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Management challenges from technological development in commercial fisheries

Ole Ritzau Eigaard

Thesis
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Propositions

1) Efficiency increases due to technological development undermines the idea of a broad-based effort regulation as a means of achieving biological sustainability of European fisheries (contra Shepherd, J.G., 2003. Fish. Res. 63, 149–153). (This thesis).

2) In not so many years, fuel costs, climate impact of CO2 emissions and environmental protection demands will lead to a complete restructuring of the European fishing fleet. In this process the technological development of more energy efficient and environmentally and economically sustainable fishing methods is a key element. (This thesis)

3) The increasing focus on publication and citation frequency has narrowed the motivation of scientific work, inflated the peer review process, and resulted in an overproduction of information (low-novelty, redundant and poorly scientifically founded information).

4) There is a conspicuous mismatch between the current high production rate of specialised scientists (PhDs) and the number of research positions at public and private institutes and companies.

5) Fishing inevitably affects the marine ecosystem. If society wants to utilise the biological productivity of our oceans, we have to accept that humans are part of the ecosystem. Management should be science based and focus on balancing fishing yield with ecosystem and socio-economic objectives.

6) The increasing political regulation and evaluation of science for its immediate economic value (e.g. the official dogma of the Danish Ministry of Science, Technology and Innovation: “From research to invoice”) undermines the role of Universities as producers of political independent knowledge and expertise, which is essential for execution, development and preservation of democracy.

Propositions belonging to the thesis, entitled

“Management challenges from technological development in commercial fisheries”

Ole Ritzau Eigaard
Wageningen, 8 October 2010

Contents

Chapter 1

General Introduction

Background

The current management of European fisheries does not comply with the objectives of the European Union's Common Fisheries Policy (CFP). Many fish stocks are overexploited, several species are endangered, and considerable overcapacity exists (Sissenwine and Symes, 2007; EC, 2008a; FAO, 2009). In response, the European Union is presently reviewing the Common Fisheries Policy. This policy has mainly been based on setting restrictive stock-based TACs (Total Allowable Catches) to control harvest rate, and on decommissioning schemes to reduce the overcapacity (EC, 2002). Yet, the CFP has led to a continued growth in effective harvest capacity and an increased pressure on fish stocks (Figure 1). One of the reasons for the limited success of the CFP so far is that its main instruments – TAC regulations, structural measures and, more recently, effort regulations – are all vulnerable to changes in the technical efficiency of the commercial fishing fleet (Ulrich *et al.*, 2002; Kirkley *et al.*, 2004; Stefansson and Rosenberg, 2005).

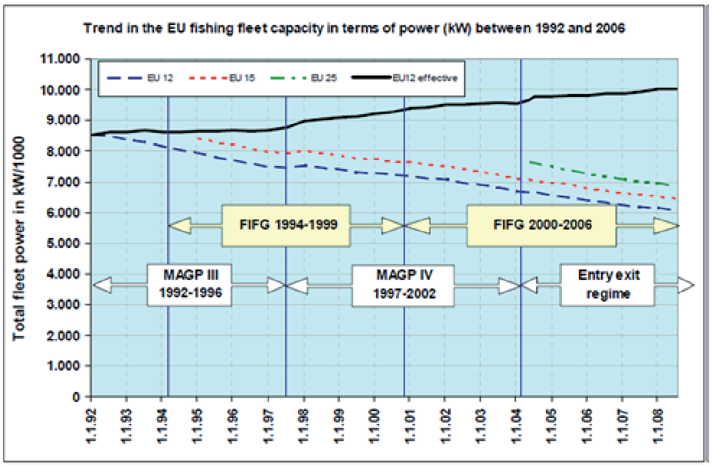

Figure 1. The development of nominal capacity (kW installed engine power) of European fishing fleets since 1992. Capacity related policies of the period [Financial Instruments for Fisheries Guidance (FIFGs) and Multi Annual Guidance Plans (MAGPs) and the entry exit regime] are indicated. The estimated effective harvest capacity of the EU 12 fleet under the assumption of an annual 3% increase in efficiency from technological development is shown with a solid line (EC, 2008a)

An input-oriented fisheries policy based on control of harvesting capacity through simply regulating numbers of vessels, their size and their activity (e.g. days of fishing) can only control these measurable physical inputs (nominal effort). It cannot capture the ongoing advances in vessel productivity through changes in the 'non-measurable' or 'non-physical' inputs of technical efficiency (Pascoe *et al.*, 2001a). Increases in technical efficiency, which in its essence is composed of i) technological development of gears and vessel equipment and ii) changes in fishermen behaviour (Figure 2), may as such counter-balance reductions in vessel numbers and nominal vessel activity. Moreover, vessels leaving the fleet through capacity reduction schemes are often the oldest, the least technologically developed and efficient, or are in the process of being taken out of the active fleet in any case (Pascoe and Coglan, 2000; Standal, 2005), which also undermines the intended capacity reductions, as illustrated by the European Commission in Figure 1.

An output-oriented policy based on Total Allowable Catches is typically defined from biological reference points, which in turn rely on scientific stock assessments. Changes in technical efficiency break the assumption of a linear and constant relation between catch rate and resource abundance with time, which is an important element of stock assessments (Beverton and Holt, 1957; Hilborn and Walters, 1992; Branch *et al.*, 2006). Consequently, TAC management relying on scientific stock advice is also impeded by changes in technical efficiency. It therefore seems a prerequisite of a successful CFP revision - and of any biological and economic sustainable resource management policy - that the issue of technical efficiency is explicitly addressed and taken into account.

This PhD thesis is focusing on the first component of technical efficiency (or non-measurable input) in commercial fisheries, the technological development, whereas fishermen behaviour (e.g. changed fishing practices in response to regulations, price conditions or resource availability), which can also have an appreciable impact on catch efficiency (Charles, 1995; Squires and Kirkley, 1999; Marchal *et al.*, 2006), is only treated rudimentary. Likewise technical interactions among various fleet segments are only treated briefly, although these are also important to integrate in management (Rijnsdorp *et al.*, 2000; Ulrich, *et al.*, 2001; Ulrich *et al.*, 2002). The economic, sociological, and regulatory drivers of technological development (and of fishermen behaviour) are important mechanisms when it comes to understanding the patterns of technology spread in the commercial fleet and perhaps even more so, when it comes to establishing efficient management measures to mitigate the effect of technological development (Figure 2). Therefore the drivers of technological development are given some attention in the thesis, within the above mentioned two contexts, but a thorough investigation of technological drivers has not been the objective. The main subject of the thesis is the understanding of technological development in commercial fisheries. Special attention is given to its influence on catch efficiency of vessels and the implications hereof for a sustainable management of fisheries and fish resources.

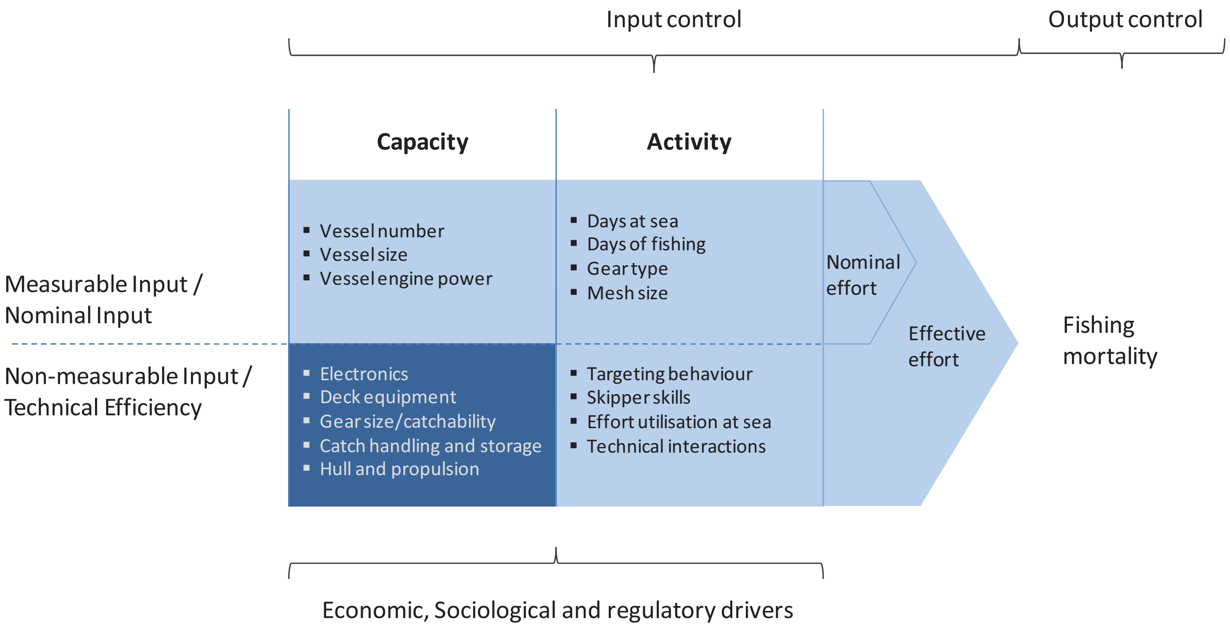

Figure 2. The main components and mechanisms of the European fisheries and management system as conceived and treated in the following. The non-measurable capacity input to the fisheries system [technological development (highlighted in a darker blue)] and its influence on vessel and fleet fishing mortality is the component in focus of this PhD thesis.

Technological development, Fishing mortality and Fisheries management

Commercial fisheries constantly introduce technology to keep pace with developments worldwide. This is essential for them to remain competitive and to take advantage of updates to equipment, which can increase fishing success, decrease costs, aid navigation, raise catch quality or price, and improve safety at sea (Hilborn and Sibert, 1988; Valdemarsen, 2001; Tietze *et al.*, 2005). Although continuous, the technological development in commercial fisheries is a complex process with many patterns and drivers of technology introduction and with heterogeneous and occasionally contradictory effects on catchability and fishing mortality. Although it is broadly accepted that there is technological development (often referred to as technological creep) and that this development complicates sustainable management of commercial fisheries (e.g. Cunningham and Whitmarsh, 1980; Marchal *et al.*, 2002; Standal, 2005), relatively little is known and documented of the process. Consequently, the implications for achieving a more sustainable fisheries management through the integration of technological development are not straightforward. In the following the intention is to meet this need by deploying a bottom-up approach, where a description of the technology itself and its temporal and structural introduction patterns is the starting point for analysing its effects on catchability and fishing mortality, before the implications for improving current fisheries management are discussed.

The main concepts and mechanisms of technological development, its drivers and its relation to fishing mortality and fisheries management are introduced below, before the methodology, the scope and the objective of the PhD thesis are given.

The development of technology in commercial fisheries

Within fisheries biology the development of technologies is often divided into two groups or typologies *a priori* to establishing their effect on catch efficiency (e.g. Rahikainen and Kuikka, 2002; Marchal *et al.*, 2007). Technological development includes both larger marked investments in new technology on board the individual vessels (e.g. the purchase of sonar, gear sensors or new navigation systems such as the Global positioning system [GPS]) as well as gradual improvements to the existing vessel technology or gear (e.g. netting materials, the design of trawl panels, hook and long line designs or deck equipment and its arrangement). This perception of a bifurcate process is also found in the economic literature - although at a more general (fleet) level - where technological change in fisheries is considered an irregular and in many cases specialized process operating in two modes: radical (breakthroughs in competing types of technology) and normal (proceeding incrementally through accumulated experience and positive feedback loops). Examples of radical technological change in fisheries is the introduction of purse seining in the 1970s in the UK herring fisheries and the introduction of beam trawls and tickler chains in the Dutch fishery for flatfish in the 1960s, which both had substantial effects on catch efficiency (Whitmarsh, 1990; Whitmarsh *et al.*, 1995; Rijnsdorp *et al.*, 2008). Either type of development described above can - but does not necessarily - result in an instant and significant change of efficiency in vessel level or they can result in smaller stepwise improvements, which in themselves do not result in marked changes in efficiency but in combination can cause a noticeable increase in vessel harvesting capacity with time (e.g. the improved utilisation of time at sea for the Danish Seiners illustrated in Figure 8, page 8).

