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An investigation of human vs. technology-induced variation in catchability for a selection of European fishing fleets

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Abstract:

The impact of the fishing effort exerted by a vessel on a population depends on catchability, which depends on population accessibility and fishing power. The work investigated whether the variation in fishing power could be the result of the technical characteristics of a vessel and/or its gear or whether it is a reflection of inter-vessel differences not accounted for by the technical attributes. These inter-vessel differences could be indicative of a skipper/crew experience effect. To improve understanding of the relationships, landings per unit effort (lpue) from logbooks and technical information on vessels and gears (collected during interviews) were used to identify variables that explained variations in fishing power. The analysis was undertaken by applying a combination of generalized additive models and generalized linear models to data from several European fleets. The study highlights the fact that taking into account information that is not routinely collected, e.g. length of headline, weight of otter boards, or type of groundrope, will significantly improve the modelled relationships between lpue and the variables that measure relative fishing power. The magnitude of the skipper/crew experience effect was weaker than the technical effect of the vessel and/or its gear.

Keywords : catchability ; fishing power ; GAM ; GLM ; skipper skill ; technical characteristics

1. Introduction

Fishing effort limitation has traditionally been a major tool in fisheries management. It has been applied in order in an attempt to prevent the decline of exploited marine populations, often within the context of mixed fisheries (Beddington and Rettig, 1984). Fishing effort is generally defined as the product of fishing power (also called fishing capacity and approximated by technical characteristics) and nominal fishing effort (also called fishing activity and approximated by hours fished) (Cunningham and Whitmarsh, 1980). A management decision in terms of effort limitation must take into account both components and consequently, this requires an accurate estimate of fishing power.

The estimation of fishing power is also a critical issue in the computation of indices for the standardisation of abundance derived from landings per unit effort (lpue). It is assumed that a proportional change in any index of abundance is expected to represent the same proportional change in stock size (FAO, 1999). However, lpue is in many circumstances unlikely to be proportional to abundance (Dobby *et al.,* 2008). Standardisation of lpue normally involves the removal of certain effects such as effort-inputs related to fishing power and/or population accessibility (Harley *et al*., 2001, Mahévas *et al*., 2004, Ye and Dennis, 2009). The level of fishing power results from the combined effects of several inputs factors with different degrees of importance (Pascoe and Robinson 1996). Fishing power may be linked with vessel equipment, gear characteristics (the technical set-up), skill of the skipper and crew, spatial population distribution and abundance, environmental conditions and fishing tactics (characterised as métiers which directly associated with the choice of fishing grounds, targeted species, gear used and fishing season).

As it is difficult to assess any changes in an absolute measure of fishing power, the concept of relative fishing power is used. A number of approaches have been developed to quantify relative fishing power. As an example, Beverton and Holt (1954) based their method on the relationship between the catch rate of a given vessel (or the whole fleet) and the catch rate of a standard vessel. Traditionally, linear models have been used to estimate fishing power while taking into account spatial and temporal heterogeneity of fish-populations and fishing activity (Gulland, 1964, Robson, 1966, Gavaris, 1980, Quirijns *et al.,* 2008). When the residuals of such models indicate that there is evidence of more complex heterogeneity than could be explained by a simple spatial and temporal change in the data, it is common either to include interactions between these effects (Large, 1992, Maunder and Punt, 2004), or to consider the importance of environmental (Gaertner *et al*., 1999) or economic variables (Kirkley *et al*., 1995; Squires and Kirkley, 1999). Given the estimation of fishing power for each vessel of a fleet, identifying the most influential elements that affect a vessel's performance is an important step towards successful fisheries management.

In this study we investigated whether the variation in fishing power could be linked to technical characteristics of the vessel (e.g. length, tonnage, electronic specifications) and the gear (e.g. type of groundrope or the length of headline), or whether it is instead a reflection of differences among vessels not accounted for by the technical information. In the latter case, if all technical factors that could have an impact on fishing power were considered in the analysis, variation in fishing power could potentially be indicative of the presence of a human (skipper-crew experience/skill) effect. The hypothesis that a human effect exists is not recent and has been debated in the literature. At one stage the "fisher effect" was considered as being little more than a myth (Palsson and Durrenberger, 1982) until Robins *et al.* (1998) managed to provide evidence of and quantify an increase in fishing power that could be directly linked to a degree of fisher experience with a plotter system. A skipper-crew effect can therefore be detected when the experience of the skipper and the crew are likely to contribute significantly to the overall fishing power of the vessel. This skipper-crew experience can sometimes be related to the age of the skipper, length of time the skipper-crew have been using one boat or have greater experience with one piece of equipment and/or gear, and assumes that their ability to catch fish improves with time (Robins *et al.,* 1998, Mahévas *et al.,* 2004). However, only a few proxy variables may allow one to detect all the other components of this human effect (like different fishing methods, varying degrees of knowledge of the ocean and adaptability to the environment, and alternative short term harvesting strategies) that Squires and Kirkley (1999) have grouped and titled 'unobserved managerial ability'.

The European research project CAFÉ (Reid, 2009) gave us the opportunity to investigate and understand the relationship between fishing power and lpue. The analysis was performed using a combination of Generalised Additive Models (GAMS) (Hastie and Tibshirani, 1990) and Generalised Linear Models (GLMs) (McCullagh and Nelder, 1989) and these approaches were applied to data on seven European fleets (and for one of their main targeted species).

The analyses consisted of 4 steps:

1) Testing the hypothesis that the variations in fishing power were linked to a spatial and temporal strata corresponding to common fleet fishing tactics or to the spatial, seasonal fluctuations in biomass.

2) Assessing the relative contributions of the skipper-crew experience effect versus technical characteristics effects on a measure of relative fishing power.

3) Relating fishing power to technical information on vessels and gears collected in a dedicated technological survey carried out around the European coast (Marchal [ed.], 2006).

4) Finally, providing some specific and generic conclusions on the robustness of fishing effort standardisation based on the technical characteristics and comparing the magnitude of the so-called skipper-crew experience effect and purely technical factors.

2. Material and methods

2.1. Fishing fleets

Data from 7 fleets were available (Table 1, Figure 1). The first fleet (Fleet 1) consists of French demersal trawlers between 12 and 24 meters, operating in the Bay of Biscay (ICES subdivision VIIIab), during the period 1999-2003. Megrim (*Lepidorhombus spp*.), hake (*Merluccius merluccius*), Monkfish (*Lophius spp.*) and Ling (*Molva molva*) are targeted by this fleet and they land mainly in ports located to the south of Brittany. The second fleet (Fleet 2) consists of demersal French trawlers between 18 and 26 meters operating in the North Western Mediterranean Sea (General Fisheries Commission for the Mediterranean (GFCM)-Geographical Sub-Area (GSA) 07, Gulf of Lions) during the period 2000-2006. Hake is one of the most important demersal target species of the commercial fisheries in the Gulf of Lions (GFCM-GSA 07), but this fleet also lands many other species, like Monkfish, Horned octopus (*Eledone cirrhosa*) and red mullet (*Mullus barbatus*). The third fleet (Fleet 3) consists of French pelagic trawlers between 16 and 25 meters operating in the Bay of Biscay during the period 2000-2005. This fleet mainly targets several pelagic species such as European anchovy (*Engraulis encrasicolus*), European sea bass, Tuna (albacore, *Thunnus alalunga*) or horse mackerel (*Trachurus trachurus*) and lands in different harbours depending on the fishing grounds being exploited, which are mainly located to the South-West of France. The fourth fleet (Fleet 4) consists of English beam-trawlers which are greater than 24 meters and targeting mainly flatfish (plaice (*Pleuronectes platessa*) and sole (*Solea spp.*) in the North

