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Impact of technological creep on fishing effort and fishing mortality, for a selection of European fleets

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Abstract:

Face-to-face interviews were conducted to identify the main changes in gear and vessel technology that may have improved the fishing efficiency of a number of French, Danish, and Basque fleets over the past few decades. Important changes include the gradual appearance of twin trawls (Danish and French trawlers) and trammel-nets (French gillnetters), and the increased polyvalence of Basque bottom trawlers. The results suggest that fishing effort descriptors that are not traditionally measured (gear type, groundrope type, length of net used per day, headline length, crew size, number of winch or net drums) may have a substantial impact on catch rates. Adjusting fishing effort using such descriptors may generally improve the relationship between fishing effort and fishing mortality.

Keywords: catch rate; fishing effort; fishing mortality; generalized linear models; groundrope; technological creep; twin trawls.

INTRODUCTION

Commercial fishers continuously adapt their activities to the prevailing conditions by changing the physical inputs of production (technological development) and the way these inputs are used to harvest target species (tactical adaptation). There is evidence that the efficiency of fishing vessels has increased over the last decades, as a result of technical creeping. Quantifying the importance of fishermen's reactions relies on the ability to define appropriate standardised effort measures, which depends on the detail of data available on fishing effort. Fishing effort is traditionally estimated by combining available physical measurements of fishing capacity (fixed production inputs) and of fishing activity (variable production inputs). Fishing capacity is frequently approached by some physical attribute of the operating vessel (engine power, gross tonnage) but is also dependent on other factors, including gear technology and on-board equipment, which are often ignored. The introduction of new gear and technology includes both larger marked technological investments (e.g. acoustic fish finding equipment, electronic navigation tools) and smaller stepwise improvements of the gear (e.g. stronger netting material, changes in the design of trawl panels), which themselves do no not result in marked changes of a vessels capacity but in conjunction give a noticeable capacity increase over time. Fishing activity is typically estimated by the duration of fishing trips. Such a definition ignores a number of factors which may potentially impact fishing pressure, including the number and the size of gears deployed, or the effective time used for fishing.

A number of studies have been carried out to evaluate time variations in fishing efficiency (Cook and Armstrong, 1985; Millischer et al., 1999; Marchal et al., 2001; Marchal et al., 2002). However, these studies did not investigate the extent to which such variations could be attributed to the technological development of the fishing fleets. A number of studies aimed at getting more insights into the key processes of technical creeping. Such investigations were often based on the analysis of variations in either catch per unit effort (CPUE), or catch value per unit effort (VPUE), or profit, using a variety of modelling approaches ranging from simple GLM (Robson, 1966; Gavaris, 1980; Kimura, 1981; Hilborn, 1985) to more complex Stochastic Production Frontier (Pascoe et al., 2001) or multi-output distance functions (Squires, 1987; Squires and Kirkley, 1996). However, the scope of such approaches was generally restricted by vessel information available from log-books, which typically include engine power, vessel length and/or gross tonnage.

This study investigates the technological development of fishing vessels, with the general objective of refining measures of fishing capacity and fishing activity. New information on historical vessel and technological developments has been collected through harbor enquiries. The information on technological developments has been analysed so to assess their importance for the catching efficiency of the fleets, using Generalised Linear Models. The most important elements of technical developments will then be used to adjust fishing effort. Finally, the benefits of adjusting fishing effort will be evaluated by examining the relationship between fishing mortality and fishing effort, for the fleets and fish stocks under investigation. The case studies examined in this study are based on a selection of Danish, French and Spanish fleets and on their main target species.

MATERIAL AND METHODS

Data

Annual changes in fishing effort

The collection of data on the evolution of fishing effort has been carried out between April and October 2004 for the French fleets, between March 2004 and April 2005 for the Danish fleets, and between June 2003 and February 2005 for the Spanish fleets. In France, the survey was conducted by 7 technicians who interviewed a pre-selected sample of fishermen located on the Channel and the Atlantic coast, from Dunkerque to Bayonne. In Denmark, the survey was conducted by student employees and aimed at complete geographical coverage within the three vessel groups: Demersal trawlers, Gill netters and Danish seiners. In Spain, the survey was conducted in two harbours of the Basque Country: Ondarroa and Pasaia.

In general, the first contact with the fishermen was made by telephone and an appointment was arranged after obtaining his consent to answer the questionnaire. Interviews lasted between 30 mn and 1 h. On some rare occasions, contacts and interviews were done upon return of the vessel in harbour.

The questionnaires were divided into three main sections. The first part concerned the vessel owner surveyed, the evolution of his career, of previously owned vessels and the different métiers practiced since 1985. The second part concerned the current vessel owned, and the evolution of key variables such as hull, engine, deck equipment, electronics, handling and conservation of catches onboard, crew size and, for trawlers only, electronic devices used for monitoring the gear. Finally, the last part of the questionnaire concerned the fishing gears, their evolution and the fishing effort deployed. This study builds on the technological data collected via the second and the third parts of the questionnaires. The key variables fishers were asked to document are shown in Table 1 (vessel attributes) and Table 2 (gear attributes).

In France, the best questionnaire returns were achieved for vessels registered in Bay of Biscay harbors, and belonging to four fleet segments. These fleets are otter-trawlers (12-16 m), (16-20 m), (20-24 m) targeting Norway lobster (*Nephrops norvegicus*) and hake (*Merluccius merluccius*), and gill-netters (>12 m) targeting sole (*Solea solea*), hake and anglerfishes (*Lophius spp*.).

In Denmark and Spain, the questionnaires were designed in a manner very similar to the French questionnaires although minor adjustments were made to accommodate differences in vessel characteristics and target species among the fleets in the three countries. In Denmark, the return quality of the questionnaires was best for the Danish otter-trawlers, and all subsequent analyses have been based on that vessel group. The main targets of the Danish otter-trawlers were cod (*Gadus morhua*), plaice (*Pleuronectes platessa*) and Norway lobster.

In Spain, three Basque fleets were considered: bottom-trawlers of length (20-30 m) registered in Ondarroa, bottom-trawlers of length (30-40 m) registered in Ondarroa and bottom-trawlers of length (30-40 m) registered in Pasaia. The main target species of these three fleets were hake and anglerfishes. As a result of relatively low sampling levels in the surveys, the Basque bottom trawlers (20-30 m) registered in Ondarroa and those (30-40 m) registered in Pasaia were excluded from further analyses.

Table 3 and Figure 1 provide some details on the sampling for the French, Danish and Spanish fleets under investigation. Effort data could be traced back to the early ‘80s (French fleets), the early ‘70s (Spanish fleets) and even back to the late ‘50s (Danish fleets).

In the fishing effort dataset, each observation was a combination of one vessel and one year. A number of vessels used several gears during one year. For the French fleets, it was possible to identify which was the main gear used by each vessel throughout the year. For this fleet, the fishing effort data set included the technological characteristics of both the fishing vessel and of the main gear used. For the Danish and the Basque fleets, it was not possible to determine which gear was the most important, and only the vessel characteristics were included in the fishing effort dataset.

Annual changes in fleet production

Landings in weight and value were extracted from the Danish, French and Spanish log-books and sales slips databases over the period 1990-2003, for all the vessels sampled during the harbor enquiries. Data were aggregated by vessel and year, and then merged with the fishing effort data set described above.

Annual changes in fishing mortality

Total international landings and estimated fishing mortality by stock were derived from the ICES advice (ICES, 2003). The stocks investigated are Celtic Sea and Bay of Biscay anglerfishes, North Sea cod, Northern hake, Bay of Biscay Norway lobster, Celtic Sea Norway lobster, North Sea plaice, Bay of Biscay sole, Celtic Sea sole and North Sea sole. Separate F estimates were given for the two anglerfish species (*Lophius budegassa* and *Lophius piscatorius*). An overall anglerfish fishing mortality was calculated by averaging the landings-weighted F of each of these two species.

Methods

Data exploration

The data collated during our enquiries were first examined to check for missing values. Poorly documented fishing effort descriptors were excluded from subsequent analyses. The annual trends of the remaining variables were then inspected visually. Special consideration was given to variables exhibiting substantial trends over the study period.

Modeling catch rates

Catch rates (CPUE, catch per unit effort), calculated for each vessel and each year, are modeled using Generalized Linear Models (Mc Cullagh and Nelder, 1989). Two models are considered. In model 1, the explained variable is CPUE, which is assumed to follow a gamma distribution. In model 2, the explained variable is Log(CPUE), which is assumed to follow a normal distribution. In order to choose between these 2 models, the distribution of CPUE is tested visually against a gamma distribution, using QQ-plots, and the distribution of Log(CPUE) is similarly tested against a normal distribution. The most appropriate combination of explained variable and probability distribution (CPUE/gamma distribution, model type 1, or log-transformed CPUE/normal distribution, model type 2) is selected. The link function is either Logarithm (model type 1) or Identity (model type 2).

The explanatory variables are year and the different descriptors of fishing effort. Some of these descriptors are discrete factors (e.g. gear unit), while others are continuous variables (e.g. soaking time). Assuming that technical creeping is described by the fishing effort variables, the "Year" effect may indicate annual abundance changes for the species (or the combination of species) under consideration. Each observation cell is a combination of vessel and year. A general formulation of the model is:

(1a) Model 1: $$\ln\left(\overline{CPUE}\right) = \hat{\alpha} + \hat{\beta}_y + \hat{\varepsilon}_h + \sum_{k=1}^{NI} \hat{\theta}_k e_k$$

(1b) Model 2: $$\overline{\ln(CPUE)} = \hat{\alpha} + \hat{\beta}_y + \hat{\varepsilon}_h + \sum_{k=1}^{NI} \hat{\theta}_k e_k$$

where α is the intercept, β is the year effect, ε is the effect of the discrete effort descriptors, θ_k is the regression coefficient associated to e_k, e is the vector of the continuous fishing effort descriptors.

The model is preliminarily parameterized using the outcomes of the data exploration, which allows the a priori selection of the most appropriate model (1 or 2). The model chosen is validated with regards to residual plots resulting from the analysis. Residuals are plotted against predicted values and are tested for normal distribution (QQ-plot, Kolmogorov-Smirnov test). Once an appropriate model type (1 or 2) is selected, the goodness of fit of the model is evaluated using the model's scaled deviance and Pearson Chi-square and also two criteria, the Akaike Information Criterion (AIC) and the Schwarz Bayesian Information Criterion (BIC). If the model chosen fits reasonably well the data, both AIC and BIC should be as low as possible. In addition, both scaled deviance and Pearson chi-square should have a chi-square distribution, with degrees of freedom equal to the number of observations minus the number of parameters estimated. It follows that the ratio between scaled deviance and degrees of freedom, and also the ratio between Pearson chi-square and degrees of freedom should be close to 1. Finally, only the most contributive explanatory variables are retained in the final model (Type III analysis).