Introduction patterns in fleet level

Apparently the concept of a bifurcate process of technology development in the commercial fishery is well accepted in both biological and economic sciences. The next question is then, how the technology, once developed, is disseminated in fleet level. Vessel size is shown to determine the speed of uptake and the technological level of electronics on board commercial fishing vessels (chapter 2), the larger the vessel the faster the uptake as illustrated by the dissemination (or spread) of GPS technology in the Danish fleet during the 1980s and 90s (Figure 3).

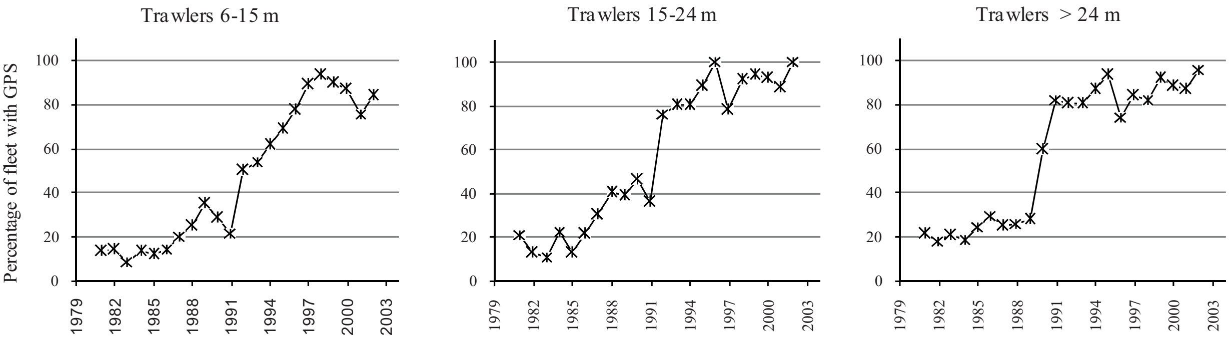

Figure 3. Diffusion rate of GPS navigation equipment by vessel size groups in the Danish otter trawler fleet in the period 1980 to 2002. The figure is based on observations from an official equipment database holding a large subsample (~ 12%) of all Danish otter trawlers actively fishing between 1981 and 2002)

Not only vessel size but also vessel type determines the speed and extent of radical technological introductions in commercial fisheries. In the Danish fleet, sonars are clearly a technology investment that is assessed profitable and worthwhile mainly by larger vessels and more so by gill netters than by trawlers (Figure 4). Such investment differences by vessel type and size exist for a range of electronic equipments (chapter 2) and no doubt reflects that commercial vessels have very heterogeneous fishing patterns with respect to gear types, target species and fishing areas and that a certain a turnover/vessel size is a prerequisite for investments in new radical technologies being economically rational.

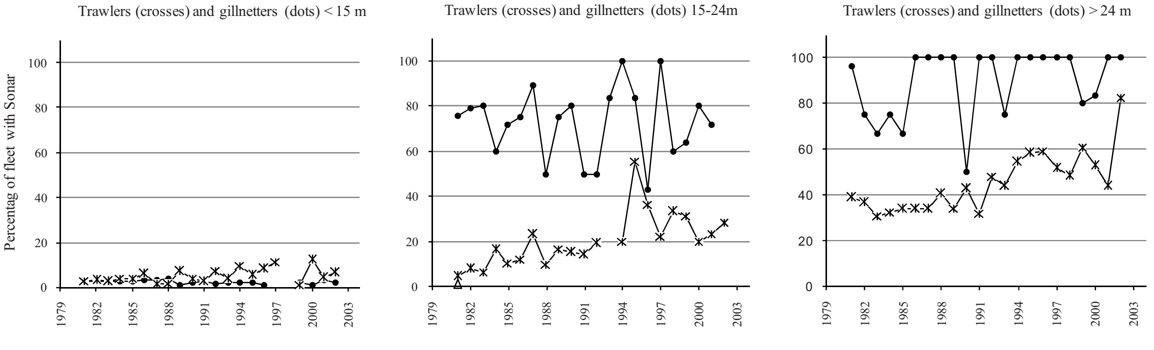

Figure 4. Prevalence and diffusion rate of sonar equipment by vessel type and size groups in the Danish otter trawler and gill netter fleet in the period 1980 to 2002. The figure is based on observations from an official equipment database holding a large subsample (~ 12%) of all Danish gill netters and otter trawlers actively fishing between 1981 and 2002.

The differences in dissemination patterns between vessel types and sizes is probably less pronounced when it comes to gradual/normal technological developments, as these are often less costly and thus more likely to be considered profitable also with moderate turnovers typical of smaller fishing vessels. Regardless of technology development mode, these structural differences in the speed of uptake and the dissemination level of new technology do, however, underpin the fact that integrating structural and temporal technological development in fisheries management is not a trivial task.

Drivers of technological development

Before attempting to identify and quantify the biological effects of technological development in commercial fisheries, it is useful to understand the many different technological vessel acquirements in an economic context. Put simply, fishermen have three basic options to become more economically viable: i) to increase revenue by catching more fish, ii) to increase revenue by raising the value of the catch, and iii) to reduce the costs of fishing. Practically all technological investments can be interpreted in this basic economic context.

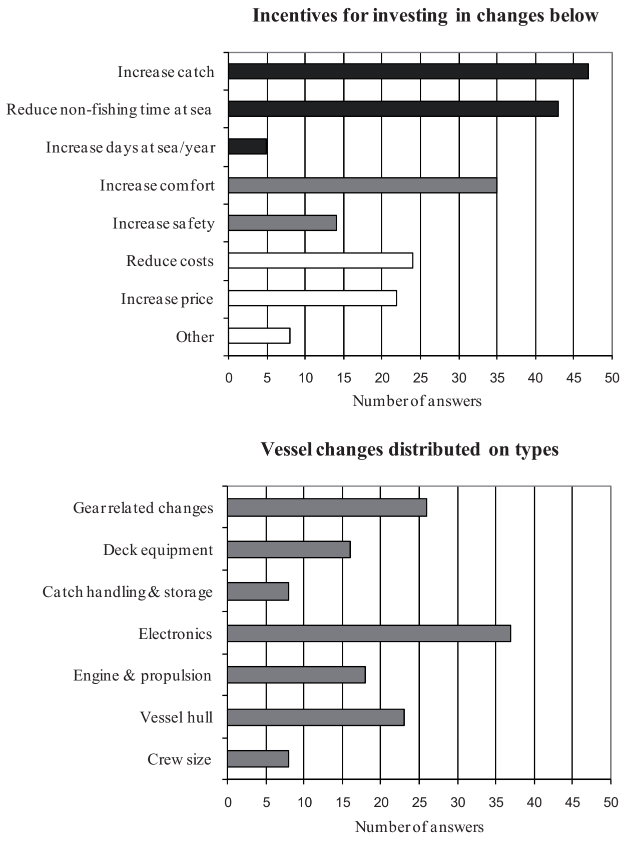

Figure 5. The incentives (top) and areas (bottom) of technological investment as informed in skipper interviews with a ~10% subsample of the Danish demersal trawler and gill netter fleet. The presumed effect on fishing mortality, stated as incentive by the fishermen, is indicated through the bar colour in the top figure, F+ (black bars), Fo (grey bars) and F- (white bars).

In the Danish demersal trawler and gillnetter fleet the most frequent motivation (and presumably also the most frequent result) of technological adoptions by commercial fishing vessels is catch increase (F+ type investments). However, catch neutral (Fo) investments in safety and comfort are not infrequent, and also potential catch negative (f-) investments to reduce costs or increase fish price (e.g. equipment for catch processing at sea) are relatively common (Figure 5, top). The areas of investment are mainly related to gears and electronics (Figure 5, bottom). Presumably, main incentives and investment types vary somewhat with time according to regulations in force. For instance it has been demonstrated in the Faroese pair trawl fishery that a regime shift from TAC control to effort regulation induced a 50% increase in saithe catches per day. This was achieved by replacing older vessels with modern ones of same nominal capacity, which enabled increases in towing speed, towing time and ultimately swept area per day (Thomsen, 2005).

Biological effects of technological development

Increased catch and reduction of non-fishing time at sea (F+ type investments) are the main incentives for technological development on board Danish commercial fishing vessels (Figure 5, top). Both primary incentives indicate that the vessels prefer technologies, which influence catch efficiency on the trip level. The catch of a fishing operation can be viewed as depending on 3 terms that all are subject to optimization: Catch = q * Density * Effort utilisation, “q” is here the catchability that can be associated with the vessel, the “density” term acknowledges that fishers seek particular grounds with high abundance of fish, and the “Effort utilisation” term designates the proportion of the trip that is actually used for fishing.

The vessel catchability term “q” is typically influenced by technological improvements of the gear deployed. An example of this is the development of the twin trawling technology, which has become a rule, rather than an exception, in many demersal fisheries during the last app. 25 years (Sainsbury, 1996; Rihan, 2005; chapter 6).

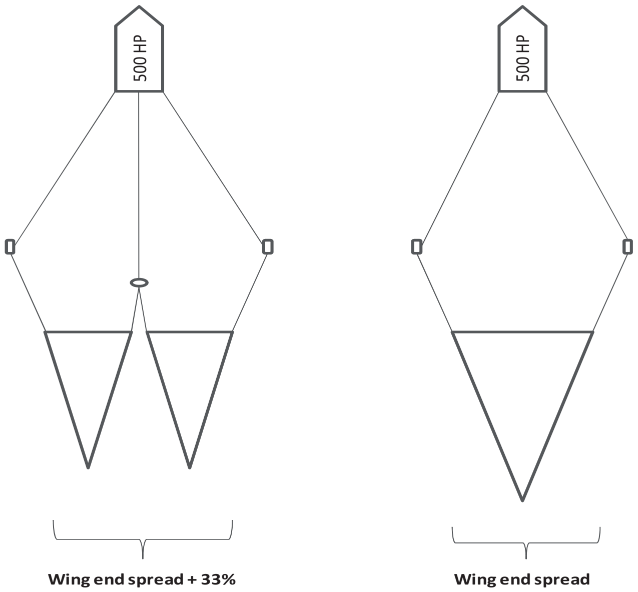

Figure 6. Increase in vessel efficiency through gear related technological development. The twin trawling technology affects catch through direct changes in the catchability (q) in terms of an app 33% increase in trawl width (Sainsbury, 1996).

Twin trawling affects catch through direct changes in the catchability (q) in terms of trawl width (Figure 6). Other gear related technological developments with influence on catchability are pelagic trawl designs (Rahikainen and Kuikka, 2002) and the use of thinner and stronger materials for trawl netting, which has enabled increasing trawl size, without equivalently increasing trawl drag resistance (chapter 5). Gill net efficiency has also improved substantially through the emergence of synthetic fibres used for thinner, stronger and more transparent filaments (Valdemarsen, 2001).

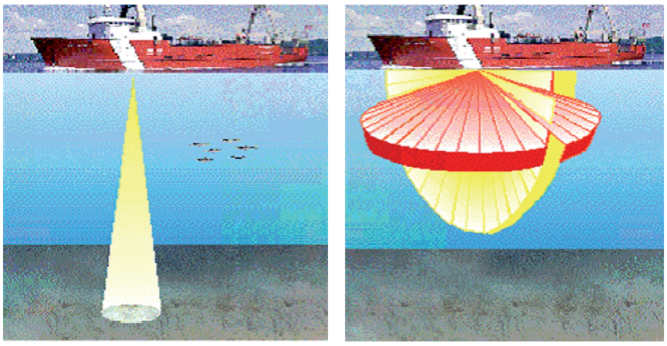

Figure 7. Indication of area prospected by echo-sounder (left) and sonar (right), when searching for fish aggregations.