Sea during the period 2000-2006. The English North Sea beam trawl fleet (>=24m) mostly fished out of the east coast ports of England, the main port being Lowestoft at one stage. The fifth fleet (Fleet 5) consists of Greek purse-seiners belonging to two fleet segment categories, 12-24 meter and 24-40 meter, in the Eastern Mediterranean (Aegean Sea) over the period 2000-2005. Catches are highly mixed with European anchovy, sardine (*Sardina pilchardus*) and horse mackerel being the main target species (Maravelias and Tsitsika, 2008). This case study involved all major purse seine fishery ports in the Greek Aegean (Pireus, Chalkis, Thessaloniki, Poligyros, Volos, Chania, Heraklion, and Kalymnos). The sixth fleet (Fleet 6) consists of Spanish Basque demersal trawlers between 24 and 39 meters fishing in the Bay of Biscay over the period 1999-2003. The target species of this fleet include hake, megrim, monkfish which are landed in the Basque Country ports of Ondarroa and Pasaia . The seventh fleet (Fleet 7) is made up by the Spanish purse-seiners between 14 and 38 meters fishing in the Bay of Biscay over the period 2000-2005. This fleet harvests mainly pelagic species such as European anchovy, horse mackerel, mackerel (*Trachurus mediterraneus*) and sardine. In addition during the summer this Fleet 7 shifts its fishing gear to pole and line and target Atlantic tuna and land their catches mainly in Guetaria, Ondarroa and Pasaia and Santoña (Cantabria).

We estimate the fishing power in relation to the main target species for each fleet: that is, hake for Fleets 1, 2 and 6; anchovy for Fleets 3, 5 and 7; and plaice for Fleet 4. This panel of fleets allowed us to investigate whether pelagic fleets (and similarly demersal fleets) share some common technical characteristics that would explain differences in fishing power. Horse power or vessel tonnage are often used to standardise fishing effort but we assume that other technical characteristics (traditionally not measured) of the vessel (e.g., date of construction) or gear (e.g., length of headline) could be better proxies of relative fishing power.

2.2. Data

Logbook information on fishing effort, catch and technical information on vessel and gear were extracted from the database (Eflalo) developed within the TECTAC project (Marchal, 2006). Greek data (Fleet 5) was acquired from the National Statistical Services of Greece and Greek Ministry of Mercantile Marine databases. For several fleets (Fleets 1, 4, 5, 6 and 7), each fishing sequence (a the logbook's row entry, the unit of catch observations) has been allocated to a particular métier (a combination of a gear, target species and ICES sub-division fished; Biseau, 1998). While logbook data are available for most registered vessels, technical information traditionally recorded in administrative regulatory orders is only available for a subset of the vessels. Within the TECTAC project, additional historic information on technical characteristics of vessel and gear were collected during face-to-face interviews with current vessel owners for some of the fleets in France and Spain (Fleets 1, 2, 3 and 6). This survey relied on the acceptance and cooperation of fishers to participate as they were asked about past changes made to their vessels. Greater detail on the data collection regime is reported by Marchal (2006). In spite of the dedicated effort to collect technical data, the Eflalo database did not systematically include technical information on vessel or gear for all the fishing trips. In order to optimise the use of this information, we compiled two new datasets, one including the information on both the Logbooks and the technical aspects of the vessel (Tecvess) and one on both the Logbooks and the technical aspects of the gear (Tecgear). Table 1 provides a representation of the vessels sampled in terms of technical information. The English, Greek and the Spanish fleets (Fleets 4, 5 and 7, respectively) have limited information on vessel and gear (Table 1, Table 2). Finally no spatial information on catch is available for the Mediterranean fleets (Fleets 2 and 5). This is also the case for the Spanish purse-seiner targeting anchovy in the Bay of Biscay (Fleet 7), where information on the ICES subdivision targeted was only available for the period 2003-2005. A summary of the average values for the physical characteristics of the fishing vessels are presented in Table 1. Summaries of logbook data, vessel technical characteristics, and gear characteristics are provides in Tables 2, 3 and 4, respectively.

2.3. Fishing power model

To account for fishing tactics, we analysed individual fishing vessels at the smallest scale available from the fishers' logbooks. Fishing tactics refers to the type of fishing operation, and can be defined by the characteristics and outcomes of a single haul. The ideal scheme would be to consider haul-by-haul lpue data, but unfortunately landings and effort in logbooks are recorded by fishing trip or by fishing day. Consequently, lpue was calculated using species catch in weight, divided the fishing time for every set of fishing trips or fishing days. We assume that catch is proportional to the product of fishing effort and population density (Mahévas *et al.,* 2004; Campbell, 2004). A realistic model for lpue can thus be described as:

lpue = Landings/FishingTime= a*P*E*N (1)

where *a* denotes the accessibility coefficient of the target population and *P* describes the fishing power of the vessel or the fleet targeting the population of abundance *N*, when exerting a nominal fishing effort *E*. The product *a*P* is known as catchability. This model allows for an analysis of lpue data per vessel and per fishing sequence/trip in order to estimate the relative fishing power of each vessel within a fleet and to relate differences in individual fishing power to factors such as technical characteristics and skipper skill effects. Multiplicative models have traditionally been used to analyse fishing power on linear regressed log-transformed lpue data. The GLM/GAM approach constitutes an extended approach as it allows for an analysis of lpue data allowing for non-normal distributions and also avoids bias caused by back-transformation (Laurent, 1963). The key drawbacks of this modelling approach are (1) the possible confusion between temporal and spatial variations owing to population abundance and fishing power changes of the fleet, and (2) the possible residual deviation in the temporal effect when catchability is density-dependent. We analysed the vessels' lpue for each fleet separately using GLMs and GAMs. The approach is performed in four steps: (1) an exploratory analysis, (2) an analysis where we obtain an estimate of individual vessel's fishing power, (3) an analysis where we estimate a vessel's technical fishing power and (4) an analysis where we obtain an estimate of the gear's technical fishing power.

2.4 Exploratory analysis

The process of model fitting requires that we make a selection of the most appropriate error distribution and covariates based on an exploratory analysis (Maunder and Punt, 2004; Bordalo-Machado, 2006). Histograms of lpue frequency and simple plots of the response variable lpue against available explanatory variables were created so that alternative models could be specified and alternative formulations could be derived for each fleet.

2.5 Individual vessel Fishing power

Secondly, we estimated the proportion of variability in lpue associated with the grouped -'vessel-crew-gear' effect in relation to the fishing tactic (or métier in operation), and spatio-temporal variation in both abundance and fishing power (Table 5). This analysis was carried out for the whole fleet over the period defined, and can be expressed as:

log(E(lpue)) ~Vessel + Area* + Month + Year + Metier* + interactions   (model 1 = “vessel logbook base” model)

The asterisk indicates that the variable was included in the model when the information was available.

Nested GLM models were fitted to lpue using an appropriate error distribution (either Normal or Gamma distribution), the choice of which was an outcome of the exploratory analysis. We systematically used a log-link to preserve the multiplicative nature of the relationship between lpue and factors which are a decomposition of catchability. The order of the variables in the model can have bearings on the significance of the factors (Bishop *et al.*, 2008). Primarily we consider the *Vessel* effect as this could be an indication of the importance of the skipper-crew’s experience combined with the physical influence of the vessel’s and the gear’s characteristics. The *Year* effect accounts for potential drift in fishing power confounded with changes in abundance of the target species.