Adjusting fishing effort

The method is adapted from the traditional approach (Kimura, 1981). The adjustment factors are the effects of the different variables characterizing fishing effort, estimated by either (1a) or (1b). If ε_* is the effect of the reference effort factor, the relationship between the adjusted (or effective) log fishing effort ln_Ee and the nominal (or untransformed) log fishing effort ln_En may be expressed as

(2) $$\ln\_Ee_{v,y} = \ln\_En_{v,y} + \left(\hat{\varepsilon}_h - \hat{\varepsilon}_*\right) + \sum_{k=1}^{NI} \hat{\theta}_k \, e_{k,v,i}$$

Evaluating the benefits of adjusting fishing effort

The benefits of adjusting fishing effort are evaluated by scrutinizing the relationship between fishing mortality and fishing effort, where effort is defined either as nominal or adjusted effort. Partial fishing mortality was calculated, for each fishing vessel, by weighting the total annual F using the ratio of the vessel's and landings to the total international landings for the stock under consideration. The relationship between F and effort was examined for the main stocks harvested by the fleets under investigation, and for which a stock assessment was available. A linear regression between log-transformed F and effort will be tested with effort defined as nominal or adjusted. The goodness of fit of the regression will be appraised by, (i) eye-balling the plots between Log(F) and Log(effort), (ii) comparing the values of R-square and, (iii) testing using the t-statistic the value of the regression slope, which should be close to 1 if the regression model (2) is appropriate.

Implementation

As a result of data availability, subsequent analyses were applied to four French fleets fishing in the Bay of Biscay (otter-trawlers of length (12-16 m), (16-20 m), (20-24 m), and gill-netters (>12 m)), one Danish otter-trawling fleet and one Basque fleet (bottom-trawlers (30-40 m) registered in Ondarroa). The methods developed in this study were mainly implemented using SAS/STAT (1999) procedure GENMOD.

RESULTS
Data exploration

Gear types have changed considerably over time for most of the fleets under investigation (Figure 2). For the French trawlers (Figure 2a) and the Danish trawlers (Figure 2c), the main feature has been the emergence of twin trawls in the ‘80es, which is associated with *Nephrops* fishing. For the French gill-netters (Figure 2b), the main feature has been the increasing importance of trammel nets, which is associated to sole fishing. Trammel nets have been the main gear on-board since 1996. For the Basque trawlers registered in Ondarroa of length (30-40 m) (Figure 2d), the proportion of the two main gear types (single otter-trawls and pair trawls with “Very High Vertical Opening”) has remained stable over the period 1990-2003. Since 1995 however, this fleet appeared to be increasingly polyvalent, as reflected by the emergence of an other trawl type (“Bou” otter-trawls) and increasing use of static gears (fixed nets and long-lines).

There has been an emergence of electronics on-board (GPS or computers) for the different fleets. In particular, GPS appeared in the 60-70es’ (Danish fleets, Figure 3c) or in the 80es’ (French fleets, Figures 3a-b). All the Basque trawlers were equipped with GPS and computers appeared on board around 1990. In 2004, all French and Basque vessels were equipped with GPS, while 10-30% of the Danish vessels were not equipped with the device.

The horsepower of the small French otter-trawlers (Figure 4a) and of the Danish (Figure 4c) has increased over time, while the horsepower of the Basque (Figure 4b) and of the larger French trawlers (Figure 4a) has either remained constant or decreased. The decrease in the horse power of the Spanish fleet results from the emergence of new vessels working as pair-trawlers. Such vessels do not need as much horsepower as the traditional single-trawl vessels. Bollard pull for the Danish fleets appeared to increase over time, along with horsepower.

For the small and large French otter-trawlers (Figures 5a and 5c), the headline length has increased slightly over the study period. Otter-trawlers equipped with twin trawls had a longer headline than those equipped with single trawls. For the medium French otter-trawlers (Figure 5b), the headline length has decreased over time. Otter-trawlers equipped with twin trawls had a similar headline length than those equipped with single trawls. For the Basque fleet, both the headline length (Figure 5d) and the vertical opening (Figure 5f) have increased over time. Trawlers equipped with “VHVO” trawls had larger headline and vertical opening than those equipped with single trawls. The vertical opening of Danish trawlers (Figure 5e) has increased over time. Danish trawlers equipped with single trawls had the largest vertical opening, while those equipped with multi-rig trawls had the smallest.

Modeling catch rates and adjusting fishing effort

Model 2 was more appropriate than model 1 in all cases. The GLM residuals diagnostics are shown in Tables 4-7 and Figure 6. The outcomes of the Kolmorov-Smirnov tests indicate that the assumption of normal distribution is not rejected only for a few cases. However, the inspection of the QQ-plots indicates that, except in few cases where outliers make the observed plot slightly deviate from the reference line (Figures 6b, 6e, 6g, 6i, 6m) the distribution of residuals is close to normal.

Results of the Generalized Linear Models are summarized in Tables 4-7 and Figures 7 and 8.

In the case of French gill-netters, the highest catch rates of hake were achieved with fixed nets, while the highest catch rates of sole and anglerfishes were reached with trammel nets (Table 4 and Figure 7). Net length had a positive effect on catch rates of both hake and sole while the effect of soaking time was unclear. Vessel length only had an effect on the catch rates for hake.

A gear type variable was created by combining the gear unit with the type of groundrope for the French trawlers. The effect of gear type was dominant for all combinations of fleets and species, but it was also fleet- and species-dependent (Table 5 and Figure 8). For the small trawlers (12-16 m) the highest *Nephrops* catch rates were achieved with twin trawls using metallic spheres, while chains were better for larger trawlers (20-24 m). The highest catch rates for hake by both small and large French trawlers were achieved with single trawls equipped with the diabolos. Single trawls equipped with chains had also high catch rates of both *Nephrops* and hake for large trawlers. The effect of gear type was not so clear for the medium trawlers (16-20 m). Headline length generally had a positive effect on catch rates for all fleets. Short hauls (reflecting either a relatively high towing speed or a short haul duration) had often a positive impact on catch rates, except for the large trawlers harvesting hake, where the effect was negative. Finally, the effect of on-board electronics and of engine power was unclear and/or limited.

The smallest Danish trawlers equipped with the largest number of winch drums had the highest catch rates for all species (Table 6). Other technological factors had a positive impact on the CPUE for some species under investigation: the crew size on cod and plaice, the number of net drums on Norway lobster and plaice, the number of sounders on plaice. Finally, the newest vessels appeared to be the least efficient at catching both Norway lobster and plaice.

The availability of variable pitch propellers increased the catch rates of both hake and anglerfish by Basque trawlers (Table 7). The number of net drums had a positive effect on anglerfish CPUEs, but a negative effect on hake CPUEs.

Evaluating the benefits of adjusting fishing effort

The relationships between Log(effort) and Log(F) were investigated in situations where reliable stock assessments were available (Table 8, Figures 9 and 10). Adjusting fishing effort generally led to an improvement of the relationship between Log-transformed fishing effort and mortality, except for the French medium trawlers (16-20 m) harvesting Northern hake and the French gill-netters harvesting Bay of Biscay sole. In two cases (French gill-netters harvesting Bay of Biscay sole and Bay of Biscay/Celtic Sea anglerfishes), the slope of the relationship was not significantly different from zero, and the model was clearly not appropriate, whatever the measure of fishing effort. The average slope of the regression with adjusted effort was not significantly different from 1 in the case of French gill-netters harvesting Northern hake and North Sea/Western Scotland anglerfish, Danish otter-trawlers harvesting North Sea cod and plaice, and Basque bottom-trawlers harvesting hake and both anglerfish stocks. For these combinations of fleets and species, the assumption that fishing mortality is directly proportional to fishing effort is not unreasonable.

DISCUSSION

An important feature revealed by the data exploration is the gradual appearance of twin trawls since the early eighties, for both Danish and French trawlers, which is clearly associated with the gradual emergence of Norway lobster as target species. For the French trawlers, the emergence of twin trawls is accompanied by the appearance of new groundropes (diabolos, metallic spheres), which allow fishing on harder grounds, on areas which could hardly be exploited before. A similar change in fishing technologies is observed for the French gill-netters, where the increased importance of trammel nets is associated with sole becoming a dominant target species. These shifts are likely to be due to both Norway lobster and sole having a high market value, and by the low abundance level of hake, the traditional target species of both fleets. For the Basque bottom-trawlers, the main feature is the increased polyvalence of fishing vessels, which may reflect the greater opportunism of skippers in recent years.

The analysis of the effects of vessel and gear properties on fishing efficiency for the six fleets clearly shows that collecting non trivial information on fine-scale technological changes would allow more insight into the factors affecting fishing power. For the four French fleets, where both vessel and gear information was compiled in the fishing effort dataset, the gear effect appeared to be dominant over the vessel effect. This result bears out the high plasticity of these fleets' fishing strategies. In the case of the French gill-netters, trammel nets were clearly designed to target sole during the night, when the fish is swimming in the water column, while fixed nets have traditionally been used to target hake. Therefore, it could be anticipated that vessels equipped with trammel and fixed nets would be more efficient with regards sole and hake fishing respectively. Other characteristics of gill nets, such as twine thickness, are thought to have a substantial effect on fishing power (Holst et al., 2002), but information could not be consistently made available on such attributes. Also, the length of net being towed had a positive effect on fishing efficiency for the main target species (sole and hake), and could henceforth be considered as an useful measure of fishing capacity. Soak time, which is sometimes evoked as a measure of the fishing activity of gill-netters (Marchal et al., 2001; Marchal et al., 2002), did not have a clear effect on catch rates. One could anticipate that increasing soak time would allow more fish to be caught in the net. However, discussion with skippers who participated with the inquiry indicated that leaving fish more than 24 h in the net would adversely alter the quality of the flesh, and hence make it unmarketable. Therefore, it is likely that soak time has a non-linear effect on catching efficiency, which would require further investigations.

We had anticipated that, within each groundrope category, French otter trawlers using twin trawls would have a greater efficiency than single trawls when fishing Norway lobster but a lower efficiency when fishing hake (Sangster and Breen, 1998). This expectation was fulfilled for the small (12-16 m) and the large (20-24 m) otter-trawlers, but not for the intermediate vessels (16-20 m). The reason why medium trawlers did not have the expected efficiency when fishing for Norway lobster and hake could be the result of vessels targeting other benthic (e.g. flatfish, anglerfish) or demersal species (e.g. cod, whiting), which were not included in our analysis. French trawlers chose different groundropes depending on the type of ground visited. For 8 out of 12 combinations of fleet, species and gear type categories, vessels equipped with hard bottom groundropes (e.g. diabolos, metallic spheres) had a greater efficiency than those equipped with soft bottom groundropes (e.g. plain wires, chains, rubber), irrespective of the target species. Before diabolos and metallic spheres could be used, fishing on hard bottom was more risky (gear breakage, etc.). The emergence of such devices made it possible for vessels to have an easier access to alternative fishing grounds, which were probably less exploited than the traditional ones. This higher local stock density could be the reason why higher efficiency was observed when trawls were equipped with diabolos and metallic spheres.

The effect of gear size on trawl selectivity and catching efficiency has been investigated in past studies (e.g. Rose and Nunnallee, 1998; Dahm et al., 2002). One would expect that increasing the trawl opening would enhance its efficiency. However, Rose and Nunnallee (1998) found that restricting the trawl opening did not necessarily lead to decreased catch rates. In our study, we found that trawl size, as reflected by the headline length, had a positive effect on catch rates for hake by all French trawlers, and on catch rates for Norway lobster by the smallest trawlers. Such results seem to be in accordance with expectations. It is however difficult to compare our results, which are based on interviews, with those of Rose and Nunnallee (1998), which are based on field experiments.

