ICES Journal of Marine Science (2011), 68(10), 2252–2263. doi:10.1093/icesjms/fsr150

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

Stéphanie Mahévas[1]*, Youen Vermard[2], Trevor Hutton[3], Ane Iriondo[4], Angélique Jadaud[5], Christos D. Maravelias[6], Antonio Punzón[7], Jacques Sacchi[5], Alex Tidd[8], Efthymia Tsitsika[6], Paul Marchal[2], Nicolas Goascoz[5], Serge Mortreux[5], and David Roos[5]

[1]*Department of Ecology and Models for Fishery Science, Ifremer, Rue de l'Ile d'Yeu, BP 21105, Nantes Cedex 3 44311, France*
[2]*Channel and North Sea Fisheries Department, Ifremer, 150 Quai Gambetta, BP 699, Boulogne sur Mer 62321, France*
[3]*CSIRO, EcoSciences Precinct, 41 Boggo Road, Dutton Park, Brisbane, QLD 4102, Australia*
[4]*AZTI–Tecnalia, Txatxarramendi ugartea z/g, Sukarrieta 48395, Spain*
[5]*Ifremer, UMR 212 EME, Boulevard Jean Monnet, BP 171, Sète Cedex 34203, France*
[6]*Hellenic Centre for Marine Research, Athens–Sounio, Anavyssos, Attica 19013, Greece*
[7]*Instituto Español de Oceanografía, CO Santander, Promontorio de San Martín s/n, PO Box 240, Santander 39080, Spain*
[8]*Cefas, Pakefield Road, Lowestoft, Suffolk NR33 0HT, UK*

**Corresponding Author: tel: +33 240 374181; fax: +33 240 374075; e-mail: stephanie.mahevas@ifremer.fr.*

Mahévas, S., Vermard, Y., Hutton, T., Iriondo, A., Jadaud, A., Maravelias, C. D., Punzón, A., Sacchi, J., Tidd, A., Tsitsika, E., Marchal, P., Goascoz, N., Mortreux, S., and Roos, D. 2011. An investigation of human vs. technology-induced variation in catchability for a selection of European fishing fleets. – ICES Journal of Marine Science, 68: 2252–2263.

Received 2 July 2010; accepted 1 August 2011; advance access publication 28 September 2011.

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.

Introduction

Fishing effort limitation has traditionally been a main tool in fishery management. It has been applied in an attempt to prevent the decline in 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 referred to as fishing capacity and approximated by technical characteristics) and nominal fishing effort (also referred to as fishing activity and approximated by the hours fished; Cunningham and Whitmarsh, 1980). A management decision in terms of effort limitation needs to take into account both components and, consequently, requires an accurate estimate of fishing power. Estimation of fishing power is also critical issue in the computation of indices for the standardization 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). Standardization of lpue normally involves the removal of 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 with different degrees of importance (Pascoe and Robinson, 1996). Fishing power may be linked with vessel equipment, gear characteristics (technical set-up), skill of the skipper and crew, spatial population distribution and abundance, environmental conditions, and fishing tactics (characterized as métiers that are associated directly with the choice of fishing grounds, targeted species, gear used, and fishing season). As it is difficult to assess an absolute measure of fishing power, the concept of relative fishing power is used here. A number of approaches have been developed to quantify relative fishing power. As an example, Beverton and Holt (1957) based their method on the relationship between the catch rate of a 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 can 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 relative importance of environmental (Gaertner *et al.*, 1999) or economic variables (Kirkley *et al.*, 1995; Squires and Kirkley, 1999). Given the estimation of relative fishing power for each vessel in a fleet, identifying the most influential elements that affect a vessel's performance is an important step towards successful fishery management.

In this study, we investigated whether the variation in fishing power could be linked to the technical characteristics of a vessel (e.g. length, tonnage, electronic specifications) and its gear (e.g. type of groundrope or 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 affect fishing power were considered in the analysis, variation in fishing power could 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 so-called fisher effect was considered as being little more than a myth (Palsson and Durrenberger, 1982), but Robins *et al.* (1998) managed to provide evidence of and quantify an increase in fishing power that could be linked directly 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 a vessel. This skipper/crew experience can sometimes be related to the age of the skipper and to the length of time the skipper/crew have been using one boat or have greater experience with one piece of equipment and/or gear, and it 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 (including 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) grouped and entitled "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 generalized additive models (GAMs; Hastie and Tibshirani, 1990) and generalized linear models (GLMs; McCullagh and Nelder, 1989), and the approach was applied to data on seven European fleets (and for one of their main targeted species). The analyses consisted of four steps:

(i) testing the hypothesis that the variations in fishing power were linked to spatial and temporal strata corresponding to common fleet fishing tactics or to the spatial and seasonal fluctuations in biomass;

(ii) assessing the relative contributions of the skipper/crew experience effect against technical characteristic effects on a measure of relative fishing power;

(iii) relating fishing power to technical information on vessels and gears collected in a dedicated technological survey carried out around the European coast (Marchal, 2006);

(iv) providing specific and generic conclusions on the robustness of fishing effort standardization based on the technical characteristics and comparing the magnitude of the so-called skipper/crew experience effect and purely technical factors.