2.6 Vessel technical fishing power

The same model as the “vessel logbook base” model was fitted to the sample of vessels contained in the Tecvess database (Table 5):

log(E(lpue)) ~Vessel + Area + Month + Year + Métier + interactions   (model 2 = “vessel tecvess base” model)

After, removing the vessel variable from *“vessel tecvess base”* model, we estimated the proportion of variability accounted for in lpue associated with vessel characteristics using the Tecvess dataset. As most of the technical characteristics of the vessel are correlated, the relative contribution of each feature was assessed using single-variable models (Mahevas *et al*., 2004; Maunder and Punt, 2004) and their goodness of fit were compared using the Akaike’s Information Criteria (AIC; Akaike, 1974). When a technical characteristic is a continuous variable, a Generalized Additive Model (GAM) was preferred to a GLM which assumes a linear relationship in log-space (Wood, 2006). Technical characteristics which indicate a model fit AIC of the associated single-variable model which was lower than the AIC of the *“vessel tecvess base”* model, were included in model 3 (Table 5), where model 3 is specified as:

log(E(lpue)) ~ g(VesselTechnicalCharacteristics) + Area + Month + Year + Métier + interactions   (model 3 = “technics tecvess base” model)

We compared the proportion explained by the vessel effect in the “vessel tecvess base” model and by all discrete vessel characteristics in the “technics tecvess base” model to assess the capacity of vessel characteristics in explaining differences in vessel fishing power (Table 5).

2.7 Gear technical fishing power

Finally, the same approach was applied to assess the role of gear characteristics. We fitted model 4, using the Tecgear database (Table 5):

log(E(lpue)) ~Vessel + Area + Month + Year + Métier + interactions   (model 4 = “vessel tecgear base” model)

Having removed the vessel effect from “vessel tecgear base” model, gear characteristics (if available) were included to estimate the contribution of the gear characteristics in lpue variability, similarly to the “technics tecvess base” model (Table 5):

log(E(lpue)) ~ g(GearTechnicalCharacteristics) + Area + Month + Year + Métier + interactions (model 5 = “technics tecgear base” model)

Again the “vessel tecgear base” and the “technics tecgear base” models were used to assess the relative ability of gear technical characteristics to affect fishing power compared to vessel effects (Table 5).

By adding significant vessel characteristics effects from the “technics tecvess base” model to explanatory variables of the “technics tecgear base” model, we estimated the global contribution of technical characteristics in fishing power (Table 5):

log(E(lpue)) ~ g(VesselTechnicalCharacteristics) + f(GearTechnicalCharacteristics + Area + Month + Year + Métier + interactions (model 6 = “technics tecvess tecgear base” model)

Assuming that (1) the vessel effect includes the human component of fishing power, and (2) technical component of fishing power is determined by both gear and vessel characteristics, the discrepancy in explanatory power of model 4 and model 6 was used as a proxy of the magnitude of the human component (or at least an upper bound of this effect) in fishing power, the so-called skipper-crew experience effect.

The type (continuous/categorical) of each explanatory variable included in statistical models is driven by the nature of the variable . Consequently, all continuous variables were treated as continuous regressors whereas discrete and non-numerical variables were considered as categorical factors. For factors, the first modality defines the reference and is set equal to 0 to make parameter estimates directly interpretable (Venables and Ripley, 2002). In models 1 to 6, the *Year* effect takes into account the annual variations in fishing power of the fleet and a change in abundance of the target species. The *Month* effect characterises seasonal variations in harvesting practices (Laurec and Le Gall, 1975) but probably also in fish accessibility. Similarly, *Area* effects describe spatial variations in abundance, accessibility and fishing tactics. The vessel effect quantifies the vessel’s fishing power that may be associated with skipper-crew skill and vessel and gear characteristics. The *Métier* effect describes variations in fishing tactics.

The GAM was estimated using the penalized version of maximum likelihood provided by the generalized cross validation method (Woods, 2006). The GLMs and GAMs were assessed for goodness-of-fit and were evaluated via exploration of the characteristic of the residuals. A comparison of the deviance residuals against the fitted values presented no systematic pattern and are normally distributed (McCullagh and Nelder, 1989; Hastie and Tibshirani, 1990). The analysis of deviance (measure of discrepancy) relies on the χ^2 approximation for differences between deviances in nested models. To select a parsimonious model, we computed Akaike’s Information Criteria (AIC) for each model (Akaike, 1974). Although a GAM is fitted using penalized regression splines and a GLM is simply a pure penalized regression model, Wood (2006) has shown that AIC is appropriate to compare GAM or GLM nested models. The absolute magnitude of the AIC value is not interpretable, therefore we used the AIC differences (ΔAIC = AIC(model)-min(AIC), where min(AIC) is computed over all candidate models in the set) to compare and rank models. Burnham and Anderson (2003) recommended that studies omit models with a ΔAIC greater than 10.

3. Results

3.1. Exploratory Analysis

For each fleet, we performed an exploratory analysis using histograms of lpues' frequency and simple plots of their relationship to explanatory variables (not shown). A first step when fitting GLMs is to choose an appropriate error distribution. Histograms of log-transformed lpue frequency were examined for each series to select between a gamma and a lognormal distribution by visual inspection. This selection was also validated using the standard model checking criteria (Q-Q plots). Most fleets are characterised by evidence of fishing seasonality and annual variations in averaged lpue. When fishing trips (sequences) are reported in logbooks at the scale of the ICES rectangle, the fishing activity at the scale of the fleet shows strong spatial patterns with preferences for particular ICES rectangles. Recently, there was an increase in effort sampling for several fleets which could lead to more accurate estimates for the last few years of the studied period. Finally, the métier variable, when available, captured reasonably well the variance in lpue within the fleet.

Variations in lpue in relation to technical characteristics were also investigated. There were obvious trends in lpue versus vessel length for Fleets 1, 4, 5, 6 and 7, and lpue versus horse power for Fleets 2 and 3, and in lpue versus date of acquisition for Fleets 1 and 6. Consequently horse power, vessel length, tonnage and the date of acquisition were identified as potential discriminant variables and were tested for all fleets. A thorough investigation of the technical characteristics of Fleets 1, 2, 3 and 6 demonstrated that engine rotation per minute, the presence/absence of a bulbous bow, the number of net drums and the presence/absence of variable pitch propeller were highlighted as discriminatory variables. More specifically, the exploratory analysis showed the relevance of the hull material variable and experts recommended this variable should be linked with bollard pull. Unfortunately, the bollard pull, which is a measure of vessels' maximal power (the zero speed pulling capability of the boat), is available only for the Fleet 2. When we considered electronic equipment (GPS, sonar and radar), little difference was observed in lpue. Overall, the acquisition of new equipment during the study period affected the pelagic trawlers more than demersal vessels. The length of headline (for Fleets 2, 3 and 6) and the weight of otter boards (for Fleets 2 and 6) affected the lpue for a limited number of fleets and in combination should be a good proxy of the volume filtered (i.e., trawl opening × gauge). On the other hand, the type of ground ropes represented a strong discriminatory variable in all the fleets that recorded this characteristic.

3.2. Individual vessel Fishing power

The best fit for the "vessel logbook base" model 1 includes all the introduced variables as well as some interaction terms for Fleets 1, 4, 5 and 6 (Table 6). The plot of the residuals did not display trends (not shown), and the Q-Q plot indicated that the residuals are consistent with the assumed error model, except for Fleet 3 where outliers made the observed plot deviate slightly from the reference line. For Fleet 3 (a pelagic fleet), the assumption of a linear relationship between lpue and the biomass is perhaps not appropriate (McCall, 1990) and leads to a slight model misspecification. With respect to most fleets, the Vessel effect has the greatest contribution towards the change in deviance and AIC (Table 6). The Mediterranean pelagic fleet (Fleet 5) distinguished itself as unique in this regard. For this fleet, the Vessel effect exerted the second largest contribution towards the observed variability in the landings (~9%) and the Month effect had the greatest contribution towards the change in deviance and in AIC (Table 6). Indeed this pelagic fishery is closed at the beginning of the year and this monthly effect is therefore largely explained by high catches after the reopening and a gradual decrease of anchovy catches from June to November.

