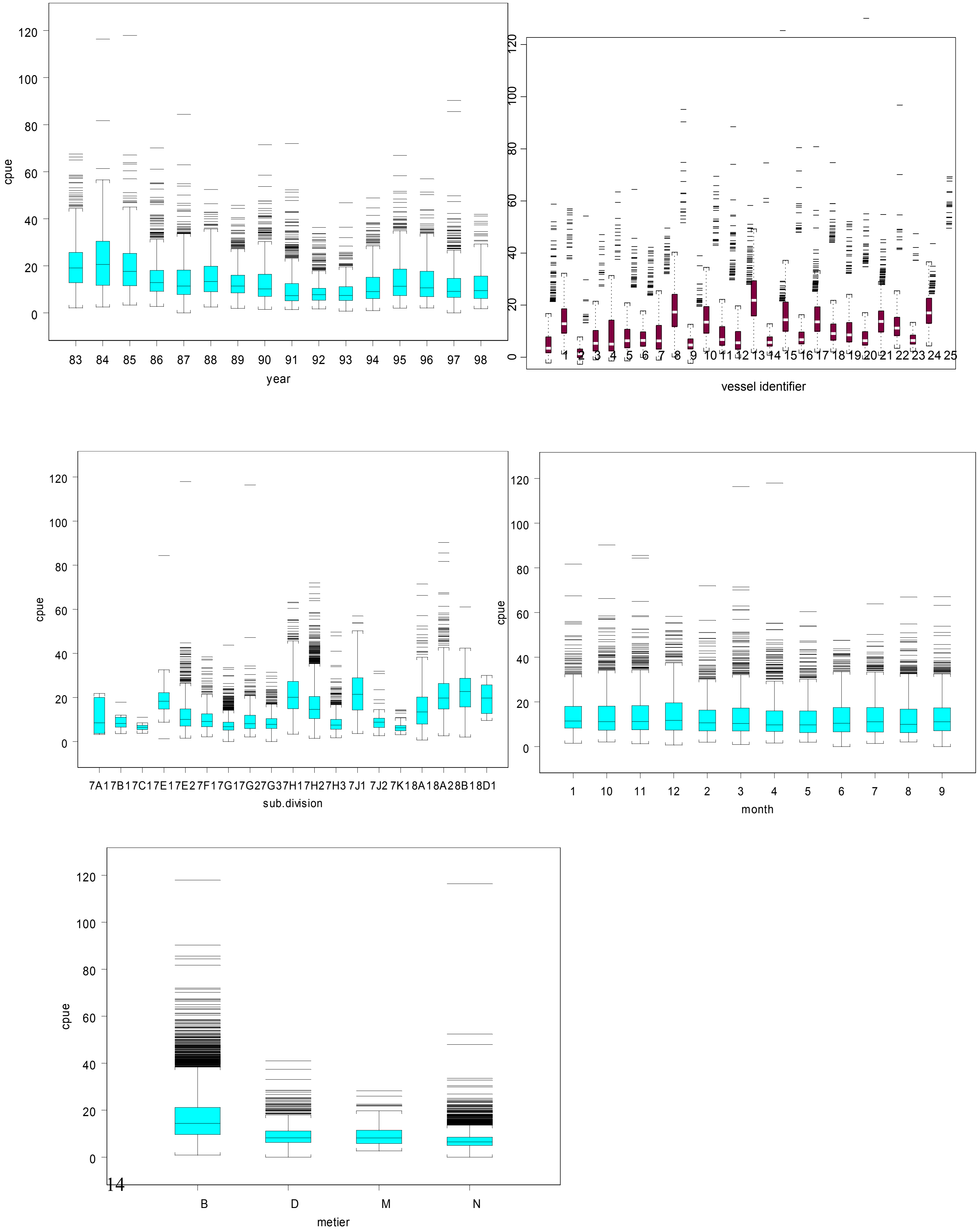


Figure 3. Anglerfish CPUE of the referent boat depending on several variables: from up to down and right to left, respectively month, year, sub-division and proportion of anglerfish in catches.