Material and methods

Fishing fleets

Data from seven fleets were available for this analysis (Table 1, Figure 1). The first (fleet 1) consists of French demersal trawlers between 12 and 24 m long operating in the Bay of Biscay (ICES Subdivision VIIIab), during the period 1999–2003. Megrim (*Lepidorhombus* spp.), hake (*Merluccius merluccius*), anglerfish/monkfish (*Lophius* spp.), and ling (*Molva molva*) are targeted by this fleet, and they land mainly into ports south of Brittany. The second fleet (fleet 2) consists of demersal French trawlers between 18 and 26 m long operating in the northwestern Mediterranean Sea [General Fisheries Commission for the Mediterranean, GFCM, Geographical Subarea (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 GFCM–GSA 07, but this fleet also lands many other species, such as anglerfish, horned octopus (*Eledone cirrhosa*), and red mullet (*Mullus barbatus*). The third fleet (fleet 3) consists of French pelagic trawlers between 16 and 25 m long operating in the Bay of Biscay during the period 2000–2005. The fleet targets mainly pelagic species such as European anchovy (*Engraulis encrasicolus*), European sea bass (*Dicentrarchus labrax*), albacore (*Thunnus alalunga*), and horse mackerel (*Trachurus trachurus*), and lands in different harbours depending on the fishing grounds being exploited, which are mainly located in SW France. The fourth fleet (fleet 4) consists of English beam trawlers $>$24 m long targeting mainly flatfish (plaice, *Pleuronectes platessa*, and sole, *Solea solea*) in the North Sea during the period 2000–2006. The English North Sea beam trawl fleet ($\geq$24 m) fished mainly out of English east coast ports, mainly Lowestoft. The fifth fleet (fleet 5) consists of Greek purse-seiners belonging to two fleet segments, 12–24 and 24–40 m, operating in the eastern Mediterranean (Aegean Sea) over the period 2000–2005. Catches by that fleet are well mixed, with European anchovy, sardine (*Sardina pilchardus*), and horse mackerel the main target species (Maravelias and Tsitsika, 2008). That case study involved all major purse-seine fishery ports in the Greek Aegean (Piraeus, Chalkis, Thessaloniki, Polygyros, Volos, Chania, Heraklion, and Kalymnos). The sixth fleet (fleet 6) consists of Basque (Spain) demersal trawlers between 24 and 39 m long fishing in the Bay of Biscay over the period 1999–2003. The target species of that fleet include hake, megrim, and anglerfish, which are landed in the Basque ports of Ondarroa and Pasaia. The final fleet (fleet 7) is made up of Spanish purse-seiners between 14 and 38 m long fishing in the Bay of Biscay over the period 2000–2005, harvesting mainly pelagic species such as European anchovy, horse mackerel, jack mackerel (*Trachurus mediterraneus*), and sardine. In addition, fleet 7 shifts its fishing gear in summer to pole and line, then targets tuna (*Thunnus* spp.)

Table 1. Fleet characteristics and average summary information from this study.

Fleet	Parameter	Eflalo	Eflalo and Tecvess	Eflalo and Tecgear
Fleet 1, French demersal trawl fleet in the Bay of Biscay	Number of vessels	311	52	38
	Number of fishing trips	1 457	692	577
	Number of fishing sequences	8 114	1 511	1 078
	Average vessel length (m)	17.2	17.31	18.24
	Average vessel tonnage (t)	4 756	4 831	5 447
	Average hake lpue (kg h^{-1})	0.08	0.1	0.09
Fleet 2, French demersal trawl fleet in the western Mediterranean Sea	Number of vessels	28	21	15
	Number of fishing trips	12 970	9 059	5 791
	Number of fishing sequences	12 970	9 059	5 791
	Average vessel length (m)	23.1	22.78	23.15
	Average vessel tonnage (t)	89.3	87.62	93.06
	Average hake lpue (kg h^{-1})	0.2	0.18	0.2
Fleet 3, French pelagic trawl fleet in the Bay of Biscay	Number of vessels	55	10	17
	Number of fishing trips	965	544	754
	Number of fishing sequences	9 128	1 496	2 718
	Average vessel length (m)	19.89	19.7	20.4
	Average vessel tonnage (t)	6 184	6 063	6 061
	Average anchovy lpue (kg h^{-1})	0.011	0.011	0.009
Fleet 4, English demersal beam trawl fleet in the North Sea	Number of vessels	60	60	60
	Number of fishing trips	4 682	4 682	4 682
	Number of fishing sequences	10 983	10 983	10 983
	Average vessel length (m)	35.2	35.2	35.2
	Average vessel tonnage (t)	296.02	296.02	296.02
	Average plaice lpue (kg h^{-1})	12.37	12.37	12.37
Fleet 5, Greek purse-seine fleet in the Aegean Sea	Number of vessels	47	47	
	Number of fishing trips	2 427	2 427	
	Number of fishing sequences	2 427	2 427	
	Average vessel length (m)	20.9	20.9	
	Average vessel tonnage (t)	51.3	51.3	
	Average vessel hp	202.9	202.9	
	Average anchovy catch (kg)	6 153.2	6 153.2	
Fleet 6, Spanish Basque demersal trawlers in the Bay of Biscay	Number of vessels	55	37	16
	Number of fishing trips	5 934	5 049	599
	Number of fishing sequences	14 806	12 294	1 419
	Average vessel length (m)	35.27	35.61	
	Average vessel tonnage (t)	283.64	298.86	
	Average vessel hp	827.02	806.97	
	Average anchovy catch (kg)	0.432	0.435	0.365
Fleet 7, Spanish purse-seine targeting anchovy in the Bay of Biscay	Number of vessels	246 (68)	246 (68)	
	Number of fishing trips	11 670 (576)	11 670 (576)	
	Number of fishing sequences	11 670 (576)	11 670 (576)	
	Average vessel length (m)	26.7 (25.8)	26.7 (25.8)	
	Average vessel tonnage (t)	99.3 (81.8)	99.3 (81.8)	
	Average vessel hp	457.4 (359.4)	457.4 (359.4)	
	Average anchovy catch (kg)	2 248 (1 061)	2 248 (1 061)	

Eflalo refers to information on catch and effort variables available in fisher logbooks; Tecvess contains data on the fishing vessel technical characteristics; Tecgear provides fishing gear technical features.

and lands its catches mainly in Guetaria, Ondarroa, Pasaia, and Santoña (Cantabria).