Subsequently the significance of the Month effect reflects a high seasonality in the fishing power. For most fleets, the Year effect does not contribute as much, compared to other effects. It certainly displays a weak change in the efficiency of fishing power probably as a result of the short length of the period over which this study is focussed (from 5 to 7 years). The only fleet which contrasts sharply with the others is the Spanish demersal fleet (Fleet 6). It is characterised by a high contributing Year effect on the change in AIC whereas Fleet 1, targeting the same hake population, shows a slightly positive Year effect. Given that stock assessments and scientific surveys over the study period (1999-2003) delivered a rather positive trend in hake biomass estimates (ICES, 2006), this negative effect could reflect a decrease in efficiency or be masking a change in tactics not evident in the data collected. When several fishing tactics are applied within a fleet, the Métier effect is significant, confirming possible differences in fishing efficiency caused by the difference in the fishing tactics of each métier. This was clearly detected for the French fleet of the Bay of Biscay (Fleet 1) and the Spanish Basque demersal trawlers (Fleet 6), but unfortunately less significant for the Greek purse Seiners (Fleet 5). The interactions of Vessel effect with Month or Métier (depending on fleet) were sometimes significant although the corresponding model had a larger AIC because of the large number of degrees of freedom required. Contrary to what we had expected from the exploratory analysis, the spatial effect was not strongly significant. It is likely that the contribution of this variable is being included in the explanatory power of the Vessel or the Métier that may include the effects associated with the skipper effect and/or the fishing tactic. Finally, the Vessel effect contribution derived from this first step analysis varied between 10% and 52% among the seven fleets (Table 6).

3.3. Vessel technical fishing power

The goodness of fit of the “vessel logbook base” model 1 and the “vessel tecvess base” model 2 are equal (Tables 5 and 6) and the rank of the contribution of each explanatory variables is similar in both models. This result confirms that the outcomes derived from the “vessel tecvess base” model can be extended to the Eflalo dataset. Time since vessel acquisition and tonnage are the most frequently identified significant variables (Table 7). Contrary to what might have been expected, the horse power is only significant for Fleet 5. The tonnage variable result in lower AIC scores with the largest explained deviance for Fleets 3, 4 and 5 (Table 7). Fleet 7 distinguishes itself from all others with vessel length as the most significant variable while the bollard pull variable was the most significant variable for Fleet 2. The latter is not unexpected because it is a measure of the maximal power of the vessel and is believed to be a good proxy of technical efficiency. Unfortunately this information was only collected for this single fleet.

We substituted the Vessel factor by the relevant vessel technical characteristics identified above for each fleet and fitted the “technics tecvess base” model (model 3). The AIC score of model 3 is still lower than the AIC score of the “vessel tecvess base” (model 2) (not shown). For most fleets, the Vessel effect is larger than measured technological effects, although this is less obvious for Fleet 3 (Table 7). The difference between the deviance explained using the Vessel effect and detailed vessel characteristics (i.e. Tecvess) may be to the result of either a genuine skipper-crew effect or to other technical characteristics of the fleet not considered in our analyses.

3.4. Gear technical fishing power

This step of the analysis was only carried out for the Fleets 1, 2, 3 and 6. As for the comparison of the “vessel logbook base” model (model 1) and the “vessel tecvess base” model (model 2), the relative contribution of factors in the “vessel tecgear base” model (model 4) and in the “vessel logbook base” model (model 1) are similar. This result suggests that the samples of trips in the Eflalo and Tecgear databases are equally representative. In the "technics tecgear base" model (model 5) the Vessel factor has been excluded and substituted by gear technical characteristics. The type of groundrope, the length of headline and the weight of the otter boards are the most common and significant gear characteristic factors (Table 8). Comparison of the last three columns of Table 8 provides an assessment of the relative contribution of human and technical effects on fishing power. As expected the Vessel effect is still larger than that of the measured technical features of the gear. The discrepancy between Vessel and gear technical effects is lower than that between Vessel and vessel technical effects (Table 7). This reveals that fishing power is more strongly associated with gear characteristics than to vessel characteristics. Adding all technical effects the explanatory power of the "technics tecvess tecgear base" model 6 is still lower than the "vessel tecgear base" model 4. Technical characteristics explained 4% for Fleet 1 and 5% for Fleet 6 of vessel effects ("T" in Figure 2). If we assume that all the technical components of fishing power are captured by the technical characteristics included in the model and that the human component of fishing power is included in the Vessel effect, then the magnitude of "H" in Figure 2 (varying from 0.2% for Fleet 3 to 5% for Fleet 1) shows the upper bound of the contribution of human skill to fishing power.

4. Discussion

Catchability is known to be affected by processes linked to fishing power, that is the technical characteristics of the fishing gear/vessel and human factors such as experience or strategy (Robins *et al.*, 1998; Goñi *et al*., 1999; Mahevas *et al*., 2004), and processes linked to the biology of the exploited population, such as variation in fish distribution and thus availability to the gear (Casey and Myers, 1998). We found that whatever the target species (anchovy, hake or plaice), and for most locations (North Sea, Bay of Biscay, Mediterranean Sea), the explanatory factor with the greatest effect on fishing power is that of the individual vessel. The range of variability explained by this factor differs from one fleet to another but it is more than 40% of explained deviance for at least two of the seven fleets.

When fishing tactics can be accurately characterized, the analysis reveals that the *Métier* variable is appropriate to significantly distinguish differences in fishing power. This confirms Quirjns *et al.*'s (2008) main conclusion which highlights the importance of accounting for targeting behaviour to avoid bias in the standardisation of lpue. Consequently, it would be relevant to associate métier to a fishing operation or a fishing trip. Two options could be considered to achieve this outcome. The most suitable one would be the obligation for fishermen to report in logbooks their intended target species (as it is already the case in New-Zealand for instance). Alternatively, the métier could be computed using catch profile and an appropriate factorial analysis. A review of the available statistical methods for defining métier was performed as part of the European study "*Development of tools for logbook and VMS data analysis*" and an operational algorithm is proposed to allocate trips described in logbooks to métiers (Deporte *et al*. 2011).

As expected, seasonal (month) and the spatial area factors explained a significant proportion of the lpue's variability. The seasonal and spatial aspects of effort stratification can be used to derive reliable lpue indices as has often been argued in the literature (e.g. Bordalo-Machado 2006). Our results indicate that changes in the fishing efficiency of a fleet can be seasonally and spatially based. This suggests that the spatial and seasonal dimension of fisheries management should be carefully investigated when designing a management measure that is spatially explicit (or its effects will have spatially explicit consequences). More specifically, the outputs of this analysis can be helpful for defining an appropriate design of a Marine Protected Area (MPA) (for example) in the context of an ecosystem approach to fisheries management (EAFM). One can suggest for instance to preferably close the fishery during the period and/or in the fishing area characterized by the highest fishing power if the objective was to minimise mortality on a vulnerable stock.

