ICES Journal of Marine Science, 58: 1232–1242. 2001
doi:10.1006/jmsc.2001.1121, available online at http://www.idealibrary.com on IDEAL®

The influence of vessel size and fishing strategy on the fishing effort for multispecies fisheries in northwestern France

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Le Pape, O., and Vigneau, J. 2001. The influence of vessel size and fishing strategy on the fishing effort for multispecies fisheries in northwestern France. – ICES Journal of Marine Science, 58: 1232–1242.

The aim of this work is to study the factors that influence nominal fishing effort in the Bay of Seine fishing fleets. The nominal fishing effort of a fishing vessel is modeled gear by gear according to the data of a 1991 investigation on practical fishing methods.

These analyses give results on the influence of vessel characteristics and fishing strategy on the fishing effort. The role of both vessel characteristics and crew size are highlighted. The influence of the use of multiple gears on monthly nominal fishing effort per gear is quantified. The differences between fixed and mobile gears are shown, especially the fact that the amount of gear used depends on fishing strategy for fixed gears and fishing time depends on vessel size for mobile gears.

These results are then discussed with regard to managing fishing effort. We conclude that management measures must be different for fixed and mobile gears and must take into account adaptability of the fishermen.

Keywords: fishing effort, fisheries management, mathematical model, multiple gear fleet.

Received 3 August 1999; accepted 9 July 2001.

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Introduction

The major challenge fisheries managers face today is striking a sustainable balance between available marine resources and fishery policy employed to exploit them. The capacity of the fishing fleets is oversized and must be reduced if a balance is to be attained (Smith and Hanna, 1990; Gréboval and Munro, 1998). Consequently, the Common Fisheries Policy of the European Community employs successive multi-annual programmes to reduce the global horsepower of the fishing fleet.

One of the main problems of these programmes is that the influence of horsepower on fishing effort has not been quantified. It is, therefore, important to determine the main factors influencing fishing capacity in order to select the adapted methods of reduction.

Here we study the main factors influencing the fishing effort in the studied area, part of the English Channel (ICES Divisions 7D and E, Figure 1). A sample survey on fishing methods is used to model the monthly nominal fishing effort of sampled vessels. These data allow us to study the influence of several factors, including vessel characteristics and the use of multiple gears, on fishing effort. These results and utility of the methods prospects are then discussed with regard to harvest capacity reduction policies.

Material and methods

Definition of the nominal fishing effort

Fishing effort can be defined as the means that fishermen use during a given period to achieve a catch (Poinsard and Le Guen, 1975). This value is called "Nominal fishing effort (f) in contrast with the effective fishing effort (f_e) which quantifies the fishing pressure exerted by fishermen on fishing stocks (Gascuel, 1993). These two notion may be linked by Equation (1):

$$f_e = f \times P_f \tag{1}$$

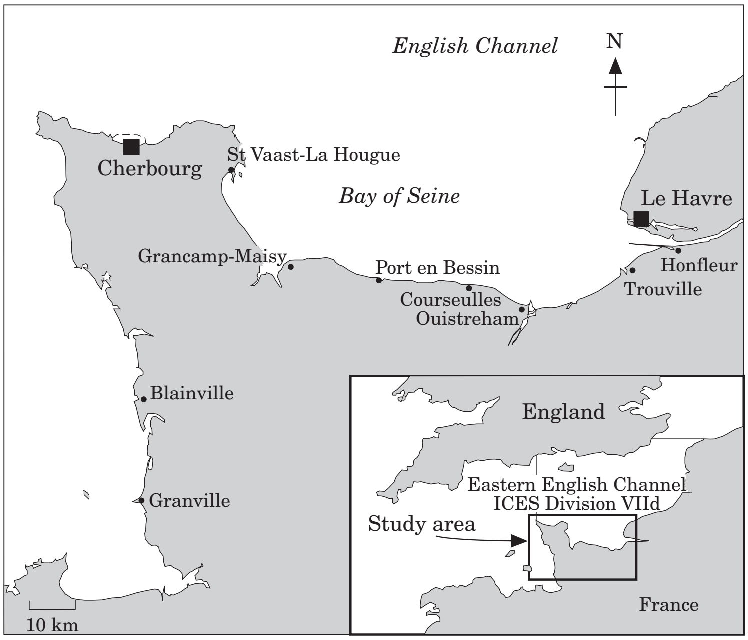

Figure 1. Location of the study site with main fishing ports.

with fishing power, P_f. This fishing power includes several factors in relation with the fishing methods (efficiency, selectivity etc.).

The fishing fleets studied

Our study focused on a fishing area off the northwestern coast of France, between the eastern and the western English Channel (Figure 1). In 1991, 773 vessels were fishing in this area and most of the fishing fleet was made up of small coastal vessels. Tétard *et al.* (1995) described the various fishing activities of this fleet which employs 24 different fishing gear (Table 1). The main feature of this fishing fleet is its ability to switch gear, each fishing vessel using an annual average of 3.3 gears.