The "density" term is often influenced by electronic developments. The most obvious technologies are echo-sounders and sonars which are typically used for detection of fish shoals (Figure 7). Electronics facilitate the finding of fish as well as fast and precise rediscovery of productive fishing grounds with GPS and plotters. These two electronic technologies in combination resulted in a 12% increase in vessel fishing power three years after introduction in the Australian tiger prawn fishery (Robins *et al.*, 1998). Another area where electronics have affected efficiency via the "density" term is the increased precision in manoeuvring and small scale navigation. This development makes it possible for vessels to fish in previously "not fishable" areas e.g. stone reefs and areas close to rocks and wrecks. The large uptake of sonars by the Large Danish gillnetters (Figure 4, page 5), which use the sonar for positioning their nets close to wrecks, is an example of this. New designs within trawl ground gears such as bobbins and rock hopper gears have also contributed to making this expansion of accessible fishing grounds possible.

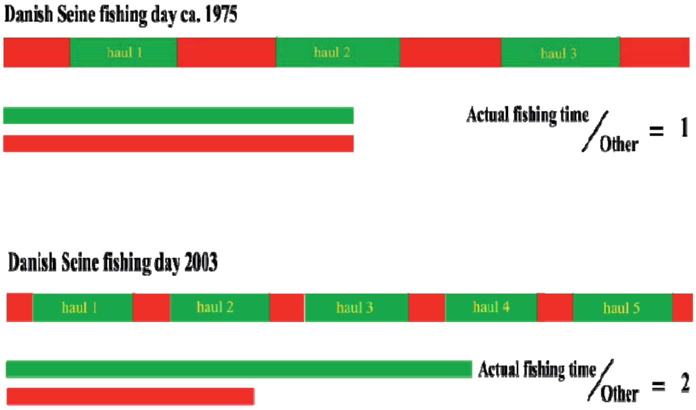

Figure 8. Illustration of how technological development on board Danish seiners has led to a substantial change in the effort utilisation at sea and consequently in catch efficiency from 1975 to 2003.

The “effort utilisation” term is typically influenced by technological development and arrangement of deck equipment such as drums and winches, but also increased durability of gears and improved electronic equipment has reduced non-fishing time at sea and increased vessel efficiency substantially with time (Rijnsdorp *et al.*, 2008; Thomsen, 2005). Anecdotal information from fishermen indicate a doubling of actual fishing time over non-fishing time in 25 years in the Danish seine fishery, owing mainly to technological development of hydraulics and seine rope winches (Figure 8).

Although the primary incentives for technological development on board fishing vessels are F+ oriented, not all technological development in commercial fishery is dedicated this purpose. Supposedly Fishing mortality neutral (Fo) motives of increasing comfort and safety are relatively widespread drivers of technological development on board demersal trawlers and gill netters (Figure 5, top). And even incentives which can be expected to result in Fishing mortality negative (F-) technological development, such as raising catch quality and price and reducing variable costs through reductions in crew size, down scaling of gear size or lowering of towing speed are not infrequent (Figure 5, top). In short, the drivers of technological development as well as the influence on fishing mortality is far from being unambiguous, which makes it clear that the integration of technological development in fisheries management cannot be completed without going into some detail with the causality of individual technologies in relation to biological effects.

Management implications of technological development

As discussed above technological development boosts vessel fishing efficiency through advances in, for example, electronic equipment (Figure 9) or gear developments (Bishop *et al.*, 2000; Mahevas *et al.*, 2004; Standal, 2005), thereby complicating efforts to balance capacity and fish resources.

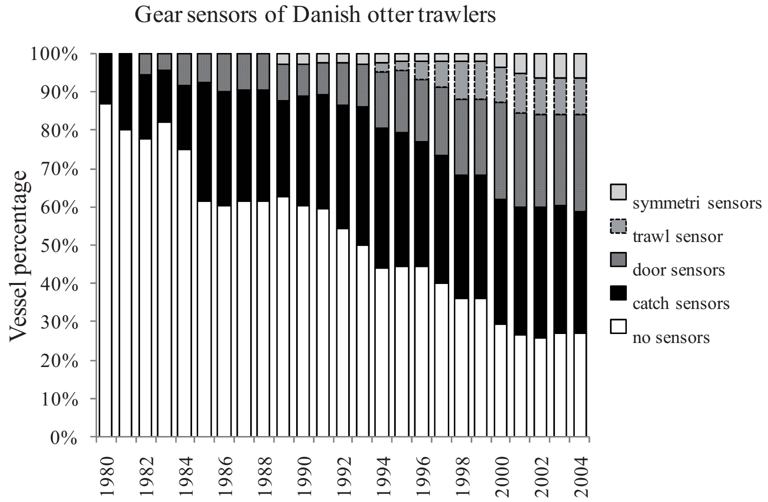

Figure 9. The appearance and prevalence of four different electronic gear sensors in the Danish trawler fleet from 1980 to 2004. The figure is based on interview data from a ~10% subsample of the demersal trawler fleet of more than 12 m length.

When vessels continuously increase their catch efficiency they break the assumption of a linear and constant relation between catch rate and resource abundance with time, which is an important element of many stock assessments

(Branch *et al.*, 2006). Often catch rate is used directly as an indicator of fishable biomass or indirectly for tuning age-based stock assessment models (Gulland, 1983; Hilborn and Walters, 1992). Therefore, the common fisheries policy, relying to a large degree on TACs founded on scientific stock advice, is also impeded by technological development.

Fisheries management is also more directly challenged by technological development when fleets and stocks are regulated through short-term input control, as with the 2002 reform of the common fisheries policy, where effort restrictions were given stronger weight (Christensen and Raakjær, 2006; Hoff and Frost, 2008). Often effort quotas are assigned to vessels as a yearly number of fishing days intended to correspond to a target share of total annual catch. However great care should be taken when defining the metric with which to manage fishing effort, as technological advances can result in nominal effort becoming more and more decoupled from effective effort (Figure 2, page 3) (Ulrich *et al.*, 2003; Stefansson and Rosenberg, 2005). In the Faroese long line fishery, which is effort regulated through yearly vessel quotas of fishing days, annual increases of app. 1.3% in number of hooks set per fishing day have taken place during the period 1986-2002 as a result of introducing and improving deck equipment and gear materials (Figure 10). This gradually increasing discrepancy between nominal and effective effort no doubt explains part of a large mismatch between intended and realized fishing mortality of the effort regulation, which has contributed to the present poor state of the Faroese cod and haddock stocks (Jákupsstovu et al, 2006; ICES, 2008).

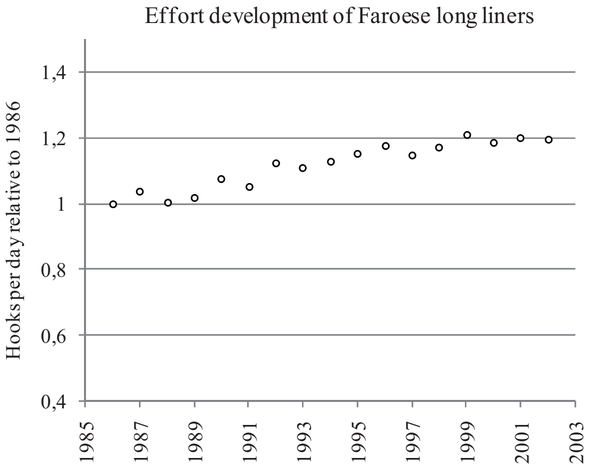

Figure 10. The development in number of hooks set per fishing day of the Faroese long line fleet from 1986 – 2002. The figure is based on logbook data from a 25 % subsample of the entire long line fleet above 110 GRT.

The problem of poor linkage between nominal and effective effort (and ultimately fishing mortality) is of general nature in the management of commercial fisheries and the identification of better effort descriptors for the many different vessel types and target species of commercial fisheries is subject to investigation worldwide (e.g. Shepherd 2003; Marchal *et al*., 2007; Rijnsdorp *et al*., 2006). Initiatives towards effort management through kilowatt days have been launched by the European Commission (EC, 2008b). Kilowatt days combine capacity and activity inputs into one measure (Figure 2), and compared to using only nominal activity to regulate fishing effort (as in the Faroese long line fishery) or to calculate cpue values for stock assessment purposes (chapter 3), the use of integrated effort measures is definitely an improvement. Logically and empirically, engine power is, however, not an appropriate descriptor of capacity in fisheries with passive gears (Pascoe *et al.*, 2001b; Marchal *et al.* 2002). Even in trawl fisheries, where engine power is strongly correlated to gear catchability and thus effective effort (chapter 3; chapter 5), this measure has potential shortcomings in that technological advances within e.g. electronics or deck equipment are not directly linked to engine power.

Also when regulating fisheries through long-term input control (capacity management), it is crucial to take account of technological development and the resulting efficiency changes. Two mechanisms of efficiency change from technological development should be considered: i) increases in individual vessel efficiency with time and ii) efficiency increases from structural (vessel composition) changes in fleets. The latter mechanism can take place through either "natural" renewal of the vessels in a fleet or through directed buy back schemes (Hatcher, 2000; Pascoe *et al.*, 2001a; Standal, 2007). In the course of many structural management plans, older, smaller vessels of a fleet are replaced with newer, larger vessels within a fixed or reduced nominal capacity limit such as total fleet tonnage or total fleet engine power. However, nominal capacity reduction in fleet level may be undermined by increases in individual fishing power of the newer and larger vessels of the restructured fleet (Figure 11) (Chapter 3; Hilborn, 1985, Pascoe and Coglan, 2000).

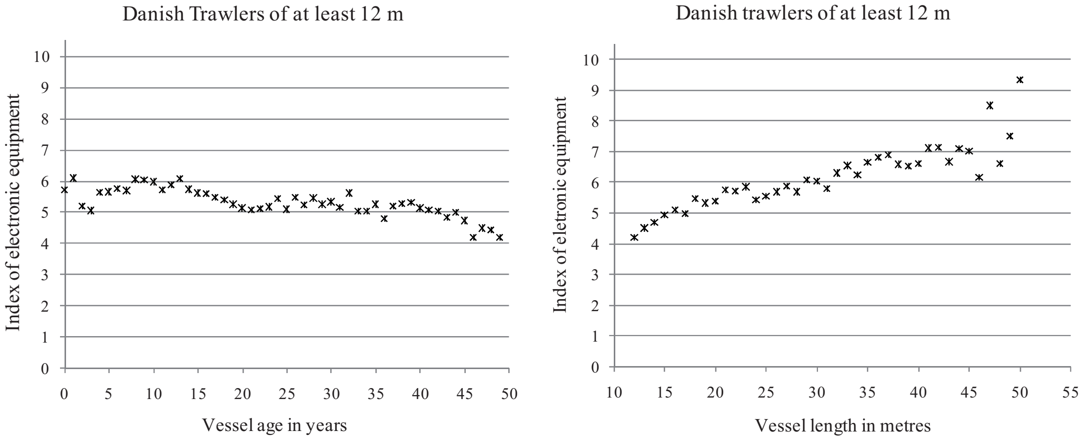

Figure 11. The variation in level of fish-finding and navigation equipment on board Danish trawlers with vessel age (left) and vessel length (right). The figure is based on observations from an official equipment database holding a large subsample (~ 12%) of Danish otter trawlers more than 12 metres actively fishing between 1981 and 2002 (Eigaard, 2009)

In general, successful Input control has been hampered by uncertainty of how to optimally define and measure capacity in fisheries. International efforts have been made (e.g. FAO, 1998; Pascoe and Gréboval, 2003; FAO, 2004) and a broadly accepted definition of capacity has been established: *the amount of fish (or fishing effort) that can be produced over a period of time (e.g. a year or a fishing season) by a vessel or a fleet if fully utilized and for a given resource condition* (FAO, 2000). However, the identification of equally broadly applicable measures of capacity, which sufficiently consider biological effects from both nominal capacity inputs and from technological development (Figure 2), has proven not to be as straightforward. Realisation of this objective is complicated by the very heterogeneous nature of fishing vessels and fishermen, their equivalent diverse effect on the resources, and the problem of non-comparable and imperfect data of fisheries (FAO, 1998; FAO, 2000; Vestergaard, 2003). At present, no successful capacity measure is broadly deployed, even in European fisheries, and the general question still remains: how to sufficiently integrate the effects of technological development into fisheries management.