A clear temporal variation was also evident from the significant *Year* effect and/or the interactions with *Year* for all demersal fleets (Fleets 1, 2, 4, 6) and the Greek pelagic fleet (Fleet 5). With the exception of the Spanish Basque demersal fleet (Fleet 6), there was no clear increasing or decreasing trend in the *Year* effect in the short period we considered. Generally, a positive trend in *Year* effect is expected and explained as technological creep and/or improvement in skills (e.g. Marchal *et al.,* 2006a; Quirijns *et al.,* 2008). In contrast the Spanish Basque demersal fleet (Fleet 6) was characterized by a decrease in the *Year* effect. Such a pattern has also been observed for a French demersal fleet targeting monkfish (*Lophius budegassa* and *Lophius piscatorius*) (Mahévas *et al.*, 2004). One potential reason to explain this trend is a change in abundance. Indeed, the estimate of the *Year* effect captures both fishing power and variations in abundance. It should also be noted that residual variations in abundance could easily swamp the influence of technical factors. As recommended by several authors, external information to accompany the logbook data could be used to represent abundance in the model to remove the possible confounding effect of temporal variations in abundance on lpue (Mahévas *et al.*, 2004; Bishop *et al.*, 2008). However, the abundance indices available for our analyses are based on juvenile surveys which are sensitive to recruitment variability and consequently are not appropriate to reflect the interannual variations of the accessible part of the population and so were not considered suitable for our modeling approach.

This study also reveals that differences in fishing power are explained by both technical and human components to various degrees. Initially, we were interested in identifying which technical characteristics could be relevant control parameters for technical management approaches. For pelagic trawlers, vessel characteristics (tonnage) explain the largest amount of fishing power variability whereas in the case of demersal trawlers, gear characteristics (type of groundrope, headline length) are dominant. Engine horse power, largely used as a control variable for regulating fishing capacity, was only significant for the Greek pelagic fleet. Therefore, this study confirms Mahevas *et al*.'s (2004) conclusion that horse power is not the most appropriate variable to standardise fishing effort and manage fishing effort. On the other hand, the type of groundrope and the length of headline are rather unused variables for controlling fishing effort and the outcomes of this analysis show their relevance for proposing technical measures aimed at regulating fishing effort. Our results also confirm the importance of bollard pull as a determinant of fishing power, and we suggest that this variable should be systematically recorded in fisheries data collection programs. Again, focussing on trawlers, we obtained the same results as presented in Marchal *et al.* (2006a). The explanatory power of the technical characteristics are mostly lower than the vessel one itself.
We acknowledge that the results from these case studies are dependent on the quality of the vessel and gear technological data collected during the harbour enquiries or reported in regular administrative registers. Only four fleets among the seven had detailed information on technological equipment onboard. For some cases, a larger sample would be needed to carry out any meaningful analyses, and consequently the widespread use of any conclusions from this study should be considered carefully. However, these data were generally useful to identify the major determinants of fishing power. The relative significance of different explanatory variables is also impacted by the degree of aggregation (i.e. using days and daily landings instead of haul-by-haul data of a fishing operation). It would therefore also be desirable that technical features of both vessels and gears be monitored, or recorded by fishers themselves, at the scale of the fishing trip (the vessel equipment) or at the very least at the scale of the fishing operation (the gear equipment).

Most studies that analyse fishing power identify the main technical characteristics accountable for changes in this variable and technical creep (Robins et al. 1998, Mahévas et al. 2004, Bordalo-Machado 2006, Marchal et al. 2006a), but few evaluate and quantify the human contribution to fishing power. The human component in fishing power could be associated with the accumulation of knowledge of population behaviour, of experience in selecting fishing grounds and in operating the fishing equipment, each of which or in combination may have a positive impact on fishing power (Squires and Kirkley, 1999; Marchal et al 2006b; Ye and Dennis, 2009). Our approach, of comparing the explanatory power of the nested fitted models allowed us to assess the relative contribution of the technical characteristics and their effects on fishing power on one hand and provides an evaluation of an upper bound of the non-technical (the human) component of fishing power on the other. For the fleets for which both gear and vessel technical characteristics are described, gear technical characteristics explained more differences in fishing power than vessel characteristics. The discrepancy between the explanatory power of the model including the vessel effect (the “vessel tecgear base” model 4) and the models substituting the vessel effect by all technical characteristics (the “technics tecvess tecgear base” model 6) provides an estimate for an upper bound of the human effect (the skipper-crew experience effect). If we considered that all important technical characteristics are included in the “technics tecvess tecgear base” model 6, then the relative measure obtained indicates that the contribution of human component in fishing power is weaker than the technical one, but in all likelihood it is not a negligible factor affecting fishing power. On the basis of these results, we can conclude that measures that ignore this human component could lead to an undesirable side-effect when management attempts to control the fishery with direct effort restrictions alone. An interesting perspective of this research will be to use some appropriate simulation models to assess the relative improvement that could be reached using alternative management measures based on the conclusions derived from this study. Several bio-economic modelling frameworks of fisheries dynamics have been recently developed to assess the impact of management strategies (e.g. ISIS-Fish (Mahévas and Pelletier, 2004) and FLR (Kell et al., 2007)). The computation of the fishing mortality of the ISIS-Fish model requires an estimate of fishing power that could be formally linked to the technical characteristics of the fleet (Pelletier et al., 2009). Moreover, this model explicitly takes into account the spatial features of the fishery dynamics and has already shown its relevance for assessing the impact of Marine Protected Areas (Kraus et al., 2008; Lehuta et al., 2010). For example, selecting as a case study the demersal fishery in the Bay of Biscay targeting hake (Drouineau et al 2006), it would be interesting to compare the impact of a new technical measures regulating the use of rockhopper gear (a type of groundrope) and of a spatial and seasonal closure to the traditional TAC regulation. The human component could be quantitatively considered as an input parameter in an uncertainty analysis to assess the robustness of the forecasts and provide an opportunity to quantify implementation error associated with this issue.

In future studies on catchability it would also be relevant to assess the relative contribution of the technological-human component and the biological component. To disentangle these two effects, real-time observations on the species population are required; unfortunately these were not available for this study. Promising results from a recent study combining the use of acoustic and cpue data from a small fleet operating in a limited spatial area during a short period (Doray *et al.*, 2010; Mahévas *et al.*, 2010) have provided insight into our greater understanding into the magnitude of the two effects (that is the technological-human component and the biological component).

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References

Akaike, H. 1974. A new look at the statistical model identification. IEEE Transactions on Automatic Control, 19: 716-725.

Beddington, J. and B. Rettig 1984. Approaches to the regulation of fishing effort. FAO Fisheries Technical Papers *243*, FAO, Rome. 39pp.

Beverton, R.J.H., and Holt, S.J. 1957. On the dynamics of exploited fish populations. UK Ministry of Agriculture Fish and Fisheries Investigations, London, (Ser. 2) 19, 533 pp.

Biseau A. 1998. Definition of a directed fishing effort in a mixed-species trawl fishery, and its impact on stock assessments. Aquatic Living Resources, 11, 119-136.

Bishop, J., Venables, W., Dichmont, C., and Sterling, D. 2008. Standardizing catch rates: is logbook information by itself enough? ICES J. Mar. Sci., 65: 255 - 266.

Bordalo-Machado, P. 2006. Fishing effort analysis and its potential to evaluate stock size. Reviews in Fisheries Science, 14 (4): 369 – 393.

Burnham K. P. and D. R. Anderson 2003. Model selection and multimodel inference. A practical Information –Theoric Approach. Springer. 488pp.

Campbell, R. 2004. CPUE standardisation and the construction of indices of stock abundance in a spatially varying fishery using general linear models. Fisheries Research, 70 (2-3): 209-227.

Casey, J.M., and Myers, R.A. 1998. Diel variation in trawl catchability: Is it clear as day and night? Canadian Journal of Fisheries and Aquatic Sciences, 55: 2329-2340.

Cunningham, S. and D. Whitmarsh 1980. Fishing effort and fisheries policy. Marine Policy, 4: 309-316.

