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Fishing strategy development under changing conditions: examples from the French offshore fleet fishing in the North Atlantic

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Abstract:

A typology is presented for the French offshore fleet fishing in the North Atlantic. The investigation was carried out separately for all years between 1985 and 2002. Two methods were combined: PCA and cluster analysis. In 1985, most vessels targeted saithe off western Scotland (vessels from Lorient) and in the northern North Sea (vessels from Boulogne and Fécamp). Then, probably because of the decline in biomass of saithe, some vessels started to target deepwater species from the early 1990s. In 2002, some vessels fished exclusively for saithe (>80%), while others targeted mainly deepwater species. In all, 12 fisheries are identified for the period 1985–2002. Results are given of a preliminary investigation trying to identify the external factors (stock biomass, catch limits, price) that may influence the shifts in fishing strategies.

INTRODUCTION

In the European Community waters, fisheries are primarily regulated by single-stock TACs and quotas. However, a large number of fisheries are of a mixed-nature. In mixed fisheries, several species are caught simultaneously during a haul, while one species may be fished by different gears (trawls, gillnets…). Ignoring the mixed nature of fisheries may result in inappropriate management. For instance, fishing for one species could lead to discards of another species, which quota has already been exceeded. Both the scientific community and decision-makers have acknowledged the need to explicitly account for the mixed nature of fisheries in advice and management (Laloë and al., 1995), and actions have been taken in that respect (ICES, 1991; ICES, 1992; ICES, 2003; EC, 2002). In order to shift from single-stock to mixed-fisheries advice, scientists first need to define operational fisheries as the keystone over which future advice to management bodies could build on (ICES, 2003).

Different approaches have been proposed to identify fisheries based on catch and/or effort data.

The first set of approaches is based on multivariate analyses. Biseau and Gondeaux (1988) proposed a method based on principal component analysis (PCA) to define French fisheries (referred to as métiers) in the Celtic Sea. Two analyzes were made on two kinds of variables. The first analysis was based on the relative landing proportion of each of the main species for each vessel. The second analysis was based on the time spent by each vessel in different spatial units. The authors then identified fisheries by contrasting the results of these two PCA. Lewy and Vinther (1994) identified Danish North Sea trawl fisheries using a hierarchical agglomerative cluster (HAC) analysis based on the fraction of the value of different species to the total landings value for each fishing trip. More recently, Pelletier and Ferraris (1999) used a two-stepped multivariate approach to identify fishing tactics in the Senegalese fisheries. First, catch profiles were obtained from trip by trip landings composition with a non normalized PCA and a HAC. Then, a Multiple Correspondence Analysis (MCA) and HAC were applied to catch profile, fishing location, gear and month. One major drawback of these approaches is that fisheries were identified over a limited period of time. Given the volatility of fleet dynamics, such fisheries definitions could not reasonably be extrapolated to other time periods.

The alternative approach found in the fisheries literature consists in classifying fishing trips based on arbitrary criteria. Such criteria could be, either a minimal catch proportion of target species in the total landings (Biseau, 1998), or a combination of fisheries inputs (gear, mesh size, fishing area) defined on the basis of experts knowledge (EC, 2002; ICES, 2002). The major drawback of this approach is the arbitrary character of the criteria used to identify the fisheries.

This paper proposes an approach based on multivariate analyses (PCA, HAC) to not only identify fisheries, but also to describe the dynamics of these fisheries over a period of time, and to get some insights into possible mechanisms that may have induced such dynamics. The concept of fisheries is here assumed to be equivalent to that of fishing strategies, which in turn are defined as the sum of fishing tactics over one year (Laloë and Samba, 1991; Ferraris, 1995). Consistent with Laloë and Samba (1991) and Laurec et al. (1991) fishing tactics, or métiers, are here characterized by a combination of target species, fishing area, gear and time of the year. Identifying fishing strategies consisted in constructing groups (or clusters) of vessels that fished the same species with the same gear in the same area during the year. Additional information was used to characterize these clusters. By contrast with earlier studies, the analyses were carried out separately for each year of a time period were different fisheries possibly emerged, shifted or disappeared. Such an approach should allow getting insight into the main strategic evolutions of the fleets and vessels. The shifts in fishing strategies were then contrasted with variables that characterize, to some extent, the dynamics of the external environment of fishing vessels (catch limits, stock abundance, price of landed species). The analysis was applied to the French off-shore otter-trawlers fishing in the North Atlantic over the period 1985-2002.

MATERIALS AND METHODS

Commercial catch and effort data

The fleet selected for this analysis was made up of French otter-trawlers above 40 m. Catch and effort data by fishing trip and fishing area were made available over the period 1985-2002. From 1994 to 1998, data from vessels of Saint-Malo were not registered in the database. In 1994 and 1995, data from freezer vessels (4 vessels) were not available.

The location of the home harbors of the fleet under examination is shown in figure 1. The main fishing harbors were Lorient and Boulogne. From 1985 to 2002, the number of French offshore vessels decreased drastically. Two categories of vessels could be distinguished. The first category included vessels of tonnage 350-800 ton and of engine power exceeding 750 kilowatts. These vessels fished exclusively in the North-East Atlantic. The second category included vessels of tonnage exceeding

1 000 ton. These vessels fished in both the North-East Atlantic and Canadian waters. Trawlers fishing in Canadian waters were mainly registered in Saint-Malo and Bordeaux (figure 1). In the eighties, vessels fished essentially demersal species (e.g. saithe (*Pollachius virens*), cod (*Gadus morhua*)) and a few deep-water species (blue ling (*Molva dypterygia*), ling (*Molva molva*)) (figure 2). Since the early nineties, trawlers started the commercial exploitation of new deep-water species (figure 3). These species mainly consisted in roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish (*Aphanus carbo*), orange roughy (*Hoplostethus atlanticus*), and deep-water sharks (mainly *Centroscymus coelopis*). The 2002 spatial distribution of the catches of the main species is shown in figure 4. This study was based on the main species harvested (table 1). The stocks definition considered in this study was that used by ICES in 2002 (http://www.ices.dk/committe/acfm/comwork/report/asp/acfmrep.asp). The stocks harvested outside ICES waters (i.e. in Canadian waters) were referred to as “Canadian stock”. Finally, the stocks harvested outside any assessment area were referred to as “other stock”.

The spatial distribution of catch and effort by ICES rectangle was poorly documented in 1985. Missing data amounted to 39% (fishing effort), 40% (saithe catches) and 70% (blue ling). In 1992, missing data amounted to 13% (fishing effort), 6% (saithe catches), 23% (blue ling) and 25% (roundnose grenadier). The spatial distribution of effort and catches by ICES division was fully documented over the whole period of investigation 1985-2002. In the following analyses, the basic spatial unit chosen to aggregate catch and effort data was the ICES division (figure 1).

The scope of this paper was to obtain an annual typology of the French off-shore trawlers exceeding 40 m fishing in the North Atlantic. Vessels likeness-unlikeness was based on their landings weight (Biseau and Gondeaux, 1988). The proportion of stock landings relative to total landings was defined as

$$Ps,v,y = Cs,v,y / \sum_{s \in S} Cs,v,y * 100$$

where C is the catch of stock s fished by vessel v during the year y. S is the total number of stocks (table 2). Matrix $X_y(V,S)$ is the matrix of the proportion of each stock landings relative to the total landings, for each vessel during the year y. Eighteen matrices were created (one per year). Subsequent analyses were based on these matrices.

Factorial analyses and classification

First, a Principal Component Analysis (PCA) was applied annually to $X_y(V,S)$. Consistent with Biseau and Gondeaux (1988), the only transformation applied to the data was centering. Rescaling the data to unit variance would imply that the same weight be given to target species and by-catches. Such a procedure would be inappropriate in the context of this study, where fishing strategies are expected to depend primarily on target species rather than on by-catches. Consequently, data were not rescaled to unit variance. PCA may be used to show principal variability sources and to identify optimal factorial plans (Blanc and al., 1976; Lebart and al., 1995).

Second, a Hierarchical Agglomerative Clustering (HAC) was applied annually to $X_y(V,S)$. This technique aims at grouping the V vessels into clusters, which are both well separated and as homogeneous as possible with respect to the observed catches. Clusters are built by single-link. Distance between individuals is a measure of dissimilarity of the closest pair. HAC agglomerates vessels by adding the shortest possible link (Jardine and Sibson, 1971). Several measures of distance could be used. Given input data are percentages, Euclidean distance appeared to be a reasonable choice (Gordon, 1981). Results are given in the form of a dendogram, which is used to identify fishing strategies. The stocks landings were grouped into 4 categories: less than 20%, 20-40%, 40-75% and upper than 75% of total landings. PCA and HAC were run with the statistical software S-PLUS 6.1 (2001).

The only theoretical limit to the number of clusters to be considered is the total number of vessels in the fleet. Increasing the number of clusters leads to a gain in precision in the definition of these clusters. However, this gain in precision decreases as the number of clusters increases. If the fishing strategies derived from those clusters are to be used as operational units for modeling purposes, there is no point inflating excessively the number of clusters up to a level where the gain in precision is negligible. In our best knowledge, there is no objective method to identify the most appropriate number of clusters (and of fishing strategies). ICES (2003) provided some guidelines to identify a number of fishing strategies that ensures a reasonable balance between precision and operational requirements. The advocated approach, consisting in combining the outcome of multivariate analyses with experts knowledge, has been applied in this paper, and it is presented below.

First, clusters were described at the most accurate level. Second, the number of clusters was reduced based on experts knowledge. Harbor origin seems to be an element of distinction between fishing strategies. It would make little sense to group vessels from Lorient and those from the North of France within the same fishing strategy. Knowledge of the ecology and distribution of deep-water species was also taken into account to reduce the number of clusters. Roundnose grenadier is distributed along the slopes of the temperate North Atlantic at depths of 180-2200 m (Fontaine, 1979; Haedrich and Merett, 1988; Quéro 1997). In the North and the West of British Isles (ICES sub-areas VI-VII), it is most abundant at about 800-1000 m (Ehrich, 1983; Magnússon and Magnússon, 1996; Quéro, 1997). Black scabbardfish and deep-water sharks are usually distributed on the same fishing ground (ICES, 2002). In addition, all these species are generally scattered over large areas (ICES, 2002). Therefore, vessels targeting roundnose grenadier may catch black scabbardfish and deep-water sharks as by-catches, and we may consider total catches of these three species to determine one single strategy. Compared to these three species, blue ling and orange roughy have a different distribution. Thus, blue ling has an aggregative behavior and is most abundant in shallower waters (350-500 m, Quéro, 1997). Orange roughy also lives within dense aggregations (Lorance and Dupouy, 2001), but it is mostly abundant in deeper waters (900-1200 m, Quéro, 1997). Therefore, the fisheries targeting blue ling and orange roughy are not grouped with targeting the three other deep-water species. These two criteria, (i) harbor origin and, (ii) deep-water species ecology were applied to finalise the identification of the main fishing strategies.

Finally, a preliminary approach was performed to get some insights into the determinism of shifts in fishing strategies. Information about the status of deep-water stocks was not available during the study period. Nevertheless, it was available for saithe, the main historical target species of the French fleet. Therefore, the approach was based on the fishing strategies identified for the Boulogne's vessels targeting saithe in ICES division IVa. First, we examined the Pearson correlation between the uptake of (i.e. proportion of vessels taking part in) theses strategies, on the one hand, and the market price, spawning biomass (SSB), and Total Allowable Catch (TAC) of saithe, on the other hand. Then, the influence of all these parameters on the determinism of fishing strategies was discussed qualitatively.

