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A comparison of three indices of fishing power on some demersal fisheries of the North Sea

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The scope of this study is to identify temporal dynamics in fishing power, by deriving three different indices (IFP1, IFP2, IFP3) based on three independent methods. IFP1 is derived from the GLM analysis of the relationship between fishing mortality and fishing effort, assuming that total fishing mortality estimates from XSA (eXtended Survivors Analysis) are accurate. IFP2 is derived from the GLM analysis of the difference between the Log-CPUE of a vessel and the average Log-CPUE of a set of reference vessels, which are chosen with regards to the stability of their Log-CPUE over time. IFP3 is derived from the GLM analysis of the Log-CPUE of a vessel relative to some external survey abundance index. Particular attention is paid to the horsepower and year effects in IFP1, IFP2, and IFP3. This methodology is applied to the Danish, Dutch, English and Norwegian demersal fisheries of the North Sea. The fishing power estimated by all indices increases with horsepower, particularly in relation to target species. Despite less consensus in the estimation of annual variations in fishing power, some important features are highlighted. First, there are cases where fishing power has consistently increased over the period of investigation, possibly through an overall increase in fishing efficiency. Second, there are examples where fishing power has increased relative to one species, and remained constant or even decreased in relation to another one. In the context of mixed-species fisheries, this feature might reveal a shift in fishing tactics.

Keywords: catchability, fishing power, fishing capacity, fishing efficiency, horsepower, annual variations, fishing tactics, North Sea demersal fisheries.

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Introduction

A common assumption underlying fish stock assessment is that CPUE (Catch per Unit of fishing Effort) may be used as an index of stock density (Mendelssohn and Cury, 1989; Lehodey *et al.* 1994; ICES, 1999a). A corollary of this assumption is that catchability, the coefficient of proportionality between CPUE and stock density, is constant over time. However, evidence is accumulating that the catchability of commercial fleets has changed over the past decades (Gordoa and Hightower, 1991; Atran and Loesch, 1995; Arreguin-Sanchez and Pitcher, 1999).

The mechanisms of time variations in catchability may include changes in fish accessibility (Crecco and Overholtz, 1990; Swain *et al.*, 1994, Arreguin-Sanchez and Pitcher, 1999) and fishing power creeping (Gascuel *et al.*, 1993; Millischer *et al.*, 1999). The dynamics in fish accessibility depend on biological processes, which lie to a large extent outside human control (e.g. migrations, density-dependence), and also on some gear attributes. However, trends in fishing power reflect changes in both fishing capacity and efficiency, which depend on fishermen's decision-making in the long-term (investment on a boat), medium-term (setting gear and equipment) and short-term (choice of a fishing strategy).

The fishing power of a particular gear is commonly defined as the product of the area of influence of this gear during a unit fishing operation and its efficiency during that operation (Gulland, 1969). Fishing power has been found to be correlated with engine power in a number of cases (Beverton and Holt, 1957). Crew size, age, tonnage and the amount of gear used have also been found to be important factors affecting CPUE in some fisheries (Pascoe *et al*., 2001). However, results from these studies suggested that overall, the largest contribution to the total variance in fishing power should be attributed to non-measurable components, including the skipper's ability to locate and catch fish, and "luck" (Hilborn and Ledbetter, 1985).

An important obstacle in identifying fishing power dynamics is that they may not easily be distinguished from fluctuations in stock density, when analyses are performed on traditional catch and effort data (Robson, 1966; Kimura, 1981; Large, 1992), unless either reliable stock abundance indices are available (Kirkley *et al*., 1995) or extended assumptions are made on biomass dynamics (Paloheimo and Chen, 1993; Reed and Simons, 1996) or fishing mortality estimates (Swain *et al*., 1994; Atran and Loesch, 1995; Millischer *et al*., 1999). Providing reliable fishing power estimates would enhance both the performances of stock assessment procedures (Sampson, 1993; Chen and Paloheimo, 1998) and the efficiency of fisheries management tools (Holden, 1994). The purpose of this exercise is to explore to which extent three different indices are able to describe the dynamics in fishing power.

A first index of fishing power (IFP1) is derived from the GLM analysis of the relationship between fishing mortality and fishing effort, assuming that total fishing mortality estimates from the outcomes of current stock assessment procedures, such as the VPA/XSA (Virtual Population Analysis/eXtended Survivors Analysis) (Shepherd, 1999), are accurate. A second index of fishing power (IFP2) is derived from the GLM analysis of the ratio between the Log-CPUE of a fleet's vessels and the average Log-CPUE of a set of reference vessels, belonging to the fleet under examination. The reference vessels are chosen with regards to the stability of their fishing power over time, using a range of statistical criteria including the mean, the variance and the first-order auto-correlation of their Log-CPUE. If a set of steady vessels could be found for each fleet, then the time variations in Log-CPUE for these reference vessels should be consistent with stock time dynamics. A third index of fishing power (IFP3) is derived from the GLM analysis of the Log-CPUE of a fleet's vessels relative to some external survey abundance index. The horsepower and year effects estimated using those analyses are compared and used to supply an overview of fishing power dynamics. This methodology is applied to the Danish, Dutch, English and Norwegian demersal fisheries of the North Sea.

Methods

Catchability model

The Log-catchability of a vessel v, belonging to fleet f, fishing in area i, in season s and in year y is often given as a function of fishing power (P) and fish accessibility (A) (Gascuel *et al*., 1993; Millischer *et al*., 1999)

$$\ln[q(f,v,y,s,i)] = \ln[P(f,v,y,s,i)] + \ln[A(f,v,y,s,i)] \qquad (1)$$

If we now make the assumptions that, (A1) annual variations in accessibility are negligible compared to annual changes in fishing power, (A2) vessels belonging to the same fleet have the same accessibility to the resource, (A3) fishing power is space-invariant and, (A4) seasonal variations in fishing power are negligible compared to annual variations in fishing power, the Log-catchability model may be simplified as

$$\ln[q(f,v,y,s,i)] = \ln[P(f,v,y)] + \ln[A(f,s,i)] \qquad (2)$$

For simplification purposes, we remove the "f" (fleet) notation in subsequent equations, keeping in mind that these equations are applicable to one specific fleet. Fishing power may be split into a fishing capacity term (FC), which is a time invariant function of vessel attributes only, and a fishing efficiency term (FE), which is a time dependent combination of skipper skill and of the quality of the equipment on-board. We assume that, (A5) fishing capacity is entirely driven by horsepower (h) and, (A6) the fishing efficiency of vessels belonging to the same fleet and having the same horsepower is log-normally distributed across vessels. If ε represents a normally distributed random noise, equation (2) then becomes

$$\ln[q(v,y,s,i)] = \ln[FC(h)] + \ln[FE(y)] + \ln[A(s,i)] + \varepsilon \qquad (3)$$

Indices of catchability dynamics

We use here three different methods to provide separate indices reflecting the dynamics of log-catchability by vessel, year and, when possible, season and area. The three indices derived from methods 1, 2, and 3 are respectively referred to as J1, J2, and J3. The three methods are described below.

Method 1 (J1)

Method 1 follows a classical approach (Gascuel *et al*., 1993; Millischer *et al*., 1999). The partial fishing mortality F(v,y) of any species, harvested by vessel v, in year y, averaged over age classes, may be related to total fishing mortality F(y), total catch in weight C(y) and partial catch in weight C(v,y)

$$F(v,y) = F(y)\frac{C(v,y)}{C(y)} \tag{4}$$

Partial Log-catchability ln[q(v,y)] may be related to partial fishing mortality F(v,y) and fishing effort E(v,y) by

$$\ln[q(v,y) = \ln[F(v,y)] - \ln[E(v,y)]$$

Therefore, J1 may simply be equated to Log-catchability, provided estimates of F are available, and it may be estimated by

$$J1 = \ln[q(v,y)] = \ln[F(v,y)] - \ln[E(v,y)] \tag{5}$$

By combining Equations (3) and (5), J1 may also be formulated as

$$J1 = \ln[FC(h)] + \ln[FE(y)] + \ln[A] + \varepsilon \tag{6}$$

Method 2 (J2)

Method 2 is developed to derive an estimate of Log-catchability (J2) from commercial fisheries data, and it is based on an approach developed by Marchal *et al.* (2001a). The calculation of J2 requires identifying a set of reference vessels, belonging to the fleet under examination. For each fleet and each fishing area, the reference vessels are characterized by a stable catchability and are identified using objective criteria including the mean, the variance and the first-order auto-correlation of the Log-CPUE generated by each vessel. It has been shown that, subject to the assumption that CPUE can be split into vessel-dependent and vessel-independent components, some statistical properties of Log-catchability, including centered mean, variance and first-order auto-correlation, are equivalent to those of Log-CPUE. Method 2 is summarized below.

The Log-catchability of vessel v, belonging to a V-vessels fleet, fishing in year y, season s and ICES rectangle i may be formulated as

$$\ln[q(v,y,s,i)] = \ln\left[U(v,y,s,i)\left[\prod_{r=1}^{R}\left(\frac{q(r,i))}{U(r,y,s,i))}\right)\right]^{\frac{1}{R}}\right] \tag{7}$$

Where r = 1, . . ., R are the reference vessels, whose catchability q(r,i) is assumed to be constant over time; U refers to the CPUE (Catch Per Unit Effort) of any fishing vessel (v or r). Note that (7) is consistent with usual definitions of catchability (Gulland, 1964; Crecco and Overholtz, 1990; Rose and Legget, 1991; Swain *et al.*, 1994; Arreguin-Sanchez and Pitcher, 1999).

We now search, amongst a fleet with V vessels, for a sub-fleet of R reference vessels, whose catchability has remained constant over the past T-time units fishing period. In practice, due to the very dynamic character of fishery systems, such a sub-fleet is unlikely to exist. Nevertheless, it is possible to look for a reference sub-fleet of R vessels (r = 1, . . ., R), responding to four criteria:

(1) Reasonable coverage over the period of investigation
(2) Catchability, averaged over the period of investigation, should not be significantly different across the reference vessels (5% significance threshold)
(3) Low random variations in catchability over the period of investigation
(4) No significant trend in catchability over the period of investigation.

The details of the selection process are given in Marchal *et al.* (2001a).