Deporte, N., Bastardie, F., Demanèche, S., Mahévas, S. and Ulrich, C., 2011. Comparative investigation of statistical methods for identifying fishing activities from logbooks data. Example of application on the international otter trawl fisheries in the North Sea. In the final Report of the EU project Development of tools for logbook and VMS data analysis MARE/2008/10 Lot 2.

Dobby, H., Allan, L., Harding, M., Laurenson, C., and McLay, H. 2008. Improving the quality of information on Scottish anglerfish fisheries: making use of fishers' data. ICES Journal of Marine Science, 65: 1334 - 1345.

Doray, M., Mahévas, S., and Trenkel, V. M. 2010. Estimating gear efficiency in a combined acoustic and trawl survey, with reference to the spatial distribution of demersal fish. ICES Journal of Marine Science, 67: 668–676.

Drouineau H., Mahévas S., Pelletier D., Beliaeff B. (2006) Assessing the impact of different management options using ISIS-Fish, and sensitivity analysis of the model. Application to the Hake-Nephrops mixed fishery of the Bay of Biscay. Aquatic Living Resources. 19 :15-29.

FAO 1999. Guidelines for the routine collection of capture fishery data. FAO Fisheries Technical Papers N° 382. Rome (1999)

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

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.

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

Gulland, J.A. 1964. Catch per Unit effort as a measure of abundance. Rapport des Procès-Verbaux de Réunion du Conseil International pour l'Exploration de la Mer, 155 : 66-70.

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

Hastie, T.J. and Tibshirani, R.J. 1990. *Generalized Additive Models*, New York: Chapman and Hall.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D., Hillary, R., Jardim, E., Mardle, S., Pastoors, M. A., Poos, J. J., Scott, F., and Scott, R. D. 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES Journal of Marine Science, 64: 640–646.

Kirkley, J.E., Squires, D., and Strand, I.E. 1995. Assessing technical efficiency in commercial fisheries: the mid-Atlantic sea scallop fishery. American Agricultural Economics Association, 77: 686-697.

Kraus, G., Pelletier, D., Dubreuil, J., Möllmann, C., Hinrichsen, H-H., Bastardie, F., Vermard, Y., and Mahévas, S. 2009. A model-based evaluation of Marine Protected Areas: the example of eastern Baltic cod (*Gadus morhua callarias* L.). ICES Journal of Marine Science, 66: 109–121.

ICES. 2006. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. ICES Document CM 2006/ACFM: 09. 981pp.

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

Laurec, A., and Le Gall, J.-Y. 1975. De-seasonalizing of the abundance index of a species. Bulletin of the Far Seas Fisheries Research Laboratory, 12: 145-169.

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

Lehuta, S., Mahévas, S., Petitgas, P., and Pelletier, D. 2010. Combining sensitivity and uncertainty analysis to evaluate the impact of management measures with ISIS–Fish: marine protected areas for the Bay of Biscay anchovy (*Engraulis encrasicolus*) fishery. ICES Journal of Marine Science, 67: 000–000.

Mahévas S., and Pelletier D., 2004. ISIS-Fish, a generic and spatially explicit simulation tool for evaluating the impact of management measures on fisheries dynamics. Ecological Modelling 171, 65-84.

Mahévas, S., Sandon, Y., and Biseau, A. 2004. Quantification of annual variations in fishing power due to vessel characteristics: an application to the bottom-trawlers of South-Brittany targeting anglerfish (*Lophius budegassa* and *Lophius piscatorius*). ICES Journal of Marine Science, 61: 71-83.

Mahévas, S., Trenkel, V. M., Doray, M., and Peyronnet, A. 2010. Hake catchability by the French trawler fleet in the Bay of Biscay: estimating technical and biological components. ICES Journal of Marine Science, 68: 107-118.

Marchal, P. [ed.] 2006. Report of the TECTAC project, Technological developments and tactical adaptations of important EU fleets. EU Project No. Q5RS-2002-01291, 651 pp.

Marchal P., Andersen B., Caillart B., Eigaard, Guyader O., Hovgaard H., Iriondo A., Le Fur F., Sacchi J., Santurtún M.. 2006a. Impact of technical creeping on fishing effort and mortality for a selection of European fleets. ICES journal of Marine Science, 64: 192-209.

Marchal P., Andersen, B., Bromley, D., Iriondo, A., Mahévas, S., Quirijns, F., Rackham, B., Santurtún, M., Tien, N., and Ulrich, C. 2006b. 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

Maravelias, C., and Tsitsika, E. 2008. Economic efficiency analysis and fleet capacity assessment in Mediterranean fisheries. Fisheries Research, 93, (1-2): 85-91.

Maunder, M., and Punt, A. 2004. Standardizing catch and effort data: a review of recent approaches. Fisheries Research, 70 (2-3): 141-159.

McCall, A. 1990. Dynamic geography of marine fish populations. University of Washington Press, Seattle, 153p.

McCullagh, P., and Nelder, J.A. 1989. Generalized Linear Models. Chapman and Hall, London, 511 pp.

Palsson, G.P., and Durrenberger, P. 1982. To dream of fish: the causes of Icelandic fishers. fishing success. Journal of Anthropology Research, 38: 227-242.

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

Pelletier, D., S. Mahévas, H. Drouineau, Y. Vermard, O. Thebaud, O. Guyaderc and Poussin, B. 2009. Evaluation of the bioeconomic sustainability of multi-species multi-fleet fisheries under a wide range of policy options using ISIS-Fish, Ecolligical Modelling,. 220: 1013–1033.

Quirijns, F., Poos, J., and Rijnsdorp, A. 2008. Standardizing commercial CPUE data in monitoring stock dynamics: Accounting for targeting behaviour in mixed fisheries. Fisheries Research, 89 (1): 1-8.

Reid, D. [ed] 2009. Final report of the EU project Capacity, F and Effort, N°022644. :pp.

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

Robson, D.S. 1966. Estimation of the relative fishing power of individual ships. ICNAF Research Bulletin, 3: 5-14.

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

Venables, W.N. and Ripley, B.D. 2002. Modern Applied Statistics with S (4th Ed.). Springer, New York, USA. 495pp.

Wood S.N. 2006. Generalized Additive Models: An Introduction with R. Chapman and Hall/CRC Press. 262pp.

Ye, Y., and Dennis, D. 2009. How reliable are the abundance indices derived from commercial catch-effort standardization? Canadian Journal of Fisheries and Aquatic Science, 66: 1169-1178.

Tables

Table 1. Fleet characteristics and average summary information from this study. Eflalo refers to information on catch and effort variables available in fishers' logbooks; Tecvess contains data on the fishing vessels technical characteristics; Tecgear provides the fishing gears technical features.