The knowledge basis for integrating technological development into fisheries management

The increasing research in the area implies that the integration of technological development into fisheries management is not far away (e.g. Robins *et al.*, 1998; Pascoe, S., and Coglan, L. 2000; Marchal *et al*., 2001). However, practically all research on technological development in fisheries takes a top-down approach. Typically, catch value or catch weight is linked to capacity or effort data (including a variety of technological information) to quantify changes in production efficiency or fishing power (e.g. Marchal *et al.*, 2002; Banks *et al.*, 2002; Kirkley *et al.*, 2004). Common to most modelling approaches is that fishing technology is often dealt with in rather general terms. Also, results are very fleet- and fishery-specific, making it difficult to interpret results on a global scale. With only few exceptions (Standal, 2005; O'Neill and Leigh, 2007) technology is included in model runs with little exploratory treatment or *a priori* verification of its relevance to the catch processes under investigation. Consequently, it seems that the number of investigations linking official landing and effort data to estimate efficiency changes from technological development has grown relatively large during the latest decade, but not much empirical work on the nature of the underlying technology exists.

The reason for this unbalance between the two types of approaches is primarily the format in which the respective data exist. Where data of European fishing effort and catches are compiled in electronic databases as public registers or in national scientific databases - and as such are relatively easily retrieved and analysed on national basis - the majority of technological data exist in a far more dispersed form. Exceptions are the crudest of the technology data, such as vessel length, Gross Register Tons and engine horsepower, vintage of hull, as well as the type of gear used, which are also relatively easy to access from the above mentioned sources. Typically, information of the bulk of the technological features of the fishing vessels is not listed in any central source and is often only obtainable through sociological approaches in the form of interviews with fishermen, gear manufacturers, ship yards, suppliers of electronic equipment, etc., or through access to written data from the same type of sources (e.g. industry order books or personal skippers logbooks).

Improving the knowledge basis

The innovative aspect of this PhD project is at large the idea that the research in technological development of commercial fisheries should not be restricted by the format of which data exist. If detailed technological data is a prerequisite of understanding the dynamics of efficiency in commercial fisheries and for carrying out the subsequent policy adjustment, then these data will have to be generated by doing the empirical work necessary. The perspective is that a bottom-up approach is essential in providing the knowledge basis for successful integration of technological development into fisheries management.

Ideally, empirical technology studies covering all the different fleet segments of European Fisheries management should be made. However, procurement of the very heterogeneous technology data is extremely time consuming and requires for fisheries biologists and economists to adapt new methodologies (which is also why empirical investigations linking fishing technology to catch efficiency are currently somewhat scarce). Considering also the complexity of; the technological development itself, its dissemination patterns in the fishing fleet, its drivers, and its effects on fishing mortality, it is not realistic to establish a comprehensive knowledge platform for technological policy adjustment by applying a bottom-up approach to each and every fishery or management unit of the European (or global) fleet. Therefore the thesis results, from applying a bottom up approach to the technological development in a selection of European fleets, are also used to explore i) whether it is possible to define valid proxies of effective effort for aggregate vessel groups/fleet segments based on standard capacity and activity data, and ii) whether there is any essential capacity or activity data to add to the list of parameters monitored routinely, which will enable i). If adequate proxies can be identified, this might circumvent the necessity of broadly applying a bottom-up approach to clarify the influence of technological development on the balance between capacity and resources in European waters.

Scope and methodology

The basis of the PhD project has been the compilation of technological data from a selection of European fisheries, which cover some main principles of how technological development influences catch rates and fishing mortality. This work has been based largely on sociological approaches in the form of interviews with fishermen, gear manufacturers, ship yards, suppliers of electronic equipment, etc., as well as exploration of historical and commercial data from the same type of sources. That is, retrieval of technological data in very incompatible formats from a broad and heterogeneous set of sources and structuring the data in an operational manner. The result has been a set of very diverse technology data from five European case studies, which forms the empirical basis of this thesis - but the approaches to understanding and analysing the influence of technological development on catch rates and fishing mortality of the fleets have been based on a common bottom-up analytical framework. The backbone of the framework is a four step approach to clarifying the effects of technological development in commercial fisheries:

The first task has been to generate a detailed description of technology in the fleets investigated: what technologies have been introduced; when were they introduced; and how have they spread among the vessels of the fleet. The means of fulfilling this task has, as described in the paragraph above, been largely based on sociological approaches. The second task has been to establish the functional mode of the identified technologies: how does each new or improved technology actually influence the catch performance of a fishing vessel depending on fishing methods and target species? Again sociological methods in terms of interviewing various industry stakeholders as well as studying sales material and semi-scientific literature from e.g. flume tank experiments and commercial sea trials have been useful. The third task has been to quantify the resulting changes in catch efficiency by linking catch performance to specific technological developments that have an *a priori* established relevance to the efficiency of the fishery analysed. This has been done either i) directly, by statistically analysing merged data sets holding technology, catch and effort observations or ii) semi-directly, by validating the use of existing logbook variables as proxies for the technology feature investigated before performing statistical analyses of variations in the technology proxy and catch and effort data, and iii) indirectly, by using documented and causal relationships between the identified technologies and vessel catch performance to define an index of fishing power, before relating this index to standard vessel features. The fourth task has been to draw stock assessment and management implications from the case study quantifications, on the case study level as well as in a broader fisheries and resource management context.

Objective

The major objective of this synthesis is to throw light on the role of technological development in fisheries management by documenting and quantifying how the propagation of new technology in fisheries can complicate efforts to balance capacity and fish resources. More specifically the objective of the following six chapters is to demonstrate how technological development can complicate output control by adding uncertainty to standard stock assessment procedures, how short-term input control (in terms of effort quotas), can be undermined by technologically induced efficiency increases, which tend to progressively decouple nominal effort from effective effort, and how long-term input control (in terms of buy back schemes and other capacity control measures) is also challenged by efficiency changes from both temporal and structural technological development. Building on this, it will be explored, i) how the main instruments of current European fisheries management are best applied and supplemented in order to mitigate the efficiency increases from technological development in commercial fisheries, and ii) whether operational and valid descriptors and projections of effective capacity and effort, based on standard capacity and activity data from logbooks, can be developed for aggregate vessel groups.

Thesis Outline

Five examples of technologically induced efficiency changes are analysed and presented in this thesis, before a synthesis of the results is made. The case studies provide examples of some main principals of how technological development influences catch rates and fishing mortality for a range of fisheries (in terms of different gear types being deployed) and management contexts.

Chapter 2 describes the introduction patterns of fish-finding and navigation equipment of Danish gillnetters and otter-trawlers. This description is made possible by recent access to a national database that holds retrospective information on the uptake and removal of electronic equipment for a large subsample (~ 12%) of this fleet between 1981 and 2002. A hypothesis of a significant linkage between standard vessel characteristics and the level of electronic equipment onboard is tested positive with logistic regression analyses and the findings demonstrate that present capacity management in Europe may very well be undermined by technological development.

Chapter 3 investigates the effect of gear and engine power development on the efficiency of the Danish otter-trawlers fishing for Northern shrimp (*Pandalus borealis*). Order book information from Danish trawl manufacturers in combination with trawl geometry data from commercial flume tank tests enables integration of trawl development in the fleet from 1987 to 2008 into a cpue time series used for stock assessment purposes, thereby substantially changing the basis of advice.

Chapter 4 makes use of technological data from questionnaires and skipper interviews to identify key technologies and quantify annual effort and catchability increases in the Faroese long line fishery for cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) from 1986 to 2002. Such increases are not accounted for in the present effort regulation scheme on the Faroe Islands thus making it vulnerable to technological development.

Chapter 5 addresses the linkage between standard capacity descriptors and fishing mortality in European otter-trawl fisheries. Options for improving the linkage between capacity and fishing mortality is explored by analysing variation in trawl size depending on; target species, trawl geometry, trawling technique and engine power. The analyses are based on 206 observations from an inventory of gears recently deployed by otter-trawlers in five EU countries, which was compiled through skipper interviews in 2006. The results give support to current initiatives favouring kilowatt days as standard descriptor of fishing effort in trawl fisheries, but the linkage between engine power and trawl size is not uniform across target species groups.

Chapter 6 describes the impact of technological development on fishing effort and fishing mortality for a selection of European fleets. Historical data on vessel acquirements of technological equipment were obtained through skipper interviews conducted between 2003 and 2005 in France, Spain and Denmark. The results suggest that the linkage between present logbook effort descriptors and fishing mortality could be substantially improved by including relevant technological descriptors.

In chapter 7, the analyses, results and implications from the individual case studies are summarized and related to the objectives given in chapter 1. The conclusions are set in a broader perspective and the main challenges for a sustainable fisheries management are pointed out, before making some suggestions on how important knowledge gaps can be filled.

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Chapter 2

A bottom-up approach to technological development and its management implications in a commercial fishery

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A bottom-up approach to technological development and its management implications in a commercial fishery

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Eigaard, O. R. 2009. A bottom-up approach to technological development and its management implications in a commercial fishery. – ICES Journal of Marine Science, 66: 916–927.

Analyses of electronic equipment on board Danish trawlers and gillnetters show that newer, larger vessels have a significantly higher “technological level” than older, smaller vessels. A hypothesis of linkage between fish-finding and navigation technology on board and standard vessel characteristics was tested based on the definition of a technological index. Using a proportional odds model, vessel length accounted for most of the variation in technological level on board, with odds of 1.17 (95% confidence interval: 1.16–1.18) of a higher index value for each increase in vessel length of 1 m. Vessel age was also significantly correlated with index values. In considering the technological index as an indicator of fishing power, the results have important implications for capacity-reduction schemes intended to reduce harvest pressure on fish stocks. In the course of such structural management plans, older, smaller vessels of a fleet are often replaced with newer, larger vessels within a fixed or reduced nominal capacity limit (e.g. total fleet tonnage), but according to the findings presented, nominal capacity reduction in fleet level may be undermined by increases in individual vessel fishing power.

Keywords: capacity, fish-finding, fishing power, navigation, technological development.

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Introduction

Commercial fisheries constantly introduce technology to keep pace with developments worldwide. This is essential for them to remain competitive and to take advantage of updates to equipment, which can increase fishing success, decrease costs, aid navigation, and improve safety at sea (Waldemarsen, 2001). Often, such development complicates efforts to balance capacity and resources by boosting vessel fishing power through advances in, for example, electronic equipment. The general question is whether the effects of technology improvement are sufficiently integrated into present fisheries management (Standal, 2005). The increasing research in the area implies that the necessary knowledge is being gained (Robins *et al.*, 1998; Pascoe and Coglan, 2000; Marchal *et al.*, 2007). However, practically all research on technological development in fisheries takes a top-down approach. Typically, catch value or catch weight is linked to capacity or effort data (including a variety of technological information) to quantify changes in production efficiency or fishing power (e.g. Bishop *et al.*, 2000; Kirkley *et al.*, 2004; O’Neill and Leigh, 2006). Common to many modelling approaches is that fishing technology is often dealt with in rather general terms. Also, the results are very fleet- and fishery-specific, making it difficult to interpret results on a global scale. With only few exceptions (e.g. Rahikainen and Kuikka, 2002; Marchal *et al.*, 2007), technology in general is included in model runs with little exploratory treatment or *a priori* verification of its relevance to the catch processes under investigation.