It is not possible to calculate directly ln[q(v,y,s,i)] based on Equation (7), since the value of q(r,i) is unknown. However, we may calculate J2, an index that reflects some of the dynamics of ln[q(v,y,s,i)]

$$J2 = \ln[q(v,y,s,i)] - \frac{1}{R}\sum_{r=1}^{R}\ln[q(r,i)] = \ln\left[U(v,y,s,i)\left[\prod_{r=1}^{R}(U(r,y,s,i)))\right]^{-\frac{1}{R}}\right] \tag{8}$$

J2 reflects the time, but not the spatial, dynamics of the Log-catchability of vessel v. By combining Equations (3) and (8), J1 may also be formulated as

$$J2 = \ln[FC(h)] + \ln[FE(y)] + \ln[A(s,i)] - \frac{1}{R}\sum_{r=1}^{R}\ln[q(r,i)] + \varepsilon \tag{9}$$

Method 3 (J3)

We assume here that detailed CPUE time series are available from research surveys, operated annually during the same quarter, and that the fishing power of the research survey is constant over time. The CPUEs of a commercial vessel v (U) and of a research survey (U′), fishing in year y and in area i, may respectively be expressed as

$$U(v,y,i) = q(v,y,i)N^{\lambda}(y) = P(v,y)A(i)N^{\lambda}(y) \tag{10}$$

$$U'(y,i) = q'(i)N^{\lambda}(y) = P'A'(i)N^{\lambda}(y) \tag{11}$$

Where λ is a power coefficient and where q′, P′, A′ refer to the catchability, fishing power and accessibility relative to the research survey. The Log-catchability of vessel v, fishing in year y and ICES rectangle i may then be expressed as

$$\ln[q(v,y,i)] = \ln\left[\frac{U(v,y,i)}{U'(y,i)}\right] + \ln[q'(i)] \tag{12}$$

It is not possible to calculate directly ln[q(v,y,i)] based on Equation (12), since the value of q′(i) is unknown. However, we may calculate J3, an index that reflects some of the dynamics of ln[q(v,y,i)]

$$J3 = \ln[q(v,y,i)] - \ln[q'(i)] = \ln\left[\frac{U(v,y,i)}{U'(y,i)}\right] \tag{13}$$

If the survey abundance indices are correct, J3 will reflect the time, but not the spatial, dynamics of the Log-catchability of vessel v. By combining Equations (3) and (13), J3 may also be formulated as

$$J3 = \ln[FC(h)] + \ln[FE(y)] + \ln\left[\frac{A(i)}{q'(i)}\right] + \varepsilon \tag{14}$$

GLM analyses

The three J-indices reflect vessel- and species-specific variations in catchability. The next step of our analysis is to extract from these signals three fleet- and species-specific indices of fishing power. The variations in J1, J2, and J3 are then analysed, for each combination of commercial fleet f and species s, by means of a number of GLM. A gaussian regression is applied to each GLM, so the link function is simply the mean response of the model. The external variables include horsepower (class), year (class or continuous) and, for some of the indices, quarter (class) and ICES rectangle (class). Four GLMs may potentially be considered

Model 1

$$Jx = \mu + \alpha_h + \beta_y + \gamma_i + \delta_s + \chi_{y,i,s} + \varepsilon_{h,y,i,s} \tag{15a}$$

Model 2

$$Jx = \mu + \alpha_h + \beta_y + \gamma_i + \delta_s + \chi_{y,s} + \varepsilon_{h,y,i,s} \tag{15b}$$

Model 3

$$Jx = \mu + \alpha_h + \beta_y + \gamma_i + \delta_s + \varepsilon_{h,y,i,s} \tag{15c}$$

Model 4

$$Jx = \mu + \alpha_h + (\beta' \cdot y) + \gamma_i + \delta_s + \varepsilon_{h,y,i,s} \tag{15d}$$

Where x takes value in {1,2,3}, μ is an average term, α_h, γ_i, and δ_s the terms relative to the effect of the hth horsepower category, ith area and sth season respectively (models 1–4); β_y, the term relative to the yth year (models 1–3); β' the annual trend in Jx (model 4). ε is the model residual; $\chi_{y,i,s}$ (resp. $\chi_{y,s}$) is the interaction term between variables year, quarter and area (resp. year and quarter). Model 1 is the most comprehensive. However, it is also the most data-sensitive as it requires estimating all the different interaction coefficients, making it difficult to estimate robust horsepower-, time- and area effects. Models 3 and 4 are the most basic models, since they ignore any possible correlation between variables, so the coefficients derived from these models are easier to interpret than those derived from models 1 and 2. The difference between models 3 and 4 is that year is either a class variable (model 3) or a continuous (regression) variable (model 4).

The statistical properties of those models (R-square, correlation between residuals and predictions) may be compared so as to determine the extent to which these models describe variations in J1. Comparing the goodness of fit between models 1, 2, 3 may be useful to appraise the contributions of variable interactions to CPUE variations. Model 2 is close to model 3 but includes interactions between year and quarter effects. Although less informative than model 3, model 4 is expected to be more useful in quantifying annual trends in Jx. In particular, should there be little difference between the R-squares derived from models 3 and 4, the regression coefficient derived from model 4 would be a simple and useful index to quantify efficiency creeping.

Not all the models may necessarily be applied to analyse the variations in J1, J2, and J3. Variations in J1 may be analysed using only models 3 and 4, with season and area effects constrained to be zero because J1 estimates are aggregated over a year and the whole stock distribution area. Variations in J3 may be analysed using only models 1, 3, and 4, with the season effect constrained to be zero because J3 estimates are available for one quarter only. Finally, variations in J2 may be analysed using models 1–4, as J2 estimates are available by vessel, year, season and ICES rectangle.

Comparing Equation (15c) with Equations (6), (9), and (14), it appears that α_h and β_y may be used as proxies for fishing capacity and efficiency respectively. Three independent indices of fishing power IFP1, IFP2, and IFP3 may be derived from J1, J2, and J3 respectively. These three indices of fishing power may be represented by

$$IFPx(h,y) = \alpha_h + \beta_y, \text{ with } x \in \{1,2,3\} \tag{16}$$

Comparing Equation (15d) with Equations (6), (9), and (14), it appears that the averaged annual trend in fishing efficiency may be approached using three proxies (φ_1, φ_2, φ_3), derived from (J1, J2, J3), which may be calculated as

$$\varphi_x = \exp(\beta') - 1, \text{ with } x \in \{1,2,3\} \tag{17}$$

Table 1. Qualitative description of the Danish, Dutch, English and Norwegian demersal fisheries in the North Sea. The codes for fishing nations, gears and fleets are also given.

Fishing nation (code)	Gear (code)	Horsepower	Fleet	Fishing effort	Species				
		HP category	Code	Unit	Cod	Haddock	Saithe	Plaice	Sole
Denmark (DK)	Gill net (GN)	—	GN	No. days	×			×	×
	Otter trawl (OTB)	0–300	OTB ⟨0–300 HP⟩	No. days	×			×	
		>300	OTB⟨300+HP⟩	No. days	×			×	
	Seine (SN)	0–300	SN	No. days	×			×	
Netherlands (NL)	Beam trawl (TBB)	0–300	TBB⟨0–300 HP⟩	No. days	×			×	×
		>300	TBB⟨300+HP⟩	No. days	×			×	×
England (EN)	Beam trawl (TBB)	—	TBB	No. hours	×			×	×
	Otter trawl (OTB)	—	OTB	No. hours	×			×	
	Fixed nets (GN)	—	GN	No. days	×			×	×
Norway (NO)	Otter trawl (OTB)	0–1000	OTB⟨0–1000 HP⟩	No. days	×	×	×		
		1000–2000	OTB⟨1000–2000 HP⟩	No. days	×	×	×		
		>2000	OTB⟨2000+HP⟩	No. days	×	×	×		
	Gill net (GN)	—	GN	No. boats	×	×	×		
	Long-line (LL)	—	LL	No. boats	×	×	×		

Assumptions

The assumptions applicable to the three methods (A1–6) are summarized below

(A1) annual variations in accessibility are negligible compared to annual changes in fishing power,
(A2) vessels belonging to the same fleet have the same accessibility to the resource,
(A3) fishing power is space-invariant,
(A4) seasonal variations in fishing power are negligible compared to annual variations in fishing power,
(A5) fishing capacity is entirely driven by horsepower,
(A6) the fishing efficiency of vessels belonging to the same fleet and having the same horsepower is log-normally distributed across vessels.

The method-specific assumptions (A7–9) are now summarized below

(A7, method 1) Total fishing mortality estimates derived from VPA are reliable,
(A8, method 2) Variations in catchability in the reference set of vessels are sufficiently low to be neglected,
(A9, method 3) The fishing power of vessels participating to research surveys is constant over time.

Data

Commercial catch and effort data

The preceding methods are applied to the Danish, Dutch, English and Norwegian demersal fleets harvesting cod, haddock, saithe, sole and plaice in the North Sea, defined as ICES area IV. These fisheries have comprehensively been described in Marchal *et al.* (2001b). A qualitative description of the international fisheries, including fleet codes used in the subsequent analyses, is given in Table 1. Fleets are here defined as a combination of gear and horsepower categories (beam-trawlers, otter-trawlers), or simply gear (seiners, netters, longliners). English horsepower data were considered imprecise and were not used to split the fleets into HP categories. Target species of the Danish, Dutch and English fisheries are cod, sole and plaice, while the Norwegian fishery is primarily targeting saithe.

Catch and effort data for these fisheries are extracted from the logbook national databases. Data are regularly available over 1980–1998 (Norway), 1987–1998 (Denmark), 1989–1998 (England) and 1991–1998 (The Netherlands). The databases incorporate information on fishing trips, landings and vessels attributes (including horsepower) by ICES rectangle. Fishing effort was estimated by combining available measures of fishing capacity and of fishing activity. Horsepower was used as a proxy for fishing capacity, while fishing time (i.e. fishing days for the Danish and the Dutch fleets, fishing hours for the English and Norwegian fleets) was taken as a proxy for the fishing activity. Such estimates are thought appropriate for vessels whose fishing operation is energy intensive (otter- or beam-trawlers), but not for those using static gears (gill-nets, long-lines) (Marchal *et al.*, 2001b). However, no alternative measures of fishing capacity and activity were available to the analyses. In order to allow calculating Log-CPUE for data cells with zero catches, the minimal landings by vessel, quarter and ICES rectangle, have been set to 0.5 kg. Figure 1 shows an illustration of the CPUE and effort time series for the Danish fleet segments under investigation.