			Eflalo	**Eflalo and Tecvess**	**Eflalo and Tecgear**
Fleet 1	French trawl demersal fleet of the Bay of Biscay	Number of vessels	311	52	38
		Number of Fishing Trips	1457	692	577
		Number of Fishing Sequences	8114	1511	1078
		Vessel length (m)	17.2	17.31	18.24
		Vessel tonnage (t)	4756	4831	5447
		Average hake lpue ($kg*hr^{-1}$)	0.08	0.1	0.09
Fleet 2	French trawl demersal fleet of the Western Mediterranean Sea	Number of vessels	28	21	15
		Number of Fishing Trips	12970	9059	5791
		Number of Fishing Sequences	12970	9059	5791
		Vessel length (m)	23.1	22.78	23.15
		Vessel tonnage (t)	89.3	87.62	93.06
		Average hake lpue ($kg*hr^{-1}$)	0.2	0.18	0.2
Fleet 3	French trawl pelagic fleet of the Bay of Biscay	Number of vessels	55	10	17
		Number of Fishing Trips	965	544	754
		Number of Fishing Sequences	9128	1496	2718
		Vessel length (m)	19.89	19.7	20.4
		Vessel tonnage (t)	6184	6063	6061
		Average anchovy lpue ($kg*hr^{-1}$)	0.011	0.011	0.009
Fleet 4	English beam trawl demersal fleet of the North Sea	Number of vessels	60	60	60
		Number of Fishing Trips	4682	4682	4682
		Number of Fishing Sequences	10983	10983	10983
		Vessel length (m)	35.2	35.2	35.2
		Vessel tonnage (t)	296.02	296.02	296.02
		Average plaice lpue ($kg*hr^{-1}$)	12.37	12.37	12.37

Fleet 5	Greek purse seine fleet of the Aegean Sea	Number of vessels	47	47	
		Number of Fishing Trips	2427	2427	
		Number of Fishing Sequences	2427	2427	
		Vessel length (m)	20.9	20.9	
		Vessel tonnage (t)	51.3	51.3	
		Vessel hp	202.9	202.9	
		Average anchovy catch (kg)	6153.2	6153.2	
Fleet 6	Spanish Basque demersal trawlers of the Bay of Biscay	Number of vessels	55	37	16
		Number of Fishing Trips	5934	5049	599
		Number of Fishing Sequences	14806	12294	1419
		Vessel length (m)	35.27	35.61	-
		Vessel tonnage (t)	283.64	298.86	-
		Vessel hp	827.02	806.97	-
		Average anchovy catch (kg)	0.432	0.435	0.365
Fleet 7	Spanish purse seine targeting Anchovy of the Bay of Biscay	Number of vessels	246 (68)	246 (68)	
		Number of Fishing Trips	11670 (576)	11670 (576)	
		Number of Fishing Sequences	11670 (576)	11670 (576)	
		Vessel length (m)	26.7(25.8)	26.7(25.8)	
		Vessel tonnage (t)	99.3(81.8)	99.3(81.8)	
		Vessel hp	457.4(359.4)	457.4(359.4)	
		Average anchovy catch (kg)	2248 (1061)	2248 (1061)	

Table 2. Catch and effort variables available in fishers' logbooks (Eflalo database).

NAME	DEFINITION	UNITS	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 7
VE_REF	Vessel's ID		X	X	X	X	X	X	X
FT_REF	Trip's ID		X	X	X	X	X	X	X
GE_UNI	Gear Unit		X	X	X	X	X	X	X
GE_MSZ	Gear's Mesh Size	mm	X	X	X	X	X	X	X
FO_RECT	Area (ICES Rectangle)		X		X	X		X	X
FT_YEAR	Year of fishing trip		X	X	X	X	X	X	X
Month	Month of fishing trip	1 to 12	X	X	X	X	X	X	X
Metier			X			X	X	X	X
lpue			X	X	X	X	X	X	X

Table 3. Fishing vessel technical characteristics (Tecvess database).

NAME	DEFINITION	VALUE/UNIT	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 7
ve_len	Vessel's length	m	X	X	X	X	X	X	X
ve_hp	Vessel horse power	hp	X	X	X	X	X	X	X
ve_ton	Vessel tonnage	grt	X	X	X	X	X	X	X
"VE_DAC"	Date of construction		x	x	x			X	
"VE_MAT"	Hull material	Steel (S); Alu (A); GRP (G); Wood (W)	x	x	x			X	
"VE_BUL"	Bulb	Yes/No	x	x	x			X	
"VE_GPS"	GPS	Yes/No	x		x			X	
"VE_SOU"	Number of Sounders	Number	x	x	x				
"VE_RPM"	Engine rotation per minute	Rotation min^{-1}	x	x	x				
"VE_PRP"	Variable pitch propeller	Yes/No	x	x	x			X	
"VE_ROL"	Nbr of net drums	Number	x	x	x			X	
"VE_TCT"	Bollard pull	t		x					

Table 4. Fishing gears technical characteristics (Tecgear database).

NAME	DEFINITION	VALUE/UNIT
"TR_WRP1"	Number of warps	2 or 3
"TR_PAN1"	Number of panels (or NA if not trawl)	2, 4 or 6
"TR_LHD1"	Length of headline	m
"TR_GRT1"	Type of groundrope	diabolo :1, rockhopper : 2, chains : 3, metallic spheres : 4, rubber : 5, plain wire : 6
"TR_OBN1"	Number of otter boards	0, 2 or 4
"TR_OBW1"	Weight of an otter board	kg

Table 5. List of required models and analyses performed at each step of the study.

Modelling step	**Useful models**	**Modelling exercise**	**Purpose of the modelling exercise**
Individual vessel fishing power	“vessel logbook base”	Fitting of “vessel logbook base” to lpue from logbook database	To estimate the relative individual fishing power of the fleet
Vessel technical fishing power	“vessel logbook base”	Fitting of “vessel Tecvess base” to lpue from Tecvess database	To estimate the relative individual fishing power of the Tecvess sample of vessels for which vessel technical characteristics are available
	“vessel Tecvess base”	Comparing the relative contribution of covariables of “vessel logbook base” and “vessel tecvess base”	To assess the bias using the Tecvess sample in the following modelling steps
	“technics Tecvess base”	Fitting of “technics Tecvess base” to lpue from Tecvess database	To identify the discriminant vessel technical characteristics of individual fishing power within the Tecvess sample of vessels
		Comparing the goodness of fit of “technics Tecvess base” and “vessel Tecvess base”	To assess the contribution of vessel technical chacateristics in the individual fishing power within the Tecvess sample of vessels
Gear technical fishing power	“vessel logbook base”	Fitting of “vessel tecgear base” to lpue from Tecgear database	To estimate the relative individual fishing power of the Tecgear sample of vessels for which gear technical characteristics are available
	“vessel Tecgear base”	Comparing the relative contribution of covariables of “vessel logbook base” and “vessel tecvess base”	To assess the bias using the Tecgear sample in the following modelling steps
	“technics tecgear base”	Fitting of “technics tecgear base” to lpue from tecgear database	To identify the discriminant gear technical characteristics of individual fishing power within the tecgear sample of vessels
	“technics Tecgear Tecvess base”	Comparing the goodness of fit of “technics Tecgear base” and “vessel Tecgear base”	To assess the contribution of gear technical chacateristics in the individual fishing power within the Tecgear sample of vessels
		Comparing the goodness of fit of “technics Tecgear base” and “technics Tecgear Tecvess base”	To assess the contribution of vessel and gear technical chacateristics in the individual fishing power within the Tecgear sample of vessels

Table 6. Outcomes of step 2 of the analysis (individual fishing power estmates), “vessel logbook base” model 1. Vessel = vessel identifier, Area = ICES-rectangle, % Dev. Exp (model) = (Resid Dev.(model = ~1) - Resid Dev.(model))/ Resid Dev.(model = ~1), DeltaAIC (model) = AIC(model) – Min(AIC), Min(AIC) = the minimum value of the AIC among the nested models