RESULTS

A PCA was run every year from 1985 to 2002. There was no correlation between the landing proportion of the different stocks. Although the two first factorial axes explained 80 to 95% of the variability, PCA did not allow defining easily a typology of strategies. For example, in 1985 (figure 5), the two first factorial axes explained 89% of the variability. This first factorial plan highlighted the main features of the fleet. It allows distinguishing between vessels targeting cod in Canadian seawater and one vessel targeting blue ling in Faroese, Western Scottish and Western Irish waters. The identification of fishing strategies for the other vessels appears to be more complex, and would require to consider additional factorial axes, despite the low variability explained by these axes. Moreover, marginal vessels may over-influence the estimation of factorial axes. Therefore, for the case study investigated here, clusters could not be identified by running only a PCA.

HAC was then run separately for all years between 1985 and 2002 after a PCA. In 1985, the first group of vessels (figure 6, A) targeted almost exclusively cod in Canadian waters (>80% for 6 vessels). The vessel from Fécamp had not exactly the same strategy. It fished mainly cod in Canadian waters (60% of total landings), but it also fished herring and saithe in the North Sea. In the late eighties, the number of vessels fishing cod in Canadian waters decreased and the fishing strategy of the remaining vessels changed. Some vessels started the exploitation of Northeast Arctic cod. In 1989 (figure 7), only 3 vessels from Saint-Malo targeted cod, mainly in Canadian waters. In 1990, the number of vessels fishing for cod in Canadian waters decreased dramatically, and from 1991, no vessels fished in Canadian waters. From 1994 to 1998, strategy shift for those vessels could not be estimated because data were not recorded. Only one vessel targeted Northeast Artic cod from 1999 onwards.

Most of the smallest vessels (350-800 tons) targeted North Sea saithe in 1985 (figure 6). One group (D) fished almost exclusively North Sea saithe (70-75%). These vessels were no more in activity in 1986. The main group (E) fished saithe (40-63%) with a variable part of blue ling (3-22%). The exploration of by-catch composition allows to distinguish between different subgroups. Vessels from Boulogne caught herring, whiting and haddock in the North Sea and Eastern Channel. Those from Lorient caught haddock, ling, cod off Western Scotland and Western Ireland. Consequently, vessels from Lorient targeted saithe more specifically in ICES sub-areas VIa (West Scotland), while vessels from Boulogne fished more particularly in ICES division IV (North Sea). A difference of strategy resulted from a difference in home harbor.

From 1985 to 1989, vessels from Lorient (and some from Boulogne) followed consistently the same strategy. Nevertheless, the majority of vessels from Boulogne specialized their activity. In 1989, a group (I) caught almost exclusively North Sea saithe. All vessels from group I were registered in Boulogne, except one vessel registered in Lorient. However, this vessel belonged until 1988 to an owner from Boulogne. Consequently, it is not unreasonable to assume that this vessel followed a strategy similar to the other Boulogne vessels from group I. Another part of the Boulogne fleet targeted blue ling (G1,G2, H figure 7). In 1989, the Lorient fleet and some Boulogne vessels began to land new deep-water species (roundnose grenadier essentially). These species were caught during experimental fishing operations (FROMNord, 1990).

In the early nineties, deep-water fisheries developed. In 1992 (figure 9), vessels from Lorient increased their catches of roundnose grenadier (20-30%), while one vessel (O) started to fish orange roughy off Western Ireland. Six vessels from Boulogne caught almost exclusively deep-water species (M7) in 1991. The main species landed was roundnose grenadier, followed by orange roughy and blue ling. The number of vessels following a similar strategy increased in 1992. Three vessels still targeted almost exclusively saithe (I) in 1991 (figure 8). In 1992, these three vessels were not part of the fleet anymore, and strategy I disappeared (FROMNord 1992,1993). Some vessels followed always a "traditional" strategy (E6**;** 7 vessels in 1991, 6 in 1992), consisting in targeting North Sea saithe.

Deep-water sharks were landed from 1994 onwards (figure 10). Most vessels landed a substantial quantity of deep-water species. Several strategies could be identified depending on the proportion of saithe, orange roughy and black scabbardfish by-catches.

The percentage of saithe landed by vessels from Lorient continued to decrease and the proportion of deep-water species landings increased. Vessels from Boulogne developed two strategies. Some increased their percentage of saithe landings, while others targeted almost exclusively deep-water species. Orange roughy landings decreased regularly and in 2002 (figure 11), no vessel appeared to target this species. The proportion of blue ling landings dropped during the early nineties, increased in the second part of nineties (figure 9), but decreased again from 2000 onwards. In 2002, one vessel group fished almost exclusively saithe. A second vessels group caught principally deep-water species, mainly roundnose grenadier. Depending on the relative importance of saithe, roundnose grenadier and blue ling landings, eight subgroups were identified (figure 12).

This data exploration suggests that the strategies of the French off-shore fleet have changed in depth over the period 1985-2002. In order to define operational fishing unit from the outcomes of this study, it was necessary to simplify the comprehensive set of strategies identified here. Fisheries knowledge and biological aspects have been used as criteria to group similar strategies into categories.

Consider the Lorient fleet (figures 13 and 14). Historically, all vessels caught principally saithe (40-75%; table 3, strategy L1) with a substantial proportion of blue ling. Different by-catches (anglerfish, haddock, hake, cod) were caught mainly in ICES divisions VIa and VII (except VIId-e). In the early nineties, this strategy was replaced by an intermediate strategy (strategy L2). Vessels caught saithe (more than 20%) and deep-water species (20-40%). From 1995, vessels targeted principally deep-water species (40-75%), and alternatively blue ling or saithe (strategy L3). An alternative strategy (strategy L4) was followed in 1993-1994 and in 2000-2001 by another vessel. This vessel targeted mainly roundnose grenadier and alternatively orange roughy (20-40%).

Consider the Boulogne fleet (figures 15 and 16). In 1985, the vessels followed a similar strategy (table 3, strategy B1) to the Lorient fleet. The main difference was the fishing area. By contrast with the Lorient vessels, which fished principally off Western Ireland, vessels from Boulogne fished in ICES divisions IV and VIId. From 1986 to 1989, some vessels stopped fishing for blue ling (strategy B2). On the other hand, some vessels specialized in blue ling fishing, with small by-catch of saithe (strategy B3). Specialization continued with some vessels targeting almost exclusively saithe (strategy B4) from 1988 onwards. From the early nineties onwards, strategy B4 disappeared. Saithe fishing was offset by new strategies based on new species (deep-water species, orange roughy). Some vessels (strategy B6) caught almost exclusively deep-water species (roundnose grenadier, blackscabbard and deep-water sharks). A few vessels followed an intermediate strategy (strategy B5), by catching both saithe (25-50%) and deep-water species (20-40%). Finally, another strategy (B8) combined catches of the deep-water species group (40-75%) and of orange roughy (>20%). Besides, strategy B3 based on blue ling was replaced by different strategies. Vessels targeted blue ling with different by-catch proportions of saithe, orange roughy and deep-water species. In the late nineties, the number of fisheries targeting almost exclusively saithe (strategy B4) increased. A real specialization took place, with vessels landing more than 90% of saithe. By contrast, other vessels specialized in deep-water species and the intermediate strategy B5 disappeared. The proportion of orange roughy in one vessel’s landings increased until 1999 and then dropped. This strategy disappeared in 2002. From 2001, a new strategy (B7) appeared. Some vessels from Boulogne targeted both deep-water species in Faeroe waters and saithe in the North Sea.

Finally, 12 strategies could be identified: 4 for Lorient and 8 for Boulogne-Dieppe-Fécamp (table 3).

To explain the reasons of strategies changes, the correlation of different parameters with the proportion of vessels targeting saithe mainly in the North Sea (saithe strategy uptake) was tested (table 4). The saithe strategy uptake appeared to be correlated with the saithe TAC (r = 0.82), but not with the saithe SSB. One possible interpretation is that catch limits, rather than stock abundance, have had an effect in determining fishing strategies. However, the skippers' decision-making mechanisms are certainly more complex. For instance, since 1992, the saithe strategy uptake has increased more quickly than the saithe TAC (figure 17). Moreover, when both SSB and TAC increased substantially in 2000-2002, the number of vessels targeting saithe did not increase as expected. The development of this strategy could have been limited by market conditions and more particularly the decrease of the saithe landings price over the period 2000-2002.

DISCUSSION

The interactions between fleets and species play a major role in the fishery dynamics. Thus, the management of fisheries requires an analysis of fishing strategies to understand the adaptability of fishing fleets. Consequently, the identification of fishing tactics and strategies is still an important on-going issue for fisheries managers. Classical methods were based on PCA and cluster analysis (Biseau and Gondeaux, 1988; Lewy et Vinther, 1994; Taquet and al, 1997; Pelletier and Ferraris, 2000; Ulrich and al. 2001). Generally, these methods were based on the landing data of the most important species. The method developed in this paper is similar in that respect. However, to our best knowledge, the methods developed in the fisheries literature were of a static nature, as they did not incorporate a time dimension. The carrying idea of this study was to use such methods annually over a time period, and to analyze which fisheries appear and disappear.

Consider the cod fishery in Canadian waters. Of the 8 vessels registered in 1985, none fished in Canadian waters from 1991 onwards. The history of the Canadian cod stock probably explains this evolution. In 1980, the Department of Fisheries and Oceans (DFO) increased by 25% the TACs of groundfish species, which applied mainly to cod in NAFO areas 2J3KL. Consequently, the foreign allocation of the cod quota also increased (Mitchell, 1997). TACs allowed to French fleet made cod fishing an economically viable activity. From 1989 onwards, the Canadian Minister of Fisheries announced a reduction on TAC, to a point where cod fishing would not be economically viable for the

French fleet. As a consequence, the vessels, mainly coming from Saint-Malo, redirected their activity towards cod fishing in the Arctic thereafter.

Historically, vessels from Lorient, Boulogne, Fécamp and Dieppe followed a similar strategy. They landed principally saithe with a complement of blue ling and different traditional species (cod, haddock, whiting). The main difference was fishing areas. Vessels from North of France fished principally in the North Sea while those registered in Lorient fished in Northern and Western Ireland waters. This difference was traditionally due to the vessels fishing on stock densities located as close as possible to their home harbor. Since 1994, the French national quota of a number of species including saithe has been shared among producers organizations (PO). There are three quotas set for saithe in European Union (EU) waters, and these are distributed in three different fishing areas: the North Sea (ICES divisions IIa[EU waters], III[EU waters], IV), the Northern Shelf (ICES divisions Vb [EU waters], VI, XII, XIV) and the Southern Shelf (ICES divisions VII, VIII, IX, X, and COPACE34.1.1[EU waters]). Most of the vessels registered in the North of France belong to a PO which has most of the North Sea saithe quota share. Most of the vessels registered in Lorient belong to POs which have most of the Northern Shelf and Southern Shelf saithe quota shares. The differences in the quota share between POs is another explanation of the different fishing strategies pursued by the vessels registered in the North of France and in Lorient.

From 1985 to 2002, strategy shifts were observed, and we have examined some mechanisms that may have induced such changes. First, changes in the saithe fisheries appeared to some extent to be linked with the saithe TAC (table 4). In 1985, the biomass of the main saithe stock (North Sea, Skagerrak and West Scotland) was below the precautionary level Bpa. The biomass of this stock continued to decrease until 1992 (ICES advice for 2002 [on line]). As a result, the saithe TAC decreased from 200 000 tons to 127 000 tons between 1989 and 1992. Vessels targeting saithe had to adapt their strategy to maintain a viable fishing activity. An option was to find alternative species to balance lower saithe catches. First, blue ling fisheries developed. Then, in the early nineties, experimental trips allowed fishermen to identify new fishing areas for e.g. roundnose grenadier, black scabbard fish, and orange roughy. Blue ling and deep-water species were mainly caught in Western Scotland and Western Ireland waters, close to the traditional fishing areas of the Lorient fleet. Subsequently, vessels increased gradually their catches of the newly discovered deep-water species.