One would expect that towing speed has an effect on catching mobile species (e.g. hake) but not on catching sedentary species (e.g. Norway lobster). Our results seem to confirm this hypothesis. However, whether increasing towing speed results in an increase or a decrease in catching efficiency is clearly fleet-dependent, and would require further investigations.

For the Danish and the Basque trawling fleets, gear information could not be used to adjust fishing effort, and only vessel characteristics were examined in relation to fishing efficiency. Small and old Danish trawlers generally appeared to be more efficient than large and new vessels, which was unexpected.
With regards the vessel size effect on catch rates, a plausible explanation could be that larger vessels periodically targeting other species (e.g. pelagics) than those included in our analysis.
The negative effect of the date of construction on fishing efficiency may indicate that vintage is a misleading descriptor of fishing effort. Because vessels can be continuously rebuilt, older vessels may in fact have more up-to-date equipment and technologies, and hence be more efficient, than newer vessels. Also, although we cannot demonstrate it with the data available, one cannot exclude in principle that more experienced skippers fish on older vessels.

The major contributors to fishing power of the Danish and Basque fleets appeared to be mainly the crew size, the number of winch drums and the number of net drums. Bollard pull, which is sometimes put forward as an appropriate metric of fishing power, had no appearant effect on catching efficiency. As for Danish trawlers, the number of net drums on Basque trawlers had an impact on fishing efficiency, but the effect was species-dependent. In fact, the main factor with a positive effect on fishing efficiency was the availability of a variable pitch propeller. In itself, this result is not surprising, since variable pitch propellers allow a more optimal transfer of energy from the engine to the propeller, especially during trawling, thereby enhancing fishing efficiency. We had not anticipated that this would be the only vessel attribute to positively impact fishing efficiency. The results obtained for the Danish and Basque fleets should however be treated cautiously, as the gear effect could not be included in the analyses.

The effect of on-board electronics and of technical efficiency was overall unclear and/or limited for the six French, Danish and Basque fleets under investigation. This unexpected result bears out findings from Kirkley et al. (2004), who suggested that the adoption of electronics (e.g. GPS) could be associated with other types of unmeasured output-dampening impacts, such as stock or regulation changes, that are being picked up as part of the electronics effect.

The CPUE analysis has been carried out using a GLM. Although it is a standard procedure in that field of research (Robson 1966, Kimura 1981, Hilborn 1985, Marchal et al. 2002), it has a number of limitations.
First, the dataset used in this investigation is unbalanced (not all vessels are present over all the time series). Not explicitly accounting for the vessel effect by a fixed effects or random effects model may lead to biased and inconsistent parameter estimates. A fixed or random effect specification could help to explain unobserved heterogeneity between vessels, including the skipper effect. In that context, one may consider using GLMMs (Generalized Linear Mixed Models) as an alternative to GLMs (Venables and Dichmont 2004). GLMMs make it possible to include both fixed and random terms in the linear predictor. Although still a research topic, this method has recently been applied in the field of fisheries research (Squires and Kirkley 1999).
Second, the model used here is fully linear. To allow for a broader use of our approach, more general models could be contemplated. For instance, the GLM model used in our study is consistent with the Cobb-Douglas function used by fisheries economists to model production in relation economic inputs (i.e.capital, labour, fuel) and various dummy variables (e.g. accounting for spatial and annual effects). A Cobb-Douglas function has thus been used by Kirkley et al. (2004) to evaluate the effect of technological effects on the production of the Sète trawl fishery (Kirkley et al. 2004). The Cobb-Douglas function is in fact a simplification of the trans-log production function which includes, in addition to the linear explanatory variables, a quadratic functional term. This quadratic term could in principle be used to account for elasticities of substitution between the fishing effort descriptors and also, to some extent, non-linear effects of the explanatory variables. However, given the relatively large number of explanatory variables, a quadratic functional form might be intractable due to multi-collinearity. A more general approach could be to account for non-linear effects of explanatory variables (e.g. the effect of soak time on the catch rates of gill-netters) using GAMs (Generalized Additive Models). GAMs may extend the scope of GLMs, by substituting the linear predictor by a generalized additive (and possibly non-linear) predictor (Maunder and Punt, 2004).
Overall, although the GLM may oversimplify the processes underlying the dynamics of fishing effort, the diagnostics and residuals analyses suggest that for our case studies, the main outcomes of this investigation are fairly robust to the assumptions made.

The link between fishing mortality and effort was investigated for a number of combinations of fleets and stocks. In most case studies, adjusting fishing effort led to, (i) a gain in the precision of the relationship between fishing mortality and fishing effort (10 out of 12 case studies) and, (ii) fishing mortality being directly proportional to fishing effort (7 out of 12 case studies). However, the results also indicated that the linkage between fishing mortality and effort could still be enhanced. This could be done by both revisiting some of the assumptions and refining the scale of the investigation.

First, it has been assumed in the GLMs that the "Year" effect is indicative of the annual abundance changes of the stocks, while technical creep is embodied in the different fishing effort descriptors. This assumption could be violated for several reasons. Thus, there may be factors contributing to improve technical efficiency which have not been captured by the survey. In particular, gear-related factors of the Danish and the Basque fleets could not be used in this study. In these cases, the annual effect may reflect a combination of both stock

fluctuations and improved gear efficiency. In addition, an implicit assumption made in this study was that the skipper's effect is captured by the different fishing effort descriptors in the GLM. It has been demonstrated that skipper skill was an important determinant in explaining catch rates (e.g. Houghton 1977, Hilborn 1985, Hilborn and Ledbetter 1985, Squires and Kirkley 1999). Skipper skill may be reflected by e.g. choice of fishing grounds (Marchal et al. 2006), experience and education levels (Kirkley et al. 1998). Shifts in target species observed for the fleets under investigation have required an adaptation of technologies, but also of skippers' skills from year to year. Moreover, it is likely that vessels' skippers have changed over time during the period examined. Not accounting for the skipper effect can likely lead to omitted variable bias for the parameter estimates. Information of skippers' skill and on comings and goings of skippers on different vessels over time was not available to our study. It is therefore likely that part of the skippers' effect has been embedded in the "Year" effect. Finally, the "Year" effect may pick up other excluded factors that are correlated with time, including changes in the environment, along with changes in institutions and markets (Pascoe et al. 2001).
Second, an improvement in our results could be expected with more appropriate F estimates. F estimates from stock assessments have high uncertainty, and estimates for the most recent years of VPA assessments may not have converged.
Third, the linkage between fishing effort and fishing mortality could be enhanced by refining both the time (month or fishing trip instead of year) and spatial scales of this analysis.

Another unsettled issue pertaining the modeling of CPUE and, more generally, of any production functions, is that of endogeneity. Some researchers have claimed that endogeneity bias may arise if input (or output) quantities are not exogenous to the dependent, left-hand-side variable, in turn leading to biased and inconsistent estimates of the parameters. Others, however, have suggested that the stochastic nature of catch levels and composition (due to weather conditions, the "luck" component of fishing and imperfect gear selectivity) implies that errors in input choice based on expected profits will be uncorrelated with the error terms associated with estimation (Bjorndal 1989, Campbell 1991, Kirkley et al. 1998, Pascoe and Coglan 2002). Zellner et al. (1966) show more formally the conditions under which such bias will not arise.

Overall, despite some limitations, this study provided good insights into the key processes of technical creeping. The results suggest that fishing effort descriptors which are not traditionally measured (gear type, length of net used per day, headline length, number of winch and net drums) may have a substantial impact on catch rates. Such variables are currently not routinely recorded in log-books. The results of this analysis suggest that they should be.

ACKNOWLEDGEMENTS

This work was funded through the TECTAC project by the European Union (DG Fisheries, study no. QLRT-2001-01291). This support is gratefully acknowledged. We are also indebted to skippers and vessels owners for their kind cooperation during harbor enquiries. Finally, we thank ICES for providing fishing mortality estimates.

REFERENCES

Bjorndal, T. 1989. Production in a Schooling Fishery: The Case of the North Sea Herring Fishery. Land Economics, 65: 49-56.

Campbell, H.F. 1991. Estimating the Elasticity of Substitution between Restricted and Unrestricted Inputs in a Regulated Fishery: A Probit Approach. Journal of Environmental Economics and Management, 20: 262-274.

Cook, R.M., and Armstrong, D.W. 1985. Changes in catchability of cod, haddock, and whiting associated with the Scottish seine-net fishery. Journal du Conseil international pour l'Exploration de la Mer, 42 : 171-178.

Dahm, E., Wienbeck, H., West, C.W., Valdemarsen, J.W., and O'Neill, F.G. 2002. On the influence of towing speed and gear size on the selective properties of bottom trawls. Fisheries Research, 55: 103-119.

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

Hilborn, R. 1985. Fleet dynamics and individual variation: why some people catch more fish than others. Canadian Journal of Fisheries and Aquatic Sciences, 42: 2-13.

Hilborn, R., and Ledbetter, M. 1985. Determinants of catching power in the British Columbia Salmon Purse Seine Fleet. Canadian Journal of Fisheries and Aquatic Sciences, 40: 968-982.

Holst, R., Wileman, D., and Madsen, N. 2002. The effect of twine thickness on the size selectivity and fishing power of Baltic cod gill nets. Fisheries Research, 56: 303-312.

Houghton, R. 1977. The fishing power of trawlers in the Western English Channel between 1965 and 1968. Journal du Conseil Inernational pour l'Exploration de la Mer, 37: 130-136.

ICES 2003. Report of the Advisory Committee on Fishery Management, October 2003. [http://www.ices.dk/committe/acfm/comwork/report/asp/acfmrep.asp].

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

Kirkley, J., Morrison Paul, C.J., Cunningham, S., and Catanzano, J. 2004. Embodied and disembodied technical change in fisheries: an analysis of the Sète trawl fishery, 1985-1999. Environmental and Resource Economics, 29: 191-217.

Kirkley, J., Squires, D., Strand, I.E. 1998. Characterizing managerial skill and technical efficiency in a fishery. Journal of Productivity Analysis, 9: 145-160.

Mc Cullagh, P., and Nelder, J.A. 1989. Generalized Linear Models. Chapman & Hall, New York.

Marchal, P., Andersen, B., Bromley, D., Iriondo, A., Mahévas, S., Quirijns, F., Rackham, B., Santurtun, M., Tien, N., and Ulrich, C. 2006. Improving the definition of fishing effort for important European fleets by accounting for the skipper effect. Canadian Journal of Fisheries and Aquatic Sciences, 63: 510-533.

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

Marchal, P., Ulrich, C., Korsbrekke, K., Pastoors, M., and Rackham, B. 2002. A comparison of three indices of fishing power on some demersal fisheries of the North Sea. ICES Journal of Marine Science, 59: 604-623.

Maunder, M.N., and Punt, A.E. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research, 70: 141-159.