As the coastal fleet mainly consists of small vessels, knowledge of landings is very poor. Landing data are mainly available for EC logbooks (vessels>17 m in 1991). In France, unrecorded landings can reach 40% of the total catch (Mettling *et al.*, 1995).

Data on vessels and fishing activities

In 1991, 343 of 773 fishing vessels were surveyed. Characteristics of each sampled fishing vessel "v" including length (L_v in m), gross tonnage (T_v in tons) and horsepower (P_v in W), were taken from the French national fishing vessels board and checked by fishermen.

For each sampled vessel, fishermen described a standard fishing month for all gears employed throughout the year: For each vessel "v", using a gear "g" at least part of the time, the following data were collected for a standard month: (i) the number of fishermen on board ($NF_{v,g}$); (ii) the number of gears used ($NGear_{v,g}$) and their size ($SGear_{v,g}$ in m); (iii) the number of trips per month ($NTrip_{v,g}$) and their duration ($DTrip_{v,g}$ in h); and (iv) the number of fishing operations per trip ($NFishOp_{v,g}$) and their duration ($DFishOp_{v,g}$ in h).

The duration of anymore fishing operation is defined differently from one gear to another, $DFishOp_{v,g}$, is the submersion time for a fixed gear but the duration between setting and hauling (the towing time) for a mobile one.

The monthly schedule of fishing activities per gear was also collected for each vessel. For each gear, the monthly schedule is completed with binary values, 1 if the gear was used during the month, 0 if not. Hence, according to this sample survey, the seasonal variations of fishing effort are binary, a gear is used or not used for a given month, and the monthly nominal fishing effort is always the same during the fishing season of this gear. Fishermen indicate, gear by gear, the nominal fishing effort that the vessel is able to develop, potentially, during an optimal fishing month, this potential not necessary being fully exploited due to external factors (weather, engine failure etc.).

The aim of this work is to study factors that may influence the nominal fishing effort of fishing vessels. Vessel characteristics are taken into account. Moreover, with respect to the use of multiple gears by the fishing vessel in the study area, the influence of the use of other gears on the nominal fishing effort with a gear has also

Table 1. Sample survey and fleet activities by gear on the study area. Asterisks indicate the gears for which there is sufficient survey data for a quantitative study.

	Target species	Number of boats	
		Sample survey	1991[a]
Fixed gears			
Prawn pot*	Prawn	19	26
Whelk pot*	Whelk	48	59
Big crustaceans pot*	Spider & edible crab, lobster	114	273
Cuttlefish pot*	Cuttlefish	68	115
Spider crab net	Spider crab	0	1
Gadoids net*	Cod, pollack . . .	35	63
Large mesh net	Turbot, brill, rays	14	27
Trammel net*	Flatfishes	69	100
Eel net	Eel	3	9
Fixed line	Sea bass	1	2
Floating longline	Porbeagle & others sharks	1	1
Bottom longline*	Spurdog, conger	27	64
Mobile gears			
Shrimp bottom trawl*	Shrimp	24	52
Bottom trawl*	Flatfish, cuttlefish	68	185
Otter trawl*	Gadoids, mackerel, etc.	81	169
Queen bottom trawl	Queen	4	15
Midwater trawl	Mackerel, sea bass, etc.	9	25
Beam trawl	Flatfishes	13	17
Queen beam trawl	Queen	4	6
Scallop dredge*	Scallop	71	208
Mussel dredge	Mussel	4	39
Clams dredge	Clams	7	47
Handline	Sea bass, pollack	12	38
Eel larvae strain	Eel larvae	1	4

[a] shows the number of vessels of the study area who used this gear in 1991 (Tétard *et al.*, 1995).

Table 2. Descriptors of fishing intensity.

Gear	$NGear_{v,g}$	$SGear_{v,g}$	Fishing intensity unit
Trawl	1	Length of net on the back	m
Pot	Number of pots	1	pot
Dredge	Number of dredges	Dredge width	m
Net	1	Total nets length	m
Longline	Number of hooks	1	hook

to be studied. First, a model of monthly nominal fishing effort and indicators of the use of multiple gears are defined.