The reasons why this increase was gradual could be that, (i) vessels and gears had to be adapted to fish on deeper grounds and also that, (ii) a market had to be developed to facilitate the sale of these new species. The vessels from the North of France specialized their vessels: some continued to target almost exclusively saithe whereas others targeted more specifically deep-water species. Besides, within the groups of vessels targeting deep-water species, strategies have changed. At the beginning, fishing trips were mostly of an experimental nature. Then catches increased as fishermen learnt where and how these species could be fished and probably also because a market developed for these species.

From 1995 onwards, the biomass of the main saithe stock recovered gradually, exceeding Bpa from 1999 onwards (http://www.ices.dk/committe/acfm/comwork/report/asp/acfmrep.asp). Consequently, the saithe TAC increased. Following the recovery of the saithe stock, some vessels from Boulogne specialized on saithe in the North Sea, while others continued to target deep-water species in the more remote areas off Western Scotland and Western Ireland. In spite of the increase of the saithe biomass, vessels from Lorient continued to target principally roundnose grenadier, which had a more attractive landing value. In addition, and unlike vessels from Boulogne, the vessels from Lorient could harvest deep-water species on fishing grounds which were relatively close to those where they traditionally fished for saithe. Although economic information was not available to this study, one would expect the difference in operating costs for these vessels be offset by the gain in gross revenue brought about by the attractive landing value of the deep-water species.

In the second part of the nineties, the interest for the orange roughy fisheries dropped. Historically, orange roughy was caught in ICES division VI. Catches in this area decreased but were partially balanced by catches in division VII. Despite the high value of this fish, catches decreased and this species was not targeted since 2002. The sharp decrease in orange roughy landings might result from biomass depletion. This species is lives in aggregation and is slow-growing. There is concern that the fleets may exploit local aggregations sequentially. Once an aggregation is fished out, these fleets could explore and harvest other concentrations (ICES, 2002). The drop of orange roughy landings might also be explained by the market competition with other vessels targeting the same species.

TAC may play an important role in fisheries dynamic (table 4). The saithe strategies uptake decreased concomitantly with the saithe TAC in the early nineties, suggesting that TAC influenced fishermen behaviour. However, despite the increase in the saithe TAC over the period 1999-2002, the saithe strategy did not prove attractive over that period, suggesting that management is not the only determinant of strategies shifts, and that other factors should be considered.

The first factor is the possibility or not to target other species. In the mid-eighties, although saithe biomass was low, no alternative was really available for fishermen. Neither the fishing technology, nor the market conditions, were suitable to catch and commercialise deep-water species.

The second factor is the species availability. For instance, the drop in the abundance of orange roughy could have had an effect on the decline of the strategy based on that species.

The third factor is the market conditions. From 1999, although saithe biomass and TAC increased, the proportion of vessels targeting saithe decreased. Saithe landings could have been restricted by the drop of the saithe landings price (figure 17).

Our method was based on the application of PCA, followed by HAC, to annual landings. There are several reasons for performing a classification after a factorial analysis (Lebart and al., 1995; Pelletier and Feraris, 1999). The factorial axes and the projections of individuals on these axes derived from PCA may be difficult to interpret. For instance, although the first two axes usually can explain most of the variance, it may in some cases be necessary to consider the higher ranked axes (Biseau and Gondeaux, 1988). Besides, some marginal individuals may be very influential in the construction of axes. Consequently, defining clusters with PCA may be unrealistic when information is diluted on many axes and when marginal vessels over-influence the definition of factorial axes. Classification methods address these reservations by summarizing information in a way that is easier to interpret than individual projections. In addition, these methods are to some extent more robust to marginal individuals than factorial analysis because of the iterative algorithms used in HAC. Nevertheless, there are also several reasons for running a factorial analysis before a classification (Pelletier and Ferraris, 1999). In particular, factorial analyses provide a geometric description of the individuals, the variables and the relationships between them, which is helpful in exploring the structure of the data set.

Different linkages (simple, average or complete) were available to run the HAC. In our case, we chose simple linkage, which is the shortest distance between two groups. It means the distance between two groups is equal to the shortest distance between one element of first group and one element of the second group. This method has mainly been selected for its simplicity (one vessel is always aggregated with the most similar vessels). Jardine and Sibson (1971) argue that this method only has all the desirable properties of a clustering method. Nevertheless, one limitation of this method may be the "chain effect", and some authors argued that average or complete-linkage could sometimes be better metrics. In any case, we have tested these different method linkages and obtained similar results. The results were therefore robust to the metric used.

One important difficulty of our method was to define the most appropriate number of clusters. It is in theory possible to define 1 to n clusters, with n, the number of individuals (vessels). Selecting too few clusters belittles the amount of information available. By contrast, exaggerating the number of clusters would adversely affect analytical possibilities based on these clusters. In the absence of objective benchmarks, the compromise number of clusters was found by combining visual exploration of the clusters properties and experts knowledge of the French offshore fisheries. This approach is consistent with current practice (Lebart et al., 1995) and also ICES recommendations to identify fisheries groups (ICES, 2003).

Neither PCA nor cluster analysis are new methods. However, the scope of the paper was not to develop a new methodology to identify fisheries, but rather to apply existing methods to characterise fleet dynamics in terms of shifts in fishing strategies. It should also be noted that classification methods are routinely used by some ICES stock assessment working groups (e.g. Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim, Working Group on the Assessment of Southern Shelf Demersal Stocks) to define tuning fleets. In addition, clustering analysis has been advocated by ICES (2003) as one of the methods to be used to identify fishing units to perform mixed-fisheries forecasts.

Alternative multi-table analysis methods, including Multiple Factorial Analysis (MFA) (Escofier and Pagès, 1984) and the STATIS method (Lavit et al., 1994), could be considered. These methods allow characterization of the underlying common structure present in several tables as well as the variability of each of them comparative to the common structure. MFA however requires a constant number of observations (vessels in this study) over the years. Therefore, MFA could not be applied here as the number of vessels belonging to the fleet examined changed from one year to another. The STATIS method is more flexible. This method has been used in the past to analyse sensory profiling data, but it has also recently been applied to characterize the spatial and temporal distribution of marine biological data (Licandro et al., 2001; Gaertner et al., 2002). Although in our best knowledge the

STATIS method has not been applied yet to classify fisheries, it could prove to be a promising alternative approach in future investigations.
The present approach was based on an analysis of catch weights. When differences in prices are high, fishing strategies may be better reflected by the value of landings than by their weight. However, the landing value may also be a misleading variable to identify fishing strategies as it depends on price fluctuations and as it does not account for operating costs which may vary dramatically from one trip to another.

The fishing strategies identified in our study are, in some occasions, defined on the basis of the fishing behavior of one vessel. In any statistical analyses, marginal points are considered as outliers or points of specific interest. In our study, a marginal point is a fishing strategy, which can be pursued year after year by one vessel, but which may then be adopted by other vessels in the future. For example, a vessel followed the strategy C from 1985 until 1989. In 1985, only one vessel from Fécamp targeted blue ling. Few years later, others vessels started this fishery. This vessel should be considered as a precursor rather than an outlier.

The results of this study evidence the plasticity of fishermen behaviour and bear out the findings of other studies, which suggest that fishermen react quickly to the modification of their external environment (Ferraris, 1995). In the case study investigated here, a number of traditional fishing opportunities where restricted by biological and management constraints (low biomass and low TAC). Therefore, some fishermen explored new opportunistic fishing strategies, such as strategy L2 in 1992 (figure 13). As this strategy proved to be economically attractive, a larger proportion of fishermen adopted it. However, the mechanisms underlying fishing strategies and fishermen behaviour are certainly more complex than those investigated here.

Although some historical dynamics of the fishing strategies of the French offshore fleets have been identified, it is not possible to forecast, based on the findings of this study, what the future fisheries development will be. From 2003, TACs on orange roughy, roundnose grenadier, black scabbard fish and blue ling were established. The French fleet owns the main part of quotas. One critical issue would now be to evaluate the influence of those quotas on future fishing strategies. There is growing interest in analysing and modelling the processes underlying fishermen behaviour and decision-making. Various aspects of fleet dynamics have already been investigated, including the spatial allocation of fishing effort (Gillis et al., 1993; Holland and Sutinen, 1999), gear developments (Pech and Laloë, 1997), and discarding practices (Stratoudakis et al., 1998). There is scope in further developing such approaches into a comprehensive operational model, which could be applied by fisheries managers to forecast the fleets response and adaptation to management measures. This issue will be addressed in a companion study.

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Table 1: list of the main species fished by the French off-shore vessels fishing in the North Atlantic with bottom trawl.

English name	Latin name	number of stocks	stocks
Alfonsino	*Beryx splendens* (Lowe, 1834) *Beryx decadactylus* (Cuvier, 1829)	1	combined stock
Anglerfish	*Lophius piscatorius* (Linné, 1758) *Lophius budgassa* (Spinola, 1807)	3	North Sea (IIIa, IV, VI), Southwest Eire (VIIb-k), Gulf of Biscay (VIIIa-b, VIIId,VIIIc, IXa)
Atlantic cod	Gadus morhua (Linné, 1758)	10	Northeast Artic (I-II), North Sea-East Chanel (IIIa, IV, VIId), Island (Va), Faroe (Vb) West Scotland (VIa), VIb, Irish Sea (VIIa), South GB (VIIe-VIIk), XIV, Canada
Atlantic herring	*Clupea harengus* (Linné, 1758)	1	combined stock
Atlantic mackerel	*Scomber scombrus* (Linné, 1758)	1	North Sea (IV)
Atlantic redfish	*Sebastes marinus* (Linné, 1758) *Sebastes viviparus* (Kröyer,1845)	2	Northeast Artic (I-II), Northwest Atlantic (V-VI, XII, XIV)
Black scabbardfish	*Aphanus carbo* (Lowe, 1839)	1	combined stock
Blackbelly rose fish	*Helicolenud dactylopterus* (Delaroche, 1809)	2	Northeast Artic (I-II), Northwest Atlantic (V-VI, XII, XIV)
Blue ling	*Molva dypterygia* (Pennant, 1784)	2	Island (Va, XIV), Faroe-West GB (Vb, VI-VII)
European hake	*Merluccius merluccius* (Linné, 1758)	2	North Atlantic (IIIa,IV, VI-VII, VIIIa, VIIIb), Iberic (VIIIc, Ixa)
Greater forkbeard	*Phycis blennoides* (Brünnich, 1768)	1	combined stock
Greenland halibut	*Reinhardtius hippoglossoides* (Walbaum, 1792)	3	Northeast Artic (I-II), Northwest Atlantic (V,XIV), Canada
Haddock	Melanogrammus aeglefinus (Linné, 1758)	7	Northeast Artic (I-II), North Sea (IIIa-IV), Faroe (Vb), West Scotland (VIa) VIb, Irish Sea (VIIa), South GB (VIIb-VIIk)
Ling	*Molva molva* (Linné, 1758)	4	Northeast Artic (II), Faroe (Va), Island (Vb), North Sea-West GB (IV, VI-VIII)
Mis. chimaeras	*Chimaeridae*	1	combined stock
Mis. megrim	*Lepidorhombus whiffiagonis* (Walbaum, 1792) *Lepidorhombus boscii* (Risso, 1810)	3	West Scotland (VI), Southwest Eire-Gulf of Biscay (VIIb-k, VIIIa-b, VIIId) Iberic (VIIIc, Ixa)
Orange roughy	*Hoplostethus atlanticus* (Collett, 1889)	3	Faroe (Vb), West Scotland (VI), Southwest Eire (VII)
Portugese dogfish or Siki	*Centroscymnus coelopis* (Bocage & Capello, 1864)	1	combined stock
Roughead grenadier	*Macrourus berglax* (Lacepède, 1801)	4	Northeast Artic (II), North Sea (III-IV),Faroe (Vb),West GB (VI-VII)
Roundnose grenadier	*Coryphaenoides rupestris* (Günner, 1765)	3	Northeast Artic (II), Scandinavia (III), Faroe-West GB (Vb, VI-VII)
Saithe	*Pollachius virens* (Linné, 1758)	4	Northeast Artic (II), North Sea (IIIa, IV, VI), Island (Va), Faroe (Vb)
Tusk	*Brosme brosme* (Ascanius, 1752)	3	Northeast Artic (II), Island(Va), Faroe-West GB (Vb, VI-VII)
Whiting	Merlangius merlangius (Linné, 1758)	6	Skagerrak (IIIa),North Sea-Est Channel (IV, VIId), West Scotland (VIa), Vib Irish Sea (VIIa), South GB VIIe-VIIk
	Epigonus telescopus (Risso, 1810)	1	combined stock