Here, the results and analyses of technological development are generated by a different approach. The perspective is that a bottom-up approach is essential in providing the knowledge basis for successful integration of technological development into fisheries management. The assignment is best completed in three steps. The first task is to generate a detailed description of technology in commercial fisheries: what technologies are introduced, when are they introduced, what are their prevalence patterns depending on vessel characteristics, and what theory building on introduction patterns can be made that is applicable in a broader context? The second task is to establish the functional mode of the identified technologies: how does each new or improved technology actually influence the catch performance of a fishing vessel depending on fishing methods and target species? The third task would be to quantify the resulting changes in catch efficiency by relating catch-and-effort data to specific technological developments that have an *a priori* established relevance to the efficiency of the type of fishery analysed.

This study focuses on the first task above and has three specific objectives: (i) to describe in detail the patterns of introduction of new electronic equipment, (ii) to examine if there is a relationship between standard vessel characteristics and the level of electronic equipment on board, and (iii) to make general inferences relevant to the management of fishing capacity, based on the linkage between vessel fishing power and the results of (i) and (ii).

Material and methods

Methodology

Patterns of introduction: electronic equipment

Access was recently given to a national database that holds retrospective information on the uptake and removal of electronic equipment for a large subsample (~12%) of Danish trawlers and gillnetters actively fishing between 1981 and 2002. Access to this database has made it possible to come up with a detailed description of the introduction patterns of electronic equipment in the fleet during this 22-year period.

In the questionnaire supporting the database, all electronic equipment reporting is organized into three main categories: navigation, fish-finding, and communication. The communication category was discarded from the analysis that follows, mainly because of difficulties with separation of individual equipment types within the communication category and the difficulty of mechanistically establishing a link between this technology type and the fishing power of the vessels. Within the remaining two categories, fish-finding and navigation technology, 11 equipment types were treated individually on a temporal scale in relation to vessel type, vessel size, and vessel home region.

Linkage between electronic equipment and standard vessel characteristics

The relationship between fish-finding and navigation equipment and vessel characteristics was analysed because previous studies have revealed differences in vessel fishing power varying with vessel size, vessel age, and vessel type, as well as with time (Marchal *et al.*, 2001; Rijnsdorp *et al.*, 2006). In addition, vessel region was included in the analysis.

By merging observations of the equipment database with observations of the official Danish register of vessels, it was possible to test the hypothesis of there being a strong linkage between the level of electronic equipment on board and the five variables given above for a 22-year period. The hypothesis was tested in two steps. First, a technological index (Tec_index), based on the technology description relating to objective *i*, was defined, and index values were calculated for each of the vessels in the dataset. Second, the response of the Tec_index values to standard vessel characteristics was modelled. A proportional odds model was chosen based on the nature of the input data, with a multinomially distributed response variable of ordinal meaning: the Tec_index value, depending on two class variables (vessel type and vessel region), and three covariates (vessel length, vessel age, and year of reporting). A proportional odds model is particularly suited to modelling categorical responses with underlying ordinal meaning (McCullagh and Nelder, 1995; Lawal, 2003).

The fleet and the fishery

The focus in this paper is on the technological development of two major vessel types of the Danish fishing fleet: otter board trawlers (OTB) and gillnetters (GN). These two vessel types have been analysed in four regional vessel groups (Figure 1): Bornholm (BO) fishing in the eastern and western Baltic; southeastern Jutland,

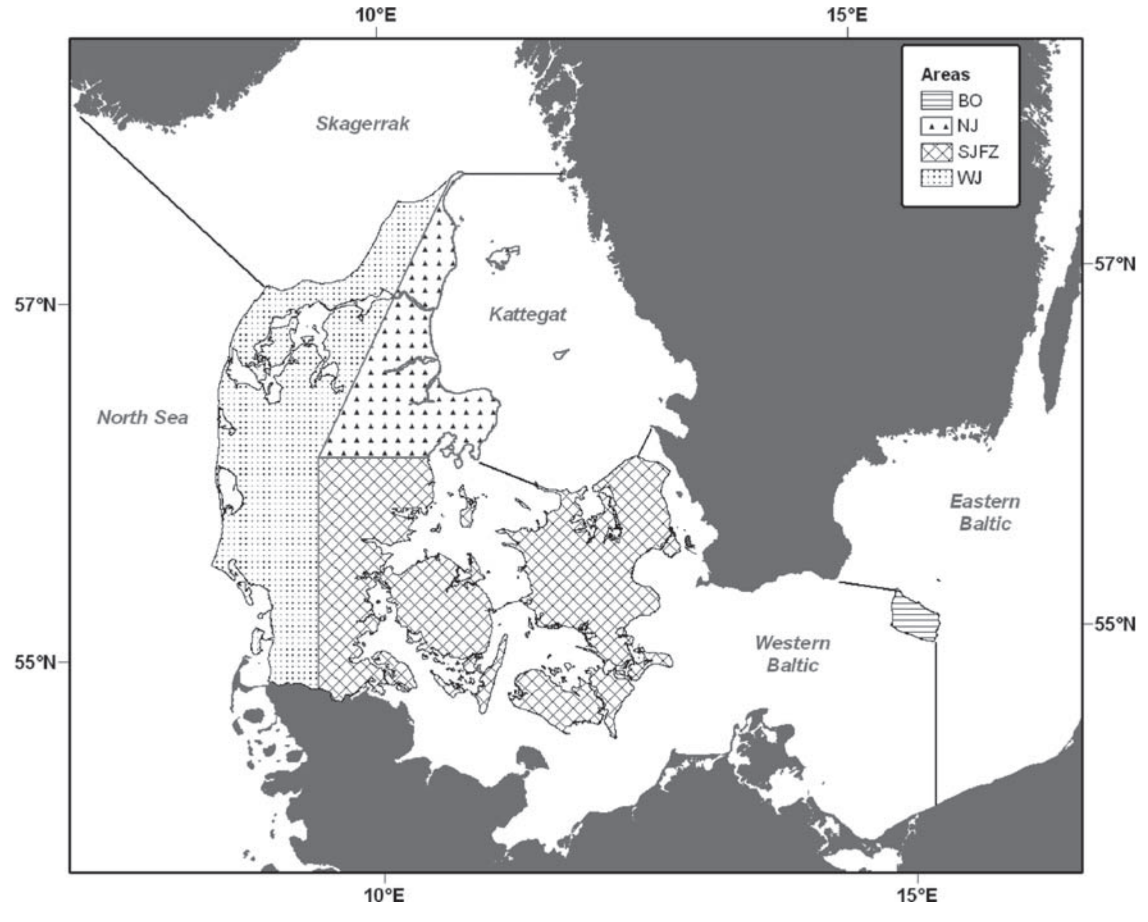

Figure 1. Map of Denmark and surrounding fishing areas divided into four regions of vessel registration: BO, SJFZ, NJ, and WJ.

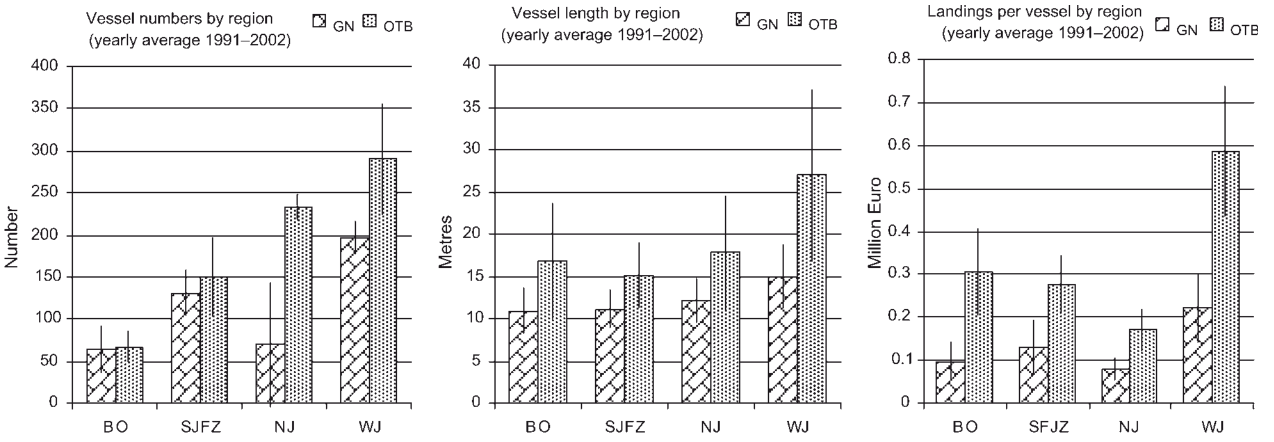

Figure 2. The annual average and standard deviation of (left) vessel number, (centre) vessel length, and (right) vessel landings values by region of Danish trawlers and gillnetters in the period 1991–2002 (data from Danish Directorate of Fisheries).

Funen, and Zealand (SJFZ) fishing in the western Baltic and the Kattegat; northeastern Jutland (NJ) fishing in the Kattegat and the Skagerrak; and western Jutland (WJ) fishing in the North Sea and the Skagerrak.

Regional and economic differences between Danish trawlers and gillnetters are summarized in Figure 2. Official economic data on vessel landings exist, however, only for a part of the 22-year period covered by the technological database and the Danish register of vessels. In the 12-year period 1991–2002, with economic data available, the annual average number of active gillnetters and trawlers in the Danish fleet was 1200 (range 993–1344). The fishery in the North Sea and the Skagerrak (vessel region WJ) supported most vessels (487 trawlers and gillnetters), and the eastern and western Baltic (BO), the fewest (130 vessels; Figure 2a). The other two regions, SJFZ and NJ, had comparable vessel numbers (280 and 303, respectively). Trawlers dominated by number in all regions, but were most dominant in NJ (Figure 2a). Vessel sizes were comparable in three of the four regions, only WJ having much larger trawlers and somewhat larger gillnetters. Trawlers were larger than gillnetters in all four regions (Figure 2b). The differences in number and size between regions and vessel types are highlighted when plotting the annual average landings values per vessel (Figure 2c). WJ trawlers had substantially larger annual landings values per vessel (€0.59 million) than the other vessel types and regions. NJ gillnetters had the lowest annual landings values, at just €0.08 million.

Underlying the regional vessel differences (Figure 2) is a pronounced spatial difference in the resources supporting the fisheries. There is a clear gradient in catch diversity outwards from the rather brackish eastern Baltic, where cod (*Gadus morhua*) is practically the only target species for both trawlers and gillnetters. The number of target species gradually increases across the western Baltic, the Kattegat, and the Skagerrak, and peaks in the North Sea (Figure 1), where many species support both the trawl and gillnet fisheries, with *Nephrops* (*Nephrops norvegicus*), cod (*G. morhua*), herring (*Clupea harengus*), plaice (*Pleuronectes platessa*), sole (*Solea solea*), and turbot (*Psetta maxima*) some of the most economically important species.

Data

The main results on technological development of electronic equipment presented here are based on information from a database administered by the Danish Directorate of Fisheries. This database contains information on technological equipment of the Danish commercial fleet as reported voluntarily in a vessel-based questionnaire since 1971. The section of the questionnaire dealing with navigation and fish-finding equipment is shown in Table 1.