The model of nominal fishing effort

To model the monthly nominal fishing effort of a fishing vessel v for one gear g ($f_{v,g}$), two main factors must be taken into account (Equation 2), the fishing intensity ($I_{v,g}$, the quantity of gears used simultaneously), and the monthly fishing time ($TFish/Month_{v,g}$):

$$f_{v,g}=I_{v,g} \times TFish/Month_{v,g} \quad (2)$$

Fishing intensity submodel

Equation (3) is used to model the fishing intensity of a vessel "v" for a gear "g" ($I_{v,g}$), the components $NGear_{v,g}$ and $SGear_{v,g}$ being detailed in Table 2. The unit of $I_{v,g}$ is hence a size (in m) for mobile gears and nets and a number of gears for pots and longlines.

$$I_{v,g}=NGear_{v,g} \times SGear_{v,g} \quad (3)$$

Monthly fishing time submodel

The fishing time during one trip ($TFish/Trip_{v,g}$ in h) is computed as Equation (4):

$$TFish/Trip_{v,g}=NFishOp_{v,g} \times DFishOp_{v,g} \quad (4)$$

The monthly fishing time ($TFish/Month_{v,g}$ in h) is then computed with Equation (5):

$$TFish/Month_{v,g}=NTrip_{v,g} \times TFish/Trip_{v,g} \quad (5)$$

Table 3. Descriptors of fishing activities (in h).

Symbol	Formula
$Acti/Year_{v,g}$	$\sum_{m=1}^{12\ months} Acti/Month_{v,g,m}$: Time spent at sea (working time) during one year for this gear $=SD_{v,g} \times (DTrip_{v,g} \times NTrip_{v,g})$ and $= \sum_{m=1}^{12\ months} Acti01/Month_{v,g,m} \times (DTrip_{v,g} \times NTrip_{v,g})$ =Season Duration in month × monthly time spent at sea for this gear
$ActiTot/Year_{v}$	$\sum_{g}^{Gears} Acti/Year_{v,g}$: Sum of the time spent at sea for all of the gears
$ActiTot/Season_{v,g1}$	$\sum_{g2}^{Gears} \left(\sum_{m}^{12\ months} (Acti/Month_{v,g2,m} \times Acti01/Month_{v,g1,m}) \right)$ Sum of the time spent at sea during the months when the gear g_1 is used

Units

The unit of nominal fishing effort is a number of gears per submersion time (in h) for pots and longlines and a total length per time (m × h) for mobile gears and nets. All of these units are different, as a number of hooks cannot be compared with a number of pots or a lenght of trawl per towing time with a length of net per submersion time. Hence, these models cannot be used to compare fishing effort of different gear but to study the determinism of fishing effort, gear by gear.

Indicators of vessel characteristics and of the use of multiple gears

The quantitative values of length (L_v), gross tonnage (T_v), horse power (P_v) and crew size ($NF_{v,g}$) are used to describe fishing vessel "v" characteristics. In order to study the influence of the use of multiple gears, three different indicators are developed. They are based on fishing schedules and on the fishing method per gear:

• Indicator 1: Season duration ($SD_{v,g}$) in months, Equation (6):

$$SD_{v,g} = \sum_{m=1}^{12\ months} Acti01/Month_{v,g,m} \quad (6)$$

with $Acti01/Month_{v,g,m}$: boolean value is equal to 1 if the vessel "v" uses the gear "g" during the month "m" and to 0 if he does not. $SD_{v,g}$ is the number of months a gear is used over a year.

Then, two other indicators are based on the working time for different gear. This working time is not equal to the monthly fishing time, which is the duration for which a gear is used. For example, the submersion time of fixed gear is not related to the time necessary to submerge the gear. On the other hand, the working time which is computed to describe the influence of the use of multiple gear has to be known for all gears together. $TSea/Month_{v,g}$, the time spent at sea for the trips when the gear g is used, represent the working time of the fishermen for a gear [Equation (7)]. There were not enough data to compute a more accurate homogeneous value for all gears.

$$TSea/Month_{v,g} = DTrip_{v,g} \times NTrip_{v,g} \quad (7)$$

Hence, the two last indicators are computed as follows. (i) Schedules of fishing activities are transformed to include the working time. The boolean values $Acti01/Month_{v,g,m}$ are transformed in $Acti/Month_{v,g,m}$ as shown in Equation (8):

$$Acti/Month_{v,g,m} = TSea/Month_{v,g} \times Acti01/Month_{v,g,m} \quad (8)$$

The fishing schedule of a vessel is hence a homogeneous representation of the time spent fishing month by month over one year for each gear used. (ii) Annual global fishing activities and the sum of fishing activities during the season of a given gear are computed (Table 3) and these values are used to compute the two ratings used as indicators (Table 4).

• Indicator 2: $Poly/Year_{v,g}$ (intermonthly interactions). As the season duration ($SD_{v,g}$), this rating quantifies the the proportion of the total fishing activity represented by this gear.

• Indicator 3: $Poly/Season_{v,g}$ (intramonthly interactions) represents the proportion of the time spent fishing in gear g during the months when gear g is used by vessel v. This rating quantifies interactions resulting from the use of several gears during the same period. Hereafter, this indicator is named "interactions between gears".

Statistical analyses and conditions of application

As there is no homogeneity between the different units of nominal fishing effort for the different gear, it is not

Table 4. Descriptors of the use of multiple gear.