<u>Table 2a:</u> Strategies description. First column indicates reference name (A1 to L). Each strategy is defined with the proportion of landings weight for different stocks

Name	>75%	40-75%	20-40%	1-20%
A1	cod (in Canadian seawater)			haddock saithe (IIIa,IV,VI)
A2	cod (in Canadian seawater)			
A3		cod (in Canadian seawater) cod (I-II)		
A4	cod (I-II)			
A5	cod (I-II)			saithe (IIIa,IV,VI)
B		blue ling (Vb,VI,VII)		blue ling (XII) redfish (V,VI,XII,XIV) saithe (Vb/IIIa,IV,VI)
C			saithe (IIIa,IV,VI) saithe (VIIb-c)	cod (VIa/IIIa,IV,VIId) haddock (VIa) hake ling (IV,VI,VII,VIII)
D		saithe (IIIa,IV,VI)		cod (IIIa,IV,VIId) haddock(IIIa,IV) mackerel redfish (I-II) whiting (IV,VIId)
E1 E2		saithe (IIIa,IV,VI)		anglerfish (IIIa,IV,VI) blue ling (Vb,VI,VII) cod (VIa/IIIa,IV,VIId) haddock (VIa) hake ling (IV,VI,VII,VIII) saithe (VIIb-c,VIII)
E3		saithe (IIIa,IV,VI)		blue ling (Vb,VI,VII) cod (IIIa,IV,VIId) haddock (IIIa,IV) hake herring (IV) ling (IV,VI,VII,VIII) redfish (I-II) whiting (IV,VIId)
E4		saithe (IIIa,IV,VI)		blue ling (Vb,VI,VII) cod (IIIa,IV,VIId) haddock (IIIa,IV) hake herring (IV) ling (IV,VI,VII,VIII) mackerel redfish (I-II) whiting (IV,VIId)
E5		saithe (IIIa,IV,VI)	blue ling (Vb,VI,VII)	halibut cod (IIIa,IV,VIId) hake herring (IV) ling (IV,VI,VII,VIII) redfish (I-II) whiting (IV,VIId)
E6		saithe (IIIa,IV,VI)		cod (IIIa,IV,VIId) haddock (IIIa,IV) hake herring (IV) ling (IV,VI,VII,VIII) mackerel redfish (I-II) whiting (IV,VIId)
F		blue ling (Vb,VI,VII)	redfish (V,VI,XII,XIV)	black scabbard fish saithe (Vb/IIIa,IV,VI)
G1		blue ling		redfish (V,VI,XII,XIV) saithe (IIIa,IV,VI/Vb) whiting (IV,VIId)
G2			blue ling (Vb,VI,VII) saithe (IIIa,IV,VI)	blue ling (IIa,IVa) redfish (V,VI,XII,XIV) whiting (IV,VIId)
H		saithe (IIIa,IV,VI)	blue ling (Vb,VI,VII)	black scabbard fish haddock (IIIa,IV) mackerel redfish (I,II/V,VI,XII,XIV) whiting (IV,VIId)
I	saithe (IIIa,IV,VI)			blue ling (Vb,VI,VII) cod (IIIa,IV,VIId) haddock (IIIa,IV) redfish (V,VI,XII,XIV) saithe (I,II / Vb) whiting (IV,VIId)
J		black scabbard fish	*Epigonus telescopus*	blue ling (Vb,VI,VII) orange roughy (VI) roundnose grenadier (XII/Vb,VI,VII)
K		roundnose grenadier (Vb,VI,VII)	blue ling (XII)	black scabbard fish blue ling (Vb,VI,VII) orange roughy (VI/VII) redfish (V,VI,XII,XIV)
L		orange roughy	roundnose grenadier (Vb,VI,VII)	black scabbard fish blue ling (Vb,VI,VII) forkbeard

Table 2b: Strategies description. First column indicates reference name (M1 to U2). Each strategy is defined with the proportion of landings weight for different stocks.

Name	>75%	40-75%	20-40%	1-20%
M1			roundnose grenadier (Vb,VI,VII) orange roughy (VI/VII 17% each) black scabbard fish	blue ling (Vb,VI,VII) redfish (V,VI,XII,XIV)
M2			roundnose grenadier (Vb,VI,VII) orange roughy (VI 19% / VII 4%) black scabbard fish	blue ling (Vb,VI,VII) redfish (V,VI,XII,XIV) saithe (Vb)
M3			roundnose grenadier (Vb,VI,VII) black scabbard fish	blue ling (Vb,VI,VII) forkbeard orange roughy (VII/VI) redfish (V,VI,XII,XIV/IV)
M4			roundnose grenadier (Vb,VI,VII) orange roughy (VII) black scabbard fish	blue ling (Vb,VI,VII) orange roughy (VI) redfish (V,VI,XII,XIV/IV)
M5			roundnose grenadier (Vb,VI,VII) orange roughy (VI 4% / VII 17%) black scabbard fish	blue ling (Vb,VI,VII)
M6		roundnose grenadier (Vb,VI,VII)	orange roughy (VI 7% / VII 17%)	black scabbard fish blue ling (Vb,VI,VII)
M7			roundnose grenadier (Vb,VI,VII) orange roughy (VI / VII)	black scabbard fish blue ling (Vb,VI,VII) redfish (V,VI,XII,XIV) saithe (IIIa,IV,VI)
N		saithe (IIIa,IV,VI)	cod (I,II)	black scabbard fish blue ling (Vb,VI,VII) redfish (V,VI,XII,XIV) roundnose grenadier (Vb,VI,VII)
O			roundnose grenadier (Vb,VI,VII) orange roughy (VI 5% / VII 16%) saithe (IIIa,IV,VI 19% / VIIbc 2%)	anglerfish (IIIa,IV,VI) haddock (VIa)
P			saithe (IIIa,IV,VI) blue ling (Vb,VI,VII)	black scabbard fish redfish (V,VI,XII,XIV) roundnose grenadier (Vb,VI,VII)
Q2			roundnose grenadier (Vb,VI,VII) saithe (IIIa,IV,VI)	anglerfish (IIIa,IV,VI) black scabbard fish blue ling (Vb,VI,VII) cod (VIa/IIIa,IV,VIId) haddock (VIa) orange roughy tusk (Vb,VI,VII)
R1		saithe (IIIa,IV,VI)		black scabbard fish blue ling (Vb,VI,VII) cod (IIIa,IV,VIId) haddock (IIIa,IV) ling (IV,VI,VII,VIII) orange roughy (VI) roundnose grenadier (Vb,VI,VII)
Q1		saithe (IIIa,IV,VI)		anglerfish (IIIa,IV,VI) black scabbard fish blue ling (Vb,VI,VII) cod (VIa) haddock (VIa) hake ling (IV,VI,VII,VIII) orange roughy (VI) roundnose grenadier (Vb,VI,VII) saithe (VIIb-c,VIII) tusk (Vb,VI,VII)
R2		saithe (IIIa,IV,VI)		blue ling (Vb,VI,VII) cod (IIIa,IV,VIId) haddock (IIIa,IV) ling (IV,VI,VII,VIII) orange roughy (VI) redfish (V,VI,XII,XIV) roundnose grenadier (Vb,VI,VII)
S		blue ling (XII 75%/Vb,VI,VII 25%)	orange roughy (VI)	black scabbard fish cod (I,II) orange roughy (VII) redfish (V,VI,XII,XIV) roundnose grenadier (Vb,VI,VII) saithe (IIIa,IV,VI)
T			roundnose grenadier (Vb,VI,VII) blue ling (Vb,VI,VII)	black scabbard fish orange roughy (VI) redfish (V,VI,XII,XIV) saithe (Vb / IIIa,IV,VI)
U1			roundnose grenadier (Vb,VI,VII) orange roughy (VII)	black scabbard fish blue ling (Vb,VI,VII) cardinalfish forkbeard siki
U2			roundnose grenadier (Vb,VI,VII) orange roughy (VII)	black scabbard fish blue ling (XII / Vb,VI,VII) blue whiting (IV,VIId) cardinalfish forkbeard ling (IV,VI,VII,VIII) saithe (IIIa,IV,VI) siki

Table 2c: Strategies description. First column indicates reference name (V1 to b2). Each strategy is defined with the proportion of landings weight for different stocks.

Name	>75%	40-75%	20-40%	1-20%
V1			roundnose grenadier (Vb,VI,VII) orange roughy (VII) black scabbard fish	blue ling (Vb,VI,VII) forkbeard orange roughy (VI) rosefish saithe (IIIa,IV,VI)
V2			black scabbard fish	blue ling (Vb,VI,VII) forkbeard orange roughy (VI) redfish (V,VI,XII,XIV) roundnose grenadier (Vb,VI,VII) saithe (IIIa,IV,VI) siki
V3			roundnose grenadier (Vb,VI,VII)	black scabbard fish blue ling (Vb,VI,VII) redfish (I-II / V,VI,XII,XIV) siki tusk (Vb,VI,VII)
V4			roundnose grenadier (Vb,VI,VII) black scabbard fish	blue ling (Vb,VI,VII) blue whiting (IV,VIId) forkbeard haddock (IIIa,IV) orange roughy (VII) ratfish redfish (I-II / V,VI,XII,XIV) saithe (IIIa,IV,VI) siki
W			roundnose grenadier (Vb,VI,VII) saithe (IIIa,IV,VI / VIIbc)	black scabbard fish blue ling (IV / XII / Vb,VI,VII) cod (VI / IIIa,IV,VIId) orange roughy (VI) redfish (V,VI,XII,XIV)
X		saithe (IIIa,IV,VI)		black scabbard fish blue ling (Vb,VI,VII) ling (IV,VI,VII,VIII) orange roughyy (VII) redfish (V,VI,XII,XIV) roundnose grenadier (Vb,VI,VII) siki
Y1			saithe (IIIa,IV,VI)	black scabbard fish blue ling (Vb,VI,VII) blue whiting (IV,VIId) cardinalfish haddock (IIIa,IV) orange roughy (VII) redfish (I,II/V,VI,XII,XIV) roundnose grenadier (Vb,VI,VII) saithe (I,II) siki
Y2			saithe (IIIa,IV,VI)	black scabbard fish blue ling (Vb,VI,VII / IV / XII) blue whiting (IV,VIId) cardinalfish haddock (IIIa,IV) orange roughy (VII) roundnose grenadier (Vb,VI,VII) saithe (I,II) siki
Z1		blue ling (Vb,VI,VII)	roundnose grenadier (Vb,VI,VII)	black scabbard fish orange roughy (VI / VII) siki tusk (Vb,VI,VII)
Z2		roundnose grenadier (Vb,VI,VII)	blue ling (Vb,VI,VII)	black scabbard fish orange roughy (VI / VII) siki tusk (Vb,VI,VII)
a		orange roughy (VII)		black scabbard fish blue ling (Vb,VI,VII) roundnose grenadier (Vb,VI,VII) siki
b1			blue ling (Vb,VI,VII) roundnose grenadier (Vb,VI,VII)	halibut orange roughy (VI / VII) ratfish saithe (IIIa,IV,VI) siki tusk (Vb,VI,VII)
b2			blue ling (Vb,VI,VII) roundnose grenadier (Vb,VI,VII) saithe (IIIa,IV,VI)	halibut orange roughy (VI / VII) ratfish siki tusk (Vb,VI,VII)

Table 2d: Strategies description. First column indicates reference name (c1 to g2). Each strategy is defined with the proportion of landings weight for different stocks.