Catch and effort data have primarily been aggregated by vessel, year, quarter and ICES rectangle, to make up

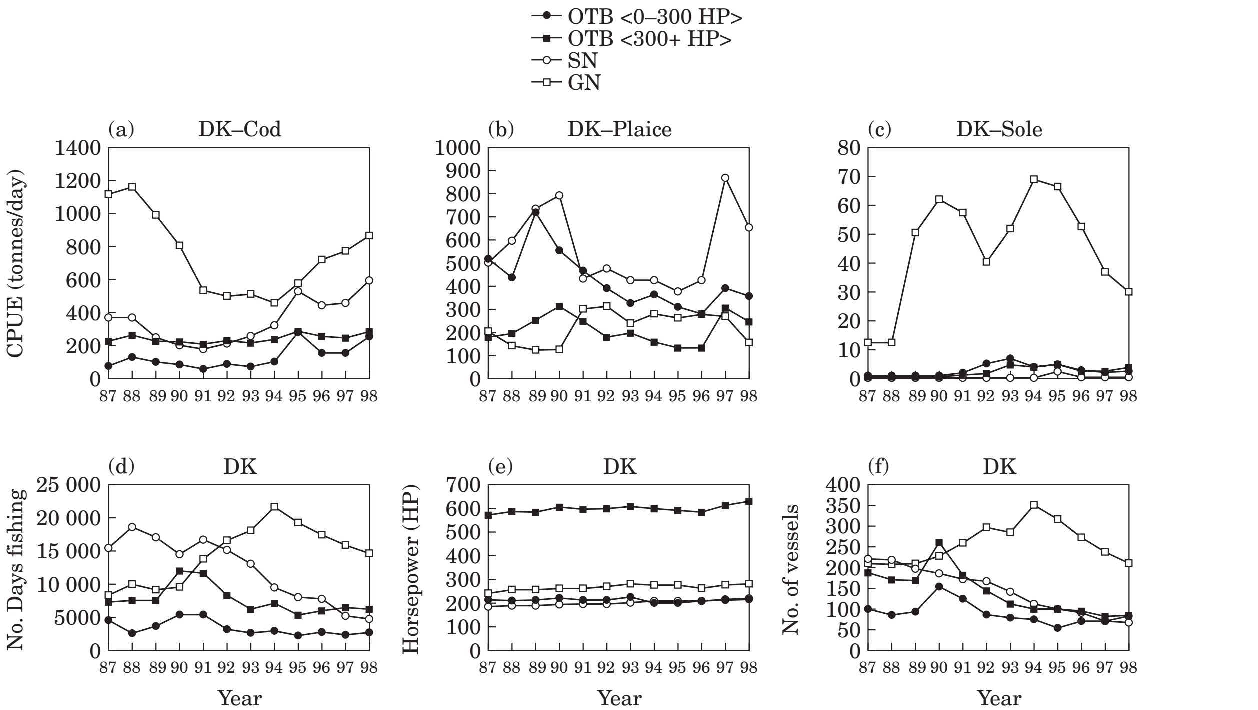

Figure 1. CPUE of (a) cod, (b) plaice, (c) sole and, (d) number of days fishing, (e) average horsepower, (f) number of vessels, for the four main Danish demersal fleet segments fishing in the North Sea.

a general commercial database. ICES rectangles represent the smallest geographical unit (30 × 60 nmi) where catch and effort data are available. Fishing time was only available at the scale of a whole fishing trip. Given fishermen could explore several ICES rectangles during the same trip, it was necessary to make an assumption to evaluate the fishing activity in each of these rectangles. The assumption made here is that the time spent by a fisherman in an ICES rectangle is proportional to the landings value taken in that rectangle, which is consistent with the perception that fishing is overall an economic activity. Fishing time in a rectangle has therefore been estimated, by weighing the total duration of a fishing trip by the proportion of the total gross revenue (over the whole trip) to the revenue by rectangle.

The general commercial database has been, to a variable extent, adjusted to account for the specifications of each method. Method 2 has been applied to the data from the global database. The application of method 3 required to match temporally the periods where commercial fishing and research surveys have been operated. Commercial catch and effort data are available all year round while, as discussed in the following sub-section, survey data are only available over one quarter. In order to combine the information provided by both commercial fisheries and surveys, the global commercial database has been restricted to the quarter where survey information is available. The application of method 1 is based on catch and effort data aggregated by year and stock assessment area. Therefore, data from the global commercial database have been aggregated over the four quarters of each year and all the ICES rectangles belonging to the stock assessment area. Note that no spatial information was available for the Norwegian long-liners and gill-netters. As a result, only method 1 was applied to these two fleets.

Research survey data

Stock abundance indices used in method 3 are derived from international (IBTS, International Bottom Trawl Survey, first quarter), Dutch (DBTS, Dutch Beam Trawl Survey, third quarter), English (EGFS, English Groundfish Survey, third quarter) and Norwegian (NAS, Norwegian Acoustic Survey, third quarter) investigations. While the IBTS and the EGFS are designed to study cod, haddock, whiting and, to some extent, plaice stocks, the DBTS focuses on flatfish (sole and plaice) and the NAS on saithe. The national surveys (i.e. EGFS, DBTS and NAS) are only used to assist the calculation of IFP3 relative to their national commercial fishery (respectively England, The Netherlands and Norway). Survey data are available

Table 2. R-squares derived from the GLM analyses of the indices of fishing power performed with 2 (IFP1), 3 (IFP3) or 4 (IFP2) different models including different levels of interactions between explanatory variables. R-squares smaller than 10% are highlighted in dark grey. In cases where R-squares are higher than 10% and the correlation between predicted values and residuals, as derived from the GLM analyses performed with models 3 and 4, is significantly different from 0 (given the 5% risk threshold), values are highlighted in medium grey.

			Index	IFP1		IFP2				IFP3 (DBTS)			IFP3 (EGFS)			IFP3 (IBTS)			IFP3 (NAS)		
Country	Fleet	Species	Model	3	4	1	2	3	4	1	3	4	1	3	4	1	3	4	1	3	4
DK	GN	Cod		0.16	0.14	0.34	0.17	0.15	0.15							0.54	0.20	0.15			
		Plaice		0.17	0.09	0.27	0.07	0.06	0.05							0.58	0.40	0.37			
		Sole		0.18	0.10	0.28	0.08	0.06	0.05												
	OTB⟨0–300 HP⟩	Cod		0.04	0.02	0.17	0.13	0.06	0.02							0.72	0.32	0.27			
		Plaice		0.04	0.00	0.14	0.09	0.03	0.00							0.68	0.37	0.25			
	OTB⟨300+HP⟩	Cod		0.11	0.08	0.49	0.25	0.22	0.20							0.60	0.23	0.21			
		Plaice		0.15	0.14	0.47	0.23	0.18	0.14							0.74	0.55	0.53			
	SN	Cod		0.05	0.04	0.38	0.10	0.09	0.08							0.43	0.17	0.15			
		Plaice		0.06	0.04	0.31	0.07	0.06	0.05							0.55	0.36	0.31			
EN	TBB	Cod		0.30	0.27	0.35	0.08	0.06	0.05				0.79	0.47	0.44	0.75	0.34	0.30			
		Plaice		0.45	0.43	0.28	0.05	0.04	0.03				0.69	0.30	0.26	0.71	0.41	0.39			
		Sole		0.15	0.03	0.34	0.10	0.06	0.04												
	GN	Cod		0.05	0.00	0.43	0.19	0.17	0.14				0.85	0.68	0.52	0.88	0.57	0.56			
		Plaice		0.04	0.00	0.45	0.33	0.16	0.13				0.70	0.44	0.35	0.81	0.52	0.46			
		Sole		0.08	0.00	0.32	0.13	0.08	0.05												
	OTB	Cod		0.04	0.02	0.31	0.10	0.08	0.08				0.71	0.36	0.30	0.72	0.33	0.29			
		Plaice		0.06	0.04	0.28	0.08	0.08	0.07				0.65	0.43	0.40	0.68	0.42	0.38			
NL	TBB⟨0–300 HP⟩	Cod		0.04	0.00	0.21	0.08	0.06	0.04							0.76	0.30	0.23			
		Plaice		0.03	0.00	0.33	0.15	0.12	0.11	0.48	0.27	0.19				0.40	0.20	0.13			
		Sole		0.03	0.02	0.32	0.09	0.07	0.06	0.81	0.59	0.26									
	TBB⟨300+HP⟩	Cod		0.20	0.18	0.23	0.07	0.07	0.06							0.85	0.33	0.28			
		Plaice		0.44	0.40	0.24	0.11	0.11	0.10	0.90	0.74	0.65				0.79	0.37	0.29			
		Sole		0.41	0.39	0.37	0.18	0.18	0.17	0.90	0.67	0.48									
NO	GN	Cod		0.15	0.10																
		Haddock		0.13	0.04																
		Saithe		0.10	0.03																
	LL	Cod		0.26	0.20																
		Haddock		0.25	0.18																
		Saithe		0.22	0.17																
	OTB⟨0–1000 HP⟩	Cod		0.32	0.10											0.38	0.30	0.22			
		Haddock		0.26	0.09											0.46	0.31	0.25			
		Saithe		0.47	0.28														0.81	0.56	0.46
	OTB⟨1000–2000 HP⟩	Cod		0.26	0.14	0.32	0.27	0.09	0.05							0.47	0.26	0.19			
		Haddock		0.23	0.14	0.40	0.18	0.09	0.03							0.49	0.30	0.21			
		Saithe		0.16	0.07	0.39	0.20	0.12	0.05										0.94	0.30	0.26
	OTB⟨2000+HP⟩	Cod		0.25	0.06	0.50	0.41	0.33	0.10							0.41	0.26	0.15			
		Haddock		0.35	0.04	0.59	0.59	0.39	0.21							0.37	0.25	0.12			
		Saithe		0.47	0.19	0.53	0.36	0.22	0.08										0.94	0.49	0.40