Meaning	Symbol	Formula
Proportion of time spent on gear g on the yearly fishing activity	$Poly/Year_{v,g}$	$\frac{Acti/Year_{v,g}}{ActiTot/Year_v}$
Proportion of time spent on gear g on the fishing activity during the season when gear g is used	$Poly/Season_{v,g}$	$\frac{Acti/Year_{v,g}}{ActiTot/Season_{v,g}}$

possible to use a single model. Hence separate linear regression between monthly nominal fishing effort per fishing gear and explanatory variables of vessel characteristics and of the use of multiple gears are used for this study. The nominal fishing effort ($f_{v,g}$) and both the submodels $I_{v,g}$ and $TFish/Month_{v,g}$ are used separately as response variables to model gear by gear the influence of the descriptive factors.

If the description of fishing activities has demonstrated that 24 gears are used in the study area (Tétard *et al*., 1995), there are sufficient survey data (sufficient number of vessels deploying the gears) to allow a quantitative study for only 11 of them (Table 1). Nevertheless, the influence of the use of all gear is taken into account in the indicators $Poly/Year_{v,g}$ and $Poly/Season_{v,g}$.

Due to strong collinearity between the variables describing vessel characteristics, studying their respective influence by multiple regression methods was not appropriate. Preliminary Principal components Analyses (PCA) was used to solve this problem. Tables of these analyses were made for each gear, fishing vessels being the individuals (the lines) represented by four variables: L_v, T_v, P_v, and $NF_{v,g}$.

Preliminary studies have shown that, with this formulation, there was not a high proportion of zero values nor high variation rate and therefore no problems applying statistical tests of linear regression. Linearity of the relation between response and explanatory variables, steadiness of variance and gaussian distributions cannot be excluded.

As the conditions of application have been verified and as all significant estimated parameters are positive, analyses of the results are based on the proportion of the variation explained by the explanatory variables. Adjusted r^2 are used to study the results of linear regressions between nominal fishing effort and vessel characteristics. An adjusted r^2 takes the number of explanatory variables into account to compare results from simple and multiple regressions. On the other hand, the influence of the three indicators of the use of multiple gears is studied with multiple linear regression models that take both vessel characteristics and these three indicators into account. Squared partial correlation coefficients (proportion of the variation explained by one explanatory variable in a multi regressive model) are used to analyse these results.

Results

A synthetic descripton of vessel characteristics

Principal Components Analyses (PCA) of vessel characteristics and crew size have been led for the 11 types of gear and the results were very much the same as shown in Figure 2 for the PCA on prawn potters. The first principal component was made from L_v, T_v, and P_v, strongly correlated, and the second from crew size. These two components synthesized the inertia of the pool of variables: of the 11 gears studied, the first component contributes, on average, to 75% (64–84%) of the whole inertia and both these components to 90% (83–97%). According to these PCA, two factors were isolated: vessel characteristics and crew size.

In order to take both these factors into account, PCA are made on the three variables L_v, T_v, and P_v. Then, for each gear, the first component of this PCA, called $PC1(L_v,T_v,P_v)$ was used as indicator of vessel characteristics. $PC1(L_v,T_v,P_v)$, linear combination of centered reduced values of L_v, T_v, and P_v, represents the pool of variables describing vessel characteristics. This first principal component contributes, on average, to 86% (78–96%) of the global inertia for the 11 gears studied. $PC1(L_v,T_v,P_v)$ and $NF_{v,g}$. were used to study the respective effects of vessel characteristics and crew size.

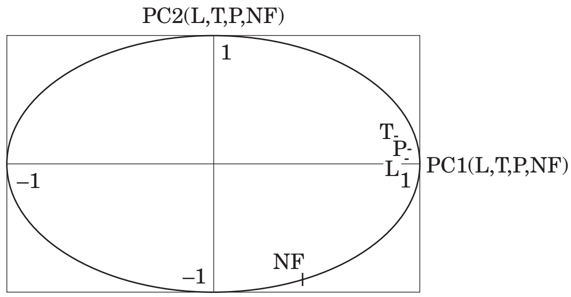

Figure 2. Two first components of the PCA on fishing vessels characteristics (length L, gross tonnage T, and horsepower P) and crew size (NF) for the prawn potters fleet (Point size is proportional to their contribution to the axis).

Table 5. Correlations between nominal fishing effort ($f_{v,g}$) and ship characteristics (adjusted r^2 in %). Asterisks indicate insignificant correlation.