Name	>75%	40-75%	20-40%	1-20%
c1			roundnose grenadier (Vb,VI,VII) blue ling (Vb,VI,VII)	black scabbard fish cod (VIa) halibut ling (IV,VI,VII,VIII) orange roughy (VI) ratfish redfish (V,VI,XII,XIV) saithe (IIIa,IV,VI) siki
c2			roundnose grenadier (Vb,VI,VII)	black scabbard fish blue ling (Vb,VI,VII) cod (VIa) halibut ling (IV,VI,VII,VIII) orange roughy (VI) ratfish redfish (V,VI,XII,XIV) saithe (IIIa,IV,VI) siki
d		roundnose grenadier (Vb,VI,VII)		halibut black scabbard fish blue ling (Vb,VI,VII) forkbeard orange roughy (VI / VII) ratfish siki
e			roundnose grenadier (Vb,VI,VII)	blue ling (Vb,VI,VII) black scabbard fish ratfish redfish (V,VI,XII,XIV) saithe (Vb) siki
f1		roundnose grenadier (Vb,VI,VII)		black scabbard fish blue ling (Vb,VI,VII) ratfish redfish (V,VI,XII,XIV) saithe (IIIa,IV,VI) siki
f2		roundnose grenadier (Vb,VI,VII)		black scabbard fish blue ling (Vb,VI,VII) ratfish redfish (V,VI,XII,XIV) siki
g1			blue ling (Vb,VI,VII) roundnose grenadier (Vb,VI,VII) black scabbard fish	saithe (IIIa,IV,VI) anglerfish (IIIa,IV,VI) ling (IV,VI,VII,VIII) ratfish redfish siki
g2			roundnose grenadier (Vb,VI,VII) black scabbard fish	anglerfish (IIIa,IV,VI) blue ling (Vb,VI,VII) ling (IV,VI,VII,VIII) ratfish redfish saithe (IIIa,IV,VI) siki

Table 3: Description of the finalised strategies (1985-2002). Each strategy is defined with the proportion (mean% / standard deviation) of landings weight for different stocks.

Strategy	>75%	40-75%	20-40%	<20%
strategy L1		saithe (53.5% / 8.3)		blue ling (13.0% / 6.0) anglerfish cod haddock hake ling
strategy L2			saithe (32.0% / 7.7) deep-sea group (29.8% / 7.3)	blue ling (13.6% / 7.7) anglerfish cod haddock hake ling redfish
strategy L3		deep-sea group (53.1% / 9.2)		saithe (16.7% / 6.2) blue ling (16.4% / 5.4) anglerfish cod forkbeard halibut orange roughy tusk redfish
strategy L4		deep-sea group (54.1% / 5.4)	orange roughy (32.4% / 4.5)	blue ling (4.72% / 5.8) saithe (1.12% / 1.3) forkbeard halibut redfish rosefish
strategy B1		saithe (55.2% / 11)		blue ling (13.8% / 6.2) cod haddock halibut herring ling mackerel redfish whiting
strategy B2		saithe (64.7% / 7.8)		cod haddock halibut herring ling mackerel redfish whiting
strategy B3		blue ling (54.7% / 11.6)		saithe (19.4% / 11) haddock ling mackerel redfish whiting
strategy B4	saithe (87.1% / 5.1)			cod haddock ling mackerel redfish whiting
strategy B5			saithe (37.5% / 6.9) deep-sea group (30.9% / 4.8)	blue ling (13.2% / 6.2) mackerel redfish tusk whiting
strategy B6		deep-sea group (65.3% / 9.1)	blue ling (21.0% / 8.7)	saithe (1.82% / 3.0) ratfish redfish
strategy B7		deep-sea group (50.8% / 6.1)	saithe (21.9% / 5.2)	blue ling (14.1% / 4.9) ratfish redfish
strategy B8		deep-sea group (52.1% / 8.5)	orange roughy (32.6% / 9.8)	blue ling (8.49% / 6.3) forkbeard ratfish redfish

Table 4: correlation coefficient of Pearson. * if p < 0.01%. Proportion: proportion of vessels taking part in the saithe strategy (strategies B1, B2, B4); SSB: spawning stock biomass of saithe; TAC: Total Allowable Catch of saithe; price: landing price of saithe

	proportion	SSB	TAC	price
proportion	1	0.08261	0.82476*	-0.26022
SSB	0.08261	1	-0.14793	0.4454
TAC	0.82476*	-0.14793	1	-0.42823
price	-0.26022	0.4454	-0.42823	1

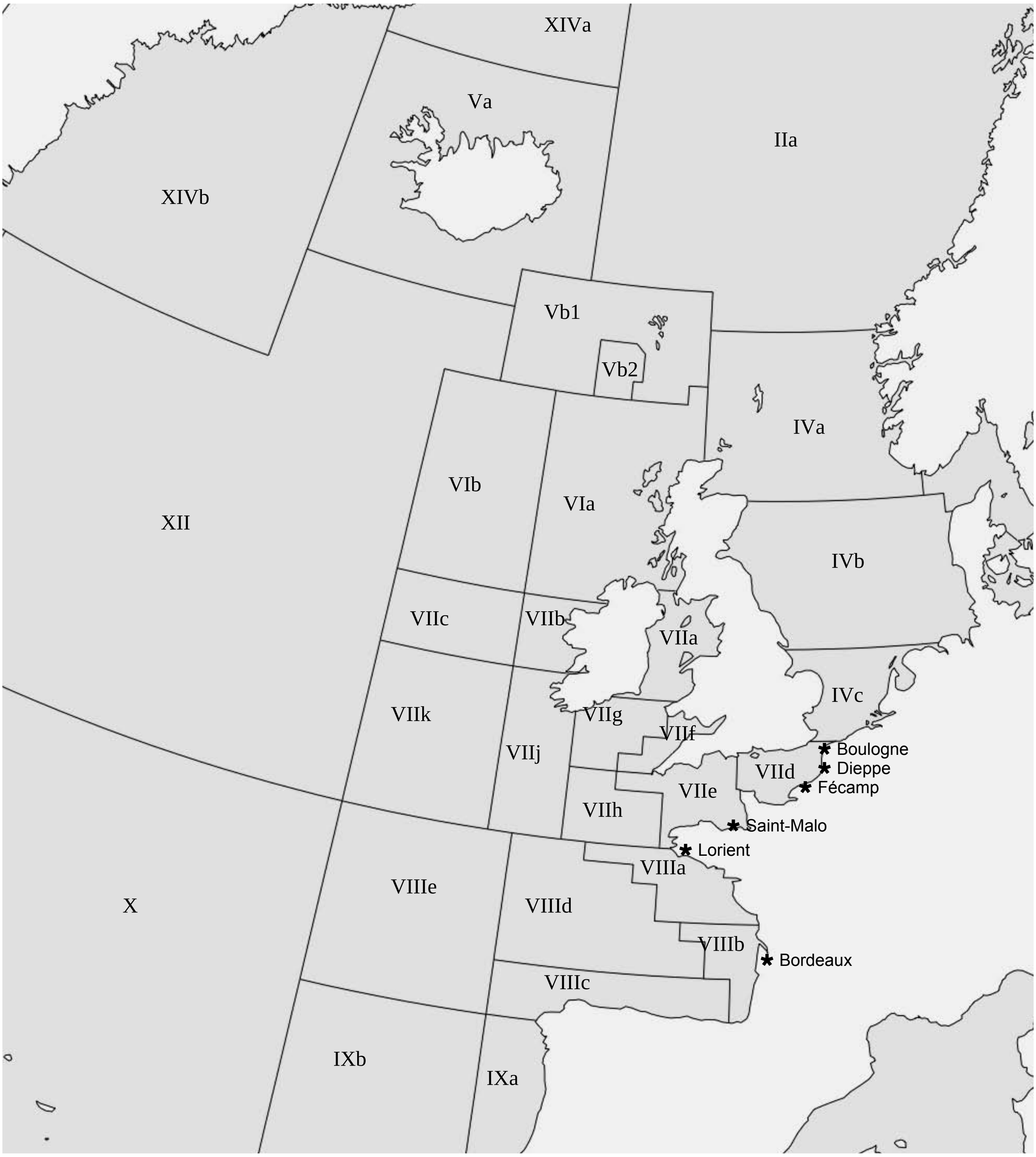


Figure 1: map of French harbors and ICES divisions.

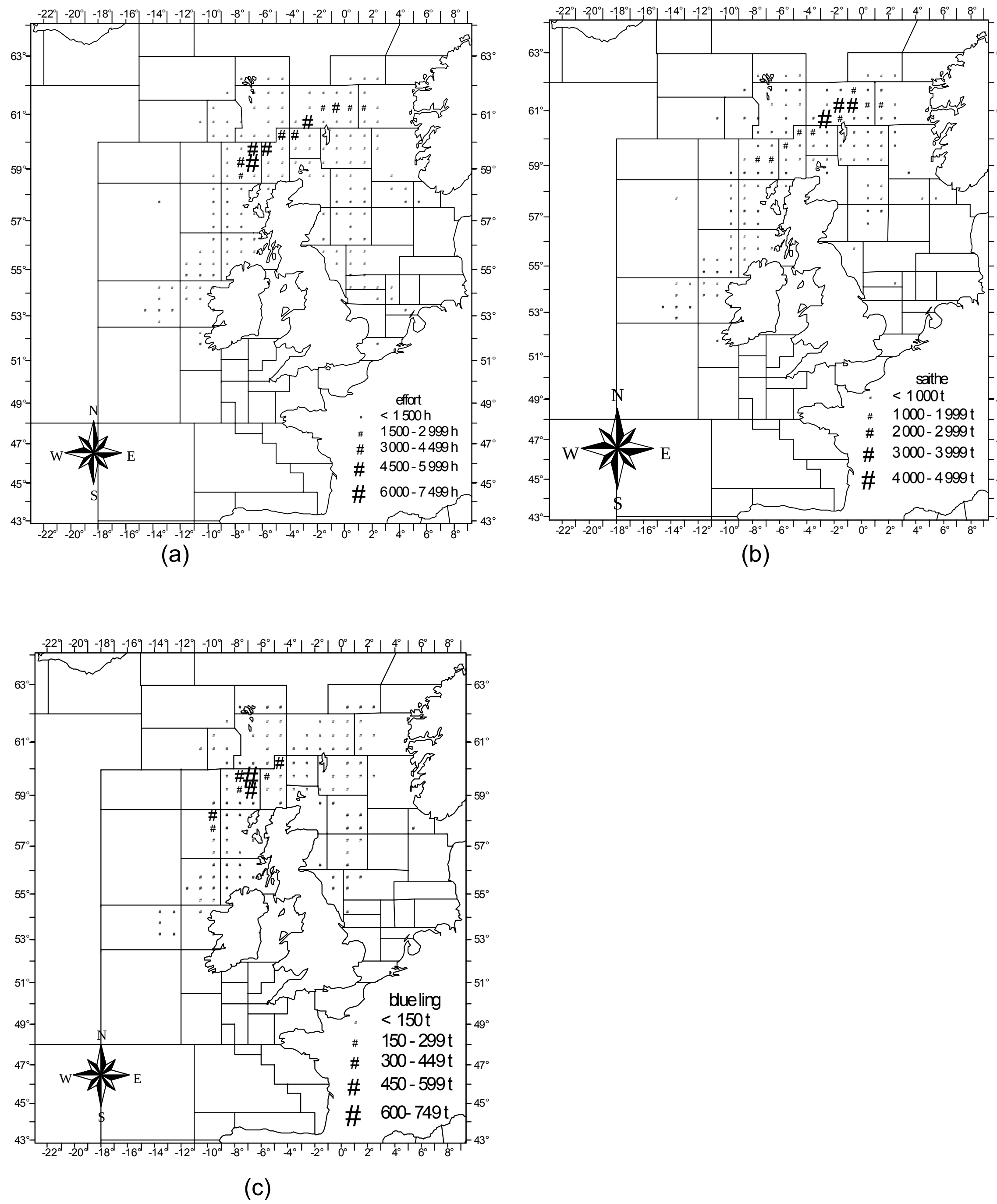


Figure 2: Spatial distribution of (a) fishing effort and of (b) saithe and (c) blue ling catches per ICES rectangle, for otter trawlers registered in Lorient, Boulogne, Dieppe and Fécamp. Missing data: fishing effort (39%), saithe catches (40%), blue ling (70%).