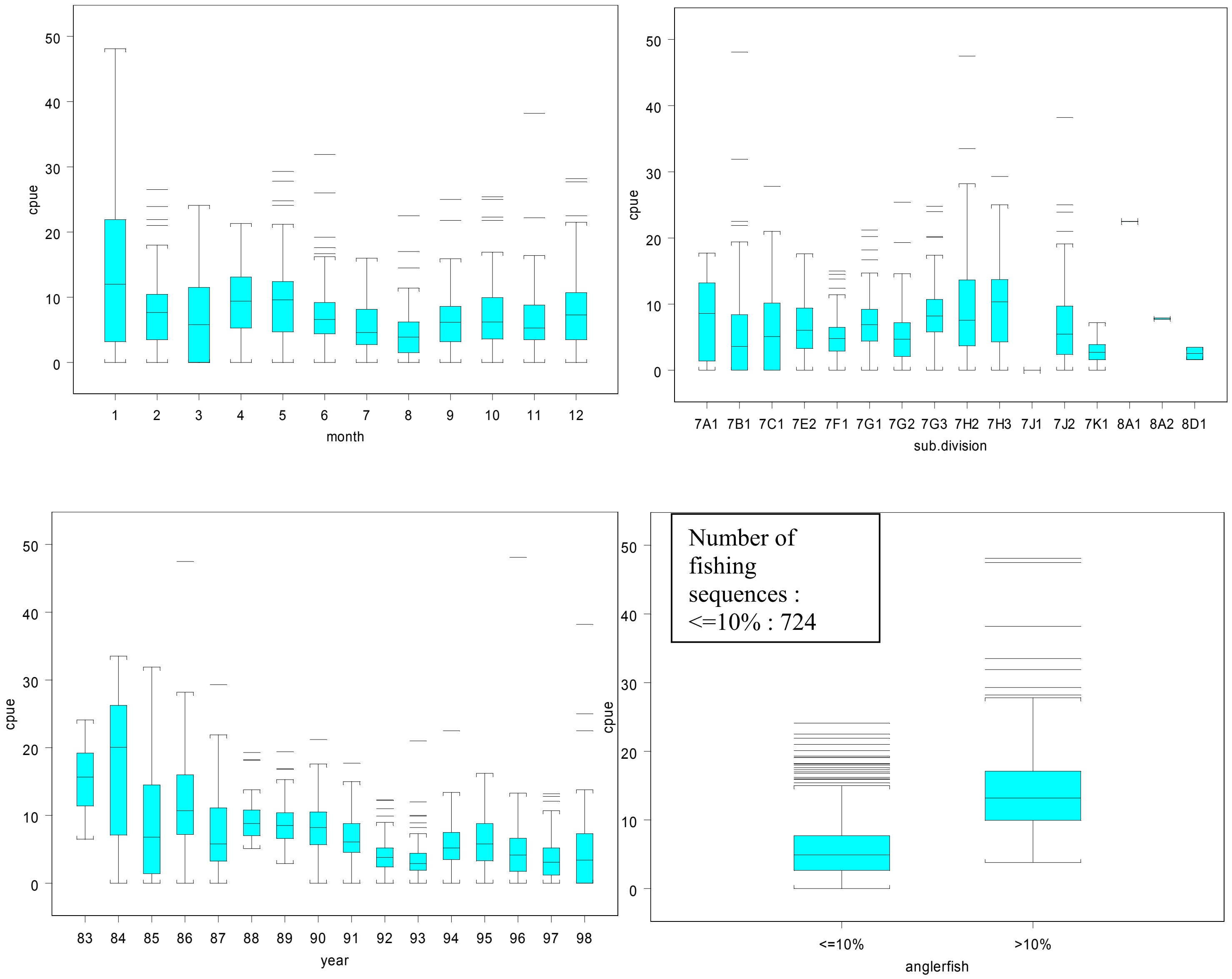


Figure 4. Year effect variations with confidence interval at level 95% from **model 1** (considered as abundance indices). Years on abscisse axis are identified by a number from 2 to 16. Year 1 (1983) is the reference, set equal to 0.

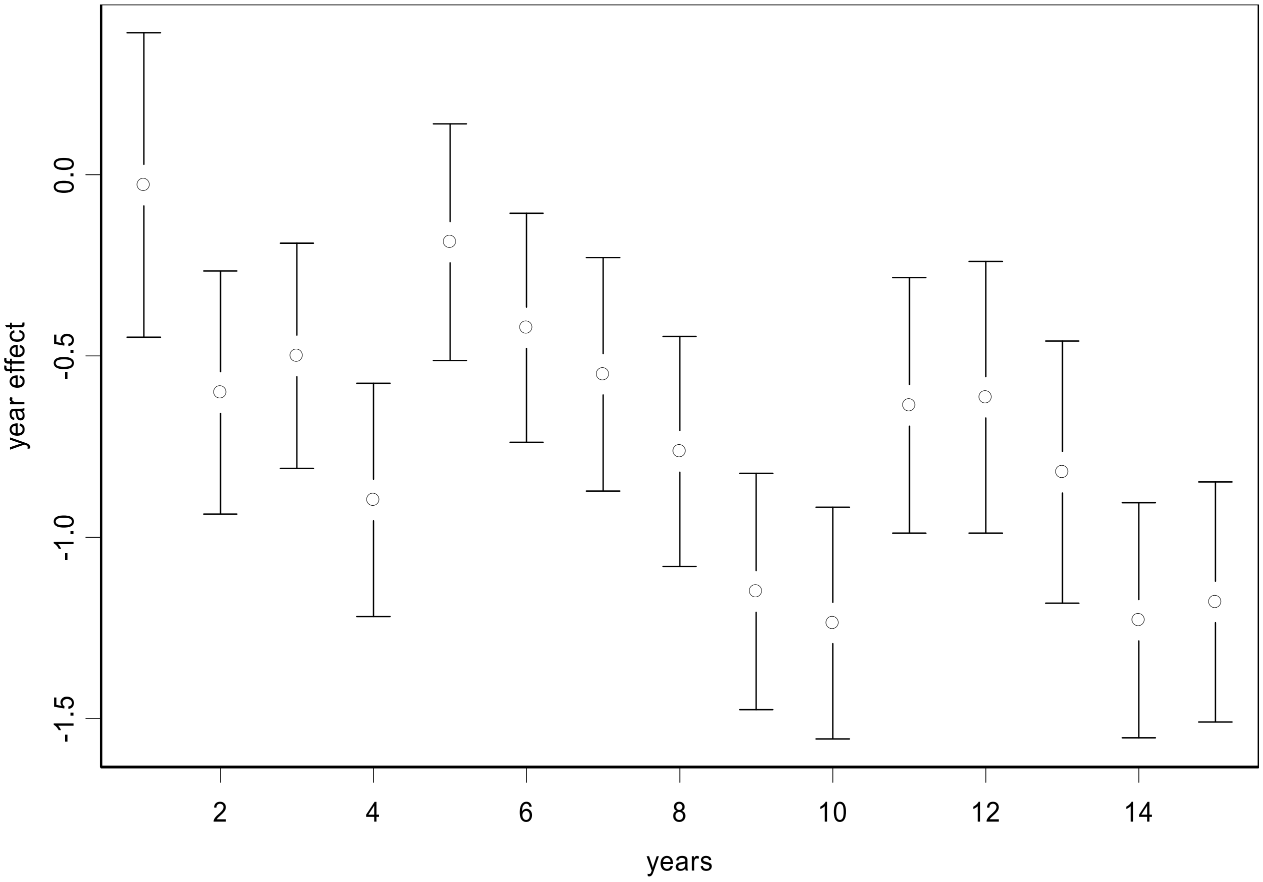


Figure 5. Residuals of **model 2**.