	$PC1(L_v,T_v,P_v)$	$NF_{v,g}$	$PC1(L_v,T_v,P_v)$ & $NF_{v,g}$	$Size_{v,g}$
Fixed gears				
Prawn pot	56	21	52	49
Whelk pot	63	48	69	70
Big crustaceans pot	48	40	50	51
Cuttlefish pot	*	*	*	*
Gadoids net	46	40	44	46
Trammel net	41	44	44	44
Bottom longline	44	45	57	58
Mobile gears				
Shrimp trawl	61	57	63	66
Bottom trawl	64	45	64	61
Otter trawl	70	54	70	67
Scallop dredge	38	46	50	48

Moreover, a synthetic variable has also been used in this approach [Equation (9)]:

$$Size_{v,g} = PC1(L_v,T_v,P_v) + (NF_{v,g})_{cr} \text{ with } (NF_{v,g})_{cr} = \frac{NF_{v,g} - \overline{NF_{v,g}}}{\sigma(NF_{v,g})} \quad (9)$$

Adding the variable $(NF_{v,g})_{cr}$ to $PC1(L_v,T_v,P_v)$ takes into account both these factors on a single variable.

The influence of vessel characteristics and crew size on fishing effort

The following results come from analyses of correlations obtained from simple linear regression between monthly nominal fishing effort ($f_{v,g}$) and the two submodels Fishing intensity ($I_{v,g}$) and monthly fishing time ($TFish/Month_{v,g}$), used separately as response variables, and the indicators of vessels characteristics and crew size.

What is the main factor contributing to fishing effort: vessel characteristics or crew size?

Correlations obtained with $PC1(L_v,T_v,P_v)$ and $NF_{v,g}$, used as explanatory variables, and nominal fishing effort lead to contrasted results (Table 5): vessel characteristics give significantly higher correlations than crew size for trawlers, potters, and gadoid netters as opposed to scallop dredgers.

But the main feature is that correlations obtained with these two explanatory variables, used separately, are lower than those given when both are used in the regression or when the synthetic variable "$Size_{v,g}$" is used (Table 5). This result can be analyzed as demonstrating that both vessel characteristics and crew size influence fishing effort. With regards to this question, comparable results are obtained when the two submodels $I_{v,g}$ and $TFish/Month_{v,g}$ are used as response variables.

According to this result, the single variable "$Size_{v,g}$" is used in the following to study the combined influence of vessel characteristics plus crew size with standardized linear regressions. Then, to study the combined influence of these two factors on fishing effort, a separate study of fixed and mobile gears was made.

Combined influence of vessel characteristics and crew size on the monthly nominal fishing effort of fixed gears

Vessels using fixed gears are generally small (Table 6). For all gears, the variability of nominal fishing effort (Table 6) is due more to fishing intensity (average variation rate: 84%) than to fishing time (40%).

For all gears, except cuttlefish pots, similar results are obtained (Table 7): the number of gears is well correlated with "$Size_{v,g}$" and the monthly fishing time is not, the correlation obtained for whelk potters between "$Size_{v,g}$" and "$TFish/Month_{v,g}$" being an artifact caused by a few number of very small vessels. These results give to understand that correlations obtained for monthly nominal fishing effort (product of the two submodels) are lower than those obtained for fishing intensity.

Combined influence of vessel characteristics and crew size on the monthly nominal fishing effort of mobile gears

These gears are used by contrasted fleets, from small shrimp trawlers to quite large offshore trawlers (Table 6) and this gradient may also be seen on trawl size and on monthly fishing time. Unlike fixed gears, the variability (Table 6) of the quantity of gears (average variation rate: 35%) is lower than of fishing time (45%).

Both the quantity of gears and the monthly fishing time are correlated to "$Size_{v,g}$" for mobile gears (Table 7), these correlations being more important for fishing intensity. Correlations obtained for the monthly

Table 6. Ship size, fishing intensity, and fishing time per gear.

	Ship length (m)		Fishing intensity[a]		Monthly fishing time (h)	
	Average	Standard error	Average	Standard error	Average	Standard error
Fixed gears						
Prawn pot	7.8	1.5	134	93	504	168
Whelk pot	8.5	1.4	439	207	480	144
Big crustaceans pot	7.7	1.6	181	189	504	144
Cuttlefish pot	7.2	1	144	81	480	144
Gadoids net	7.7	1.6	1 411	1 448	408	192
Trammel net	8.2	1.9	2 162	2 219	360	120
Bottom longline	11.4	6.4	2 777	2 881	253	183
Mobile gears						
Shrimp trawl	9	1.6	8.1	2.3	130	49
Bottom trawl	12	2.9	13.5	4.4	235	123
Otter trawl	16	4.8	18	6.6	348	150
Scallop dredge	12.4	2.4	7.4	3	315	145

[a] given in number of pots and hooks and total size (in m) of nets, trawls, and dredges (Table 2).

fishing time are explained by the transition between small vessels fishing 12 hours per day, six days a week and larger ones fishing 24 hours a day over ten day tides with two day breaks.

This part of the work reaches two main conclusions: (i) vessel characteristics (length, gross tonnage and horsepower) and crew size both contribute to monthly nominal fishing effort, and (ii) there are significant differences in monthly nominal fishing effort determinism between fixed and mobile gears.