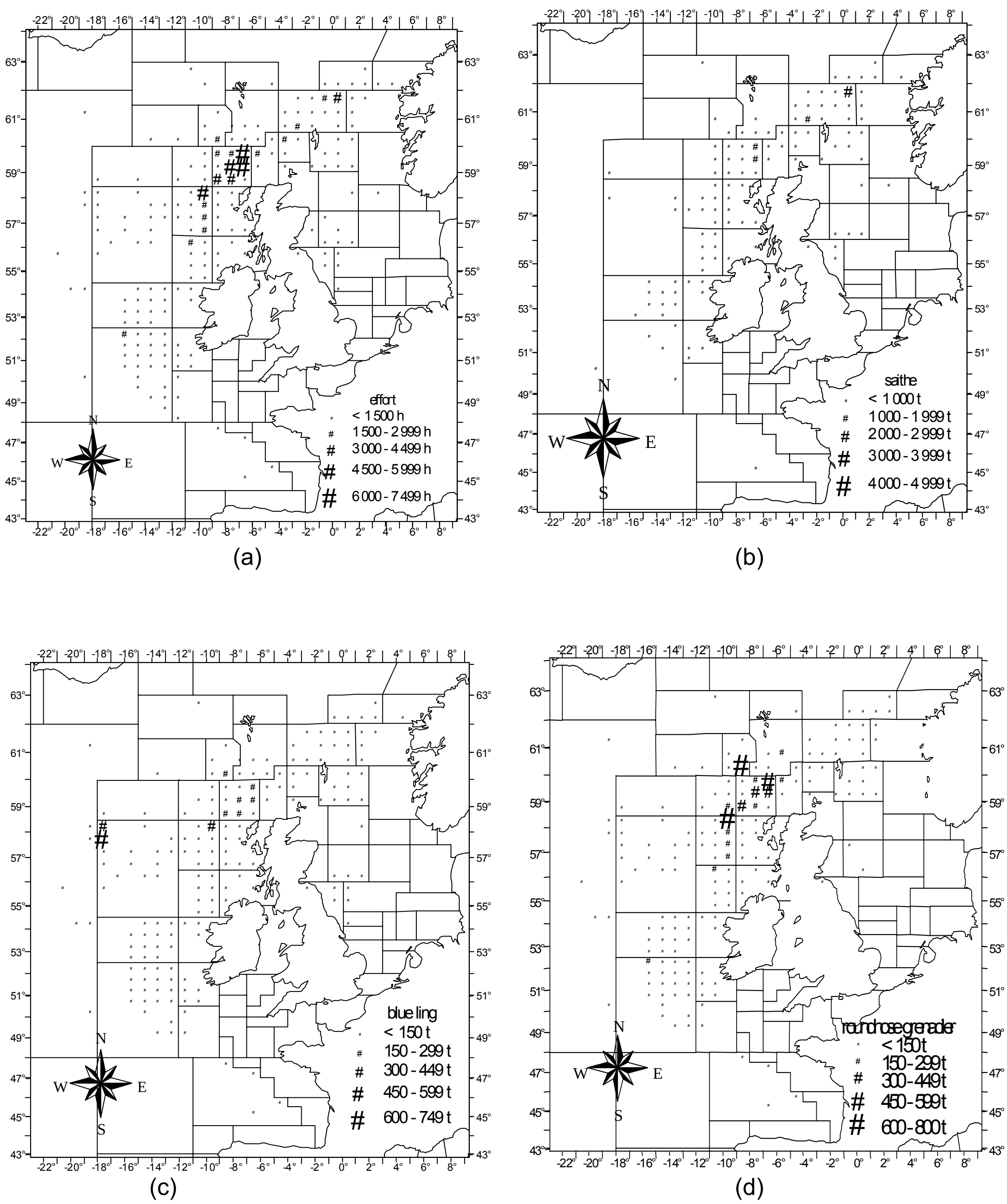


Figure 3: Spatial distribution of (a) fishing effort and of (b) saithe, (c) blue ling and (d) roundnose grenadier catches per ICES rectangle, for otter trawlers registered in Lorient, Boulogne, Dieppe and Fécamp. Missing data: fishing effort (13%), saithe catches (6%), blue ling (23%), roundnose grenadier (25%).

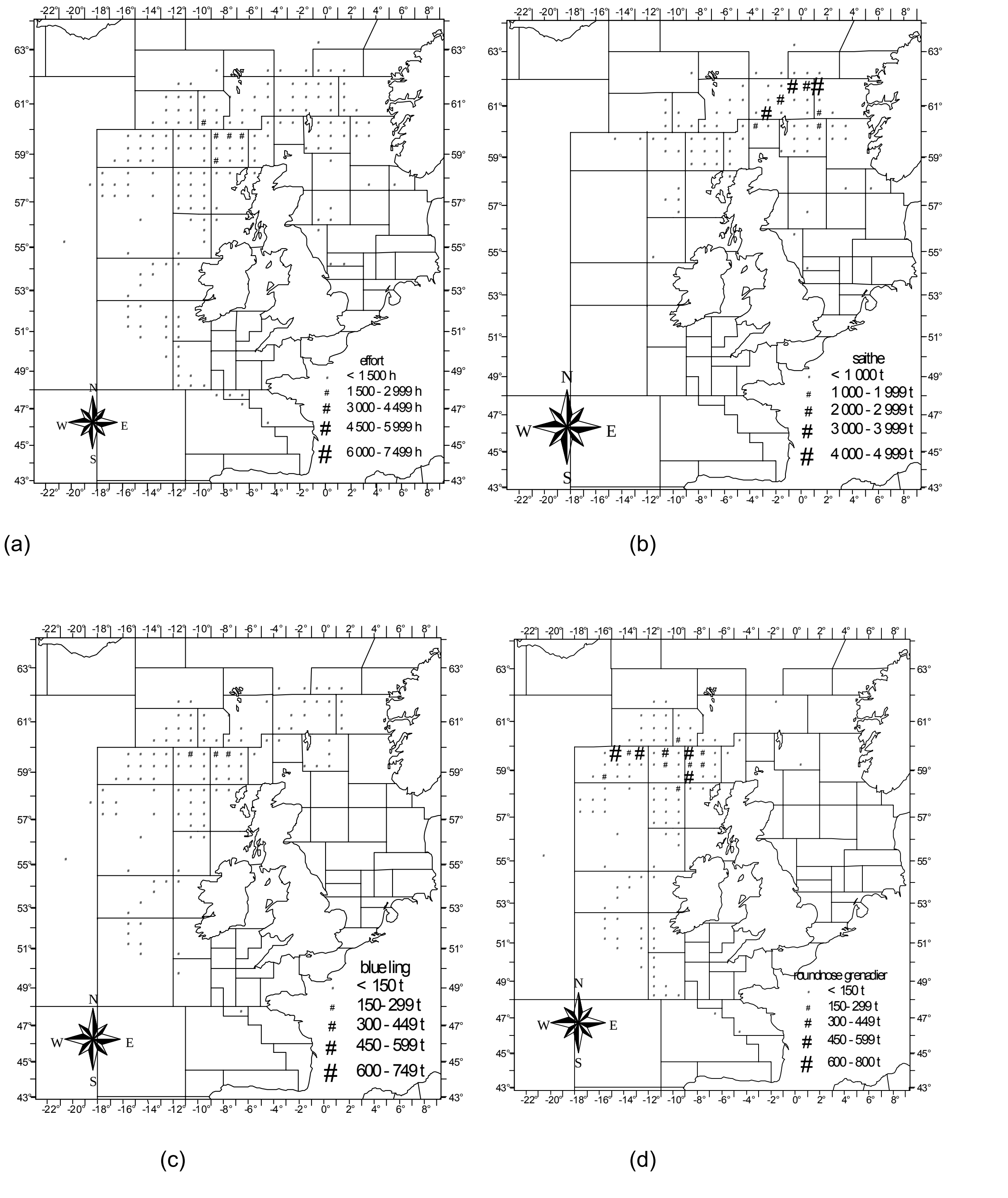
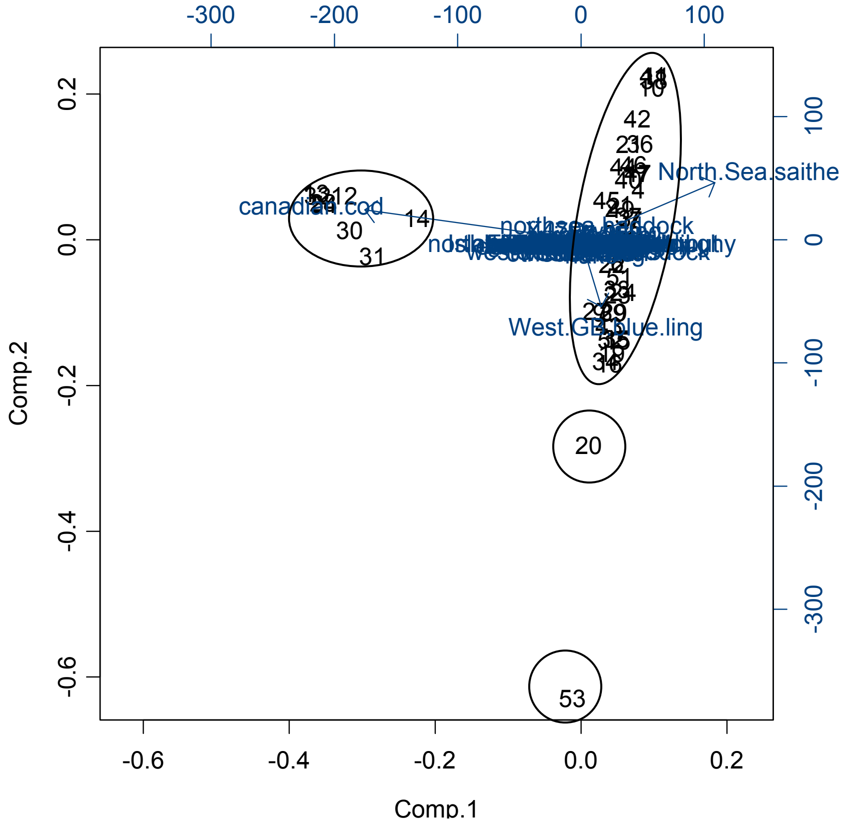


Figure 4: Spatial distribution of (a) fishing effort and of (b) saithe, (c) blue ling and (d) roundnose grenadier catches per ICES rectangle, for otter trawlers registered in Lorient, Boulogne, Dieppe and Fécamp. No missing data.