Millischer, L., Gascuel, D., and Biseau, A. 1999. Estimation of the overall fishing power : a study of the dynamics and fishing strategies of Brittany's industrial fleets. Aquatic Living Resources, 12: 89-103.
Pascoe, S., Andersen, J.L., and de Wilde, J.W. 2001. The impact of management regulation on the technical efficiency of vessels in the Dutch beam trawl fishery. European Review of Agricultural Economics, 28: 187-206.
Pascoe, S., Coglan., L. 2002. The contribution of unmeasurable inputs to fisheries production: an analysis of technical efficiency of Fishing vessels in the English Channel. American Journal of Agricultural Economics, 84: 585- 597.
Robson, D.S. 1966. Estimation of the relative fishing power of individual ships. ICNAF Research Bulletin, 3: 5-14.
Rose, C.S., and Nunnallee, E.P. 1998. A study of changes in groundfish trawl catching efficiency due to differences in operating width, and measures to reduce width variation. Fisheries Research, 36: 139-147.
Sangster, G.I., and Breen, M. 1998. Gear performance and gear comparison between a single trawl and a twin rigged gear. Fisheries Research, 36: 15-26.
SAS/STAT 1999. SAS Institute Inc., SAS/STAT User's Guide, Version 8, Cary, NC, 3884 pp.
Squires, D. 1987. Fishing Effort: Its Testing, Specification, and Internal Structure in Fisheries Economics and Management. Journal of Environmental Economics and Management, 14, 268-282.
Squires, D., and Kirkley, J. 1996. Individual Transferable Quotas in a Multiproduct Common Property Industry. The Canadian Journal of Economics, 29: 318-342.
Squires, D., and Kirkley, J. 1999. Skipper skill and panel data in fishing industries. Canadian Journal of Fisheries and Aquatic Sciences, 56: 2011-2018.
Venables, W.N., and Dichmont, C.M. 2004. GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. Fisheries Research, 70: 319-337.
Zellner, A., Kmenta, J., and Dreze, J. 1966. Specification and Estimation of Cobb-Douglas Production Function Models. Econometrica, 34: 784-795.

Table 1. Variables describing vessel attributes collected during the harbor enquiries for the French and Danish fleets.

Type	Variable	Unit
General characteristics (hull, equipment)	Date of construction	DD/MM/YYYY
	Date of acquisition	DD/MM/YYYY
	Date of sale	DD/MM/YYYY or NA
	Overall length	m
	Tonnage	GT
	Main engine power	HP
	Number of rotations per minute	$rot.mn^{-1}$
	Date of acquisition of engine	DD/MM/YYYY
	Maximal speed	knots
	Bollard pull	tonnes
	Crew size	Number
	Hull type (displacement, surfing, catamaran)	D/S/C
	Hull material (steel / Alu / GRP / wood)	S/A/G/W
	Bulb	YES/NO
	Knozzle	YES/NO
	Storing room capacity	m^3
	Freezer room capacity	m^3
	Ice making machine	Y/N
	Deck surface	m^2
	Variable pitch propeller	YES/NO
	Winch (or net hauler) capacity (power)	KW
	Winch (loading) capacity	m (of cable)
	Winch speed (or net hauler)	m/s or r/mn
	Number of winch drums	number
	Number of net drums	number
	Net disentangling machine	YES/NO
	Net washing machine	YES/NO
Electronics	GPS	YES/NO
	Fax	YES/NO
	Radar	YES/NO
	Shore / ship confidential communication	YES/NO
	Computer	YES/NO
	Charting software (dedicated plotter or computer)	YES/NO
	Number of sounders	number
	Sounder 1 frequency	kHz
	Computer interface of sounder 1	YES/NO
	Sounder 2 frequency	kHz
	Computer interface of sounder 2	YES/NO
	Number of sonars	number
	Sonar frequency	kHz
	Computer interface of sonar	YES/NO
Catch handling	Conveyor	YES/NO
	RSW system	YES/NO
	Container / Boxes on-board	YES/NO
	Deck crane	YES/NO

Table 2. Variables describing gear attributes collected during the harbor enquiries for the French and Danish fleets.

Type	Variable	Unit
All gears	Gear unit	
	Number of fishing trips per year	number
	Number of days per fishing trip	days
	Number of fishing days per fishing trip	days
Trawls	Number of warps	2, 3 or NA if not trawl
	Number of panels	2, 4, 6 or NA if not trawl
	Yarn material	
	Yarn diameter in codend	mm
	Vertical opening	m or NA if not trawl
	Horizontal opening	m or NA if not trawl
	Mesh size of codend	mm or NA if not trawl
	Mesh size of wings	mm or NA if not trawl
	Length of headline	m or NA if not trawl
	Length of groundrope	m or NA if not trawl
	Type of groundrope	
	Rigging	
	Scanmar sensors	Y/N or NA if not trawl
	Trawleye (or Netsonde)	Y/N or NA if not trawl
	Number of otter boards	0, 2, 4 or NA if not trawl
	Weight of an otter board	kg or NA if not trawl
	Average trawling speed	knots or NA if not trawl
	Selectivity device	
	Volume of water filtered per time unit	m^3/s
	Number of hauls per fishing day	number or NA if not trawl
	Mean duration of one haul	hours or NA if not trawl
Nets	Number of panels	number
	Smallest stretched mesh size	mm or NA if not net
	Stretched mesh size of the external panel	mm or NA if not net
	Net material	
	Total length of net set per fishing trip	m or NA if not net
	Total length of net set per fishing day	m or NA if not net
	Total height of net	m or NA if not net
	Soaking time of nets	hours or NA if not net
Seines	Diameter of the seine rope	mm or NA if not seine
	Length of the seine rope	m or NA if not seine
	Number of panels	2, 4, 6 or NA if not seine
	Yarn material	
	Yarn diameter in codend	mm
	Vertical opening	m or NA if not seine
	Horizontal opening	m or NA if not seine
	Mesh size of codend	mm or NA if not seine
	Mesh size of wings	mm or NA if not seine
	Length of headline	m or NA if not seine
	Length of groundrope	m or NA if not seine
	Type of groundrope	
	Rigging	
	Tickler chain	Y/N or NA if not seine
	Selectivity device	
	Number of hauls per fishing day	number or NA if not seine
	Mean duration of one haul	hours or NA if not seine

Table 3. Details on the sampling procedure for the harbor enquiries for the French, Danish and Basque fleets.

Country	Fleet	Population (2003)	Sample	Sampling rate
France	Gill-netters	99	21	21%
	Otter-trawlers (12-16 m)	125	35	28%
	Otter-trawlers (16-20 m)	87	19	22%
	Otter-trawlers (20-24 m)	106	26	25%
Denmark	Otter-trawlers	531	76	14%
	Gill-netters	459	36	8%
	Danish Seiners	81	8	10%
Spain (Basque Country)	Bottom-trawlers (Ondarroa), (20-30 m)	5	4	80%
	Bottom-trawlers (Ondarroa), (30-40 m)	27	25	93%
	Bottom-trawlers (Pasaia), (30-40 m)	9	9	100%

Table 4. Summary of the results of the analysis of CPUE by Generalised Linear Models for French gill-netters targeting hake (*Merluccius merluccius*), sole (*Solea solea*) and anglerfishes (*Lophius sp.*). The statistics include the degrees of freedom (DF), ratio of scaled Pearson chi-square to DF (SCC/DF) and the values of the coefficients associated to the significant fishing effort descriptors (p<0.05). Gear types are fixed nets (GNS) or trammel nets (GTR). A '*' indicates that the hypothesis that residuals are normally distributed is not rejected by based on the Kolmogorov-Smirnov test (p<0.05).

Species	DF	SCC/DF	Gear type		Net length	Soaking time	Vessel length
			GNS	GTR			
Hake	136	1.04	2.15	0.00	0.04	-0.05	0.001
Sole	113	1.04	-3.06	0.00	0.04	0.04	
Anglerfishes*	137	1.02	-0.78	0.00			

Table 5. Summary of the results of the analysis of CPUE by Generalised Linear Models for French otter-trawlers targeting hake (*Merluccius merluccius*) and Norway lobster (*Nephrops norvegicus*). The statistics include degrees of freedom (DF), ratio of scaled Pearson chi-square to DF (SCC/DF) and the values of the coefficients associated to the significant fishing effort descriptors ($p<0.05$). Gear types are single-trawls (OTB) or twin-trawls (TTB), combined to different groundropes: diabolo (1), chains (3), spheres (4), rubber (5), plain wire (6). A '*' indicates that the hypothesis that residuals are normally distributed is not rejected by based on the Kolmogorov-Smirnov test ($p<0.05$).

Length (m)	Species	DF	SCC/DF	Gear type										Headline	Towing	Haul	Computer		Vessel
				OTB1	OTB3	OTB4	OTB5	OTB6	TTB1	TTB3	TTB4	TTB5	TTB6	Length	Speed	duration	Yes	No	HP
(12-16)	Norway lobster	176	1.14	1.23	0.48	0.33	1.22	1.30	1.55	0.32	1.85	0.92	0.00	0.03					
	Hake*	176	1.15	0.11	0.16	1.03	0.51	0.58	-0.01	-0.42	0.19	-0.40	0.00	0.04	0.62		0.00	0.49	
(16-20)	Norway lobster	107	1.18	0.38	-2.96		-0.23		-0.38		0.33	0.00							
	Hake	96	1.24	0.53	1.67		0.37		0.46		1.24	0.00		0.04	1.29		0.00	-0.44	-0.01
(20-24)	Norway lobster	88	1.22	-0.77	0.14				-0.65	0.38		0.00				-1.87			
	Hake*	160	1.13	0.97	0.74				-0.53	-0.21		0.00		0.02	-0.56	0.23			

Table 6. Summary of the results of the analysis of CPUE by Generalised Linear Models for Danish otter-trawlers targeting cod (*Gadus morua*), Norway lobster (*Nephrops norvegicus*) and plaice (*Pleuronectes platessa*). The statistics include degrees of freedom (DF), ratio of scaled Pearson chi-square to DF (SCC/DF) and the values of the coefficients associated to the significant fishing effort descriptors ($p<0.05$). A '*' indicates that the hypothesis that residuals are normally distributed is not rejected by based on the Kolmogorov-Smirnov test ($p<0.05$).

Species	DF	SCC/DF	Date of construction	Crew size	Vessel length	No. winch drums	No. net drums	No. sounders
Cod	208	1.09		0.70	-0.27	1.00		
Norway lobster	180	1.11	$-5.0\ 10^{-4}$		-0.25	2.55	1.87	
Plaice*	178	1.12	$-3.0\ 10^{-4}$	0.77	-0.31	1.38	1.38	0.74

Table 7. Summary of the results of the analysis of CPUE by Generalised Linear Models for Basque bottom-trawlers, registered in Ondarroa, of length (30-40 m), targeting hake (*Merluccius merluccius*) and anglerfishes (*Lophius spp.*). The statistics include degrees of freedom (DF), ratio of scaled Pearson chi-square to DF (SCC/DF) and the values of the coefficients associated to the significant fishing effort descriptors (p<0.05).

Species	DF	SCC/DF	Variable pitch propeller		Number of net drums
			Yes	No	
Hake	114	1.10	0.86	0.00	-0.37
Anglerfishes	114	1.10	0.83	0.00	0.79

Table 8. Outputs comparison of, (a) the regression between Log fishing mortality (LF) and Log nominal fishing effort (LEn) and, (b) the regression between Log fishing mortality (LF) and Log adjusted fishing effort (LEe). The standard error of the slope of regression (b) is provided, and marked with a "*" when the slope is not significantly different from 1 (p<0.05). BB: Bay of Biscay, CS: Celtic Sea, NS: North Sea, WS: Western Scotland.