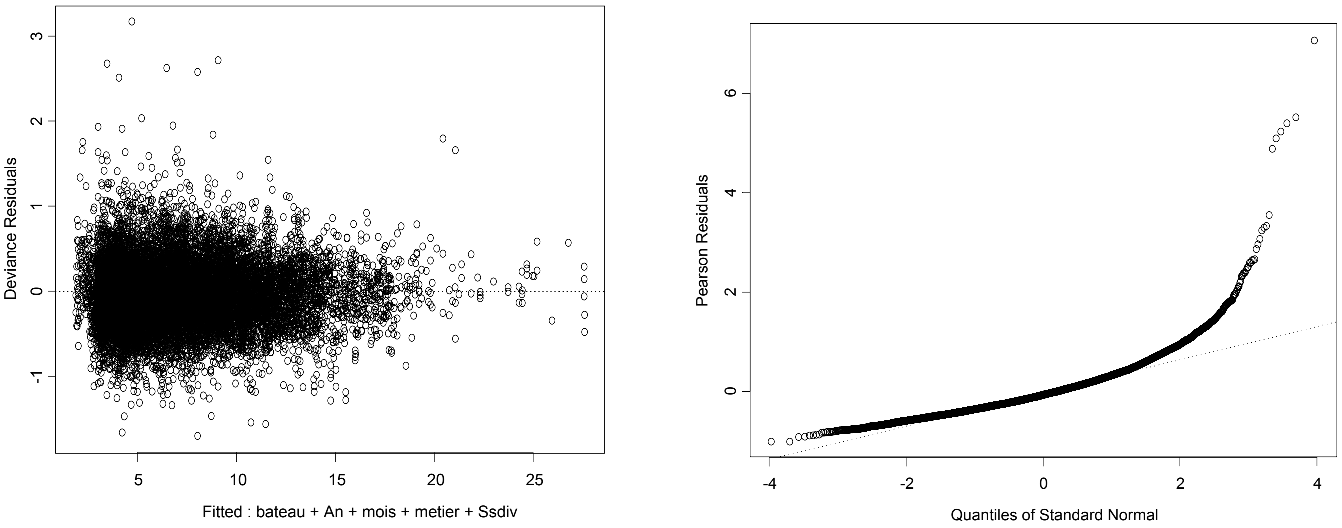


Figure 6. Vessel effect with confidence interval at level 95%: heterogeneity of individual efficiencies within the fleet from **model 2**. Vessels on abscisse axis are identified by a number from 2 to 25. Vessel 1 is the reference, set equal to 0.

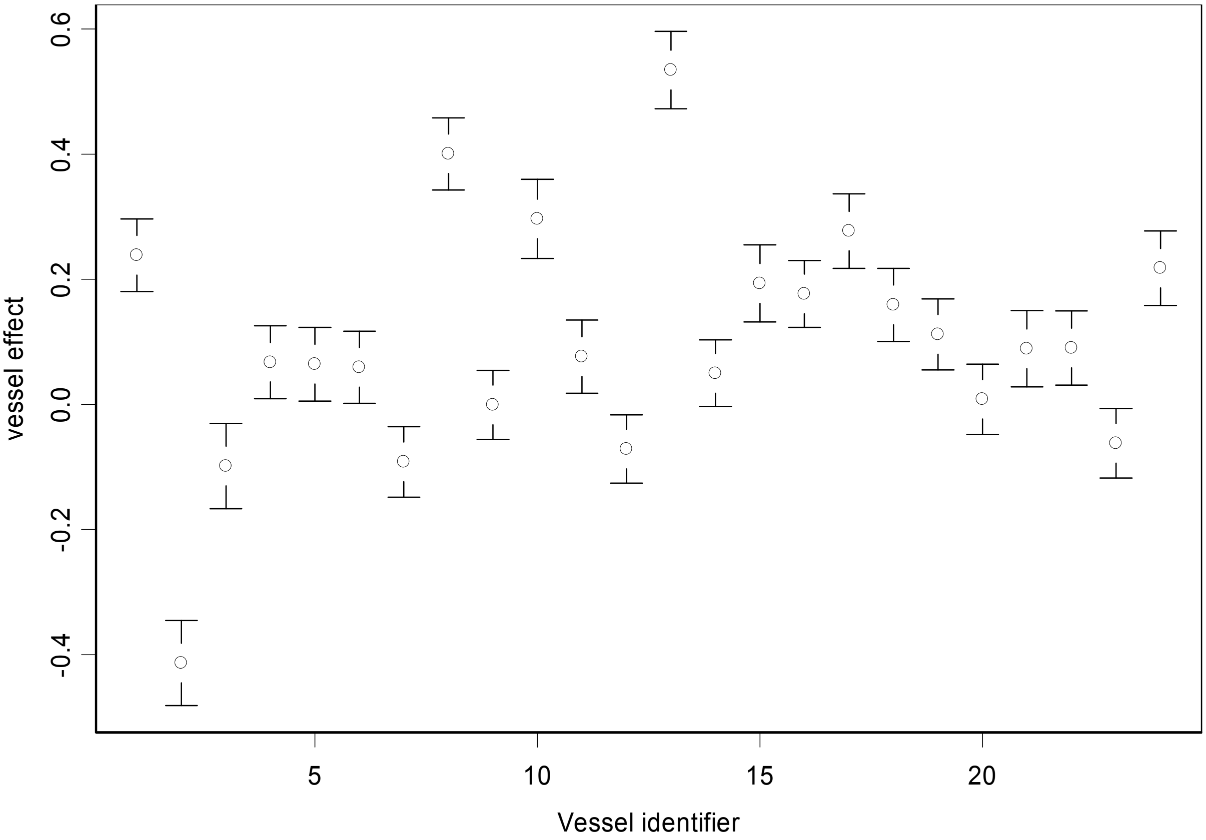


Figure 7. Métier effect with confidence interval at level 95% from **model 2**. Métiers on abscisse axis are identified by a number from 2 to 4 (respectively D, M, N). Métier 1 (B) is the reference, set equal to 0.