We estimate the fishing power in relation to the main target species for each fleet, i.e. hake for fleets 1, 2, and 6, anchovy for fleets 3, 5, and 7, and plaice for fleet 4. This set of fleets allowed us to investigate whether pelagic fleets (and demersal fleets) share common technical characteristics that would explain the differences in fishing power. Horsepower (hp) and vessel tonnage (generally grt, gross registered tonnage) are often used to standardize fishing effort, but we assume that other technical characteristics (traditionally not measured) of the vessel (e.g. the date of construction) or its gear (e.g. length of headline) could be better proxies of relative fishing power.

Data

Logbook information on fishing effort and 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) were acquired from the National Statistical Services of Greece and the Greek Ministry of Mercantile Marine databases. For several fleets (fleets 1 and 4–7), each fishing sequence (a logbook entry, the unit of catch observations) was allocated to a métier (a combination of gear, target species, and ICES Subdivision fished; Biseau, 1998). Although logbook data were available for most registered vessels, technical information traditionally recorded in administrative regulatory orders is only available for a subset of those vessels. Within the TECTAC project, additional historical information on technical

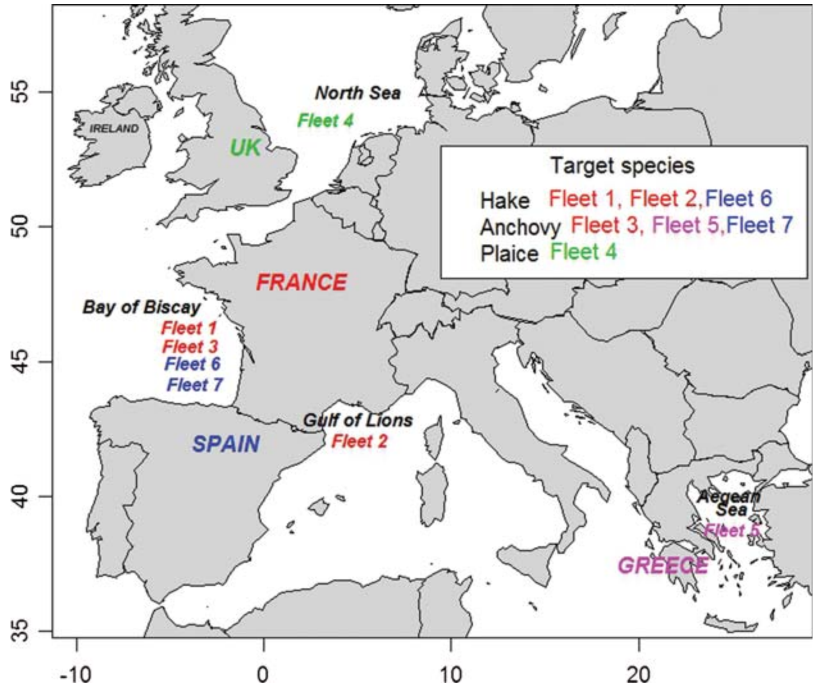

Figure 1. Geographic location of studied fleets per country. The targeted species on which fishing power was assessed is presented in the legend box.

characteristics of vessel and gear were collected through face-to-face interviews with vessel owners for some of the fleets in France and Spain (fleets 1–3 and 6). That survey relied on the acceptance and cooperation of fishers to participate, because they were asked about past changes made to their vessels. Greater detail on the data-collection regime is provided by Marchal (2006). Despite the dedicated effort devoted to collecting technical data, the Eflalo database did not include technical information on vessel or gear for all the fishing trips, at least not systematically. To optimize the use of the information, therefore, we compiled two new datasets, one including the information on both logbooks and technical aspects of each vessel (Tecvess) and one on both logbooks and technical aspects of the gear (Tecgear). Table 1 provides a representation of the vessels sampled in terms of technical information. The English, Greek, and Spanish fleets (fleets 4, 5, and 7, respectively) provided limited information on vessel and gear (Tables 1 and 2). Finally, no spatial information on catch was available for the Mediterranean fleets (fleets 2 and 5) or for Spanish purse-seiners targeting anchovy in the Bay of Biscay (fleet 7), and in the latter case, information on ICES Subdivision was only available for the period 2003–2005. A summary of the average values for the physical characteristics of the fishing vessels is presented in Table 1. Summaries of logbook data, vessel technical characteristics, and gear characteristics are provides in Tables 2–4, respectively.

Fishing power model

To account for fishing tactics, individual fishing vessels were analysed at the smallest scale available from fisher logbooks. Fishing tactics refer 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 landings and effort in logbooks are unfortunately recorded by fishing trip or by fishing day, so lpue was calculated using species catch by weight, divided by the fishing time for every set of fishing trips or fishing days. We assume here that catch is proportional to the product of fishing effort and population density (Campbell, 2004; Mahévas *et al.*, 2004). A realistic model for lpue is therefore

$$\text{lpue} = \frac{\text{landings}}{\text{fishing time}} = aPEN, \qquad (1)$$

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 nominal fishing effort E. The product aP is known as the catchability. This model allows for analysis of lpue data per vessel and per fishing sequence/trip 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. Multiplicative models have traditionally been used to analyse fishing power on linear regressed log-transformed lpue data. The GLM/GAM approach is an extended process because it allows for an analysis of lpue data with non-normal distributions and avoids the bias caused by back-transformation (Laurent, 1963). The key drawbacks of this modelling approach are (i) the possible confusion between temporal and spatial variations as a result of population abundance and fishing power changes in the fleet, and (ii) the possible residual deviation in the temporal effect when catchability is density-dependent. Vessel lpue was analysed for each fleet separately using GLMs and GAMs. The approach is performed in four steps: (i) an exploratory analysis, (ii) an analysis where we obtained an estimate of the fishing power of individual vessels, (iii) an analysis where an estimate was made of a vessel's technical fishing power, and (iv) an analysis leading to an estimate of the gear's technical fishing power (Table 5).