		Df	Resid. Dev	AIC	% Dev. Expl.	Delta AIC
Fleet 1	1	1	13584	-25144		7801
	Vessel	310	6469	-31610	52	1335
	Vessel + Area	15	6370	-31610	53	1335
	Vessel + Area + Month	11	6094	-31719	55	598
	Vessel + Area + Month + Year	4	5926	-32347	56	598
	Vessel + Area + Month + Year + Metier	1	5853	-32457	57	488
	Vessel + Area + Month + Year + Metier + Vessel*Metier	100	5490	-32835	60	0
Fleet 2	1	1	15132	138078		5132
	Vessel	27	12802	135606.8	15	2660
	Vessel + Month	11	12253	134976	19	2029
	Vessel + Month + Year	6	10670	132946	29	0
Fleet 3	1	1	14394	139332		6384
	Vessel	54	11202	136694	22	3746
	Vessel + Area	37	9913	135463	31	2515
	Vessel + Area + Month	10	9255	134758	35	1809
	Vessel + Area + Month + Year	5	7770	132948	46	0
Fleet4	1	1	5128	22790		7998
	Vessel	59	3878	19843	24	5051
	Vessel + Area	112	3288	18257	36	3465
	Vessel + Area + Month	11	3163	17855	38	3063
	Vessel + Area + Month + Year	6	2708	16163	47	1371
	Vessel + Area + Month + Year + Year*Month	66	2574	15738	50	946
	Vessel + Area + Month + Year + Year*Month + Month*Area	708	2075	14792	60	0
Fleet5	1	1	3249	7957		1322
	Vessel	46	2928	7829	8,6	1195
	Vessel + Month	8	1731	6767	41.3	132
	Vessel + Month + Year	5	1639	6663	43.9	29
	Vessel + Month + Year + Year*Month	40	1323	6299	53.35	0
Fleet6	1	1	28999	120697		13641
	Vessel	54	17263	111441	40	4385
	Vessel + Area	121	16140	110517	44	3461
	Vessel + Area + Month	11	15773	110142	46	3086
	Vessel + Area + Month + Year	4	14979	109264	48	2208
	Vessel + Area + Month + Year + Metier	3	14642	108880	50	1824
	Vessel + Area + Month + Year + Metier + Vessel*Metier	135	12940	107056	55	0
Fleet7	1	1	1876	2121090		49
	Vessel	67	1650	21091	12	48
	Vessel + Area	17	1581	21134	18	5
	Vessel + Area + Month	2	1576	21139	26.4	0

Table 7. Outcomes of step 2: most salient vessel characteristics and their effect on Ipue variability (Fleets 1-7) using the two nested models “vessel tecvess base” model 2 and “technics tecvess base” model 3.

Fleets	**Percent deviance with Common factors (Area, Year, Métier Month from model 3)**	**Significant Vessel technical characteristics (Tecvess variables in model 3)**	**Percent deviance with Common factors and Tecvess variables (from model 3)**	**Percent deviance with Common factors and VE_REF variable (from model 2)**
Fleet 1	41.3	Year of acquisition	44.8	60
Fleet 2	13.1	Bollard pull	24.4	31.0
Fleet 3	33	Tonnage and Bulb	35	36
Fleet 4	48	Tonnage	50	60
Fleet 5	36.3	Tonnage, Horse Power	53	60
Fleet 6	23.5	Year of acquisition	23.7	55
Fleet 7	19	Vessel length	21.8	26.4

Table 8. Outcomes of step 3: 1) most salient gear characteristics and their effect on Ipue variability (Fleets 1 to 3 and 6) using the two nested models (model 4 and model 5); 2) contribution of technical characteristics (of vessel and gear) in the vessel effect using model 6.

Fleets	**Percent deviance with Common factors (Area, Year, Métier Month from model 5)**	**Significant gear technical characteristics (TECGEAR variables in model 5 and model 6)**	**Percent deviance with Common factors and TECGEAR variables (from model 5)**	**Percent deviance with Common factors, TECGEAR and TECVESS variables in VE_REF (from model 6)**	**Percentdeviance with Common factors and VE_REF variable (from model 4)**
Fleet 1	48.9	weight of boards length of headline	54.3	56.8	61.3
Fleet 2	11.7	length of headline	19.5	23.8	24.4
Fleet 3	31.5	type of groundrope and length of headline	35.9	36.3	36.5
Fleet 4	no data	no data	no data	no data	no data
Fleet 5	no data	no data	no data	no data	no data
Fleet 6	40	weight of boards	64.5	68	73.5
Fleet 7	no data	no data	no data	no data	no data

Figures

Figure 1: Geographical location of studied fleets per country. The targeted species on which fishing power was assessed is presented in the legend box.

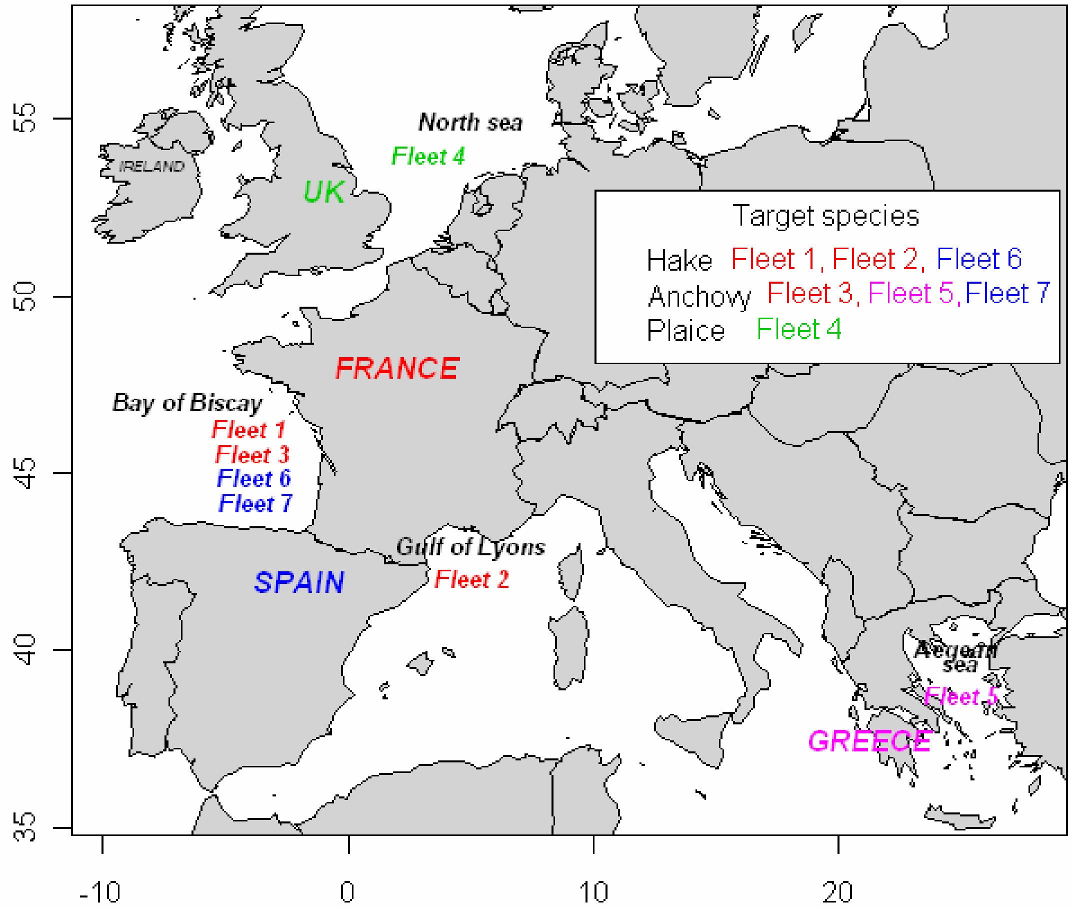

Figure2. Relative contribution of human component (H) and technical component (T) in fishing power estimates (Vessel). The human component means the residual vessel effects after controlling for measured vessel and gear characteristics. The height of the bars represents the variability in LPUE of the dataset used to fit model 4 and model 6. Each block within the bar reflects the proportion of variability explained by the explanatory factors (A :Area, Y :Year, Mé : Métier, and Mo :Month, TecGear: combinations of gear characteristics, TecVess : combinations of vessel characteristics: onthe left for model 4 and on the right for model 6 (see Table 8). The portion of each of the bars not labelled represents the “unexplained” variance.