The influence of the use of multiple gears on fishing effort

Taking the influence of vessel characteristics into account

Vessel characteristics and crew size strongly influence fishing effort. Considering this effect, the study of multiple gear influence is made on the following regressions [Equation (10)]:

$$\text{Response}_{v,g}=a_1 \times (\text{Size}_{v,g})+a_2 \times (\text{Indicator})+a_3 \qquad (10)$$

where $\text{Response}_{v,g}$ is the studied response variable, the nominal fishing effort($f_{v,g}$) or one of his two components ($I_{v,g}$ or $\text{TFish/Month}_{v,g}$), $\text{Size}_{v,g}$ is the synthetic indicator of vessel characteristics plus crew size (included only if the simple regression between $\text{Response}_{v,g}$ and $\text{Size}_{v,g}$ is significant), and Indicator is $SD_{v,g}$, $\text{Poly/Year}_{v,g}$ or $\text{Poly/Season}_{v,g}$, indicators of the use of multiple gears, tested separately as explanatory variables.

Table 7. Correlations between the variable $\text{Size}_{v,g}$ and nominal fishing effort and its components (r^2 in %). Asterisks indicate insignificant correlation.

	$f_{v,g}$	$I_{v,g}$	$\text{TFish,Month}_{v,g}$
Fixed gears			
Prawn pot	49	68	*
Whelk pot	70	68	37
Big crustaceans pot	51	53	*
Cuttlefish pot	*	*	*
Gadoids net	46	53	*
Trammel net	44	50	*
Bottom longline	58	78	*
Mobile gears			
Shrimp trawl	66	48	38
Bottom trawl	61	64	32
Otter trawl	67	76	35
Scallop dredge	48	61	18

The influence of the use of multiple gears on the monthly nominal fishing effort of fixed gears

These tests lead to contrasted conclusions (Table 8): (i) partial correlations with $I_{v,g}$ are better for $SD_{v,g}$ or $\text{Poly/Year}_{v,g}$, representing the proportion of the annual fishing activity represented by gear g, than for $\text{Poly/Season}_{v,g}$ representing interactions between gear for tremmel nets and large crustacean pots but the contrary for whelk pots and gadoid nets. (ii) For prawn and large crustaceans pots, partial correlations between monthly fishing time and fishing season duration are significant. (ii) The results on submodels $I_{v,g}$ and $\text{TFish/Month}_{v,g}$ are synthesized on the model $f_{v,g}=I_{v,g} \times \text{TFish/Month}_{v,g}$. For Prawn, large crustacean pots and tremmel nets, partial correlations are higher with $SD_{v,g}$ or $\text{Poly/Year}_{v,g}$ than with $\text{Poly/Season}_{v,g}$. Due to the relation between $\text{TFish/Month}_{v,g}$ and $\text{Poly/Season}_{v,g}$ it is the contrary for whelk pots.

Table 8. Partial correlations (in %) between nominal fishing effort (and his components) and polyvalence descriptors. Asterisks indicate insignificant correlation.

	Response variable	Polyvalence descriptors		
		$SD_{v,g}$	$Poly/Year_{v,g}$	$Poly/Season_{v,g}$
Fixed gears				
Prawn pot	$f_{v,g}$	21	15	*
	$I_{v,g}$	*	*	*
	$TFish/Month_{v,g}$	32	*	*
Whelk pot	$f_{v,g}$	3	11	11
	$I_{v,g}$	4	11	11
	$TFish/Month_{v,g}$	*	13	19
Big crustaceans pot	$f_{v,g}$	10	15	9
	$I_{v,g}$	8	13	7
	$TFish/Month_{v,g}$	14	*	*
Cuttlefish pot	$f_{v,g}$	*	*	*
	$I_{v,g}$	*	*	*
	$TFish/Month_{v,g}$	*	*	*
Gadoids net	$f_{v,g}$	*	*	*
	$I_{v,g}$	*	*	11
	$TFish/Month_{v,g}$	*	*	*
Trammel net	$f_{v,g}$	4	*	*
	$I_{v,g}$	4	*	*
	$TFish/Month_{v,g}$	*	*	*
Bottom longline	$f_{v,g}$	*	*	*
	$I_{v,g}$	*	*	*
	$TFish/Month_{v,g}$	*	*	*
Mobile gears				
Shrimp trawl	$f_{v,g}$	*	*	*
	$I_{v,g}$	*	*	*
	$TFish/Month_{v,g}$	*	*	*
Bottom trawl	$f_{v,g}$	*	*	*
	$I_{v,g}$	*	*	*
	$TFish/Month_{v,g}$	*	*	*
Otter trawl	$f_{v,g}$	*	*	*
	$I_{v,g}$	2	*	*
	$TFish/Month_{v,g}$	*	*	*
Scallop dredge	$f_{v,g}$	6	6	3
	$I_{v,g}$	*	*	*
	$TFish/Month_{v,g}$	11	13	7

The influence of the use of multiple gears on the monthly nominal fishing effort of mobile gears

Except for a very low partial correlation between the size of the trawl and the season duration for otter trawl, there is no significant relation between fishing intensity, either monthly fishing time and indicators of the use of multiple gears for trawlers (Table 8). On average, a vessel using at least partly a trawling gear spends 48% of his annual fishing time using this gear, the rest of its time being distributed as following: another trawling gear (16%), scallop dredge (28%), and fixed gears (4%).