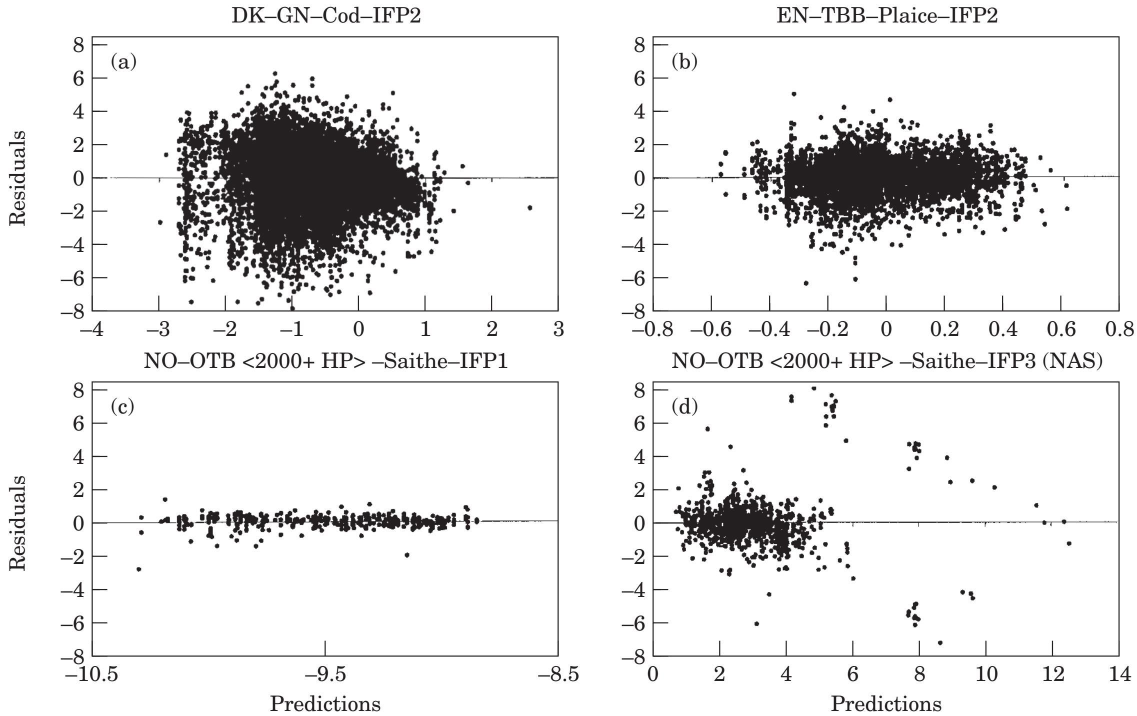

Figure 2. Plots of residuals versus predicted values derived from selected GLM analyses of fishing power: (a) predicted IFP2 for the Danish gill-netters fishing cod; (b) predicted IFP2 for the English beam-trawlers fishing plaice; (c) predicted IFP1 for the Norwegian large otter-trawlers fishing saithe; (d) predicted IFP3 (calculated using the NAS index) for the Norwegian large otter-trawlers fishing saithe.

over the same period as the commercial catch and effort data, except for the NAS data, which are only available over 1991–1998 (no data available for 1994). In order to allow comparisons across methods, IFP1 and IFP2 for Norwegian otter-trawlers harvesting saithe have been estimated over two time periods: 1980–1998 and 1991–1998.

ICES assessment data

The total catch and fishing mortality for cod, haddock, sole, plaice and saithe in the North Sea, which are required to apply method 1, are derived from the outputs of the ICES stock assessments (ICES, 1999a). Fishing mortality (F) trajectories for haddock, saithe, plaice and sole do not show substantial retrospective patterns, suggesting that F estimates are not substantially affected by trends in the catchability of the tuning fleets. For cod, there does appear to be a retrospective pattern in the SSB (Spawning Stock Biomass) and F (averaged over ages 2–4) trajectories. However, this retrospective pattern in fishing mortality is only moderate, when F is averaged over ages 2–8. As a result, method 1 is applied to cod, using F(2–8). The cod and saithe stocks have reached their historical minimal biomass level in the beginning of the nineties, and are currently considered to be in a critical state. The biomass level of sole and plaice was high in the early nineties, and has been declining since then. By contrast, the haddock biomass was considered low in the early nineties, and has increased since then.

Results

Statistical properties of the different GLM analyses are presented in Table 2 and Figure 2. Particular attention has been paid to the value of R-squares (for models 1–4) and to the relationship between residuals and predicted values (for models 3 and 4). The correlation between residuals and predictions have been tested using the non-parametric test of Spearman. Selected plots of residuals and predictions have been presented in situations with low R-square (Figure 2a and b), significant correlation between residuals and predictions (Figure 2a and d), medium R-square and residuals independent from predictions (Figure 2c).

For IFP1, the overall difference in R-squares observed between models 3 and 4 suggests that trends in fishing power are not constant over the years (Table 2). The R-squares were generally low, even for model 3, particularly for Danish small otter-trawlers and seiners, English otter-trawlers and gill-netters and Dutch small

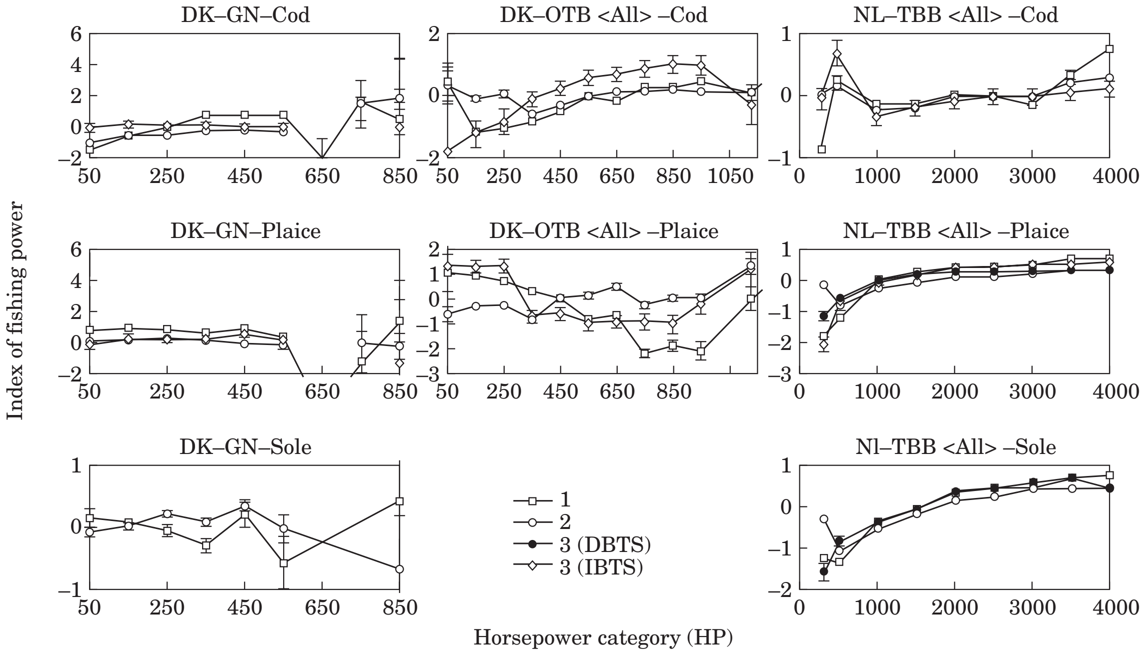

Figure 3. Variations against horsepower (X-axis given in HP units) of the horsepower component (α_h) of the Indices of Fishing Power, scaled to average over horsepower categories, of the Danish and Dutch fleets. The α_h-coefficients are derived from the different methods being investigated [1: IFP1; 2: IFP2; 3(''survey''): IFP3(''survey'')], applying model 3. Error bars have also been represented.

beam-trawlers (R^2<10%). Residuals are not significantly correlated with predictions, irrespective of the model being used. The generally large differences in R-squares between models 1 and 2 in IFP2 suggest a substantial contribution of interactions between time and area effects to the total variance of IFP2. There are little differences in R-squares between models 2 and 3, suggesting little interactions between season and year effects. The R-squares derived from model 3 were lower than 10%, with rare exceptions. The R-squares for models 3 and 4 are similar. The highest R-squares are also associated with significant correlation between residuals and predictions (e.g. Norwegian otter-trawlers). For IFP3, the large differences in R-squares between models 1 and 3 suggest substantial interactions between area and year effects. The R-squares for models 3 and 4 are similar. It may hence be anticipated that annual trends in IFP3 may reasonably be modelled using a simple regression of the period of investigation. The R-squares derived from models 3 and 4 were generally high. There are significant correlations between residuals and predicted values relative to a number of combinations (survey; country; fleet; species), including (DBTS; NL; TBB⟨300+HP⟩; sole), (EGFS; EN; OTB; cod), (IBTS; DK; OTB⟨300+HP⟩; plaice), (NAS; NO; OTB⟨2000+HP⟩; saithe).

The α_h estimates are presented in Figures 3 and 4. Table 3 summarizes the information presented in these figures, by showing the correlations between the three α_h-coefficients derived from methods 1, 2, and 3, applying model 3. There is good correspondence between the α_h-coefficients calculated for the Dutch beam-trawl fishery (Figure 3), and also for the Norwegian otter-trawlers harvesting saithe (Figure 4), despite one outlier (HP=2550), which is due to few data points. There is generally good consistency between the two α_h-coefficients derived from methods 1 and 2, relative to the Norwegian otter-trawlers harvesting cod and haddock, but $\alpha_{3,h}$ behaves rather differently. Although there is overall poor consistency between the three α_h-coefficients calculated relative to the Danish fleets, none of the series indicate a clear trend in the variations of fishing power against horsepower, except for otter-trawlers harvesting cod. In the absence of reliable data on horsepower, it was not possible to examine the variations of the α_h-coefficients for the English fleets.