Fleet	Stock	N	R^2 (a)	R^2 (b)	Standard error of slope (b)	Equation (b)
French otter-trawlers (12-16 m)	Northern hake	246	0.29	0.39	0.05	LF = -23.73 + 0.59*LEe
French otter-trawlers (16-20 m)	Northern hake	246	0.63	0.31	0.07	LF = -25.46 + 0.76*LEe
French otter-trawlers (20-24 m)	Northern hake	246	0.00	0.07	0.05	LF = -19.38 + 0.22*LEe
French gill-netters	Northern hake	194	0.00	0.43	0.07*	LF = -21.51 + 0.90*LEe
	BB sole	49	0.21	0.03	0.21	NS
	BB/CS anglerfishes	130	0.01	0.01	0.29	NS
	NS/WS anglerfishes	45	0.00	0.09	0.50*	LF = -23.45 + 1.06*LEe
Danish otter-trawlers	NS cod	64	0.03	0.51	0.14*	LF = -13.92 + 1.14*LEe
	NS plaice	73	0.06	0.79	0.07*	LF = -22.11 + 1.14*LEe
Basque bottom-trawlers (30-40 m)	Northern hake	170	0.11	0.19	0.17*	LF = -14.76 + 1.06*LEe
	BB/CS anglerfishes	95	0.03	0.35	0.14*	LF = -18.35 + 0.98*LEe
	NS/WS anglerfishes	47	0.01	0.35	0.24*	LF = -19.03 + 1.16*LEe

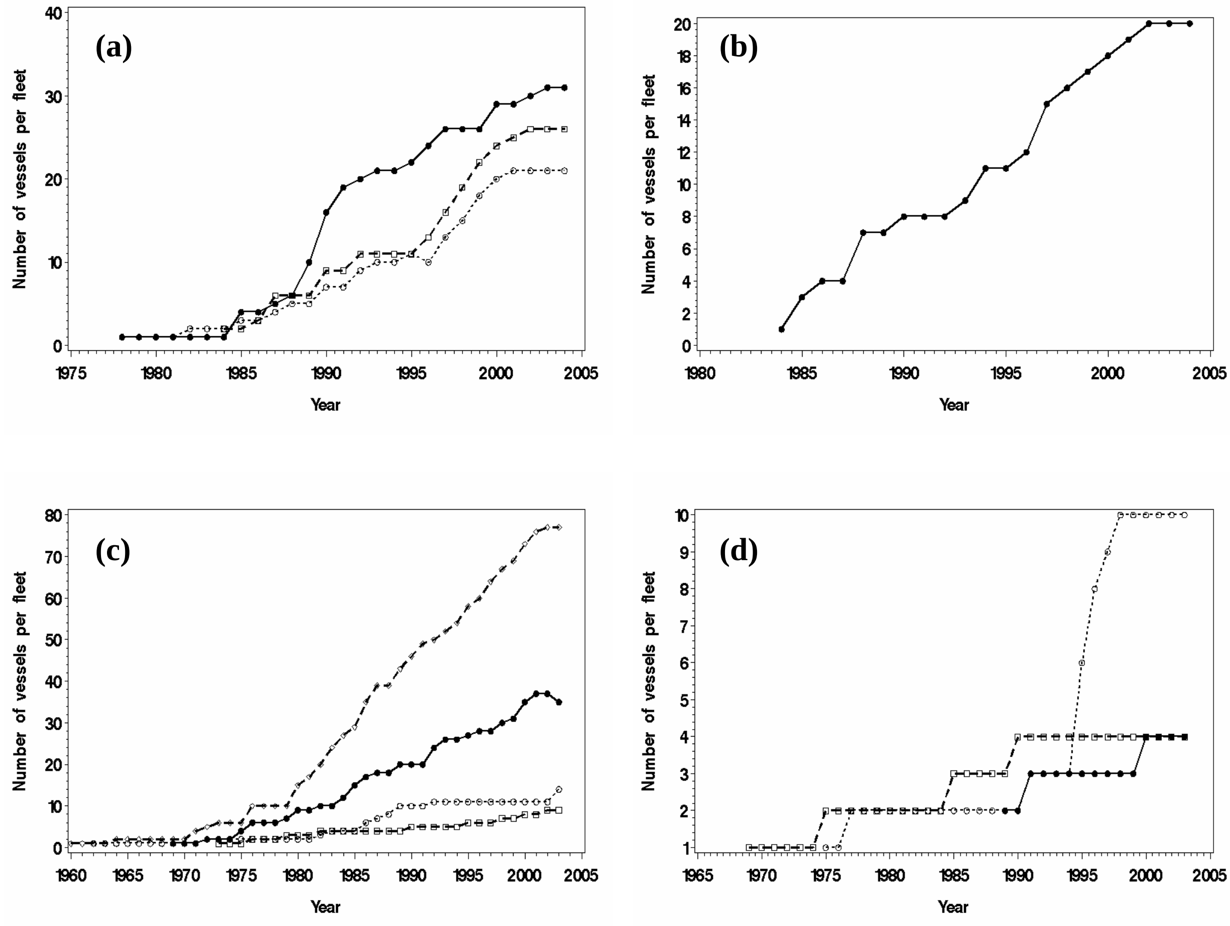

Figure 1. Number of vessels, by year, for which fishing effort data were recorded: (a) French otter-trawlers (black dot: (12-16 m), circle: (16-20 m), square: (20-24 m)), (b) French gill-netters, (c) Danish fleets (black dot: gill-netters, square: Danish seiners, diamond: trawlers, circle: others) and, (d) Basque bottom-trawlers (black dot: (20-30 m) registered in Ondarroa, circle: (30-40 m) registered in Ondarroa, square: (30-40 m) registered in Pasaia).

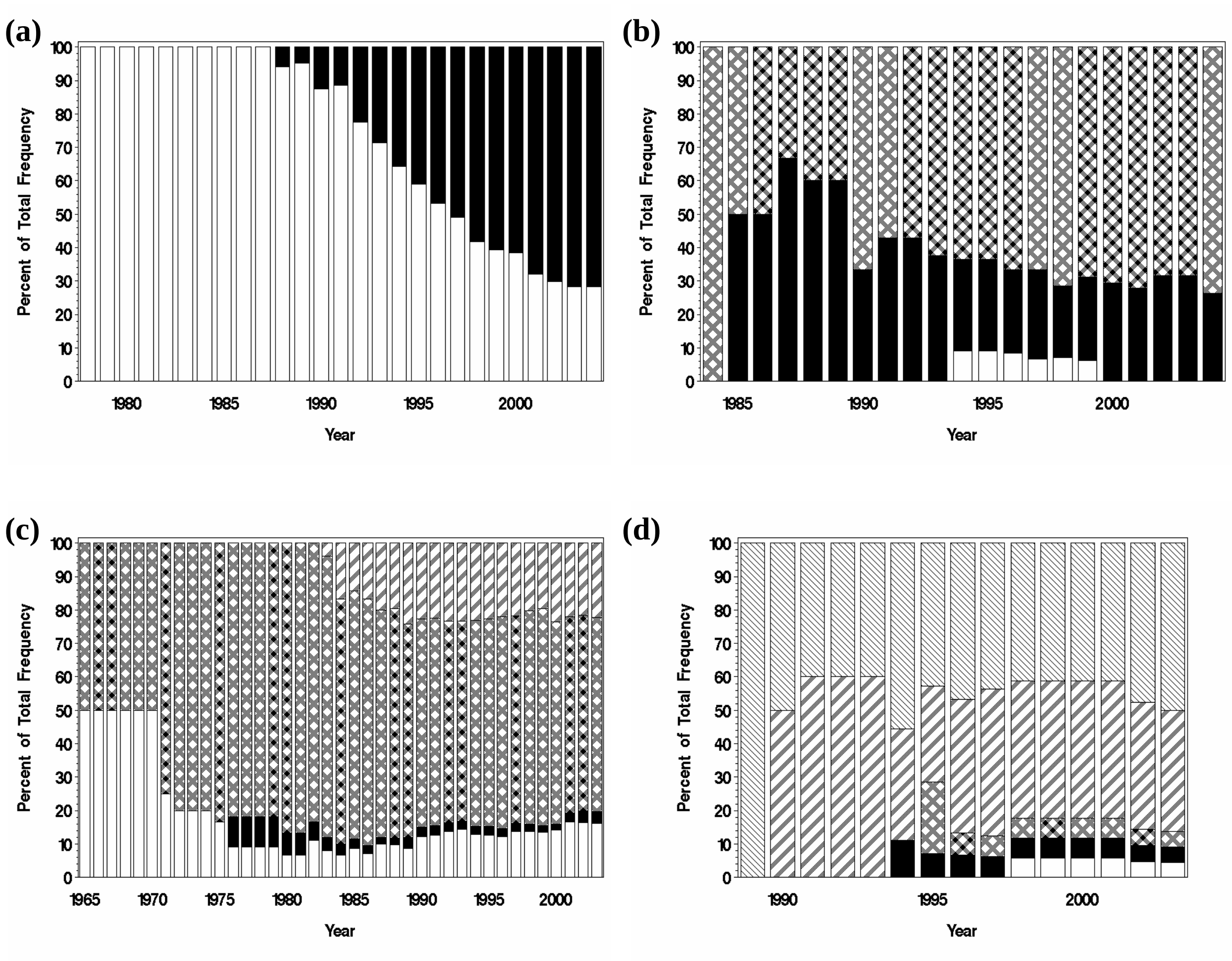

Figure 2. Annual changes in gear types for: (a) French otter-trawlers, all length classes (white: single otter-trawls, black: twin trawls), (b) French gill-netters (white: drift nets, black: fixed nets, double hashed: trammel nets), (c) Danish otter-trawlers (white: multi-rig trawls, black: pelagic trawls, double hashed: single trawls, single hashed: twin trawls) and, (d) Basque bottom-trawlers (30-40 m) registered in Ondarroa in 2003 (white: fixed nets, black: long-lines, double hashed: "Bou" otter-trawls, thick single hashed: single otter-trawls, thin single hashed: "Very High Vertical Opening" bottom-trawls).