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

Variable	Definition	Unit	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 7
VE_REF	Vessel ID		X	X	X	X	X	X	X
FT_REF	Trip ID		X	X	X	X	X	X	X
GE_UNI	Gear unit		X	X	X	X	X	X	X
GE_MSZ	Gear 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	1–12	X	X	X	X	X	X	X
Métier			X			X	X	X	X
lpue			X	X	X	X	X	X	X

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

Characteristic	Definition	Value/unit	Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 7
ve_len	Vessel length	m	X	X	X	X	X	X	X
ve_hp	Vessel hp	hp	X	X	X	X	X	X	X
ve_ton	Vessel tonnage	grt	X	X	X	X	X	X	X
VE_DAA	Year of acquisition		X	X	X			X	
VE_MAT	Hull construction material	Steel (S); aluminium (A); glass-reinforced plastic (G); wood (W)	X	X	X			X	
VE_BUL	Bulbous bow	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 rpm	rpm	X	X	X				
VE_PRP	Variable pitch propeller	Yes/no	X	X	X			X	
VE_ROL	Number of net drums	Number	X	X	X			X	
VE_TCT	Bollard pull	t		X					

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

Characteristic	Definition	Value/unit
TR_WRP1	Number of warps	2 or 3
TR_PAN1	Number of panels (or N/A if not trawl)	2, 4, or 6
TR_LHD1	Length of headline	m
TR_GRT1	Type of groundrope	Diabolo,1; rock-hopper, 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 otter board	kg

Exploratory analysis

The process of model-fitting requires a selection to be made 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 derived for each fleet.

Individual vessel fishing power

It was also necessary to estimate 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 above and can be expressed as

$$\log[E(\text{lpue})] \sim \text{vessel} + \text{area}^* + \text{month} + \text{year} + \text{métier}^* + \text{interactions}. \quad (2)$$

The asterisk indicates that the variable was included in the model when the information was available. This is referred to here as model 1, the "vessel logbook base" model.

Nested GLMs were fitted to the lpue using an appropriate error distribution (either normal or gamma distribution), the choice of which was an outcome of the exploratory analysis. A log-link was systematically used to preserve the multiplicative nature of the relationship between lpue and the factors that are a decomposition of catchability. The order of the variables in the model can have a bearing on the significance of the factors (Bishop *et al.*, 2008). Primarily, we considered the vessel effect because it could be an indication of the importance of the skipper/crew experience combined with the physical influence of the vessel's and its gear's characteristics. The year effect accounts for potential drift in fishing power confounded with changes in the abundance of the target species.

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

Modelling step	Model and (equation)	Modelling exercise	Purpose of modelling exercise
Individual vessel fishing power	1. Vessel logbook base (2)	Fitting vessel logbook base to lpue from logbook database	To estimate the relative individual fishing power of the fleet
Vessel technical fishing power	1. Vessel logbook base (2)	Fitting vessel tecvess base to lpue from the Tecvess database	To estimate the relative individual fishing power of the tecvess sample of vessels for which vessel technical characteristics are available
	2. Vessel tecvess base (3)	Comparing the relative contribution of covariables of vessel logbook base and vessel tecvess base	To assess the bias using the Tecvess sample in the subsequent modelling steps
	3. Technics tecvess base (4)	Fitting technics tecvess base to lpue from the 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 characteristics in the individual fishing power within the tecvess sample of vessels
Gear technical fishing power	1. Vessel logbook base (2)	Fitting vessel tecgear base to lpue from the Tecgear database	To estimate the relative individual fishing power of the tecgear sample of vessels for which gear technical characteristics are available
	4. Vessel tecgear base (5)	Comparing the relative contribution of covariables of the vessel logbook base and vessel tecvess base	To assess the bias using the tecgear sample in the following modelling steps
	5. Technics tecgear base (6)	Fitting technics tecgear base to lpue from the Tecgear database	To identify the discriminant gear technical characteristics of individual fishing power within the tecgear sample of vessels
	6. Technics tecgear tecvess base (7)	Comparing the goodness of fit of technics tecgear base and vessel tecgear base	To assess the contribution of gear technical characteristics 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 characteristics in the individual fishing power within the tecgear sample of vessels

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):

$$\log[E(\text{lpue})] \sim \text{vessel} + \text{area} + \text{month} + \text{year} + \text{métier} + \text{interactions}. \quad (3)$$

This is referred to here as model 2, the “vessel tecvess base” model.

After removing the vessel variable from the vessel tecvess base model, we estimated the proportion of variability accounted for in the 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 (Mahévas *et al.*, 2004; Maunder and Punt, 2004), and their goodness of fit was compared using Akaike’s information criteria (AIC; Akaike, 1974). When a technical characteristic is a continuous variable, a GAM was preferred to a GLM, because the latter assumes a linear relationship in log-space (Wood, 2006). Technical characteristics that indicate a model fit AIC of the associated single-variable model that was lower than the AIC of the vessel tecvess base model were included in model 3 (Table 5), where model 3 is specified as

$$\log[E(\text{lpue})] \sim \text{g (vessel technical characteristics)} + \text{area} + \text{month} + \text{year} + \text{métier} + \text{interactions}. \quad (4)$$

This is referred to here as model 3, the “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 evaluate the capacity of vessel characteristics in explaining the differences in vessel fishing power (Table 5).