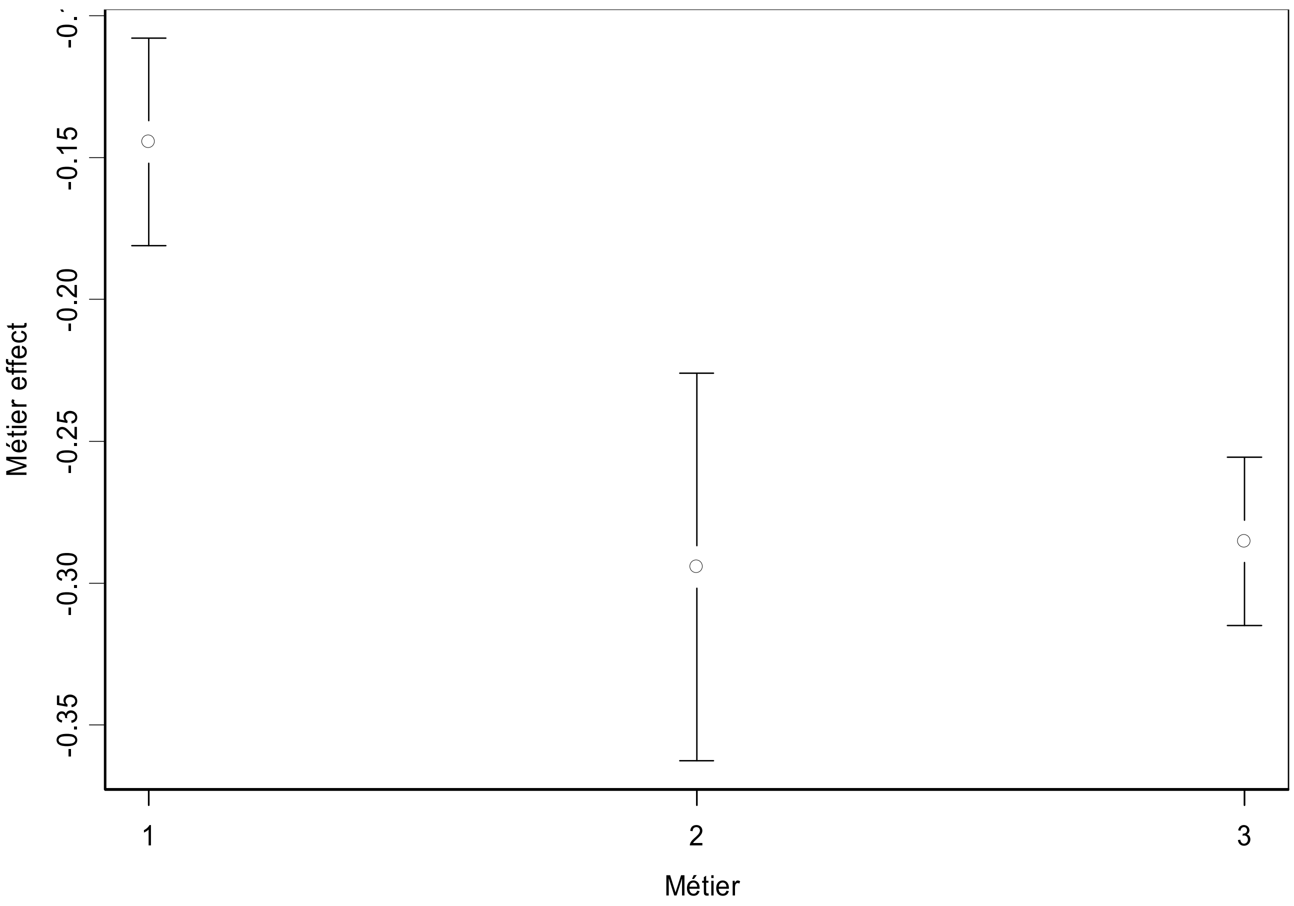


Figure 8. Month effect with confidence interval at level 95% from **model 2**. Month on abscisse axis are identified by a number from 2 to 12. Month 1 (january) is the reference, set equal to 0.