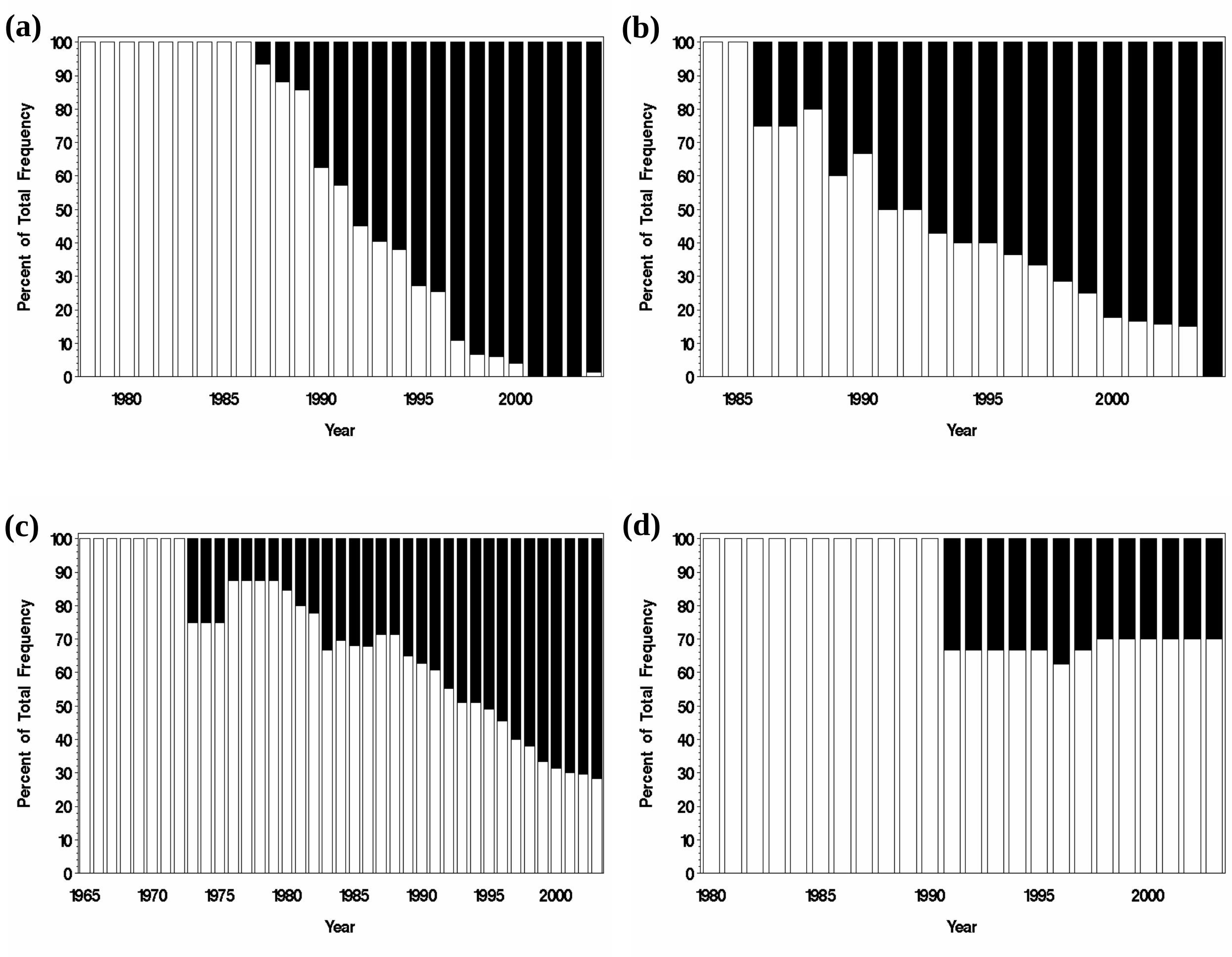

Figure 3. Annual changes in (a, b, c) GPS availability and in (d) computer availability for: (a) French otter-trawlers, all length classes confounded, (b) French gill-netters, (c) Danish otter-trawlers, and, (d) Basque bottom-trawlers (30-40 m) registered in Ondarroa. White bars represent the absence of electronic devices (GPS or computers), black bars represent their presence.

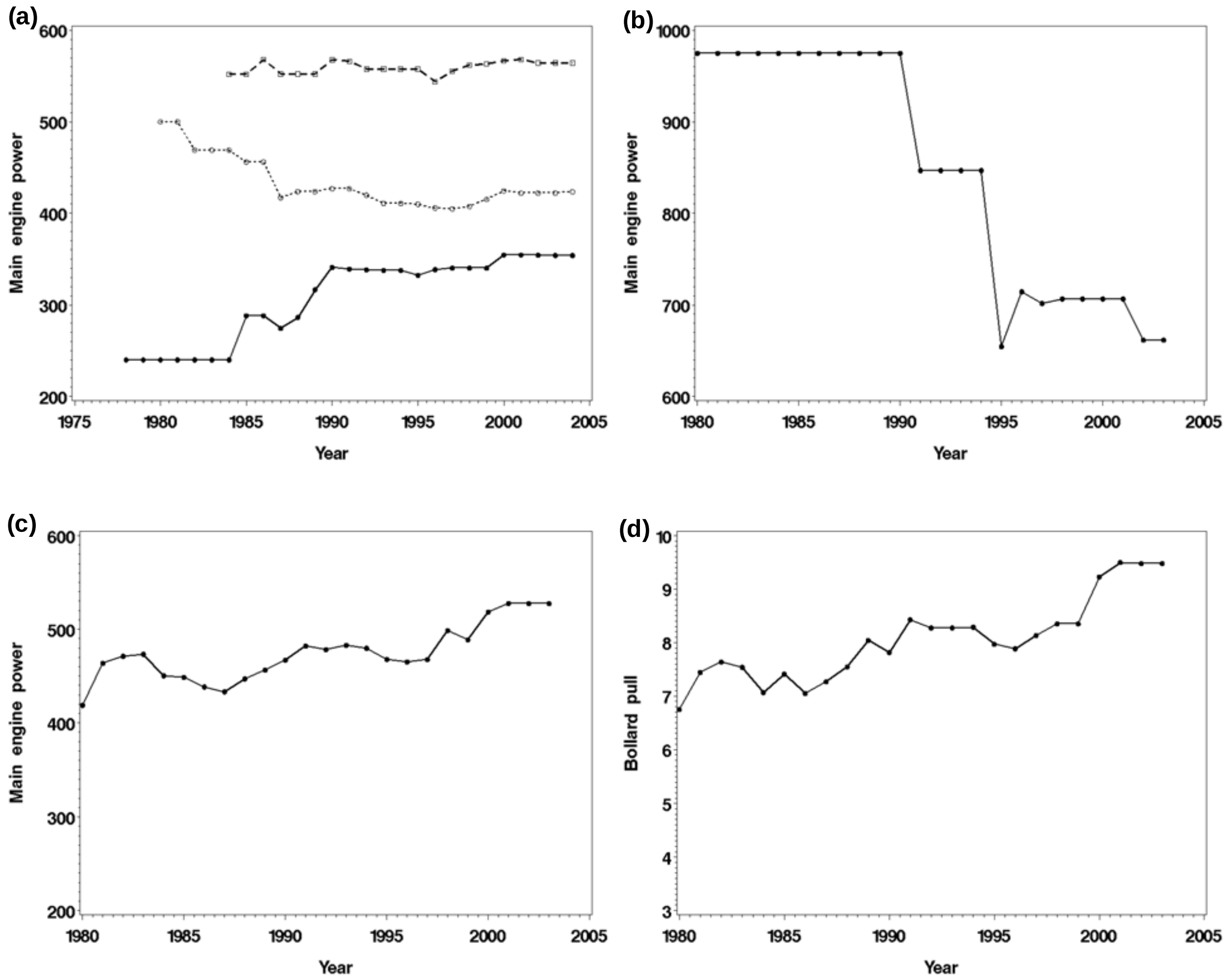

Figure 4. Annual changes in average (a, b, c) horse power (HP) and (d) bollard pull (t) for: (a) French otter-trawlers (black dot: (12-16 m), circle: (16-20 m), square: (20-24 m)), (b) Basque bottom-trawlers (30-40 m) registered in Ondarroa and, (c, d) Danish otter-trawlers.

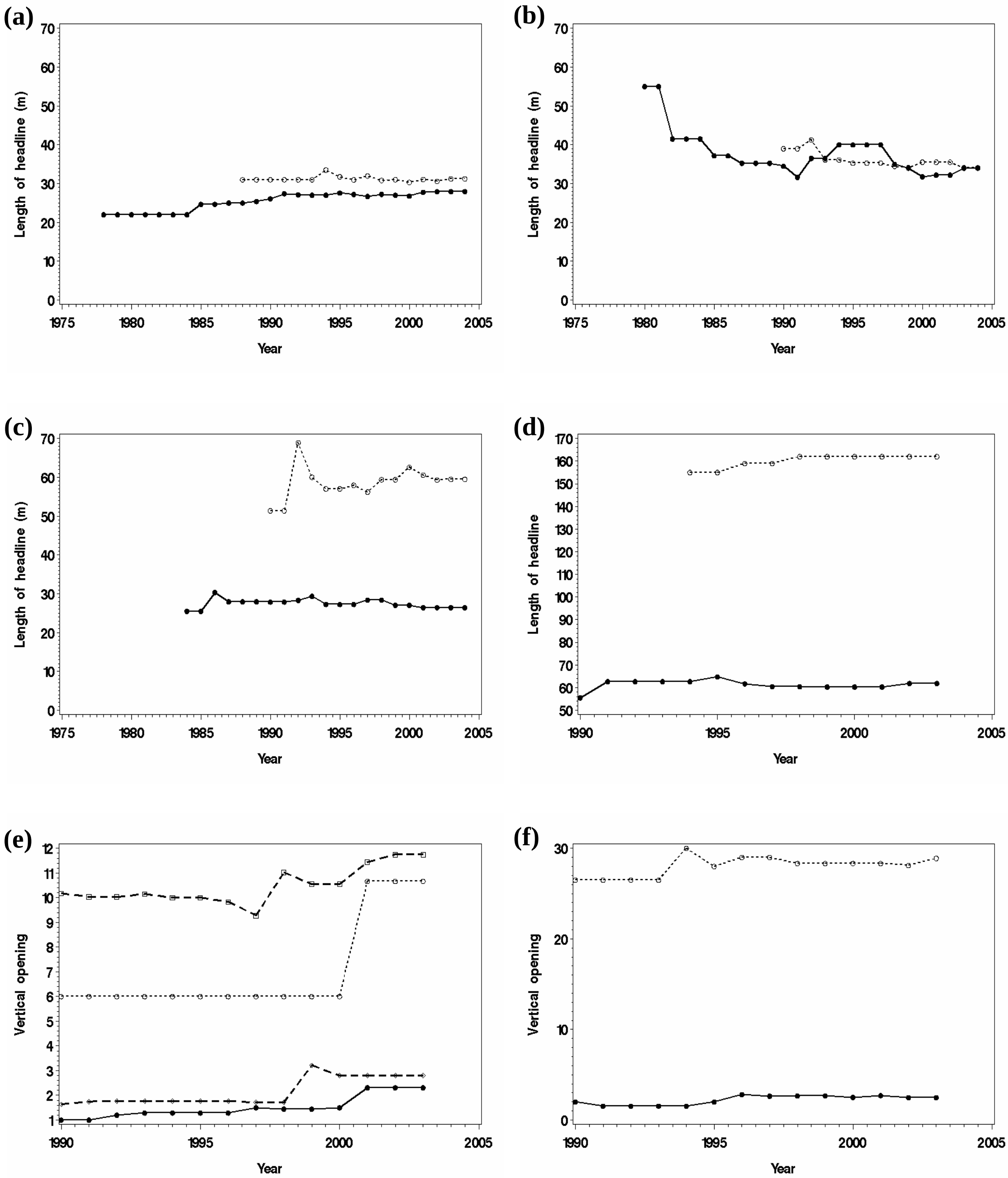

Figure 5. Annual changes in (a, b, c, d) headline length (m) and (e, f) vertical opening (m) for: (a) French otter-trawlers (12-16 m) (black dot: single trawls, circle: twin trawls), (b) French otter-trawlers (16-20 m) (black dot: single trawls, circle: twin trawls), (c) French otter-trawlers (20-24 m) (black dot: single trawls, circle: twin trawls), (d, f) Basque bottom-trawlers (30-40 m) registered in Ondarroa (black dot: single trawls, circle: "Very High Vertical Opening" trawls) and, (e) Danish otter-trawlers (black dot: multi-rig trawls, circle: pelagic trawls, square: single trawls, diamonds: twin trawls).