0.103

0.791

<u>Figure 5:</u> position of vessels (number 1 to 54) and stock variable in axes 1-2 of PCA (year:1985). 4 groups could be identified on these axes.

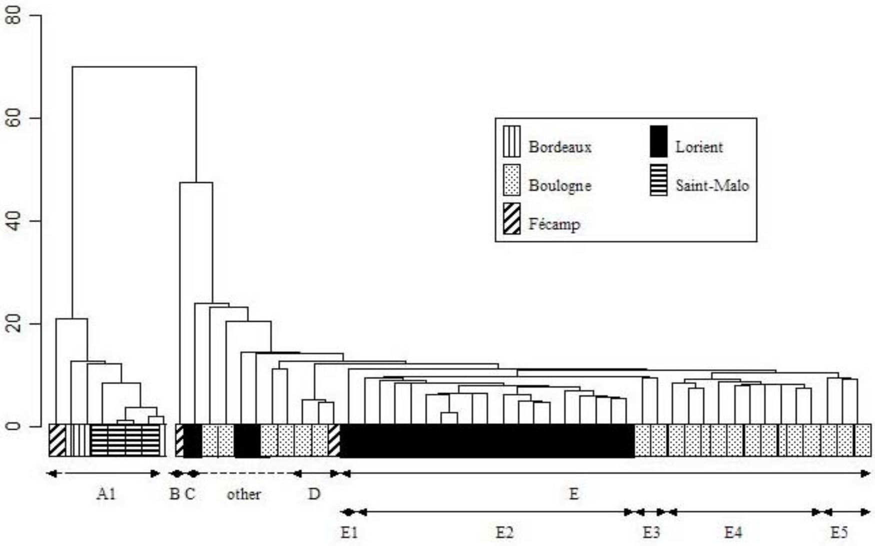


Figure 6: dendrogram of vessels fishing in 1985 obtained from hierarchical agglomerative cluster based on Euclidian inter-individual distance. Name of group is indicated on abscissa with details in table 2a.

Figure 7: dendrogram of vessels fishing in 1989 obtained from hierarchical agglomerative cluster based on Euclidian inter-individual distance. Name of group is indicated on abscissa with details in table 2a.

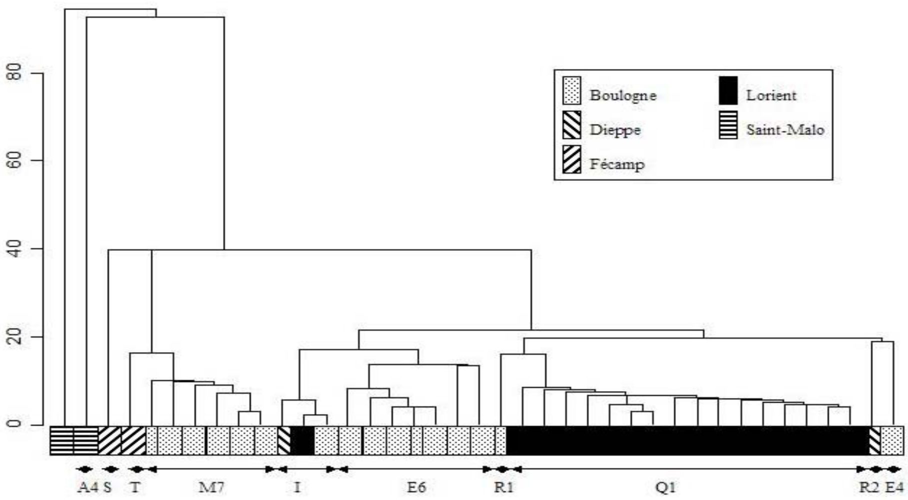


Figure 8: dendrogram of vessels fishing in 1991 obtained from hierarchical agglomerative cluster based on Euclidian inter-individual distance. Name of group is indicated on abscissa with details in table 2a and 2b.

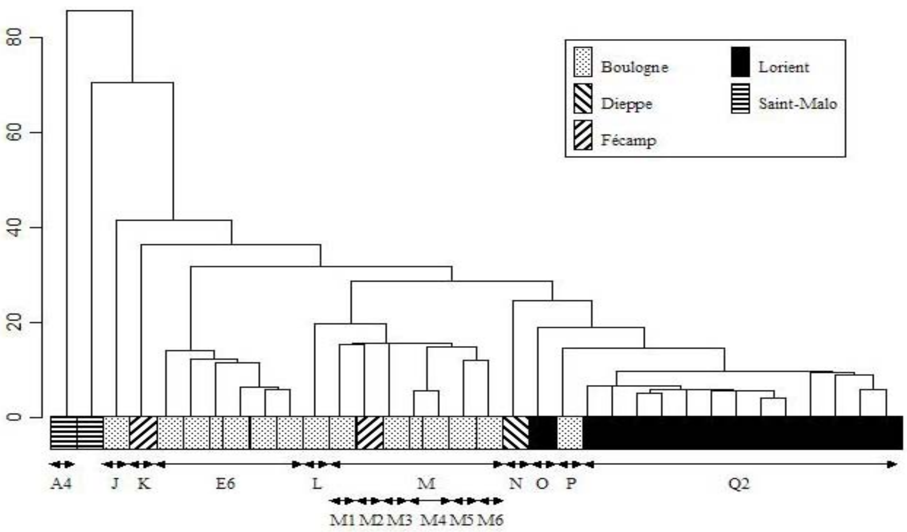


Figure 9: dendrogram of vessels fishing in 1992 obtained from hierarchical agglomerative cluster based on Euclidian inter-individual distance. Name of group is indicated on abscissa with details in table 2a, 2b and 2c.

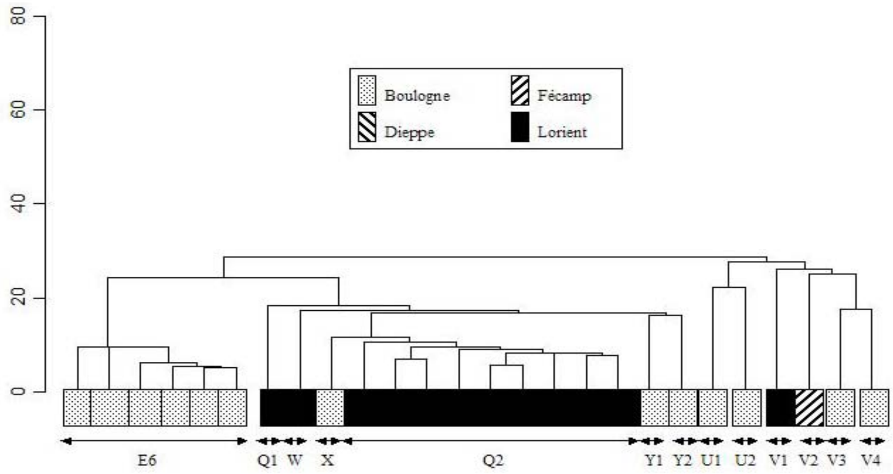


Figure 10: dendrogram of vessels fishing in 1994 obtained from hierarchical agglomerative cluster based on Euclidian inter-individual distance. Name of group is indicated on abscissa with details in table 2a, 2b and 2c.

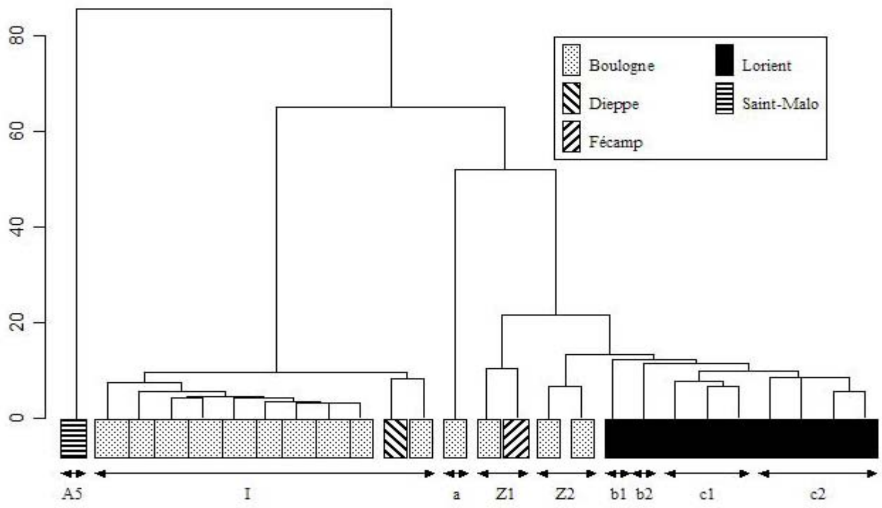


Figure 11: dendrogram of vessels fishing in 1999 obtained from hierarchical agglomerative cluster based on Euclidian inter-individual distance. Name of group is indicated on abscissa with details in table 2a, 2b, 2c and 2d.

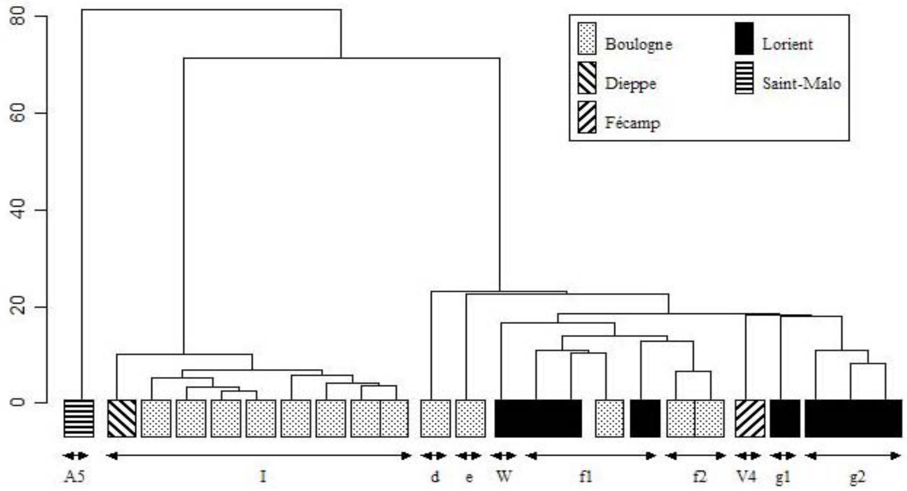


Figure 12: dendrogram of vessels fishing in 2002 obtained from hierarchical agglomerative cluster based on Euclidian inter-individual distance. Name of group is indicated on abscissa with details in table 2a, 2b, 2c and 2d.

Figure 13: Number of vessels by fishing strategy for the Lorient fleet over the period 1985-2002.