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):

$$\log[E(\text{lpue})] \sim \text{vessel} + \text{area} + \text{month} + \text{year} + \text{métier} + \text{interactions}. \quad (5)$$

This is referred to here as model 4, the “vessel tecgear base” model.

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

$$\log[E(\text{lpue})] \sim g(\text{gear technical characteristics}) + \text{area} + \text{month} + \text{year} + \text{métier} + \text{interactions}. \quad (6)$$

This is referred to here as model 5, the “technics tecgear base” model.

Again the vessel tecgear base and technics tecgear base models were used to assess the relative ability of gear technical characteristics to affect fishing power compared with vessel effects (Table 5). By adding significant vessel characteristic 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):

$$\log[E(\text{lpue})] \sim g(\text{vessel technical characteristics}) + f(\text{gear technical characteristics}) + \text{area} + \text{month} + \text{year} + \text{métier} + \text{interactions}. \quad (7)$$

This we refer to as model 6, the "technics tecvess tecgear base" model.

Assuming that the vessel effect includes the human component of fishing power and that the technical component of fishing power is determined by both gear and vessel characteristics, the discrepancy in explanatory power of models 4 and 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 effect.

The type (continuous/categorical) of each explanatory variable included in statistical models is driven by the nature of the variable, so 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 zero to make parameter estimates directly interpretable (Venables and Ripley, 2002). In models 1–6, the year effect takes into account the annual variations in fishing power of the fleet and any changes in abundance of the target species. The month effect characterizes seasonal variations in harvesting practice (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 a 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 (Wood, 2006). The GLMs and GAMs were assessed for goodness of fit and were evaluated through an exploration of the residuals. A comparison of the deviance residuals against the fitted values presented no systematic pattern, but were normally distributed (McCullagh and Nelder, 1989; Hastie and Tibshirani, 1990). The analysis of deviance (a measure of discrepancy) relies on the χ^2 approximation for differences between deviances in nested models. To select a parsimonious model, we computed an 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) showed that the AIC is appropriate to compare GAM or GLM nested models. The absolute magnitude of the AIC value is not interpretable, so 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) suggested that studies omit models with a ΔAIC value of $>$10.

Results

Exploratory analysis

For each fleet, exploratory analysis was performed using histograms of lpue frequency and simple plots of their relationship with explanatory variables (not shown). A first step when fitting GLMs is to select 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 characterized by evidence of fishing seasonality and annual variations in averaged lpue. When fishing trips (sequences) are reported in logbooks at the scale of an ICES rectangle, the fishing activity at the scale of the fleet shows strong spatial patterns with preference for certain ICES rectangles. Recently, there was an increase in effort sampling for several fleets, which could have led to more-accurate estimates for the final few years of the periods studied. 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 plotted against vessel length for fleets 1 and 4–7, for lpue against hp for fleets 2 and 3, and for lpue against date of acquisition for fleets 1 and 6. Consequently hp, vessel length, grt, and the year of acquisition were identified as potential discriminant variables and tested for all fleets. A thorough investigation of the technical characteristics of fleets 1–3 and 6 demonstrated that engine revolutions per minute (rpm), the presence/the absence of a bulbous bow, the number of net drums, and the presence/the absence of a variable pitch propeller were highlighted as discriminatory variables. More specifically, the exploratory analysis showed the relevance of the hull material variable, and experts proposed that this variable should be linked with bollard pull. Unfortunately, bollard pull, which is a measure of a vessel's maximum power (the zero-speed pulling capability of the boat), was available only for fleet 2. When we considered electronic equipment (GPS, sonar, radar), little difference was observed in lpue. Overall, the acquisition of new equipment during the study period affected pelagic vessels more than demersal trawlers. 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 groundrope represented a strong discriminatory variable in all the fleets that recorded this characteristic.

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 and 4–6 (Table 6). The plot of the residuals did not show trends (not shown), and the Q–Q plot indicated that the residuals were consistent with the assumed error model, except for fleet 3 where outliers caused the observed plot to deviate slightly from the reference line. For fleet 3 (a pelagic fleet), the assumption of a linear relationship between lpue and biomass is perhaps inappropriate (MacCall, 1990) and leads to slight model misspecification. With respect to most fleets, the vessel effect makes 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 that fleet, the vessel effect exerted the second biggest contribution towards the observed variability in the landings (~9%), and the month effect made the greatest contribution towards the change in deviance and AIC (Table 6). Indeed, that pelagic fishery is closed at the beginning of the year, so this monthly effect is largely explained by

Table 6. Outcomes of step 2 of the analysis (individual fishing power estimates), with vessel logbook base model 1.