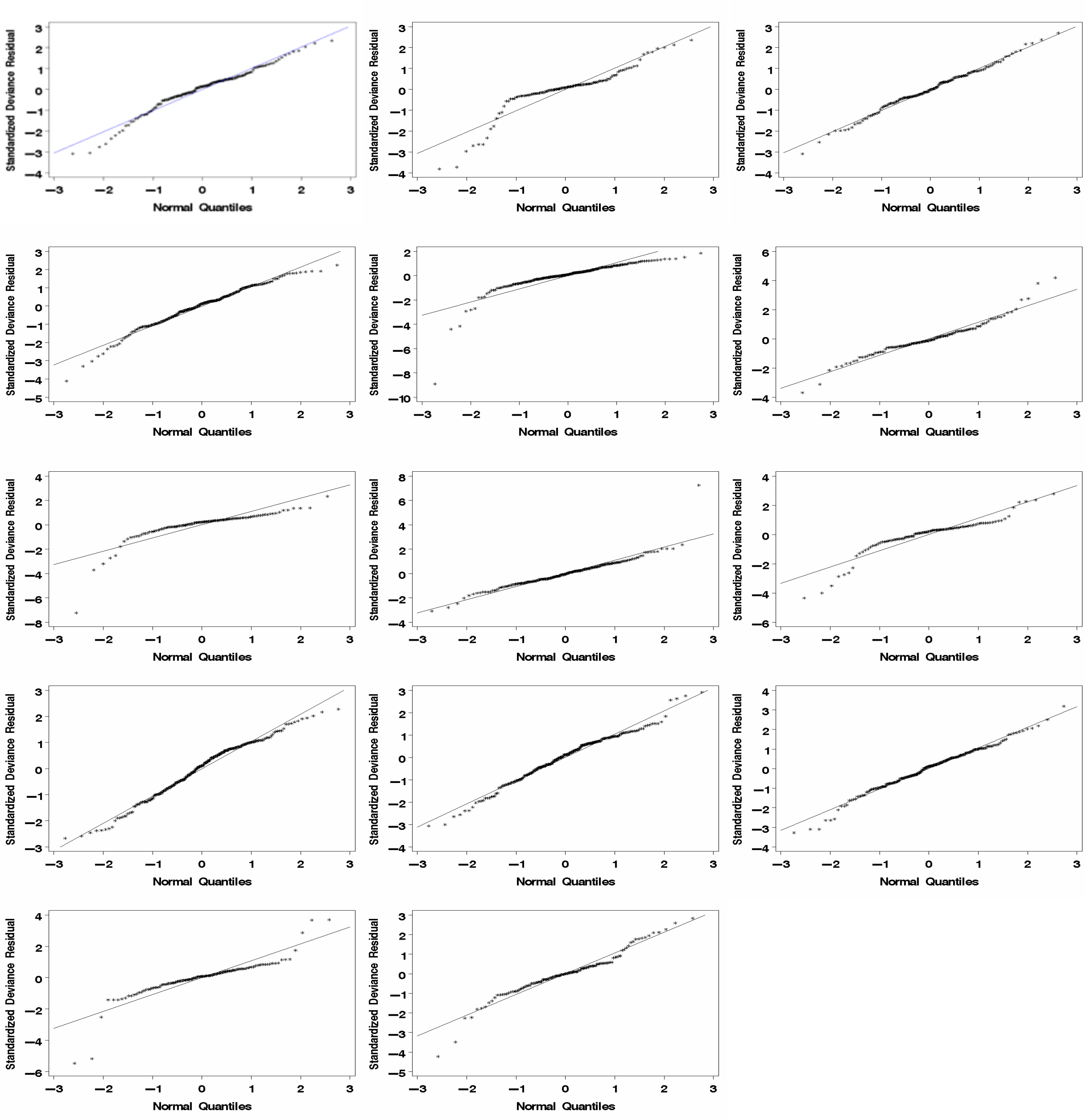

Figure 6. GLM residuals inspection through QQ plots. French gill-netters harvesting (a) hake, (b) sole, (c) anglerfishes; French otter-trawlers (12-16 m) harvesting (d) hake, (e) Norway lobster; French otter-trawlers (16-20 m) harvesting (f) hake, (g) Norway lobster; French otter-trawlers (20-24 m) harvesting (h) hake, (i) Norway lobster, Danish otter-trawlers harvesting, (j) cod, (k) Norway lobster, (l) plaice; Basque bottom-trawlers (30-40 m) registered in Ondarroa harvesting, (m) hake, (n) anglerfishes.

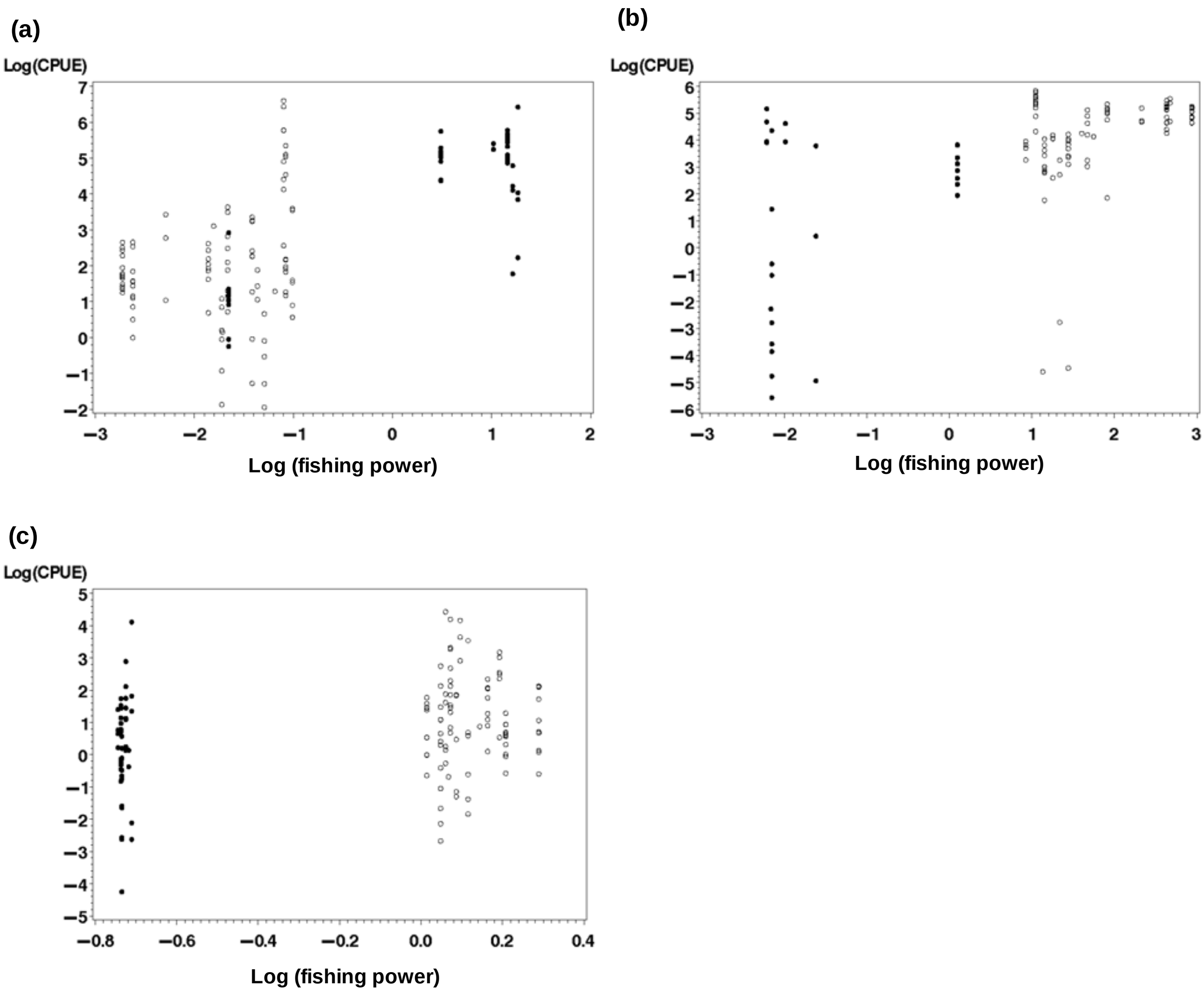

Figure 7. Relationships between log-transformed catch per unit effort (CPUE) and fishing power by net type (black dot: fixed nets, circle: trammel nets), as derived from the Generalized Linear Models. French gill-netters harvesting, (a) hake (*Merluccius merluccius*), (b) (*Solea solea*) and, (c) anglerfishes (*Lophius sp.*).