Overall, the standard error associated to the estimates is negligible compared to variations across horsepower, except for some horsepower categories which are under-represented, such as those relative to the most powerful gill-netters and long-liners. The fishing power of towed-gear fleets increases with horsepower, particularly in relation to target species (Danish otter-trawlers harvesting cod, Dutch beam-trawlers harvesting flatfish, Norwegian otter-trawlers harvesting saithe). By

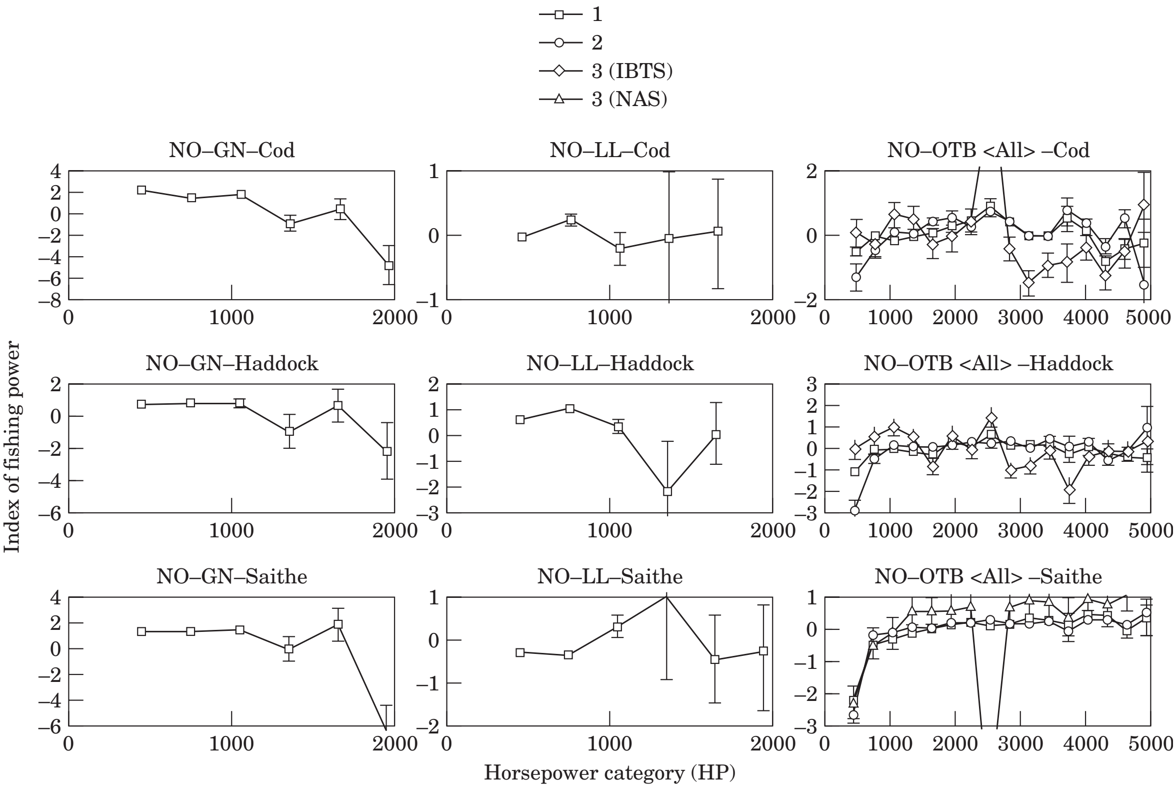

Figure 4. Variations against horsepower (X-axis given in HP units) of the horsepower component (α_h) of the Indices of Fishing Power, scaled to average over horsepower categories, of the Norwegian fleets. The α_h-coefficients are derived from the different methods being investigated [1: IFP1; 2: IFP2; 3("survey"): IFP3("survey")], applying model 3. Error bars have also been represented.

contrast, there are no clear indications of trends for the fishing power of towed-gear fleets (relative to by-catches) and of non towed-gear fleets such as gill-netters and long-liners (relative to any species).

Table 4 shows the correlations between the three β_y-coefficients derived from methods 1, 2, and 3, applying model 3. There is less consistency in the β_y-coefficients than there was between the α_h-coefficients. In order to examine trends in fishing power, we selected the combinations (IFP; country; fleet; species) characterized by reasonable statistical properties, i.e. (i) R-square greater than 10% and, (ii) no significant correlation between residuals and predicted values (as shown in Table 2). Note that, given these two criteria, method 2 is only applied to the Norwegian otter-trawlers harvesting saithe and the English gill-netters harvesting plaice. By contrast, method 1 could be applied in most of cases. The annual variations in fishing power corresponding to these combinations are presented in Figures 5–8. Table 5 suggests that these annual variations are always significant, given the 5% statistical threshold.

The fishing power of Danish seiners has increased with respect to both target species (cod and plaice), especially since 1994, which could be due to this fleet becoming more efficient overall (Figure 5). The fishing power of otter-trawlers has increased for plaice fishing over period 1991–1998, but no clear trend could be identified for cod fishing over the same period. There has been a substantial increase in the fishing power of gill-netters for plaice and sole fishing, over period 1989–1992. No clear trend in fishing power could be identified for this fleet fishing for cod. Since 1989, there has been little change in the fishing power of the English fleets under investigation, except for beam-trawlers harvesting plaice (Figure 6). The fishing power of both Dutch fleets fishing cod and of large beam-trawlers harvesting sole has shown an increase (Figure 7). By contrast, the fishing power of both fleets fishing plaice has remained constant, or even decreased.

In the case of the Norwegian fleets, there is reasonable agreement in the time series derived from the different methods, with the exception of small otter-trawlers harvesting haddock (Figure 8). The fishing power of long-liners has increased since 1980 for cod, haddock and saithe, particularly over period 1980–1993 and very recent years. The fishing power of gill-netters harvesting cod and haddock has increased over the period

Table 3. Correlation between the α_h-coefficients derived from the analysis of IFP1, IFP2, and IFP3, applying model 3. IFP3(D), IFP3(I), and IFP3(N) respectively represent IFP3 calculated using the DBTS, IBTS, and NAS survey data.

Country	Fleet	Species	Index	IFP1	IFP2	IFP3(D)	IFP3(I)	IFP3(N)
DK	GN	Cod	IFP1	1.00				
			IFP2	0.67	1.00			
			IFP3(I)	0.07	− 0.16		1.00	
		Plaice	IFP1	1.00				
			IFP2	0.07	1.00			
			IFP3(I)	− 0.60	0.53		1.00	
		Sole	IFP1	1.00				
			IFP2	− 0.37	1.00			
	OTB⟨All⟩	Cod	IFP1	1.00				
			IFP2	0.62	1.00			
			IFP3(I)	0.42	0.01		1.00	
		Plaice	IFP1	1.00				
			IFP2	− 0.22	1.00			
			IFP3(I)	0.71	0.04		1.00	
NL	TBB⟨All⟩	Cod	IFP1	1.00				
			IFP2	0.63	1.00			
			IFP3(D)			1.00		
			IFP3(I)	0.39	0.69		1.00	
		Plaice	IFP1	1.00				
			IFP2	0.75	1.00			
			IFP3(D)	0.99	0.67	1.00		
			IFP3(I)	0.97	0.59	0.99	1.00	
		Sole	IFP1	1.00				
			IFP2	0.91	1.00			
			IFP3(D)	0.96	0.78	1.00	1.00	
NO	OTB⟨All⟩	Cod	IFP1	1.00				
			IFP2	0.62	1.00			
			IFP3(I)	0.49	0.08		1.00	
		Haddock	IFP1	1.00				
			IFP2	0.70	1.00			
			IFP3(I)	0.23	0.00	1.00	1.00	
		Saithe	IFP1	1.00				
			IFP2	0.97	1.00			
			IFP3(N)	0.37	0.32	1.00		1.00

1980–1992, although it has remained constant, or possibly declined, since then. By contrast, the fishing power of this fleet has declined for saithe over 1980–1991 and increased since then. The fishing power of small otter-trawlers has steeply increased for cod over period 1982–1991, and decreased since then, while the opposite trend holds for saithe. These contrasting trends could be interpreted, as for long-liners, by a shift in fishing strategies from one species to another. No clear trends could be detected in the fishing power of small otter-trawlers fishing for haddock. The fishing power of medium and large otter-trawlers for cod follows similar trends as for the other trawl fleet. The fishing power of medium otter-trawlers for haddock has steadily increased over the whole time period, but no clear trend could be identified for the large otter-trawlers fishing this species. The fishing power of medium and large otter-trawlers fishing saithe has increased over 1980–1993, and stabilized or possibly decreased since then.

The annual trends in fishing power (φ_1, φ_2, φ_3) derived from model 4 are quantified in Table 6. The values are overall coherent with variations observed in Figures 5–8. Thus, strong positive trends are observed for most of the Danish fleets fishing flatfish (12–27%), Dutch small beam-trawlers fishing cod (22%), Norwegian long-liners fishing all gadoids over 1980–1998, Norwegian gill-netters and small trawlers fishing saithe over 1991–1998 (18–44%), Norwegian small trawlers fishing cod (11%). Note that the most outstanding trend estimated for IFP3(N) (44%) is due to few data points. Besides, more moderate positive trends are confirmed for the Danish large otter-trawlers and seiners fishing cod (4–9%), large Dutch beam-trawlers fishing cod and sole (6–8%), Norwegian gill-netters and medium trawlers fishing haddock (6–8%), Norwegian medium and large trawlers fishing cod and saithe over 1980–1998 (2–10%). The other trends estimated are either not significant (5% risk) or inconsistent across the different estimation methods.

Table 4. Correlation between the β_y-coefficients derived from the analysis of IFP1, IFP2, and IFP3, applying model 3. IFP3(D), IFP3(E), IFP3(I), and IFP3(N) respectively represent IFP3 calculated using the DBTS, EGFS, IBTS, and NAS survey data.