Table 1. The section of the official questionnaire dealing with navigation and fish-finding equipment on board Danish vessels.

Equipment	Number (to be completed by correspondent)
Navigation equipment	
Other types of navigator	
Track plotter	
Loran C	
Satellite navigator	
Radio bearing	
Radar	
Gyro compass	
Autopilot	
Other navigation equipment	
Fish-finding equipment	
Colour sounder	
Black and white sounder	
Fish magnifier	
Sonar/Asdic	
Trawl sensor	
Other fish-finding equipment	

A reduction in the reports to just those from trawlers and gillnetters >6 m and from the years 1981–2002 (where the questionnaire remained unchanged and the reporting rate was fairly consistent) left the database with 7118 reports from 3015 different vessels during the 22-year period (Table 2). The average number of vessel reports per year was 324, from a maximum of 984 in 1981 to a minimum of 114 in 2002. This reflects both varying fleet size (notably decreasing during the period) and a varying annual response rate of the fleet to the questionnaire. The average response rate across all 22 years is estimated to have been ~12%.

Table 2. The number of reports by vessel type, vessel region, and reporting year for the technological dataset.

	Gillnetters				Trawlers				
Year	**BO**	**SJFZ**	**NJ**	**WJ**	**BO**	**SJFZ**	**NJ**	**WJ**	**Total reports**
1981	57	156	65	118	93	125	145	225	984
1982	31	128	83	107	28	60	115	245	797
1983	22	68	36	55	32	30	85	77	405
1984	28	60	33	53	46	47	75	115	457
1985	16	57	40	43	38	44	64	105	407
1986	18	54	31	42	25	32	58	87	347
1987	18	46	28	62	17	24	56	53	304
1988	17	36	28	37	12	26	39	53	248
1989	32	44	16	49	14	14	35	77	281
1990	20	37	18	47	9	18	27	54	230
1991	18	37	15	48	11	17	28	44	218
1992	14	43	25	52	13	18	31	52	248
1993	6	29	22	38	7	8	20	21	151
1994	8	26	18	37	6	13	17	20	145
1995	8	30	18	44	10	18	18	30	176
1996	5	34	19	34	7	33	17	29	178
1997	8	28	16	28	13	35	19	35	182
1998	7	36	13	26	7	24	19	24	156
1999	17	58	28	48	17	53	64	114	399
2000	27	81	40	53	24	59	66	89	439
2001	12	37	26	32	14	43	35	53	252
2002	6	21	8	18	1	18	16	26	114
Total	395	1 146	626	1 071	444	759	1 049	1 628	7 118

Trends in equipment

Given that the temporal resolution of each vessel's acquirement is low (each equipment change can only be dated to some point between the vessel report listing the change and the previous report from the same vessel, which on average is a 9-year period), it was decided to operate with the relative frequencies of "yes" and "no" of the various technologies reported in a given year. In other words, of the total number of vessels filling in the questionnaire in a given year, some percentage reported that they purchased a particular technology whereas the remaining percentage reported that they had not. This fraction of "yes" reports of any individual fish-finding or navigation equipment in the questionnaire was plotted by year to give the extent and temporal pattern of introduction of 11 electronic aids (fish-finding equipment: "ordinary sounder", "colour sounder", "sonar", "catch sensor", and "fish magnifier"; navigation equipment: "track plotter", "decca navigation", "satellite navigation", "gyro compass", "automatic pilot", and "radar").

Index definition

An index of the technological status of each vessel in each reporting year was defined as follows: a value of 1 was additively assigned for each type of reported equipment, resulting in Tec_index values ranging from 0 to 11.

Logistic regression analyses

The following logistic regression analyses only included reports with Tec_index values above 0 and from vessels at least 9 m long, in an attempt to exclude vessels having fishing as a subsidiary occupation.

The linkage between standard vessel characteristics and Tec_index values was analysed using a proportional odds model (McCullagh and Nelder, 1995; Lawal, 2003). This type of multinomial logit model is based on the assumption of a continuous variable underlying a categorical response variable of ordinal meaning, in this case the Tec_index value. The model returns the log odds of a lower ordered response with each unit of increase in the covariates (1 m length, year of vessel age, and year of observation), and for each pairwise constellation of factors individually (e.g. the odds of gillnetters having a lower Tec_index value than trawlers) or interacting (e.g. the odds of gillnetters having a lower Tec_index value than trawlers of a particular vessel length). All possible interactions were tested using the log-likelihood value of the full parameterized model as a baseline. Model reductions were made at a 0.1% significance level (log-likelihood ratio test), resulting in the following end model:

$$\log\left(\frac{\gamma_i}{(1-\gamma_i)}\right) = \theta_k - (\alpha A_i + \beta Y_i + \pi R_i + \mu T_i + \lambda L_i + \sigma(L_i, T_i) + \phi(L_i, R_i)), \tag{1}$$

where γ_i is the probability of a Tec_index$_i \leq \theta_k$.

In all, 5556 vessel reports (i) were included in the model runs. Tec_index values ranged from 1 to 11, resulting in ten (k) threshold values (θ) being estimated by the proportional odds model. Vessel age (A) varied from 0 to 49 years, observation year (Y) from 1981 to 2002, and vessel length (L) from 9 to 74 m. R denotes four regions (BO, SJFZ, NJ, and WJ), and T denotes two vessel types (OTB and GN). Data and model compatibility were validated by plotting the logarithm of the cumulated odds of each of the variables against the estimated threshold values in Table 3, which confirmed approximate linearity and common slopes. Estimations were carried out with the GENMOD procedure of SAS software (SAS Institute Inc., 1996).

The model was defined as "descending", meaning that odds were reversed to give the odds of a higher Tec_index level instead of a lower level.

Results

Equipment trends

The fraction of positive to total reports of 11 electronic aids included in the questionnaire was treated individually within the two equipment categories fish-finding (Figures 3 and 4) and navigation (Figures 5 and 6). The temporal introduction patterns are shown for different vessel types and regions for three vessel-size groups (6–15, 15–24, and >24 m).

Fish-finding equipment

During the period analysed, the ordinary echosounder was replaced by the colour sounder, the latter becoming dominant across all vessel types and sizes in the late 1980s (Figure 3). There is a tendency that gillnetters kept their ordinary sounders longer and were somewhat slower in adopting the colour sounder than trawlers. It also seems for both vessel types that the larger the vessel, the faster the uptake, but also the longer the disposal time for the outdated technology. There were no visible regional differences (Figure 4). Fish magnifiers were only common on board vessels in the two larger size groups of trawlers, but showed a decreasing trend from 30–50% in 1981 to 10–20% in 2002 (Figure 3). Across regions, there were no obvious differences in the prevalence patterns (Figure 4). The presence of sonar on board was heavily dependent on vessel size and type (Figure 3). Practically no smaller trawlers or gillnetters carried

Table 3. Estimates of model parameters and statistical test values.

Parameter	d.f.	Estimate	Standard error	Chi-square	Pr> Chi-square
Intercept 1	1	−317.05	8.05	1 550.24	<0.0001
Intercept 2	1	−315.17	8.04	1 535.07	<0.0001
Intercept 3	1	−313.49	1 521.88	<0.0001	
Intercept 4	1	−312.14	8.03	1 511.19	<0.0001
Intercept 5	1	−310.74	8.02	1 500.00	<0.0001
Intercept 6	1	−309.52	8.02	1 490.49	<0.0001
Intercept 7	1	−308.25	8.01	1 481.22	<0.0001
Intercept 8	1	−306.95	8.00	1 472.00	<0.0001
Intercept 9	1	−304.95	7.99	1 456.84	<0.0001
Intercept 10	1	−303.46	7.99	1 444.23	<0.0001
Vessel length	1	0.16	0.00	1 057.75	<0.0001
Vessel age	1	−0.04	0.00	296.17	<0.0001
Reporting year	1	0.15	0.00	1 466.18	<0.0001
Vessel region					
BO	1	0.72	0.21	11.98	0.0005
NJ	1	−1.24	0.16	60.23	<0.0001
SFJZ	1	−1.48	0.22	46.95	<0.0001
WJ	0	0	0		
Vessel type					
GN	1	−3.09	0.20	250.71	<0.0001
OTB	0	0	0		
Vessel type by length					
GN	1	0.20	0.01	188.78	<0.0001
OTB	0	0	0		
Vessel region by length					
BO	1	−0.03	0.01	7.30	0.0069
NJ	1	0.08	0.01	97.92	<0.0001
SFJZ	1	0.09	0.02	38.60	<0.0001
WJ	0	0	0		

Intercepts 1–10 are the estimated threshold values corresponding to the ten thresholds between the 11 Tec_index values.

sonar in the period considered. The trawlers of medium size gradually increased the positive reporting fraction from virtually none in 1981 to ~25% in 2002, whereas the same size of gillnetters had a steady fraction of "yes" reportings of ~70% across the period. The largest trawlers showed a gradually increasing percentage from ~40% in 1981 to ~60% in 2002, and practically all the largest gillnetters had sonar throughout the period. There was a tendency for fewer vessels from BO than from the other regions to have sonar on board (Figure 4). Not surprisingly, trawl sensors were restricted to trawlers, and the larger the vessel, the more frequent a trawl sensor was carried. There were no obvious temporal trends in carrying this equipment, although there were tendencies for a declining frequency among small trawlers and for an increasing frequency among larger vessels (Figure 3). Between regions, it appears that more vessels from BO carried this equipment than vessels in the other three regions (Figure 4).

Navigation equipment

The autopilot was widespread across all vessel types, sizes, and home regions (Figures 5 and 6). However, ~40% of the small gillnetters and ~20% of the small trawlers were not equipped with an autopilot in the period analysed. This pattern was relatively stable throughout the period, although there was a slightly increasing trend in autopilot prevalence for both vessel groups (Figure 5). Radar was also widespread across almost all vessel types, sizes, and home regions (Figures 5 and 6). Some 20% of the small gillnetters and 10% of the small trawlers remained without radar. During the period analysed, navigation by radio bearings was replaced with satellite navigation, the latter dominating from the early 1990s (Figure 5). There was a tendency for small gillnetters to be a little slower and larger gillnetters a little faster in adopting satellite navigation technology than trawlers of equivalent size. It also seems, for both vessel types, that the larger the vessel the faster and more widespread the uptake, but also the longer the disposal time for the outdated technology. Vessels with track plotters on board showed an increasing trend for all sizes and types during the period analysed (Figure 5). The smaller gillnetters introduced the track plotter more slowly and less frequently (40%) than trawlers of equivalent size (70%). All medium-size trawlers and gillnetters had track plotters in 2002, but for the largest size category, the proportion dropped to <80% for trawlers and to ~50% for gillnetters. Across regions, there were no differences (Figure 6). The frequency of vessels with a gyro compass on board showed no dependence on type of vessel but strong dependence on vessel size (Figure 5). Practically no 6–15 m gillnetters or trawlers were equipped with a gyro compass. A small fraction of vessels 15–24 m long had a gyro compass, and the fractions of both vessel types >24 m with the equipment increased gradually, approaching 70% in 2002. There was a slight tendency for large vessels in NJ and WJ to have a higher and more rapidly increasing prevalence of gyro compasses than those in the other two regions (Figure 6).

Model results

Estimates of model parameters and statistical test values are listed in Table 3.