The use of other gears by trawlers is mainly induced by the fact that they practice scallop dredging in season. Their trawling activity, conducted throughout the rest of the year, is not affected.

There is no correlation between the total width of dredges ($I_{v,g}$) and the use of other gears by scallop dredgers. According to the results on trawlers and dredgers, fishing intensity does not depend on the use of multiple gears for mobile gears.

The higher the percentage of scallop dredging on the annual time spent fishing the higher the monthly fishing time for this gear. These correlations, and those obtained for the monthly fishing effort of dredgers, is better for $Poly/Year_{v,g}$ than for $Poly/Season_{v,g}$.

Two main conclusions may be drawn on the influence of the use of multiple gears on fishing effort: (i) the penalizing influence of the interactions with other gears on monthly fishing effort is less important than the fishing season duration or the proportion of the yearly fishing activity represented by this gear. (ii) Nominal fishing effort is very different between fixed and mobile gears.

Discussion

The model limits

Monthly nominal fishing effort models per gear, made from a survey on practical fishing methods, could have been improved. If the empirical formula of the nominal fishing effort, based on the knowledge of fishing gear and fishing operations, seems realistic, two main limits should be noticed: (i) the towing speed is not taken into account for mobile gear as it was not included in the survey questions. Consequently the unit of monthly nominal fishing effort for mobile gear is a length per time and not a covered surface. Van Marlen (1996) found that there were compensations between gear size and towing speed for beam trawlers and such an effect is not included here. (ii) The monthly fishing time of fixed gear is roughly modelled, the submersion time of these gears being unknown for several of them. Moreover, expression of the fishing time for a fixed gear is difficult to quantify.

On the other hand, indicators of the use of multiple gears could have also been improved, the knowledge of the working time being imprecise.

Nevertheless, even if the results could have been improved with more data and more accurate models and indicators, they cannot be considered as biaised. Correlations can be analysed with regards to nominal fishing effort even if some insignificant results arise from the model limits.

The few correlations obtained for the fixed gear fishing time have to be analysed with regards to the rough corresponding model. The lack of correlation between monthly fishing time and size for the fixed gears seems logical but other correlations with descriptors of the use of multiple gears should perhaps have been obtained with a more precise description of the fishing time.

The lack of correlations obtained for cuttlefish pots shows another limit of the studied model. This gear is deployed for a short season (maximum three months) by small vessels. The model does not seem to be adapted to describe such ‘‘secondary’’ gear. It provides results only for the gears that represent a consequent part of the global fishing activity.

Information on fishing effort

The influence of vessel characteristics and crew size

Previous authors have studied the relationships between vessel characteristics and crew size on fishing power or fishing effort, with contradictory results on the best explanatory variable. For trawlers, Beverton and Holt (1957) and Houghton (1977) found that gross tonnage was nearly proportional to fishing power, Zijlstra and De Veen (1964) that main engine power was the factor that most correlated with fishing power and Biseau (1991) that vessel length was the best factor; Gulland (1956) found a combined effect of gross tonnage and horse power on fishing power. For fixed gears, Pouvreau and Morizur (1995) found that total net length was proportional to vessel size and Taylor and Prochaska (1985) found that fishing power of longliners was best explained by both crew size and vessel size.

As shown by the PCAs and according to Smith and Hanna (1990) the correlations between vessel characteristics are strong and their influence cannot be discriminated.

On the other hand, this study demonstrates that both vessel characteristics and crew size are necessary for an optimal description of nominal fishing effort. Both these components determine fishing effort, their respective influence being variable from gear to gear. Factors such as quotas per fisherman for scallop dredgers certainly influence this determinism but such an accurate analysis was not included in this study.

The influence of the use of multiple gears

Two sorts of indicators, proportion of the annual fishing activity represented by a gear and interactions between gears are tested and the difference between the variation explained by these different explanatory variables is used to estimate the main driving factor.

For one gear, monthly fishing effort is more influenced by the relative importance of this gear on the yearly fishing activity than by interactions with other gears. This result is quite surprising as it appears more penalizing to deploy several gears during a given period than to use multiple gears throughout the year without technological interactions. In fact, fishermen do not use two incompatible gears during any one period which is why these interactions are not found to penalize fishing effort.

Generalization

According to these results, several differences appear between fixed and mobile gears on the fleet studied for fishing effort determinism.