Country	Fleet	Species	Index	IFP1	IFP2	IFP3(D)	IFP3(I)	IFP3(N)
DK	SN	Cod	IFP1	1.00				
			IFP2	0.61	1.00			
			IFP3(I)	0.21	0.48	1.00		
		Plaice	IFP1	1.00				
			IFP2	− 0.18	1.00			
			IFP3(I)	0.51	− 0.10	1.00		
	GN	Cod	IFP1	1.00				
			IFP2	− 0.02	1.00			
			IFP3(I)	0.13	0.62	1.00		
		Plaice	IFP1	1.00				
			IFP2	0.57	1.00			
			IFP3(I)	0.81	0.52	1.00		
		Sole	IFP1	1.00				
			IFP2	0.29	1.00			
	OTB⟨0–300 HP⟩	Cod	IFP1	1.00				
			IFP2	− 0.02	1.00			
			IFP3(I)	0.06	− 0.05	1.00		
		Plaice	IFP1	1.00				
			IFP2	− 0.23	1.00			
			IFP3(I)	− 0.04	0.00	1.00		
	OTB⟨300+HP⟩	Cod	IFP1	1.00				
			IFP2	0.15	1.00			
			IFP3(I)	0.18	0.38	1.00		
		Plaice	IFP1	1.00				
			IFP2	0.47	1.00			
			IFP3(I)	0.49	− 0.23	1.00		
NL	TBB⟨0–300 HP⟩	Cod	IFP1	1.00				
			IFP2	− 0.05	1.00			
			IFP3(I)	− 0.49	0.57		1.00	
		Plaice	IFP1	1.00				
			IFP2	0.65	1.00			
			IFP3(D)	− 0.31	0.27	1.00		
			IFP3(I)	0.24	0.54	0.55	1.00	
		Sole	IFP1	1.00				
			IFP2	0.32	1.00			
			IFP3(D)	0.74	0.41	1.00		
	TBB⟨300+HP⟩	Cod	IFP1	1.00				
			IFP2	0.89	1.00			
			IFP3(I)	0.33	0.15		1.00	
		Plaice	IFP1	1.00				
			IFP2	0.17	1.00			
			IFP3(D)	− 0.08	0.71	1.00		
			IFP3(I)	0.17	0.66	0.90	1.00	
		Sole	IFP1	1.00				
			IFP2	− 0.48	1.00			
			IFP3(D)	0.33	− 0.41	1.00		

Discussion

The scope of this study was to examine variations in fishing power in relation to fishing capacity (here represented by horsepower) and fishing efficiency (here associated to a year effect). Fishing power is estimated by means of three independent indices. It is shown that overall, the fishing power of towed-gear fleets increases with horsepower, particularly in relation to target species (e.g. Danish otter-trawlers harvesting cod, Dutch beam-trawlers harvesting flatfish, Norwegian otter-trawlers harvesting saithe). This outcome was expected and it bears out the conclusions from a wide range of earlier investigations (Beverton and Holt, 1957; Robson, 1966; Hilborn and Ledbetter, 1985; Marchal *et al.*, 2001a). Fishing power was to a large extent independent of horsepower, for gill-netters and long-liners. This result was also expected, as these gears become active when physically separated from the fishing vessel.

There was less consensus in the estimation of annual variations in fishing power provided by the three indices.

Table 4. *Continued*

Country	Fleet	Species	Index	IFP1	IFP2	IFP3(D)	IFP3(I)	IFP3(N)
EN	TBB	Cod	IFP1	1.00				
			IFP2	− 0.02	1.00			
			IFP3(E)	− 0.12	− 0.47	1.00		
			IFP3(I)	0.13	− 0.67	0.60	1.00	
		Plaice	IFP1	1.00				
			IFP2	0.08	1.00			
			IFP3(E)	0.43	0.07	1.00		
			IFP3(I)	0.34	− 0.05	− 0.08	1.00	
		Sole	IFP1	1.00				
			IFP2	− 0.33	1.00			
	GN	Cod	IFP1	1.00				
			IFP2	0.64	1.00			
			IFP3(E)	0.39	− 0.09	1.00		
			IFP3(I)	0.41	0.42	0.22	1.00	
		Plaice	IFP1	1.00				
			IFP2	0.44	1.00			
			IFP3(E)	0.08	0.16	1.00		
			IFP3(I)	0.20	− 0.08	0.54	1.00	
		Sole	IFP1	1.00				
			IFP2	0.38	1.00			
	OTB	Cod	IFP1	1.00				
			IFP2	0.82	1.00			
			IFP3(E)	− 0.02	− 0.14	1.00		
			IFP3(I)	0.57	0.56	− 0.07	1.00	
		Plaice	IFP1	1.00				
			IFP2	0.77	1.00			
			IFP3(E)	0.19	− 0.23	1.00		
			IFP3(I)	0.17	− 0.09	− 0.10	1.00	
NO	OTB⟨0–1000 HP⟩	Haddock	IFP1	1.00				
			IFP3(I)	0.05		1.00		
		Saithe	IFP1	1.00				
			IFP3(N)	0.43			1.00	
	OTB⟨1000–2000 HP⟩	Cod	IFP1	1.00				
			IFP2	0.34	1.00			
			IFP3(I)	0.63	− 0.22	1.00		
		Haddock	IFP1	1.00				
			IFP2	− 0.01	1.00			
			IFP3(I)	0.71	0.24	1.00		
		Saithe	IFP1	1.00				
			IFP2	0.44	1.00			
			IFP3(N)	0.48	0.51		1.00	
	OTB⟨2000 + HP⟩	Cod	IFP1	1.00				
			IFP2	0.54	1.00			
			IFP3(I)	0.52	0.37	1.00		
		Haddock	IFP1	1.00				
			IFP2	− 0.12	1.00			
			IFP3(I)	0.53	0.27	1.00		
		Saithe	IFP1	1.00				
			IFP2	0.40	1.00			
			IFP3(N)	0.81	0.41		1.00	

As a result, a selection of the most relevant indices had to be made on the basis of the statistical properties associated to the outputs of the GLMs (i.e. R-squares, correlation between residuals and predicted values). Some important features are highlighted.

First, there are examples where fishing power has consistently increased over the period of investigation, in relation to all the species being harvested (e.g. Danish seiners harvesting cod and plaice over 1987–1998, Norwegian long-liners harvesting cod, haddock and saithe over period 1980–1998, Norwegian medium and large otter-trawlers harvesting cod, haddock and saithe over period 1980–1992). This overall development in fishing efficiency could be due to one or more of the following factors: decommissioning of less efficient vessels, admission of newer vessels in the fishery, modernization of existing vessels and increased experience and knowledge among the fishermen.

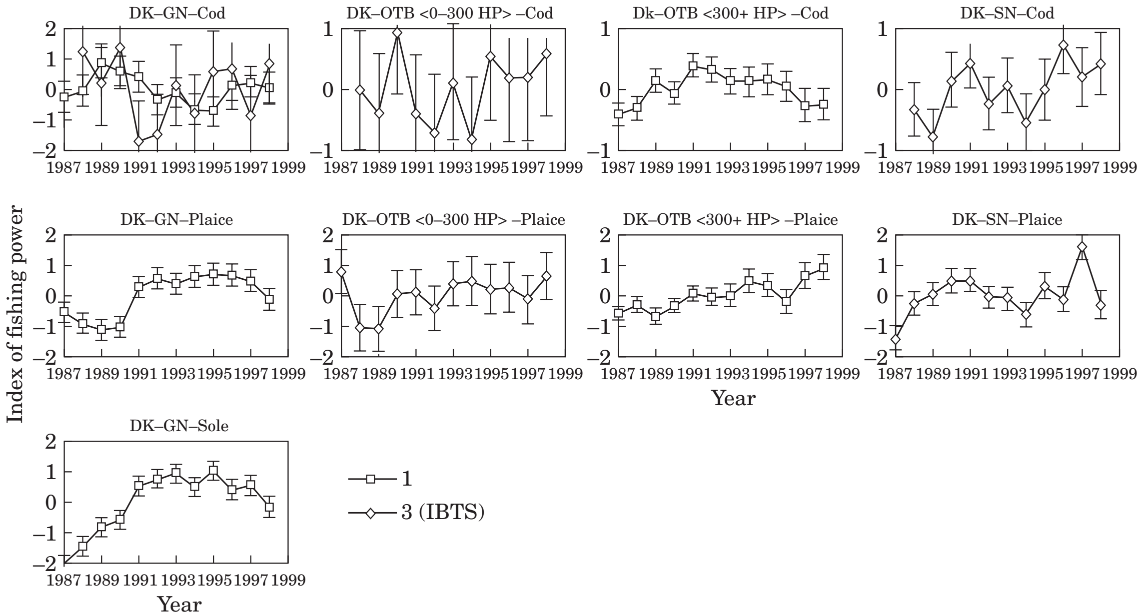

Figure 5. Annual variations of the annual component (β_y) of the Indices of Fishing Power, scaled to average over years, of the Danish fleets. The β_y-coefficients are derived from the different methods being investigated [1: IFP1; 2: IFP2; 3("survey"): IFP3("survey")], applying model 3. Error bars have also been represented.

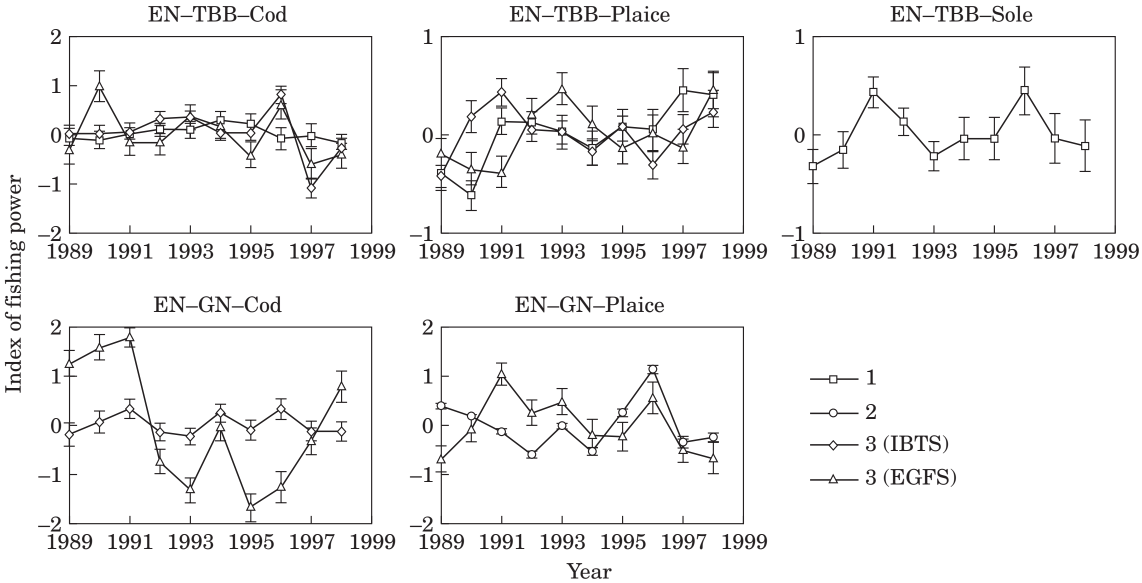

Figure 6. Annual variations of the annual component (β_y) of the Indices of Fishing Power, scaled to average over years, of the English fleets. The β_y-coefficients are derived from the different methods being investigated [1: IFP1; 2: IFP2; 3("survey"): IFP3("survey")], applying model 3. Error bars have also been represented.