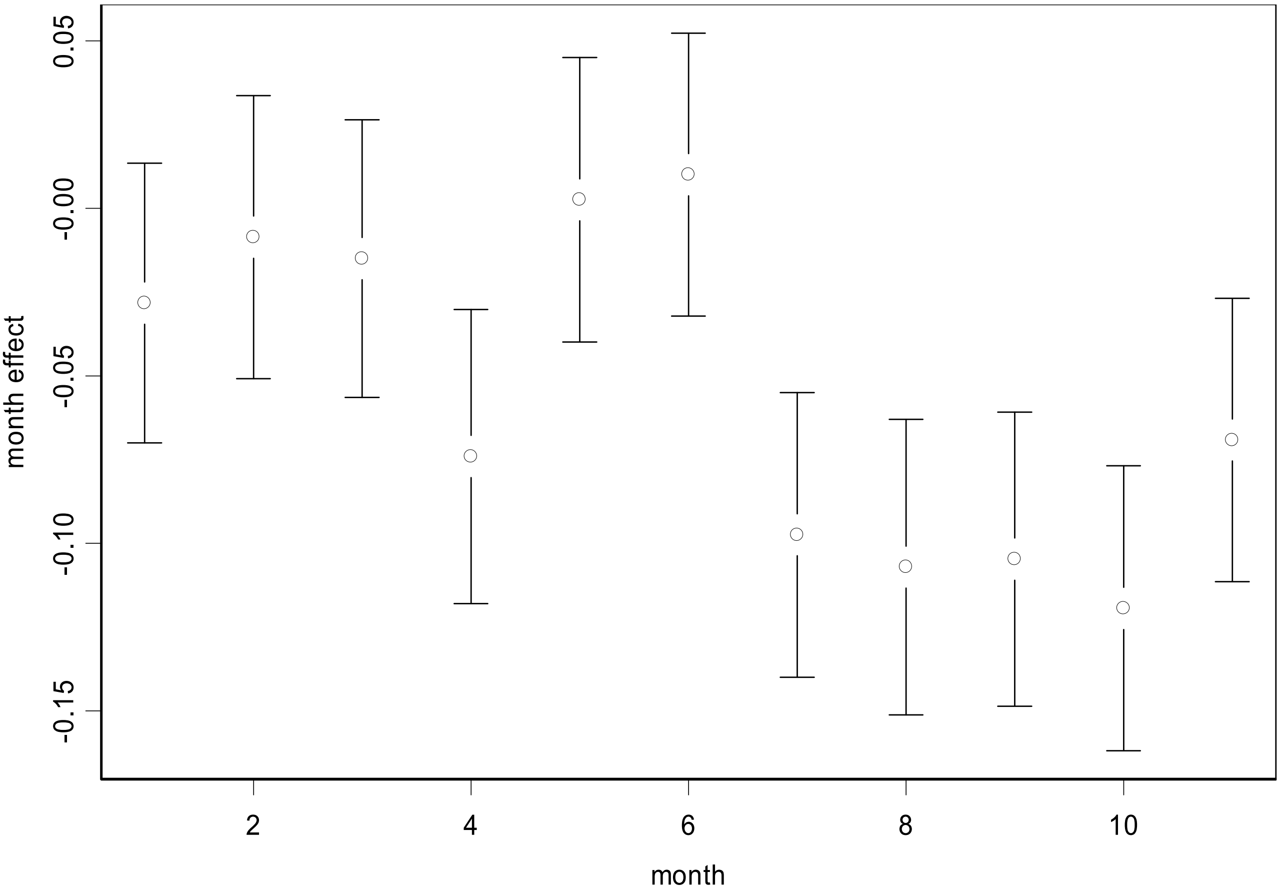


Figure 9. Sub-division effect with confidence interval at level 95% from **model 2**. Sub-divisions on abscisse axis are identified by a number from 2 to 19. Sub-division 1 is the reference, set equal to 0.

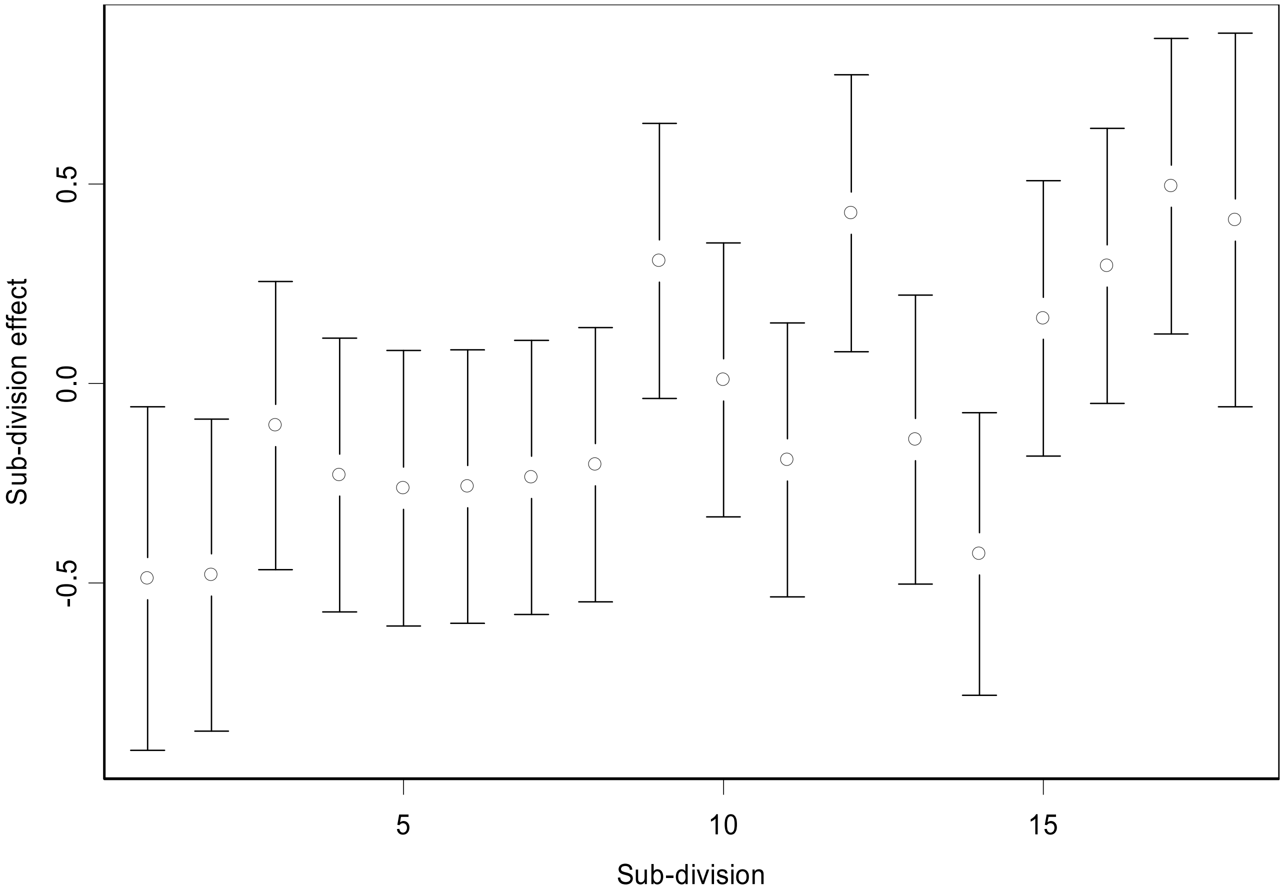


Figure 10. Year effect with confidence interval at level 95% from **model 2**. Years on abscisse axis are identified by a number from 2 to 16. Year 1 (1983) is the reference, set equal to 0.