(i) Fishing intensity is the main source of variability in the monthly nominal fishing effort for fixed gears conversely to mobile gears whose monthly fishing time is the main source of variability.
(ii) Vessel characteristics influence the monthly fishing time for mobile gears but not for fixed gears.
(iii) Trawlers and dredgers use the larger gears they can but for the fixed gears, the number/size of the gears depends on the importance of this gear on the fishing activity of the vessel.

These results lead to different formulae in order to represent nominal fishing effort of fixed and mobile gears.

(i) For fixed gears [Equation (11)]:

$$f_{\text{Fixed gears}}(\text{Size,Strategy}) = I_{\text{Fixed gears}}(\text{Size,Strategy}) \times \varepsilon \quad (11)$$

where ε is an imprecise model of monthly fishing time. ε is not correlated to "Size" and $\sigma(I_{\text{Fixed gears}}) > \sigma(\varepsilon)$.

(ii) For mobile gears (Equations 12 and 13):

$$f_{\text{Trawlers}}(\text{Size}) = I_{\text{Trawlers}}(\text{Size}) \times \text{TFish/Month}_{\text{Trawlers}}(\text{Size}) \quad (12)$$

$$f_{\text{Scallop dredgers}}(\text{Size,Strategy}) = I_{\text{Scallop dredgers}}(\text{Size}) \times \text{TFish/Month}_{\text{Scallop dredgers}}(\text{Size,Strategy}) \quad (13)$$

where $\sigma(\text{TFish/Month}_{\text{Mobile gears}}) > \sigma(I_{\text{Mobile gears}})$.

Implications for management measures

Due to the low economic performance of fisheries managed with restricted catches (Smith and Hanna, 1990; Holland and Sutinen, 1998), measures to reduce harvesting capacity are used to replace quotas in fishery management policy. The following part of the text examines the interest of these results for such management measures.

Fishing fleet reduction – Multiannual Guidance programmes

Several fisheries are managed with fishing fleets reduction policies, similar to the multiannual guidance programmes employed by European Community which are based on global fleet horsepower reduction.

Results on the influence of vessel characteristics confirm that horsepower can be taken as a fleet size indicator. Length, tonnage, and horsepower are correlated and any one of these values can be chosen to quantify fleet reduction.

On the other hand, this study shows that the best way to model nominal fishing effort is to take both vessel characteristics and crew size into account. Including crew size in the reduction criteria would improve the method to quantify this fishing effort and allow to take social aspects into account in these measures.

Some other limits of such a policy can also be pointed out from these results: (i) for mobile gear, vessel characteristics influence the monthly fishing time. A reduction of the fishing fleet should take this property into account. This is the case of the late Multiannual Guidance Programmes in which the fleet were segmented into several categories of size to apply reduction criteria. (ii) For fixed gear, monthly nominal fishing effort depends on the relative importance of this gear on the yearly fishing activity, which means on the fisherman strategy. This result seems to demonstrate that, for a given gear, vessels using multiple gears have a margin to increase their fishing effort. Such potential has to be taken into account to avoid reduction measures being inefficient.

The other management methods are based on fishing effort distribution. If they maintain fishing activities at a profitable level, they can be socially preferable as they do not exclude some economic actors from the system (Rey *et al*., 1997). Nevertheless, the difficulties to apply such measures often lead to fleet reduction policies. Two sorts of method are used:

(i) Reduction of the time spent at sea

The time spent fishing is not correlated with the fishing time for fixed gear. For these gears, monthly fishing time could at least partially be maintained in the case of reduction of the time spent at sea. Such a measure cannot be considered as efficient for this group of gears, season restriction excepted. This method could be used for mobile gears.

(ii) Reduction of fishing intensity

Vessels using mobile gears fish with the largest gears possible. It would be difficult to obtain agreement on such measures. Moreover, this policy can be compensated by an increase in towing speed (Van Marlen, 1996). On the contrary, this method is appropriate for fixed gears whose variability in fishing intensity is relatively high.

Taking fisherman strategy into account

The most interesting result of this study is that nominal fishing effort depends on the strategy of the fisherman; their adaptability is the main factor effecting the efficiency of management measures. Periodic studies on the trends of monthly nominal fishing effort, by comparable methods, would be necessary to control the efficiency of different measures of fishing effort reduction.

Acknowledgements

We thank Patrick Berthou, Marie-Laure Cochard, Pierre Duval, Liliane Fiant, Liliane Hélie, Dominique Miossec, Claude Morel, Jocelyne Morin, Thierry Pannier, Alain Tétard, (IFREMER) and Véronique Legrand (Regional Fishing commitee of Basse Normandie) for the sample survey. We also thank Philippe Gros (IFREMER) for his helpful advice, Alison Chalm (IFREMER) and Michael Chadwick (ICES journal editor) for the English language and Alain Biseau, Jean Bernard Pérodou, Arnauld Souplet, Benoit Mesnil, Dominique Pelletier (IFREMER) and the two anonymous reviewers for their fruitful suggestions.

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