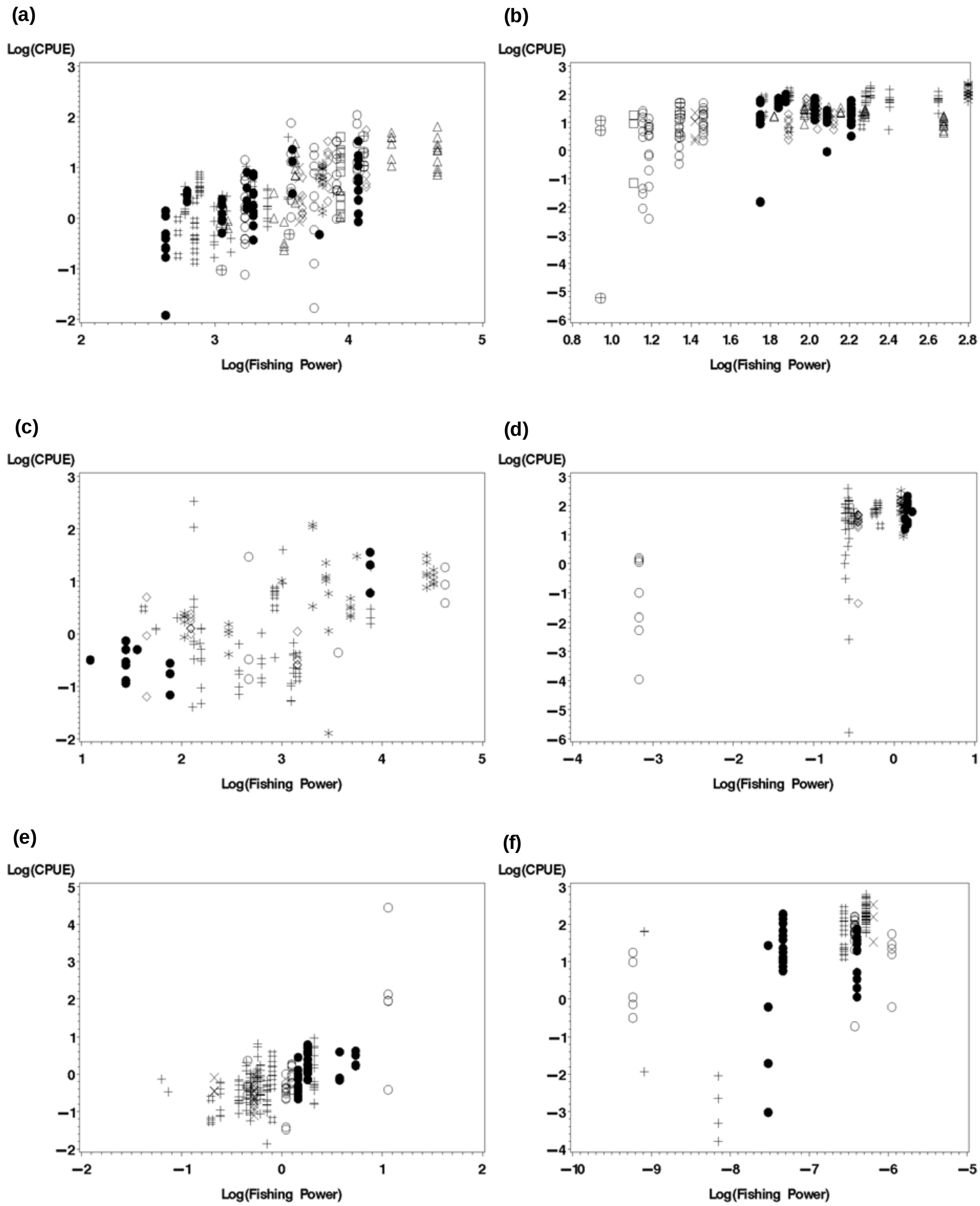

Figure 8. Relationships between log-transformed catch per unit effort (CPUE) and fishing power by trawl type trawl type and groundrope type: single trawl equipped with diabolos (dot), chains (circle), metallic spheres (square), rubber (diamond), plain wire (triangle); twin trawl equipped with diabolos (plus), chains (cross), metallic spheres (star), rubber (hash), plain wire (encircled plus), as derived from the Generalized Linear Models. French otter-trawlers of length range (a, b) (12-16 m), (c, d) (16-20 m), (e, f) (20-24 m) harvesting, (a, c, e) hake (*Merluccius merluccius*) and, (b, d, f) Norway lobster (*Nephrops norvegicus*).

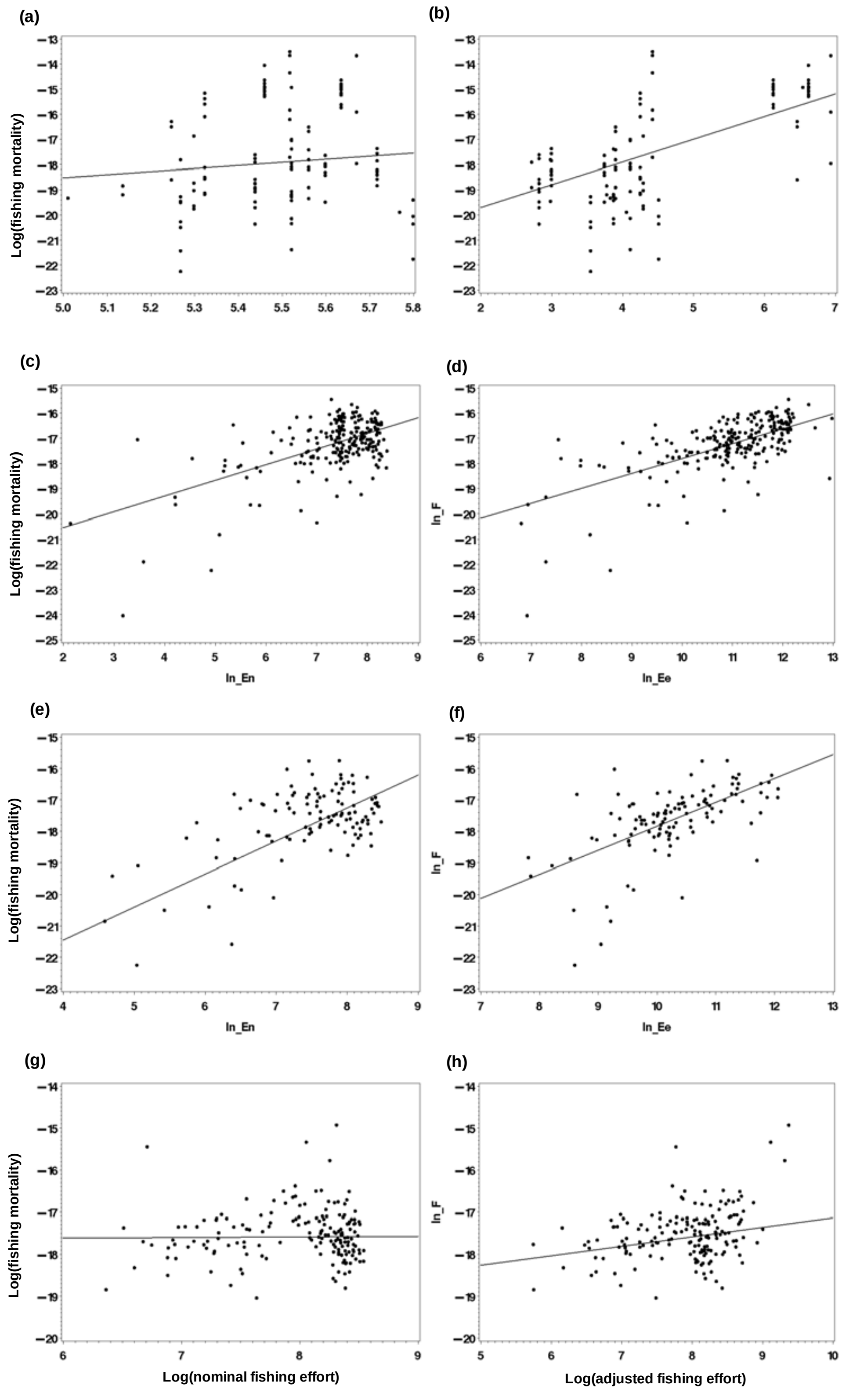

Figure 9. Relationships between log-transformed; (a, c, d, g) partial fishing mortality, Log(F), and nominal fishing effort, Log(En); (b, d, f, h) partial fishing mortality, Log(F), and adjusted fishing effort, Log(Ee). French (a, b) gillnetters, (c, d) otter-trawlers (12-16 m), (e, f) otter-trawlers (16-20 m) and, (g, h) otter-trawlers (20-24 m) harvesting Northern hake (*Merluccius merluccius*).

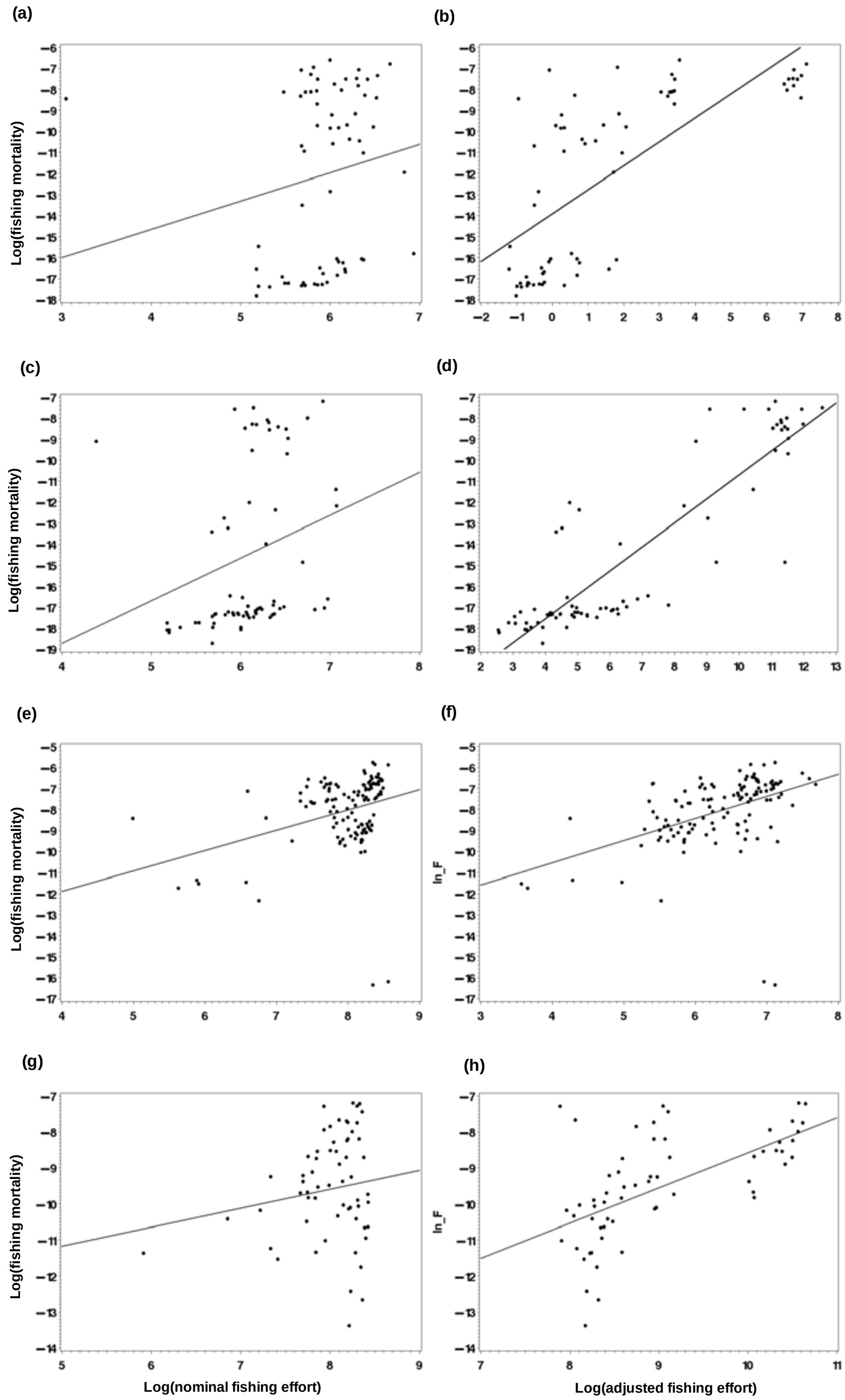

Figure 10. Relationships between log-transformed; (a, c, d, g) partial fishing mortality, Log(F), and nominal fishing effort, Log(En); (b, d, f, h) partial fishing mortality, Log(F), and adjusted fishing effort, Log(Ee). (a, b) Danish otter-trawlers harvesting North Sea cod (*Gadus morhua*), (c, d) Danish otter-trawlers harvesting North Sea plaice (*Pleuronectes platessa*), (e, f) Basque bottom-trawlers harvesting Northern hake (*Merluccius merluccius*), (g, h) Basque bottom-trawlers harvesting Celtic Sea and Bay of Biscay anglerfish (*Lophius spp.*).