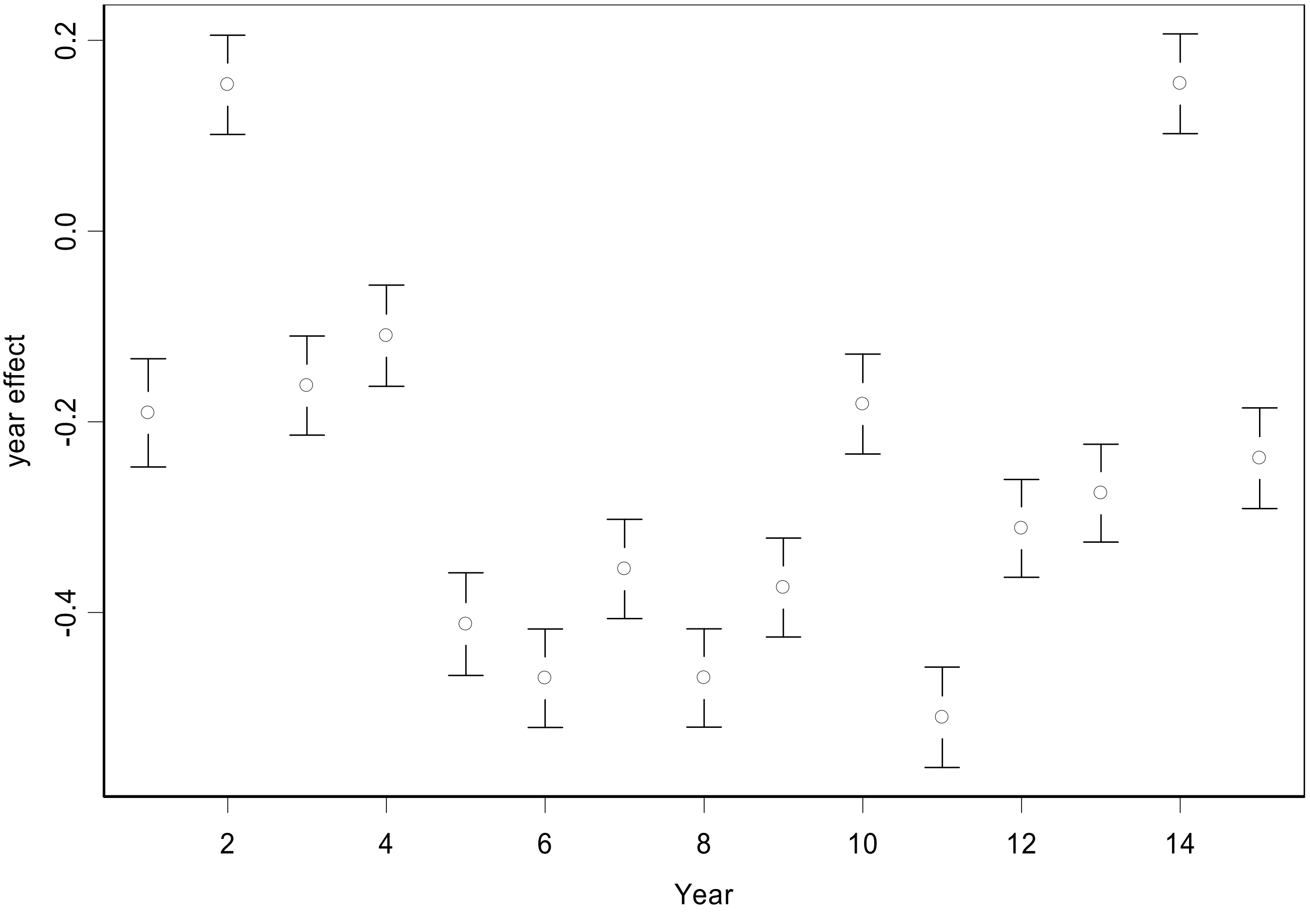
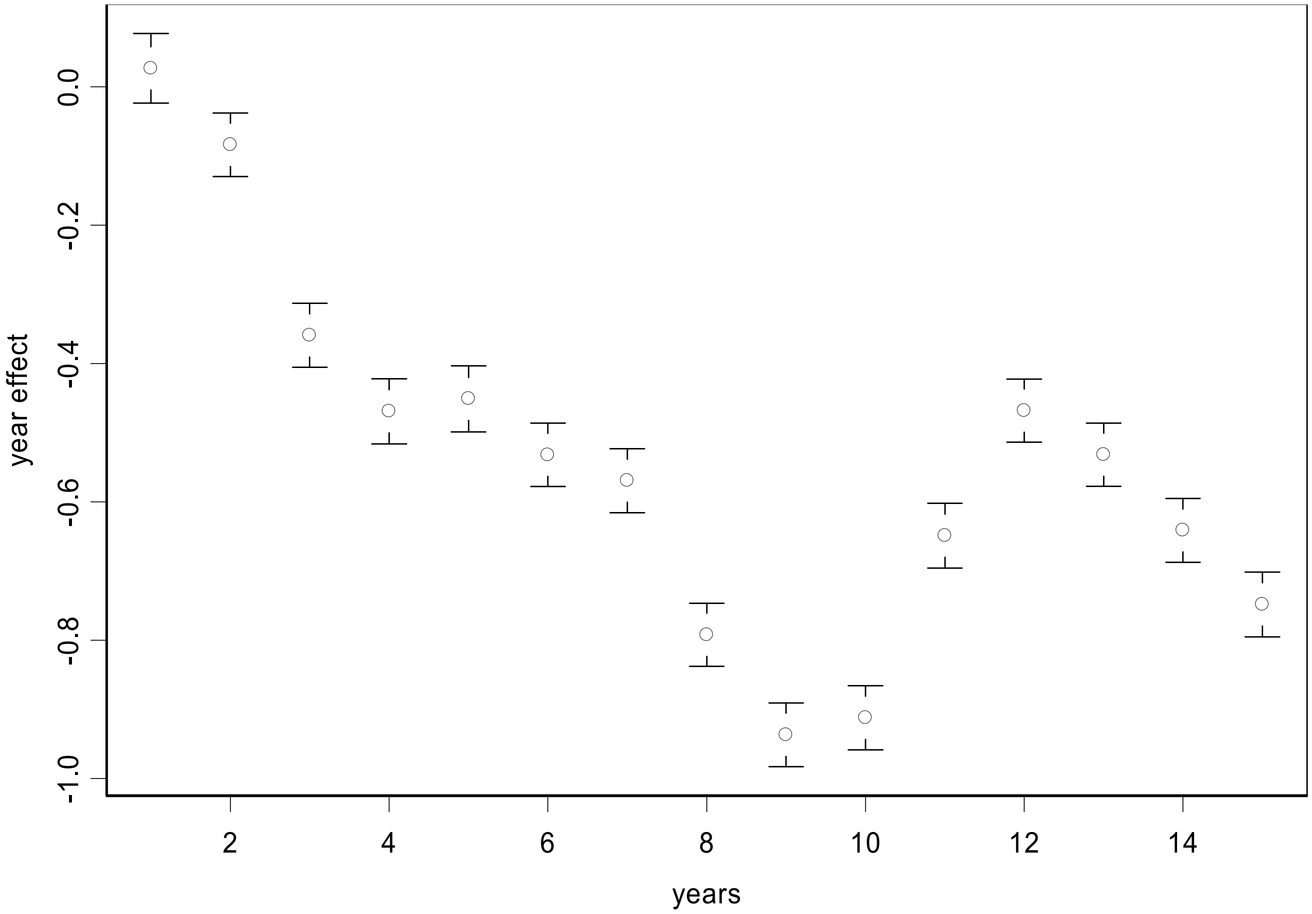