	Variables	d.f.	Residual deviance	AIC	% deviance explained	ΔAIC
Fleet 1	1	1	13 584	−25 144	–	7 801
	Vessel	310	6 469	−31 610	52	1 335
	Vessel + area	15	6 370	−31 610	53	1 335
	Vessel + area + month	11	6 094	−31 719	55	598
	Vessel + area + month + year	4	5 926	−32 347	56	598
	Vessel + area + month + year + métier	1	5 853	−32 457	57	488
	Vessel + area + month + year + métier + vessel × métier	100	5 490	−32 835	60	0
Fleet 2	1	1	15 132	138 078	–	5 132
	Vessel	27	12 802	135 607	15	2 660
	Vessel + month	11	12 253	134 976	19	2 029
	Vessel + month + year	6	10 670	132 946	29	0
Fleet 3	1	1	14 394	139 332	–	6 384
	Vessel	54	11 202	136 694	22	3 746
	Vessel + area	37	9 913	135 463	31	2 515
	Vessel + area + month	10	9 255	134 758	35	1 809
	Vessel + area + month + year	5	7 770	132 948	46	0
Fleet 4	1	1	5 128	22 790	–	7 998
	Vessel	59	3 878	19 843	24	5 051
	Vessel + area	112	3 288	18 257	36	3 465
	Vessel + area + month	11	3 163	17 855	38	3 063
	Vessel + area + month + year	6	2 708	16 163	47	1 371
	Vessel + area + month + year + year × month	66	2 574	15 738	50	946
	Vessel + area + month + year + year × month + month × area	708	2 075	14 792	60	0
Fleet 5	1	1	3 249	7 957	–	1 322
	Vessel	46	2 928	7 829	8.6	1 195
	Vessel + month	8	1 731	6 767	41.3	132
	Vessel + month + year	5	1 639	6 663	43.9	29
	Vessel + month + year + year × month	40	1 323	6 299	53.4	0
Fleet 6	1	1	28 999	120 697	–	13 641
	Vessel	54	17 263	111 441	40	4 385
	Vessel + area	121	16 140	110 517	44	3 461
	Vessel + area + month	11	15 773	110 142	46	3 086
	Vessel + area + month + year	4	14 979	109 264	48	2 208
	Vessel + area + month + year + métier	3	14 642	108 880	50	1 824
	Vessel + area + month + year + métier + vessel × métier	135	12 940	107 056	55	0
Fleet 7	1	1	1 876	2 121 090	–	49
	Vessel	67	1 650	21 091	12	48
	Vessel + area	17	1 581	21 134	18	5
	Vessel + area + month	2	1 576	21 139	26	0

Vessel, vessel identifier; area, ICES rectangle; % deviance explained (model), residual deviance (model = ∼1) − residual deviance (model)/residual deviance (model = ∼1); ΔAIC (model), AIC (model) − min (AIC); min (AIC), the minimum value of the AIC among the nested models.

high catches after the reopening and a gradual decrease of anchovy catches from June to November. Subsequently, the significance of the month effect reflects great seasonality in fishing power.

For most fleets, the year effect does not contribute as much as other effects. It certainly displays a weak change in the efficiency of fishing power, probably as a result of the short length of period over which this study focused (from 5 to 7 years). The only fleet that contrasts sharply with others is the Spanish demersal fleet (fleet 6). It is characterized by a high contributing year effect on the change in AIC, whereas fleet 1, targeting the same population of hake, shows a slightly positive year effect. Given that stock assessments and scientific surveys over the study period (1999–2003) revealed a rather positive trend in hake biomass (ICES, 2006), this negative effect could reflect a decrease in efficiency or perhaps 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 operating in the Bay of Biscay (fleet 1) and for the Basque demersal trawlers (fleet 6), but unfortunately it was less significant for 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 was expected from the exploratory analysis, the spatial effect was not highly significant. It is likely that the contribution of this variable is included in the explanatory power of the vessel or métier that may encompass the effects associated with the skipper effect and/or fishing tactic. Finally, the contribution of the vessel effect derived from this first-step analysis varied between 10 and 52% among the seven fleets (Table 6).

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

Table 7. Outcomes of step 2, the salient vessel characteristics and their effect on lpue variability (fleets 1–7) using the two nested models vessel tecvess base model 2 and technics tecvess base model 3.

Fleet	Percentage deviance with common factors (area, year, métier, month from model 3)	Significant vessel technical characteristics (tecvess variables in model 3)	Percentage deviance with common factors and tecvess variables (from model 3)	Percentage deviance with common factors and VE_REF variable (from model 2)
1	41.3	Year of acquisition	44.8	60
2	13.1	Bollard pull	24.4	31.0
3	33	Tonnage and bulbous bow	35	36
4	48	Tonnage	50	60
5	36.3	Tonnage, hp	53	60
6	23.5	Year of acquisition	23.7	55
7	19	Vessel length	21.8	26.4

Table 8. Outcomes of step 3, the salient gear characteristics and their effect on lpue variability (fleets 1–3 and 6) using the two nested models (models 4 and 5) and the contribution of technical characteristics (of vessel and gear) in the vessel effect using model 6.

Fleet	Percentage deviance with common factors (area, year, métier, month from model 5)	Significant gear technical characteristics (tecgear variables in models 5 and 6)	Percentage deviance with common factors and tecgear variables (from model 5)	Percentage deviance with common factors, tecgear and tecvess variables in VE_REF (from model 6)	Percentage deviance with common factors and VE_REF variable (from model 4)
1	48.9	Weight of boards length of headline	54.3	56.8	61.3
2	11.7	Length of headline	19.5	23.8	24.4
3	31.5	Type of groundrope and length of headline	35.9	36.3	36.5
4	No data	No data	No data	No data	No data
5	No data	No data	No data	No data	No data
6	40	Weight of boards	64.5	68	73.5
7	No data	No data	No data	No data	No data

rank of the contribution of each explanatory variable 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. Year of acquisition and tonnage (grt) are the most frequently identified significant variables (Table 7). Contrary to what might have been expected, hp is only significant for fleet 5. The grt variable resulted in lower AIC scores, with the largest explained deviance for fleets 3–5 (Table 7). Fleet 7 distinguishes itself from the others with vessel length as the most significant variable, whereas bollard pull was the most significant variable for fleet 2. The latter is not unexpected, however, because it is a measure of the maximum power of the vessel and is believed to be a good proxy for technical efficiency.

Vessel factor was substituted by the relevant vessel technical characteristics identified above for each fleet and fitted to the technics tecvess base model 3. The AIC score of model 3 was still lower than the AIC score of the vessel tecvess base model 2 (not shown), however. For most fleets, the vessel effect was larger than the measured technological effects, although this was 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 the result of either a genuine skipper/crew effect or other technical characteristics of the fleet not considered in these analyses.