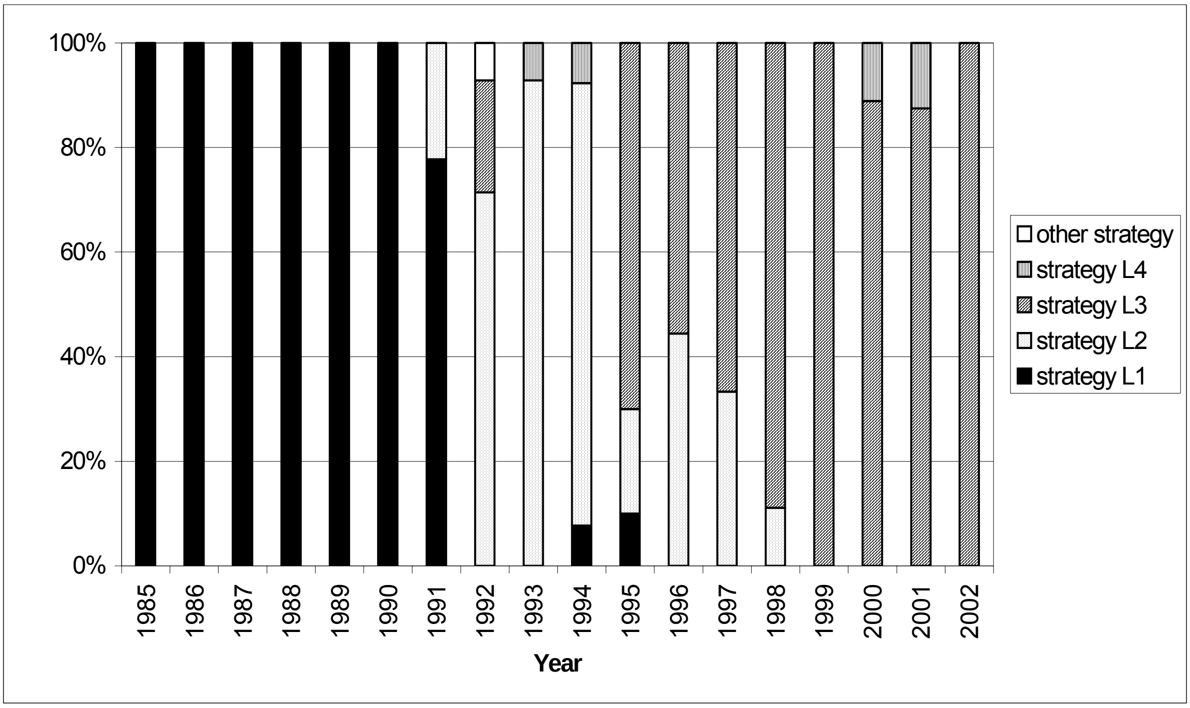


Figure 14: Proportion of vessels by fishing strategy for the Lorient fleet over the period 1985-2002.

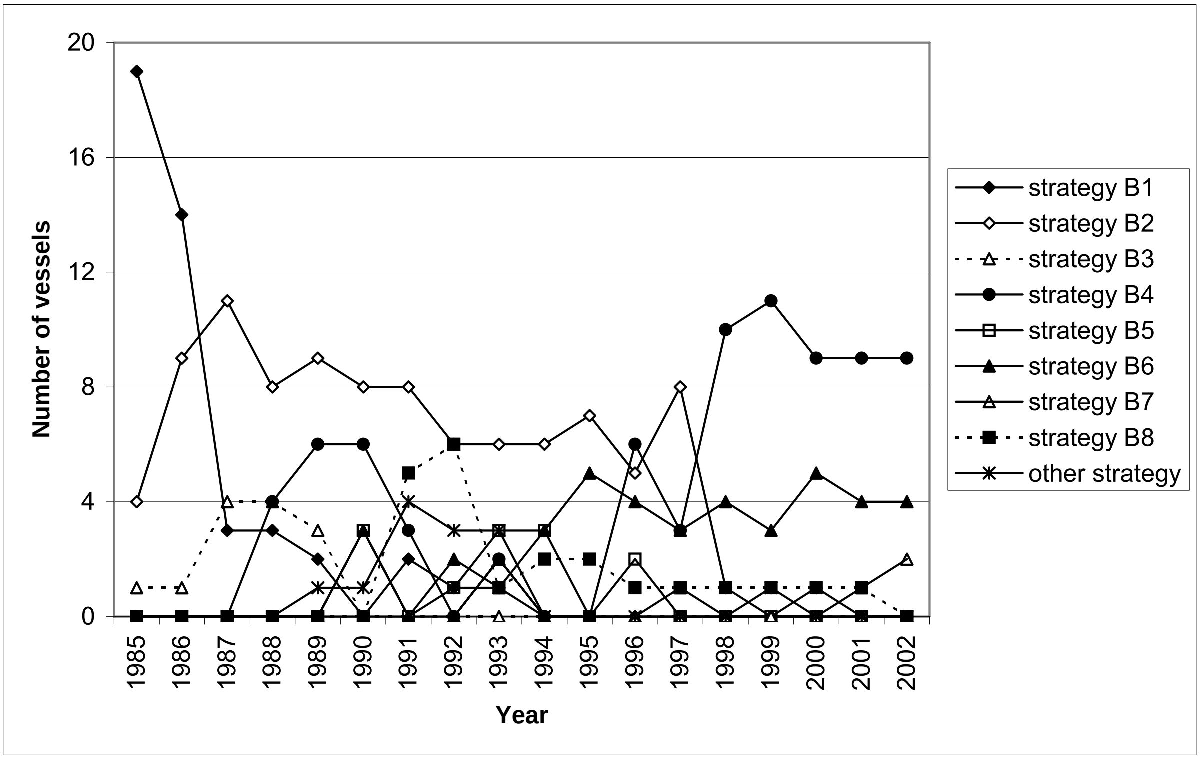


Figure 15: Number of vessels by fishing strategy for the Boulogne fleet over the period 1985-2002. Strategies of freezer vessels in 1994 and 1995 do not figure on this figure.

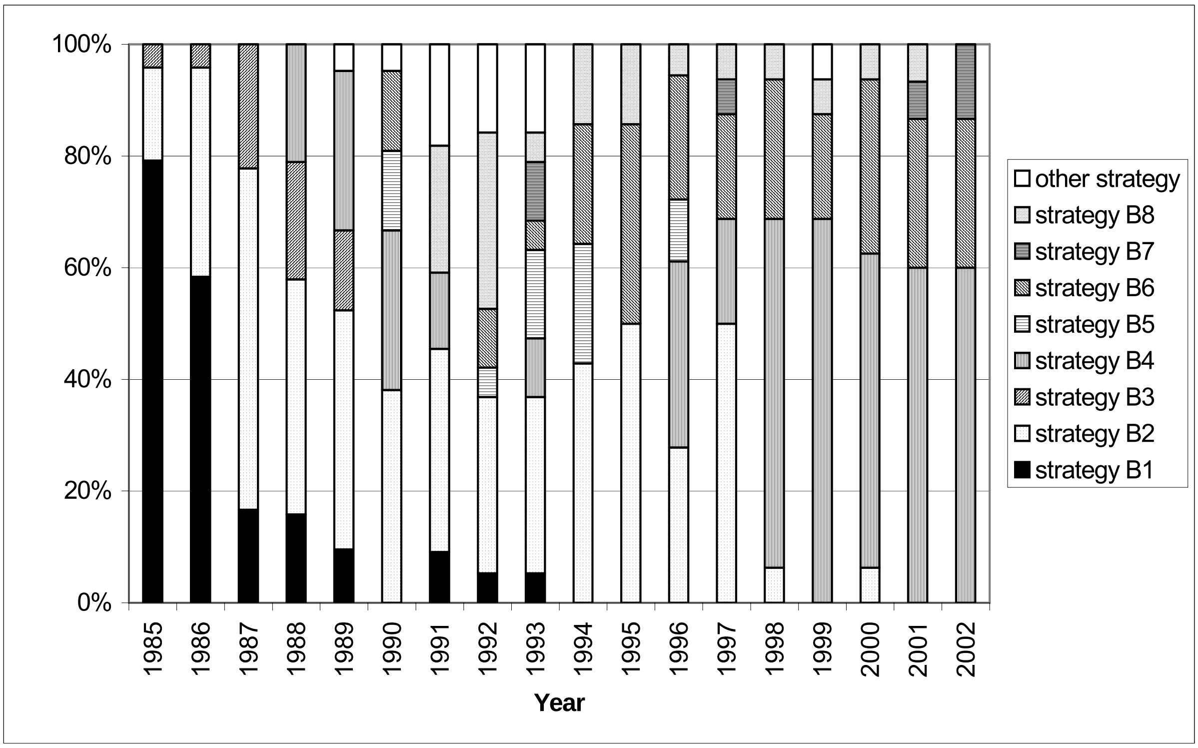


Figure 16: Proportion of vessels by fishing strategy for the Boulogne fleet over the period 1985-2002. Strategies of freezer vessels in 1994 and 1995 do not figure on this figure.

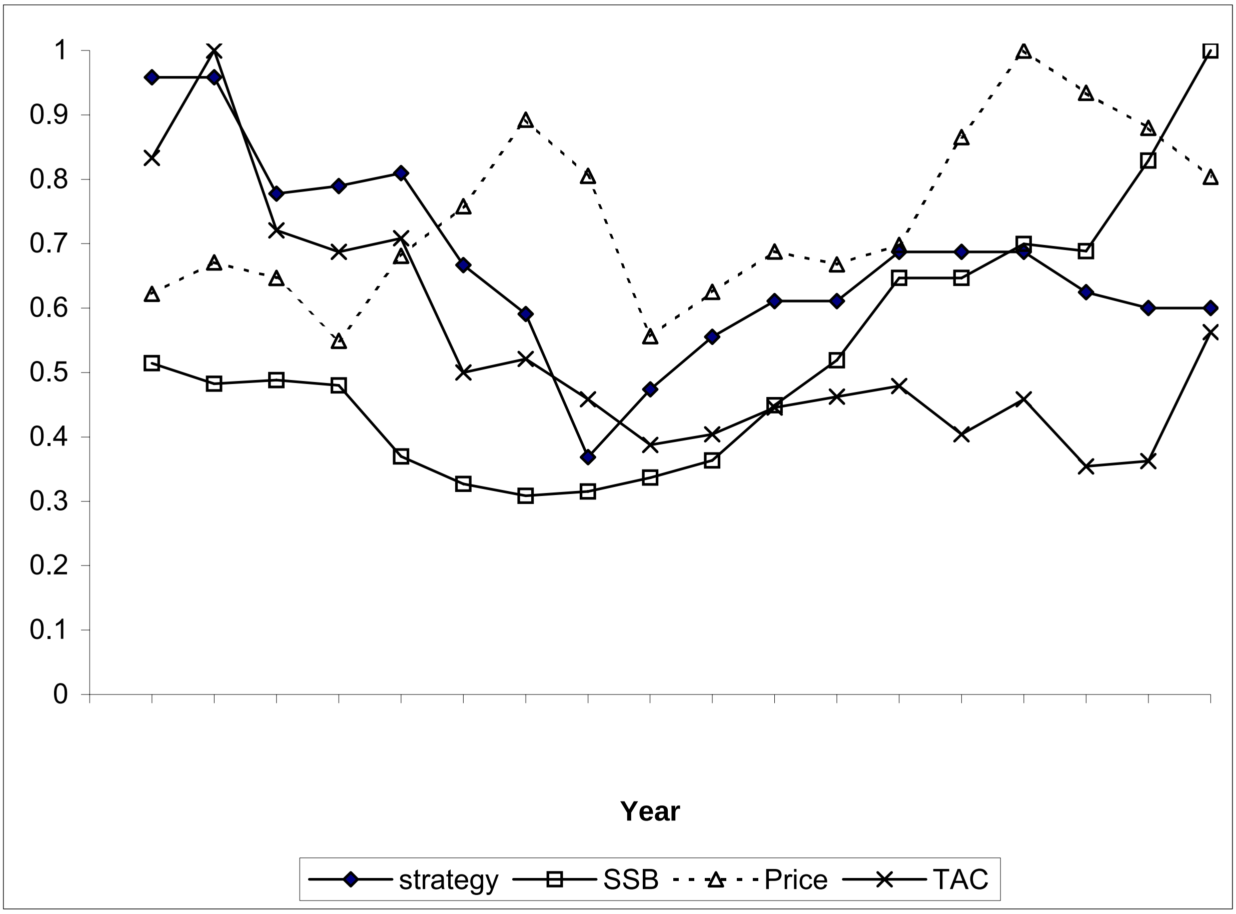


Figure 17: Annual variations of, (diamond) the proportion of Boulogne vessels which targeted mainly saithe (strategies B1, B2, B4), (square) saithe SSB,(star) saithe TAC (ICES areas IIIa and IV) and, (triangle) mean of saithe price. Each of these four variables has been scaled to its maximum value.