Second, there are examples where fishing power has increased relative to one species, and stagnated or even decreased in relation to another one. In the context of mixed-species fisheries, this feature might reveal a shift in fishing tactics, which could possibly be driven by, (i) the scarcity of the resource (e.g. North Sea cod in the North Sea) or, (ii) searching for the most valuable species or, (iii) shifts in management regimes. The first fishing pattern (i) is exemplified by the Danish gill-netters, which have apparently switched target species from cod to plaice. The second fishing pattern (ii) might explain why Dutch beam-trawlers have switched

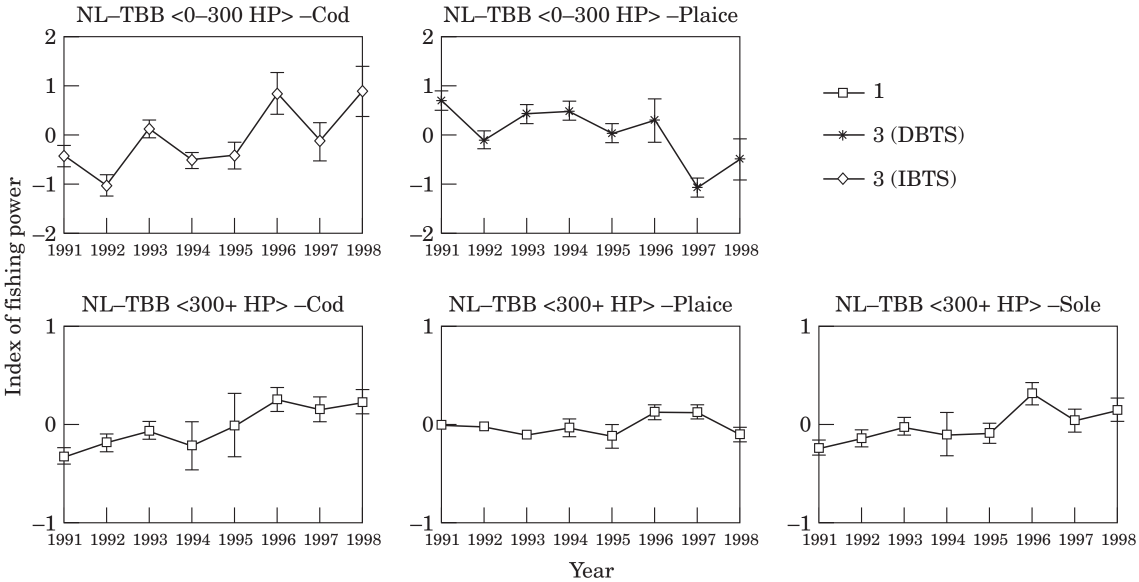

Figure 7. Annual variations of the annual component (β_y) of the Indices of Fishing Power, scaled to average over years, of the Dutch fleets. The β_y-coefficients are derived from the different methods being investigated [1: IFP1; 2: IFP2; 3("survey"): IFP3("survey")], applying model 3. Error bars have also been represented.

from fishing medium-valued plaice to fishing high-valued sole. Fishing pattern (ii) might also explain why the Norwegian gill-netters and small otter-trawlers have apparently switched from cod to saithe fishing since 1992, as a result of higher increases in prices for saithe relative to cod through that period. The third fishing pattern (iii) might explain the dramatic increase in fishing power estimated for the Danish gill-netters fishing for plaice and sole. This fleet is made up of small vessels, which to a large extent fish inside the "Plaice Box", an exclusive fishing area where fishing has been prohibited to towed-gear vessels exceeding 300 HP since 1989 (ICES, 1999b). In this context, these gill-netters might have taken advantage of the decreasing competitive interactions with larger trawlers (Rijnsdorp *et al.*, 2000a,b). Such an increase in fishing power was not observed for the Dutch small otter-trawlers (with horsepower lower than 300 HP) and the English gill-netters, which could result from these fleets operating partially or entirely outside the Plaice Box.

Third, there are examples where no clear conclusion could be drawn, because of inconsistencies across indices (Danish and English gill-netters harvesting cod), or because the signal was too noisy to detect a clear trend (Norwegian large otter-trawlers harvesting haddock), or simply because the time series could not easily be interpreted (English beam-trawlers harvesting sole, Dutch beam-trawlers fishing cod). The inconsistencies across indices of fishing power and the poor statistical properties of some GLM outputs are likely due to violations of some of the assumptions underlying each estimation method.

The three methods have six assumptions in common: (A1) fish accessibility varies without trends over time, (A2) vessels belonging to the same fleet have the same accessibility to the resource, (A3) fishing power is space invariant, (A4) seasonal variations in fishing power are negligible compared to annual variations in fishing power, (A5) fishing capacity is entirely driven by horsepower and, (A6) the fishing efficiency of vessels belonging to the same fleet and having the same horsepower is log-normally distributed across vessels.

Assumption (A1) may neither be validated, nor invalidated, in the absence of accurate survey data. The validity of assumption (A2) is a matter of how well fishing fleets have been identified. In this study, fleets have typically been defined as a combination of gear and horsepower category. Factors influencing the gear selectivity, such as mesh size for trawlers and netters have not been accounted for, although vessels with different mesh sizes are unlikely to have the same accessibility to the resource. However, the mesh size of the fleets fishing in the North Sea, including those under examination, is restricted by law (Marchal *et al.*, 2001b). Thus, the mesh size of any otter-trawler or Danish seiner fishing in the North Sea must be above 100 mm. The same mesh size limit applies to beam-trawlers targeting flatfish in the Northern part of the North Sea (mainly the English vessels), but those fishing in the Southern part of the North Sea (mainly the Dutch vessels) may use a mesh

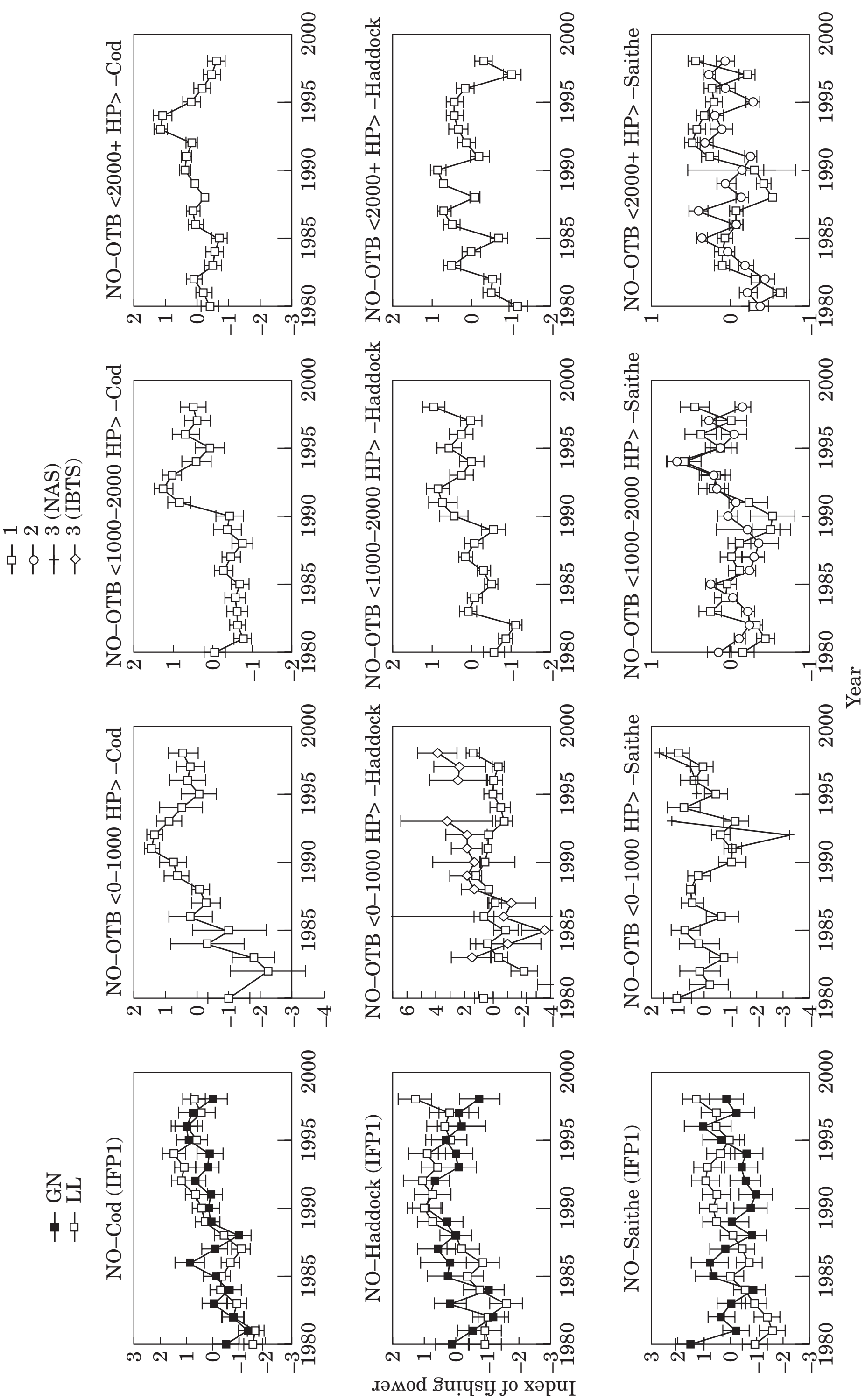

Figure 8. Annual variations of the annual component (β_y) of the Indices of Fishing Power, scaled to average over years, of the Norwegian fleets. The β_y-coefficients are derived from the different methods being investigated [1: IFP1; 2: IFP2; 3("survey"): IFP3("survey")], applying model 3. Error bars have also been represented.