Gear technical fishing power

This step of the analysis was only carried out for fleets 1–3 and 6. As for the comparison of the vessel logbook base model 1 and the vessel tecvess base model 2, the relative contributions of factors in the vessel tecgear base model 4 and in the vessel logbook base model 1 are similar, suggesting that the samples of trips in the Eflalo and Tecgear databases are equally representative. In the technics tecgear base model 5, the vessel factor was excluded and substituted by gear technical characteristics. Type of groundrope, length of headline, and weight of otter boards were the most common and significant gear characteristic factors (Table 8). Comparison of columns 2, 3, and 5 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 greater 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), suggesting that fishing power is more closely associated with gear characteristics than with vessel characteristics. Adding all technical effects together, 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% of the vessel effects for fleet 1 and 5% for fleet 6 (T in Figure 2). If it is assumed that all 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) is at the upper bound of the contribution of human skill to fishing power.

Discussion

Catchability is influenced by processes linked to fishing power, i.e. the technical characteristics of the fishing gear/vessel and human factors such as experience or strategy (Robins *et al.*, 1998; Goñi *et al.*, 1999; Mahévas *et al.*, 2004), along with processes linked to

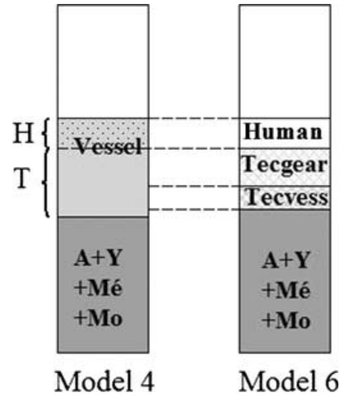

Figure 2. Relative contribution of the human component (H) and the technical component (T) in fishing power estimates (vessel). The human component refers to the residual vessel effects after controlling for measured vessel and gear characteristics. The height of the bars represents the variability in lpue in the dataset used to fit model 4 (left) and model 6 (right). Each block within the bar reflects the proportion of variability explained by the explanatory factors (A, area; Y, year; Mé, métier; Mo, month; Tecgear, combinations of gear characteristics; Tecvess, combinations of vessel characteristics; Table 8). The portion of each of the bars not labelled represents the "unexplained" variance.

the biology of the exploited population, such as variation in fish distribution and hence 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 was that of the individual vessel. The range of variability explained by that factor differed from one fleet to another, but it accounted for >40% of the explained deviance for at least two of the seven fleets.

When fishing tactics can be characterized accurately, the analysis reveals that the métier variable is appropriate to distinguish differences in fishing power significantly, confirming the main conclusion of Quirijns *et al.* (2008) that it is important to account for targeting behaviour to avoid bias in the standardization of lpue. Consequently, it would be relevant to associate métier with a fishing operation or a fishing trip. Two options could be considered to achieve this outcome. The most suitable would be an obligation for fishers to report in logbooks their intended target species (as 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 was proposed to allocate trips described in logbooks to métiers (Deporte *et al.*, 2011).

As expected, seasonal (month) and spatial factors explained a significant proportion of lpue variability. The seasonal and spatial aspects of effort stratification can be used to derive reliable lpue indices, as has been argued in the literature (e.g. Bordalo-Machado, 2006). The present results indicate that changes in the fishing efficiency of a fleet can be both seasonally and spatially based, suggesting that the spatial and seasonal dimension of fishery management needs to be investigated carefully 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 designing an appropriate marine protected area (MPA), for example, in the context of the ecosystem approach to fisheries management. One may suggest, for instance, closing a fishery during the period and/or in the fishing area characterized by the greatest fishing power if the objective is to minimize mortality on a vulnerable stock.

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, and 6) and the Greek pelagic fleet (fleet 5). Except the Spanish Basque demersal fleet (fleet 6), there was no clear increasing or decreasing trend in the year effect in the short period considered. Generally, a positive trend in year effect was expected and can be explained as technological creep and/or improvement in skills (Marchal *et al.*, 2006a; Quirijns *et al.*, 2008). In contrast, the Basque demersal fleet (fleet 6) was characterized by a decrease in the year effect. Such a pattern has been observed too for a French demersal fleet targeting anglerfish (*Lophius budegassa* and *Lophius piscatorius*; Mahévas *et al.*, 2004). A potential reason for this trend is a change in abundance. Indeed, the estimate of the year effect captures both fishing power and variations in abundance. It should be noted too that residual variations in abundance can easily swamp the influence of technical factors. As proposed by several authors already, external information to accompany logbook data can be used to represent abundance in a 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 were based on juvenile surveys that are sensitive to recruitment variability, so not appropriate to reflect interannual variations in the accessible part of the population and hence not suitable for the modelling approach here.

The results of this study have also revealed 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 most of the fishing power variability, but for demersal trawlers, gear characteristics (type of groundrope, headline length) dominate. Engine hp, largely used as a control variable for regulating fishing capacity, was only significant for the Greek pelagic fleet. Therefore, this study confirms the conclusion of Mahévas *et al.* (2004) that hp is not the most appropriate variable for use in standardizing and managing fishing effort. On the other hand, type of groundrope and length of headline are generally unused variables for controlling fishing effort, whereas the outcomes of this analysis show their relevance for proposing technical measures aimed at regulating fishing effort. The results also confirm the importance of bollard pull as a determinant of fishing power, and we believe that there is a case for this variable to be recorded systematically in fishery data-collection programmes. Again focusing on trawlers, we obtained the same results as Marchal *et al.* (2006a), with the explanatory power of technical characteristics mostly less than that of the vessel.