Figure 11. Year effect with confidence interval at level 95% from **model 2** without cleaning CPUE from abundance variations. Years on abscisse axis are identified by a number from 2 to 16. Year 1 (1983) is the reference, set equal to 0.



Tables

Table 1. Technical factors tested in **model 3**.

Technical factor	Origin of the data	Construction of the variable	Dispersion of the variable
Engine power	Logbooks	Mean value over the period	[211;442] (kW)
Twin trawls	Face to face survey	Number of years using twin trawls	(0,...,11)
GPS	Face to face survey	Number of years using GPS	(6,...,11)
Skipper	Face to face survey	Number of years with the last skipper	(9,...,16)
Head line	Face to face survey	Length of the last gear used (*2 if twin trawls)	[22;56] (m)
Ground rop	Face to face survey	Kind of ground rop used	Diabolo, Rockopper or Other

Table 2. Analysis of deviance of **model 1** describing the cpue of the referent boat.

	Df	Deviance	Resid.Df	Resid. Deviance	Pr (Chi)
Null			903	588.57	
Year	15	159.59	888	428.98	0.0000
Month	11	39.42	877	389.56	4.49^{E}-05
Metier	1	100.21	876	289.36	0.0000
Sub-Div.	15	97.08	861	192.28	0.0000

Table 3. Analysis of deviance of **model 2** describing the cpue$_c$ of the whole fleet.

	Df	Deviance	Resid.Df	Resid. Deviance	Pr (Chi)
Null			13774	5038.52	
Vessel	24	1776.42	13750	3262.09	0.0000
Year	15	630.16	13735	2631.93	0.0000
Month	11	63.09	13724	2568.85	2.46^{E}-09
Metier	3	265.44	13721	2303.41	0.0000
Sub-Div.	18	243.45	13703	2059.96	0.0000

Table 4. Explanation of the differences of efficiency according to technical factors **(model 3)**.

Technical factors	Degrees of freedom	% variance explained	**F-statistic**	p-value
Engine power	22	58.3	30.82	0.000
Twin trawls	22	29.8	9.324	0.006
Head line	22	27.8	8.453	0.008
Skipper	22	1.9	0.417	0.525
Ground rop	21	0.1	0.011	0.989
GPS	22	0.04	0.008	0.929

Table 5. Annual evolution of total number of vessels getting twin trawls or GPS within the fleet.

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Twin trawls	0	2	4	6	6	7	8	9	10	10	11	13
GPS	0	2	16	21	21	24	25	25	25	25	25	25

Table 6. Analysis of deviance of model describing the monkfish cpue inside the whole fleet (without cleaning cpue from abundance variations).

	Df	Deviance	Resid.Df	Resid. Deviance	Pr (Chi)
Null			13774	5417.74	
Vessel	24	1685.41	13750	3732.33	0.0000
Year	15	1099.09	13735	2633.23	0.0000
Month	11	63.09	13724	2570.15	2.46^{E}-09
Metier	3	265.44	13721	2304.71	0.0000
Sub-Div.	18	243.45	13703	2061.26	0.0000

References

Allen, R. and Punsly, R. 1984. Catch rates as indices of abundance of yellowfin tuna, Thunnus Albacares, in the Eastern Pacific Ocean. Inter-American Tropical Tuna Commission.

Beverton, R. J. H. and Holt, S. J. 1954. Fishing mortality and effort,C. a. Hall,533.

Biseau, A. 1998. “Definition of a directed fishing effort in a mixed-species trawl fishery and its impact on stock assessments.” Aquatic living resources, 11 (3): 119-136.

Biseau, A. and Kettab, M. O. e. 1999. Etude bio-économique de l'exploitation des ressources sous diverses hypothèses de gestion. Application à la mer Celtique., Ifremer

Biseau, A., Mahévas, S., Perodou, J. B. and Berthou, P. 1999. Puissances de pêche et relations avec les caractéristiques techniques des navires. Exemple de flottilles pratiquant les arts trainants en Manche Ouest, Atlantique et Méditerranée., CE,97/0027: 234

Biseau, A., Mahévas, S., Perodou, J. B. and Berthou, P. 1999. Puissances de pêche et relations avec les caractéristiques techniques des navires. Exemple de flottilles pratiquant les arts trainants en Manche Ouest, Atlantique et Méditerranée. Annexes, CE,97/0027

Francis, R. C. 1974. Effects of Fishing Modes on Estimates of Fishing Power, Relative Abundance and Surplus Production in the Eastern Pacific Yellowfin Tuna Fishery. ICCAT Workshop on tuna population dynamics, Nantes.

Gaertner, D., Pagavino, M. and Marcano, J. 1996. “Utilisation de modèles linéaires généralisés pour évaluer les stratégie de pêche thonière à la senne en présenced'espèces associées dans l'Atlantique ouest.” Aquatic Living resources, 9: 305-323.

Gaertner, D., Pagavino, M. and Marcano, J. 1999. “Influence of fishers'behavior on the catchability of surface tuna schools in Venezuelan purse-seiner fishery in the caribbean sea.” Canadian Journal of Fisheries and Aquatic Sciences, 56: 394-406.