Table 5. F-test operated to check the significance of the annual effects (β_y) in IFP1, IFP2, and IFP3, as derived from model 3. IFP3 is calculated using different survey data (IBTS, EGFS, DBTS or NAS). If (Prob. <0.05), the annual variations in fishing power are significant at the 5% statistical threshold.

IFP_x	Country	Fleet	Species	F	Prob.	No. obs.	R-Square
IFP1	DK	GN	Cod	8.90	0.00	3 013	0.16
			Plaice	51.26	0.00	3 006	0.17
			Sole	54.55	0.00	2 789	0.18
		OTB⟨300+HP⟩	Cod	5.23	0.00	1 584	0.11
			Plaice	3.97	0.00	1 492	0.15
	EN	TBB	Cod	129.40	0.00	14 065	0.18
			Plaice	234.31	0.00	17 104	0.56
			Sole	75.52	0.00	12 212	0.08
	NL	TBB⟨300+HP⟩	Cod	26.53	0.00	1 580	0.12
			Plaice	15.45	0.00	1 562	0.41
			Sole	36.69	0.00	1 553	0.35
	NO	GN	Cod	4.94	0.00	780	0.15
			Haddock	3.70	0.00	501	0.13
			Saithe	3.64	0.00	783	0.10
		LL	Cod	17.13	0.00	920	0.26
			Haddock	13.60	0.00	801	0.25
			Saithe	13.16	0.00	859	0.22
		OTB⟨0–1000 HP⟩	Cod	3.61	0.00	142	0.32
			Haddock	1.92	0.02	137	0.26
			Saithe	4.42	0.00	153	0.47
		OTB⟨1000–2000 HP⟩	Cod	7.32	0.00	382	0.26
			Haddock	6.02	0.00	365	0.23
			Saithe	3.56	0.00	398	0.16
		OTB⟨2000+HP⟩	Cod	4.82	0.00	352	0.25
			Haddock	9.64	0.00	340	0.35
			Saithe	16.71	0.00	357	0.47
IFP2	EN	GN	Plaice	5.13	0.00	631	0.14
	NO	OTB⟨1000–2000 HP⟩	Saithe	5.80	0.00	1 178	0.12
		OTB⟨2000+HP⟩	Saithe	11.82	0.00	992	0.22
IFP3 (IBTS)	DK	GN	Cod	54.11	0.00	6 467	0.20
		OTB⟨0–300 HP⟩	Cod	4.61	0.00	405	0.32
			Plaice	7.54	0.00	470	0.37
		SDN	Cod	12.80	0.00	2 875	0.17
			Plaice	53.44	0.00	3 211	0.36
	EN	TBB	Cod	18.19	0.00	1 738	0.34
			Plaice	7.14	0.00	1 733	0.41
		GN	Cod	6.00	0.00	1 118	0.57
	NL	TBB⟨0–300 HP⟩	Cod	33.66	0.00	2 303	0.22
	NO	OTB⟨1000–2000 HP⟩	Haddock	8.54	0.00	613	0.30
IFP3 (EGFS)	EN	TBB	Cod	5.98	0.00	894	0.47
			Plaice	7.05	0.00	974	0.3
		GN	Cod	31.33	0.00	480	0.68
			Plaice	3.61	0.00	227	0.44
IFP3 (DBTS)	NL	TBB⟨0–300 HP⟩	Plaice	79.36	0.00	2 463	0.27
IFP3 (NAS)	NO	OTB⟨0–1000 HP⟩	Saithe	8.22	0.00	194	0.56

size included in the range 80–100 mm. The mesh size limit applicable to gill-netters is of 120 mm. Although there are a few exemptions to the main regulation (industrial, *Nephrops* or shrimp fishing), these are not applicable to the fleets and vessels selected in this study. While the mesh size of the fleets is bounded downwards to comply with legislation, it is also bounded upwards, for economic reasons. Therefore, it is not unreasonable to assume that fishermen from the same country, harvesting the same species, using the same gear, use a mesh size close to the limit imposed by the legislation and hence have comparable accessibility to the resource. Assumptions (A3) and (A4) are not critical in this study. This is because seasonal and spatial effects, irrespective of their origin, have been cancelled out in the analyses, in order to emphasize the horsepower and the year effects associated to the vessels dynamics. Assumption (A5) is not unreasonable, since fishing capacity is determined by a number of static vessel attributes including vessel length, gross tonnage, storage capacities, which are generally well correlated with horsepower (Smith and Hanna, 1990; Chifamba, 1995). Other vessel

Table 6. Annual trend (φ_1, φ_2, φ_3) in the Indices of Fishing Power derived from model 4. Non-significant trends (5% risk) are set to 0. IFP3(D), IFP3(E), IFP3(I), and IFP3(N) respectively represent IFP3 calculated using the DBTS, EGFS, IBTS, and NAS survey data.

Country	Fleet	Species	IFP1	IFP2	IFP3(D)	IFP3(E)	IFP3(I)	IFP3(N)
DK	GN	Cod	− 2%				2%	
		Plaice	17%					
		Sole	27%					
	OTB⟨0–300 HP⟩	Cod					0%	
		Plaice					0%	
	OTB⟨300+HP⟩	Cod	4%					
		Plaice	12%					
	SN	Cod					9%	
		Plaice					13%	
EN	TBB	Cod	− 12%			0%	− 4%	
		Plaice	0%			5%	0%	
		Sole	0%					
	GN	Cod				− 19%	0%	
		Plaice		0%		0%		
NL	TBB⟨0–300 HP⟩	Cod					22%	
		Plaice			− 16%			
	TBB⟨300+HP⟩	Cod	8%					
		Plaice	0%					
		Sole	6%					
NO	GN	Cod	10%					
		Haddock	6%					
		Saithe (80–98)	− 4%					
		Saithe (91–98)	18%					
	LL	Cod	18%					
		Haddock	15%					
		Saithe (80–98)	15%					
		Saithe (91–98)	0%					
	OTB⟨0–1000 HP⟩	Cod	11%					
		Haddock	0%				39%	
		Saithe (80–98)	0%					
		Saithe (91–98)	20%					44%
	OTB⟨1000–2000 HP⟩	Cod	10%					
		Haddock	8%					
		Saithe (80–98)	3%	2%				
		Saithe	(91–98)	0%	− 3%			
	OTB⟨2000+HP⟩	Cod	3%					
		Haddock	0%					
		Saithe (80–98)	4%	2%				
		Saithe (91–98)	− 4%	6%				

attributes such as vessel age, which could affect fishing power, are independent of horsepower. However, the dynamic nature of the age of a vessel leads to consider it as a component of fishing efficiency rather than fishing capacity. Assumption (A6) may only be checked through harbour enquiries. In the absence of such investigations, it does not appear unreasonable to assume that, while most fishermen have an average efficiency, a minority of them performs either outstandingly or poorly.

The characteristic assumption underlying method 1 is that fishing mortality estimates found in ICES (1999a) are valid. Fishing mortality estimates from ICES (1999a) are subject to the hypothesis of constant catchability for the recruited ages. No dramatic retrospective patterns were identified in the fishing mortality trajectories calculated by ICES (1999a) for the stocks under investigation, suggesting that the estimates were not much sensitive to the assumption of constant catchability. However, the most recent values of fishing mortality, i.e. values belonging to the non-converged part of the XSA, should always be treated with caution, as these values could, to an unknown extent, be re-evaluated as a result of updated assessments.

The characteristic assumption underlying method 2 is that the variations in catchability in the reference set of vessels are sufficiently low to be neglected. The key to the analysis is the identification of a reference set of vessels for which catchability has remained stable over time. Strictly speaking in practice, due to the very dynamic character of fishery systems, such a set of vessels is unlikely to exist. This is in fact a key issue for this method but also for any other method based on comparisons.

The characteristic assumption underlying method 3 is that the fishing power of research surveys is constant over time. This is a basic assumption underlying most survey programs. However, a major drawback of research surveys is the high variability of stock abundance indices (Helser and Hayes, 1994). Such variability may be due to heterogeneous spatial distribution (Byrne *et al*., 1981), which could be a problem if the survey does not cover the complete stock range. Also, variability may occur as a result of year-to-year changes in the gear's catchability. As a result, the hypothesis of constant fishing power could occasionally be at fault.

Despite these limitations, this study supplies three methods that could be used to examine trends in fishing power. Beside the specific assumptions they are subject to, these methods have contrasted merits. Thus, methods 2 and 3 make use of the most desegregated spatial and possibly seasonal CPUE data available, while method 1 cannot take such information into account. The volume of data available to apply methods 2 and 3 is hence substantially larger than for method 1. Nevertheless, method 1 is more generic than methods 2 and 3, and it may be used in cases where no survey data are available or where no reference vessels may be found. Compared to method 2, method 3 has the advantage of including external survey data on stock indices. Method 2 is more generic than method 3 as it only requires catch and effort data, its main limitation being that it may not be applied if a set of reference vessels of stable fishing power does not exist. Using these three methods, it has here been possible to get better insights into historical developments of fishing power and also fishing tactics for a number of important fisheries of the North Sea.

This study could be expanded in three ways. First, independent data should be collected through research surveys or harbour enquiries so as to examine the validity of the various assumptions underlying the estimation of the three indices of fishing power. Second, the same data sets could be explored using GAMs (Generalized Additive Models) as an alternative to GLMs (Generalized Linear Models). An important limitation of Generalized Linear Models is that the predictor (here the index of fishing power) is assumedly a linear function of the parameters in the model. The significant correlation observed between residuals and predicted values derived from a number of GLMs applied in this study suggest that this assumption may occasionally be at fault. In such cases, the Generalized Additive Model would extend the analytical possibilities of the GLM, by fitting non-parametric functions between the response and the predictors. Third, in order to better understand its mechanisms, fishing efficiency creeping should be contrasted to additional sources of information relative to equipment on-board, skipper's skill, but also market conditions and management regulations.

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