The results from these case studies depend heavily on the quality of the vessel and gear technological data collected during harbour enquiries or reported in administrative registers. Only four fleets of the seven had detailed information on technological equipment carried on board. For some cases, however, a larger sample would be needed to carry out meaningful analysis, so widespread use of any conclusions from this study should be considered with care. However, the data were generally useful in identifying the major determinants of fishing power. The relative significance of different explanatory variables is also impacted by the extent of aggregation used, i.e. days and daily landings rather than haul-by-haul data during a fishing operation. Therefore, it is also desirable that technical features of both vessels and gears be monitored, or recorded by fishers, at the scale of a fishing trip (vessel equipment) or at least at the scale of a fishing operation (gear equipment).

Most studies of fishing power identify the main technical characteristics accountable for changes in power and technological creep (Robins *et al.*, 1998; Mahévas *et al.*, 2004; Bordalo-Machado, 2006; Marchal *et al.*, 2006a), but few evaluate and quantify the human contribution. The human component in fishing power could be associated with the accumulation of knowledge of fish population behaviour and of experience in selecting fishing grounds and/or in operating fishing equipment, each of which or in combination may have a positive impact on the power (Squires and Kirkley, 1999; Marchal *et al.*, 2006b; Ye and Dennis, 2009). Our approach here, comparing the explanatory power of nested fitted models, allowed us to assess the relative contribution of the technical characteristics and their effects on fishing power on the one hand and provided an evaluation of an upper bound of the non-technical (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 with 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 consider that all important technical characteristics are included in the technics tecvess tecgear base model 6, then the relative measure obtained demonstrates that the contribution of the human component in fishing power is weaker than the technical one, but in all likelihood it is not negligible.

Based on these results, we conclude that measures that ignore the human component could lead to undesirable side effects when managers attempt 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 here. Several bioeconomic modelling frameworks of fisheries dynamics have been developed recently to assess the impact of management strategies (e.g. ISIS–Fish: Mahévas and Pelletier, 2004; FLR: Kell *et al.*, 2007). Computation of the fishing mortality of the ISIS–Fish model requires an estimate of fishing power that can be linked formally to the technical characteristics of the fleet (Pelletier *et al.*, 2009). Moreover, that model explicitly takes into account the spatial features of a fishery's dynamics and has already shown its relevance for assessing the impact of MPAs (Kraus *et al.*, 2009; 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), there is value in comparing the impact of a new technical measure regulating the use of rock-hopper gear (a type of groundrope) with that of a spatial and seasonal closure of the fishery. The human component could be considered quantitatively as an input parameter in an uncertainty analysis to assess the robustness of the forecasts and to provide an opportunity to quantify implementation error associated with this issue.

In future studies on catchability, it would also be appropriate to assess the relative contribution of the technology–human component and the biological component. To disentangle these two effects, real-time observations on the fish populations are required; unfortunately these were not available for this study. Indeed, promising results from a recent study combining the use of acoustic data and catch per unit effort from a small fleet operating in a limited area for a short period (Doray *et al.*, 2010; Mahévas *et al.*, 2011) have provided insight into the magnitude of the two effects.

Acknowledgements

We acknowledge support from the TECTAC project (Technological developments and Tactical Adaptations of Important EU Fleets, Q5RS-2002-01291) along with that of our colleagues involved in the French Fisheries Information System managed by Ifremer. The research was funded by the European Commission, project contract CAFE (CApacity, F, and Effort; DG-Fish contract EC FP6 022644).

References

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

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

Beverton, R. J. H., and Holt, S. J. 1957. On the dynamics of exploited fish populations. Fishery Investigations, London, Series 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 Journal of Marine Science, 65: 255–266.

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

Burnham, K. P., and Anderson, D. R. 2003. Model Selection and Multimodel Inference. A Practical Information–Theoric Approach. Springer, New York. 488 pp.

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: 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 Whitmarsh, D. 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. 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., and 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 Paper, 382. 113 pp.

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. Rapports et Procès-Verbaux des Réunions du Conseil Permanent 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. Chapman and Hall, New York.

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. 981 pp.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D., Hillary, R., Jardim, E., *et al.* 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., *et al.* 2009. A model-based evaluation of marine protected areas: the example of eastern Baltic cod (*Gadus morhua callarias*). ICES Journal of Marine Science, 66: 109–121.

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: 1063–1075.

MacCall, A. 1990. Dynamic Geography of Marine Fish Populations. University of Washington Press, Seattle. 153 pp.

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. 2011. 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.

Maravelias, C., and Tsitsika, E. 2008. Economic efficiency analysis and fleet capacity assessment in Mediterranean fisheries. Fisheries Research, 93: 85–91.

Marchal, P. (Ed.). 2006. Report of the TECTAC project, Technological Developments and Tactical Adaptations of Important EU Fleets. EU Project, Q5RS-2002-01291. 651 pp.

Marchal, P., Andersen, B., Bromley, D., Iriondo, A., Mahévas, S., Quirijns, F., Rackham, B., *et al.* 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.

Marchal, P., Andersen, B., Caillart, B., Eigaard, O., Guyader, O., Hovgaard, H., Iriondo, A., *et al.* 2006a. Impact of technological creep on fishing effort and mortality, for a selection of European fleets. ICES Journal of Marine Science, 64: 192–209.

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

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., Mahévas, S., Drouineau, H., Vermard, Y., Thébaud, O., Guyaderc, O., 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. Ecological 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: 1–8.

Reid, D. (Ed.). 2009. Final Report of the EU project Capacity, F and Effort. Contract 022644. 578 pp.

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

Robson, D. S. 1966. Estimation of the relative fishing power of individual ships. ICNAF Research Bulletin, 3: 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 edn. Springer, New York. 495 pp.

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

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