The odds of increasing Tec_index values with increasing vessel length were 1.17 (95% confidence interval: 1.16–1.18) for each 1 m of vessel length (Table 4). The odds of an increasing

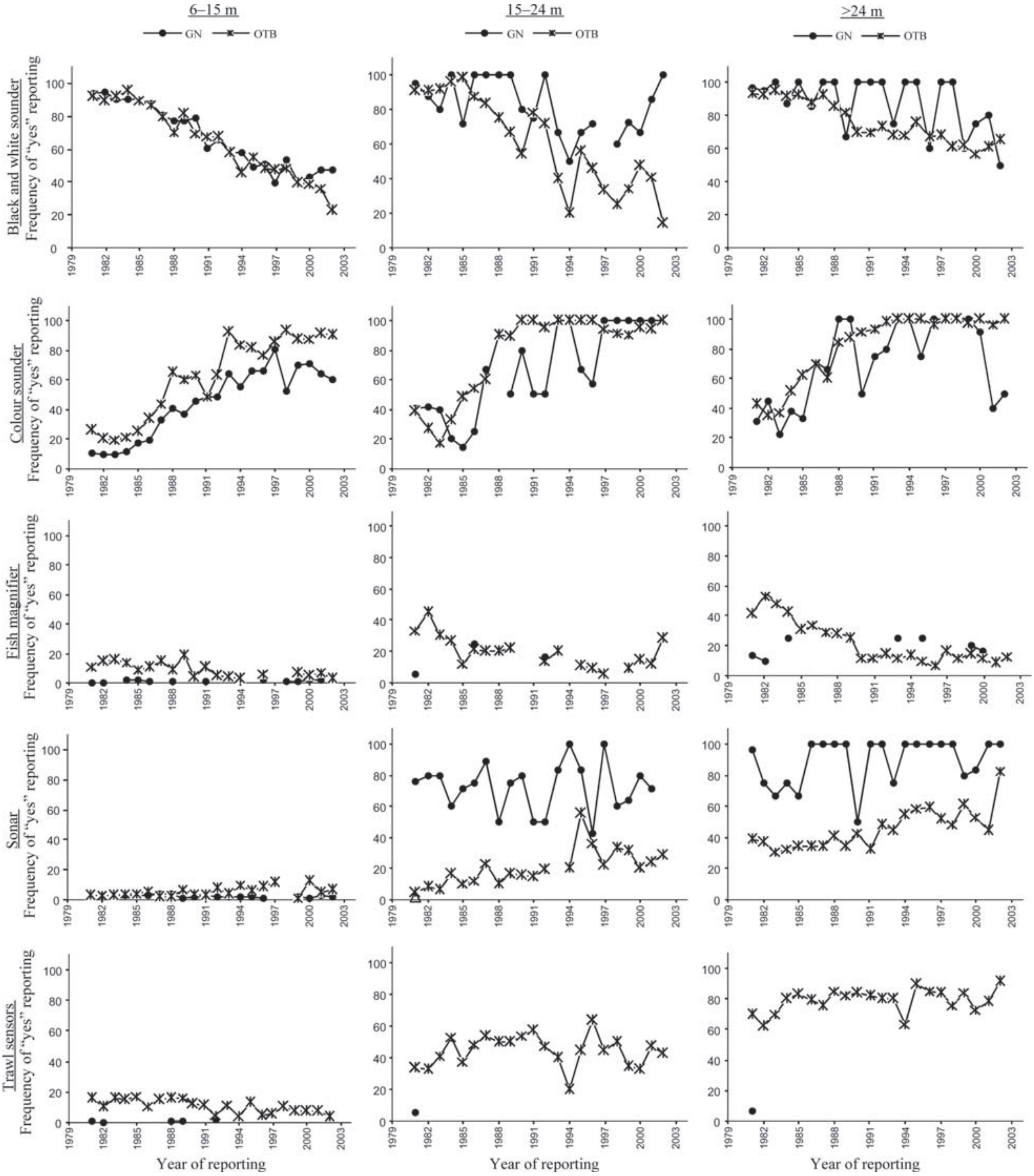

Figure 3. Trends in fish-finding equipment by Danish vessel size and vessel type during the period 1981–2002.

Tec_index value with increasing vessel age were 0.96 (0.96–0.97) per year, meaning that there were small but significant odds of older vessels having lower Tec_index values than newer ones. The odds of increasing Tec_index values with increasing reporting year were 1.17 (1.16–1.18). The odds between regions [e.g. odds of 2.05 (1.37–3.08) of higher index values for BO compared with WJ] as well as between vessel types [e.g. odds of 0.05 (0.03–0.07) of gillnetters having higher index values than trawlers] were markedly different from 1, but when taking into account the interactions with vessel length, the odds differences for both factors turned out to be rather small (0.97–1.22), though significant (Table 4).

Discussion

Technological trends and their effects on fishing power

The most widespread technological events in the fleet were: (i) ordinary sounders being replaced by colour sounders during the late 1980s, which improved the fish-finding capabilities of the

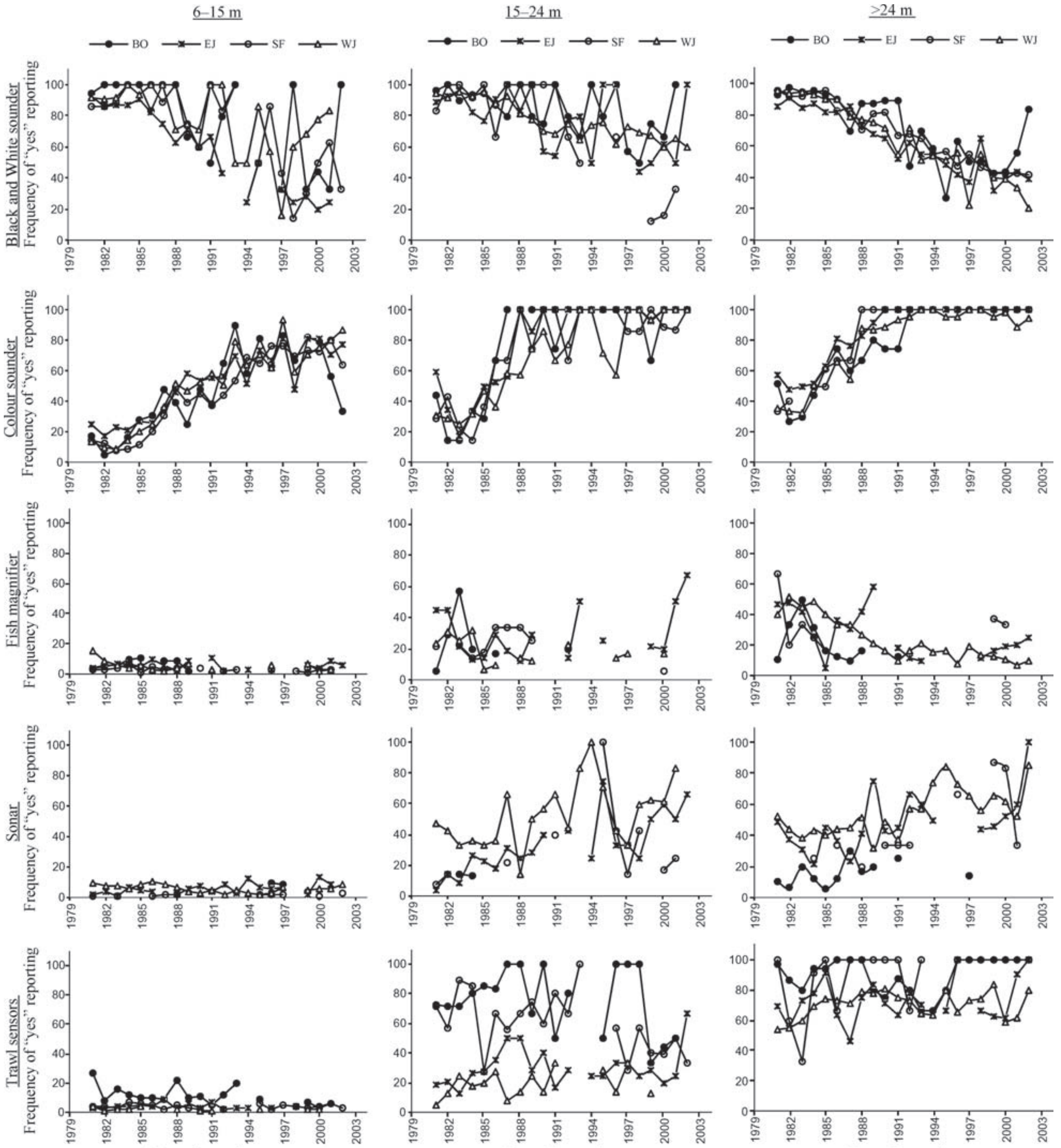

Figure 4. Trends in fish-finding equipment by Danish vessel size and vessel region during the period 1981–2002.

vessels, and (ii) satellite navigation replacing navigation by radio bearings in the early 1990s, which enhanced navigation speed and position accuracy of the vessels. Both events undoubtedly led to a marked increase in the fishing power of the fleet (Robins *et al.*, 1998; Mahevas *et al.*, 2004). The track plotter became widespread almost in parallel with satellite navigation and almost certainly added significantly to the improvement in fishing power by allowing vessels to monitor and store trawl tracks, fishing positions, and wreck positions better than previously (O'Neill *et al.*, 2003).

Trawl sensors and sonar were common in the fleet, mainly on board larger vessels, at a stable to slightly increasing level during the period analysed. Based only on their introduction patterns, these technologies are not expected to add noticeably to increases in the fishing power of the fleet. Both equipment types, however, have most likely undergone improvements during the period analysed. This could be in terms of gradual increases in range and precision, ultimately leading to a better catch efficiency that is not captured in the Tec_index. The improvement in sonar in particular can be expected to have

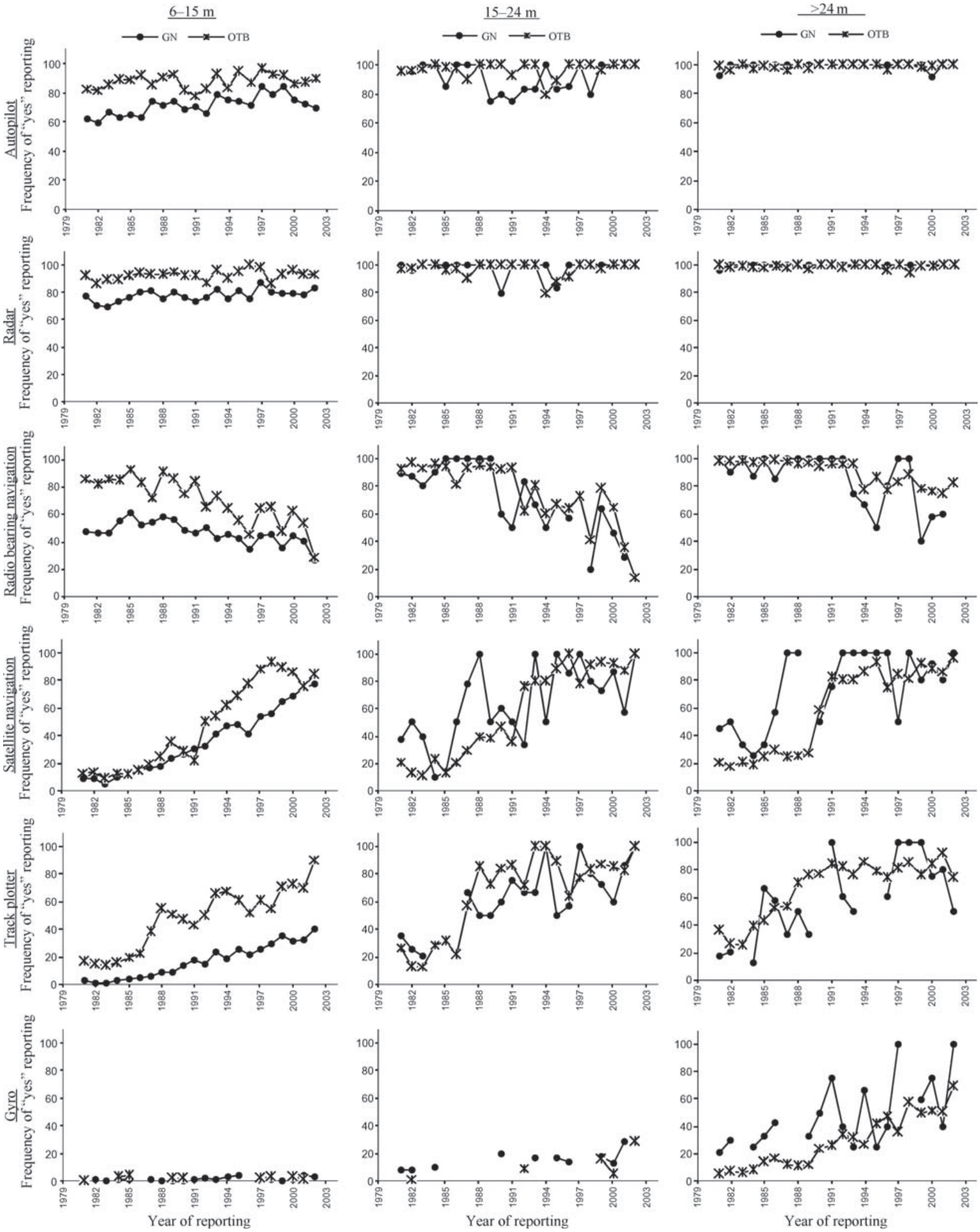

Figure 5. Trends in navigation equipment by Danish vessel size and vessel type during the period 1981–2002.

influenced the fishing power of pelagic trawlers, for which scouting for fish (e.g. mackerel and herring) is a key component of the fishing operation.