Gascuel, D., Fonteneau, A. and Foucher, E. 1993. “Analyse de l'évolution des puissances de pêche par l'analyse des cohortes: application aux senneurs exploitant l'albacore (Thunnus albacares) dans l'atlantique est.” Aquatic living resources, 6: 15-30.

Gavaris, S. 1980. “Use of a multiplicative model to estimate catch rate and effort from commercial data.” Canadian Journal of Fisheries and Aquatic Sciences, 37: 2272-2275.

Gillis, D. M. 1999. “Behavioral inferences from regulatory observer data: catch rate variation in the Scotian Shelf silver hake.” Canadian Journal in Fisheries and Aquatic Sciences, 56: 288-296.

Gillis, D. M. and Peterman, R. M. 1998. “Implications of interference among fishing vessels and the ideal free distribution to the interpretation of the cpue.” Canadian Journal of Fisheries and Aquatic Sciences, 55: 37-46.

Goni, R., Alvarez, F. and Adlerstein, S. 1999. “Application of generalized linear modeling to catch rate analysis of Western Mediterranean fisheries: the Castellon trawl fleet as a case study.” Fisheries Research, 42: 291-302.

Gulland, J. A. 1956. On the fishing effort in English demersal fisheries. London, Fish. Invest.,41.

Gulland, J. A. 1983. Fish Stock Assessment: A Manual of Basic Methods. New York,Wiley

Harley, S. J., Myers, R. A. and Dunn, A. 2001. “Is catch-per-unit-effort proportional to abundance?” Canadian Journal of Fisheries and Aquatic Sciences, 58: 1760-1772.

Hilborn, R. and Walters, C. 1992. Quantitative Fisheries Stock Assessment. Choice, Dynamics and Uncertainty,C. a. Hall,570.

Johnson, N. L., Kotz, S. and Balakrishnan, N. 1994. Continuous Univariate Distributions,J. W. Sons

Kimura, D. K. 1981. “Standardized measures of relative abundance based on modelling log(cpue), and their application to Pacific ocean perch (Sebastes alutus).” Journal du Conseil International pour l'Exploration de la Mer, 39: 211-218.

Kirkley, J. E., Squires, D. and Strand, I. E. 1995. “Assessing Technical Efficiency in Commerciaz Fisheries: The Mid-Atlantic Sea Scallop Fishery.” American Agricultural Economics Association, 77: 686-697.

Large, P. A. 1992. “Use of a multiplicative model to estimate relative abundance from commercial cpue data.” ICES Journal of Marine Science, 49: 253-261.

Laurec, A. and Le Gall, J.-Y. 1975. “De-seasonalizing of the abundance index of a species.” Bull. Far. Seas Fish. Res. LAb., 12: 145-169.

Laurent, A. G. 1963. “The lognormal distribution and the translation method: description and estimation problems.” Journal of the American Statistical Association., 58: 231-235.

Marchal, P. and Horwood, J. 1996. “Long-term targets for celtic sea mixed-species multi-metiers fisheries.” Aquatic living resources, 9: 81-94.

Marchal, P., Nielsen, J. R., Hovgard, H. and Lassen, H. 2001. “Time changes in fishing power in the Danish cod fisheries of the Baltic Sea.” ICES Journal of Marine Science, 58: 298-310.

McCullagh, P. and Nelder, J. A. 1989. Generalized Linear Models,C. a. Hall,511.

Millisher, L., Gascuel, D. and Biseau, A. 1999. “Estimation of the overall fishing power: a study of the dynamics and fishing strategies of Brittany's industrials fleets.” Aquatic living resources, 12(2): 89-103.

Paloheimo, J. E. and Cheng, Y. 1993. “Estimation of Effective Effort from Catch-at Age-Data.” Canadian Journal of Fisheries and Aquatic Sciences, 50: 2421-2428.

Pascoe, S. and Robinson, C. 1996. “Measuring changes in technical efficiency over time using catch and stock information.” Fisheries Research, 28: 305-319.

Pelletier, D. and Ferraris, J. 2000. “A multivariate approach for defining fishing tactics from commercial catch and effort data.” Canadian Journal of Fisheries and Aquatic Sciences, 57(1): 51-65.

Philippeau, G. 1989. Théorie des plans d'expérience. Application à l'agronomie.,I. t. d. c. e. d. f.-S. d. é. statistiques.

Rijnsdorp, A. D., Dol, W., Hooyer, M. and Pastoors, M. A. 2000. “Effects of fishing power and competitive interactions among vessels on the effort allocation on the trip level of the Dutch beam trawl fleet.” ICES Journal of Marine Science, 57: 927-937.

Robins, C. M., Wang, Y. G. and Die, D. 1998. “The impact of global positioning systems and plotters on fishing power in the northern prawn fishery, Australia.” Canadian Journal of Fisheries and Aquatic Sciences, 55: 1645-1651.

Robson, D. S. 1966. “Estimation of the relative fishing power of individual ships.” ICNAF Research bulletin, 3.

Salthaug, A. and Godo, O. R. 2001. “Standardisation of commercial CPUE.” Fisheries Research, 49: 271-281.

Sampson, D. B. 1991. “Fishing tactics and fish abundance, and their influence on catch rates.” ICES Journal of Marine Science, 48: 291-301.

Sampson, D. S. 1993. “The assumption of constant selectivity and the stock assessment for widow rockfish, Sebastes entomelas.” Fishery Bulletin, 91: 676-689.

Smith, S. J. and Showell, M. A. 1996. Analysis of Catch-per-unit Effort FOR Sctian Shelf Silver Hake 1977-1995, Northwest Atlantic Fisheries Organization,2690: 1-8

Squires, D. and Kirkley, J. 1999. “Skipper skill and panel data in fishing industries.” ICES Journal of Marine Science, 56: 2011-2018.

Stefansson, G. 1996. “Analysis og groundfish survey abundance data: combining the glm and delta approaches.” ICES Journal of Marine Science, 53: 577-588.

Stocker, M. and Fournier, D. 1981. Estimation of relative fishing power and allocation of effective fishing effort with fore casts in a multi-species fishery. North Pacific Commission.