The gyro compass was introduced gradually during the entire period analysed here, and it was already common among the larger vessels of the fleet by 2002. It adds to the precision

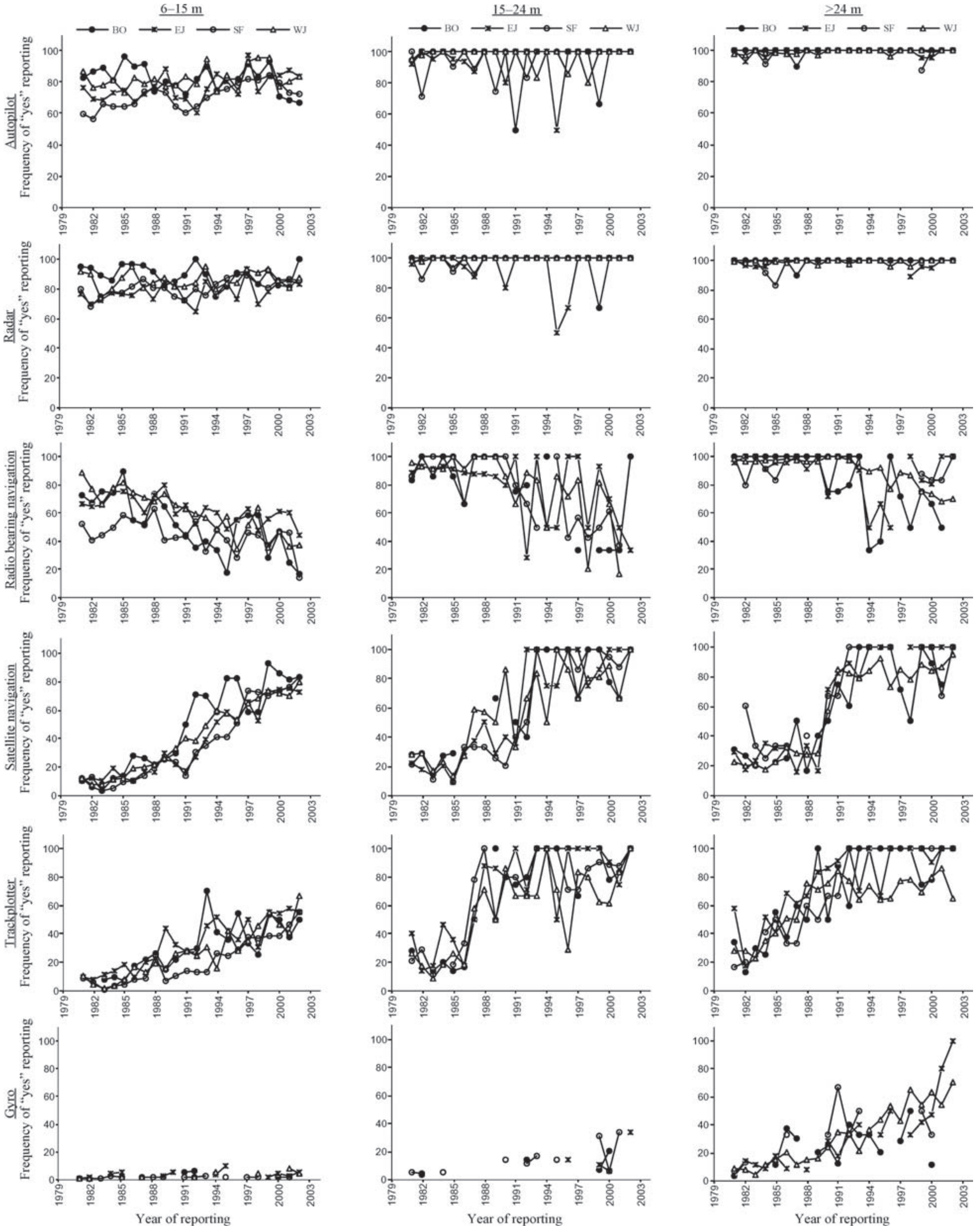

Figure 6. Trends in navigation equipment by Danish vessel size and vessel region during the period 1981–2002.

of navigation on a fine scale, and as such it is not expected to have added markedly to any increases in the fishing power of the vessels.

Radar and autopilot equipment is also widespread across all vessel types, sizes, and regions. Radar is used almost exclusively for security purposes (possibly also to monitor other vessels'

Table 4. Odds with 95% confidence intervals for vessel length, vessel age, reporting year, vessel type, vessel region, and interactions between vessel type and vessel length, and between vessel region and vessel length.

Parameter	Odds	95% confidence limits	
Vessel length	1.17	1.16	1.18
Vessel age	0.96	0.96	0.97
Reporting year	1.17	1.16	1.18
Bornholm	2.05	1.37	3.08
Northern Jutland	0.29	0.21	0.40
Southern Jutland, Funen, Zealand	0.23	0.15	0.35
Western Jutland	1	1	1
Gillnetters	0.05	0.03	0.07
Trawlers	1	1	1
Vessel type by length			
Gillnetters	1.22	1.19	1.26
Trawlers	1	1	1
Vessel region by length			
Bornholm	0.97	0.95	0.99
Northern Jutland	1.09	1.07	1.11
Southern Jutland, Funen, Zealand	1.10	1.07	1.13
Western Jutland	1	1	1

fishing activities and fishing grounds), and an autopilot mainly for reducing or relaxing the manpower needs on board. It is not impossible that, in some fisheries, an autopilot can increase navigation precision and reduce steaming time, so saving more time for actual fishing. Therefore, the two technologies cannot be completely excluded from having had an effect on catch efficiency, but the possible linkages to fishing power are weak, although autopilots had a positive effect on the technical efficiency of vessel groups fishing with mobile gears in the English Channel (Tingley *et al.*, 2005).

Tec_index values as indicators of vessel fishing power

According to the causal relationships between individual technologies and catch efficiency described above, all equipment types included in the Tec_index value have positive to neutral influence on fishing power. This interpretation is supported by other findings that cite general technological development as being responsible for increases in fishing power over time (e.g. Rahikainen and Kuikka, 2002; Branch *et al.*, 2006). In this context, it makes good sense to interpret the Tec_index values as indicators of individual vessel fishing power, giving specific biological relevance to the analysis and discussion of variation in Tec_index values of the vessels given below.

Tec_index values in relation to standard vessel characteristics

Model runs show that vessel length is a major determinant of the technological level on board with odds of 1.17 (1.16–1.18) of a higher index value with each 1 m of vessel length. This result is in line with expectations, because physical vessel size typically reflects vessel turnover, and often a certain turnover is a prerequisite for new technological investments being economically rational. Vessel size also has a more direct physical control of the level of fish-finding and navigation equipment on board, because there is only room for a certain amount of electronic equipment on the bridge of a vessel: the larger the vessel, the more room for back-up equipment. Vessel size positively affects efficiency (Pascoe and Robinson, 1996; Rijnsdorp *et al.*, 2006), and although vessel efficiency is not directly comparable with vessel technology, some proportionality of the two measures is feasible, as discussed above, so giving support to the results from other studies.

The odds of increasing Tec_index values with increasing vessel age are 0.96 (0.96–0.97) per year, meaning that there is a small but significant probability that the technological level on board older vessels is less than on newer vessels. This is not surprising of course, because newly built vessels are typically equipped with state-of-the-art technology, whereas owners are typically more hesitant to invest in new technology as their vessel itself becomes outdated. Other studies support this result by reporting that fishing power increases with decreasing vessel age (Pascoe *et al.*, 2001b; Rijnsdorp *et al.*, 2006).

Observation year has odds of 1.17 (1.16–1.18) of a higher Tec_index value with each year of the period analysed. This result is in line with the expectation that new technologies gradually emerge and spread throughout a fleet, leading to an overall increase in Tec_index values with time. If Tec_index values are accepted as indicators of fishing power, the results here are supported by similar findings from other studies (Marchal *et al.*, 2001; O'Neill *et al.*, 2003).

A comparison of vessel types across all sizes shows that gillnetters have dramatically lower odds of 0.05 (0.03–0.07) of higher Tec_index values than trawlers. This is in line with expectations based on vessel type differences in size and landings values (Figure 2), and supporting these results is a study showing that Baltic gillnetter and trawler fleets differ significantly in fishing-power trends with time (Marchal *et al.*, 2001). However, model runs taking into account vessel length reduced this rather dramatic difference between gillnetters and trawlers to practically zero. In fact, when compared by length, gillnetters turn out to have slightly higher odds of 1.22 (1.19–1.26) of a higher Tec_index value than trawlers (Table 4), leading to the conclusion that vessel type plays only a minor role in the technological level of a fishing vessel.

Likewise, seemingly substantial regional differences in Tec_index values are explained by vessel-length differences between regions, rather than by the regional factor itself. This is demonstrated by the odds between regions being very close to 1 when taking into account regional vessel-length differences (Table 4). This is perhaps not surprising, because distances between different fishing areas and resources are small, and the Danish fleet is volatile in terms of shifting areas and métiers (Ulrich and Andersen, 2004).

Management implications

When considering the Tec_index values as indicators of individual vessel fishing power, the results presented and discussed here have several management implications. The annual increases in technology level (and fishing power) of vessels bias the time-series of catch rate that are used widely in stock assessments. Moreover, the fact that the level of technology of fishing vessels also varies significantly with vessel length and age has consequences for the structural management of fleets worldwide. This is in particular the case when dealing with directed capacity plans, e.g. buy-back schemes and initiatives under the EU–MAGP (European Union–Multi-Annual Guidance Plan). A frequent outcome of such structural measures is the replacement of older, smaller vessels with newer, larger ones within a fixed stable or reduced nominal capacity limit, e.g. in terms of tonnage or horsepower (Pascoe and Coglan, 2000; Pascoe *et al.*, 2001a). Seemingly, an intention of controlling capacity is driven by exclusively allowing structural changes within a given nominal capacity limit. In reality, however, the induced changes in vessel size and age also increase the total fishing power of a fleet by upgrading the fish-finding and navigational equipment on board the vessels. According to the results presented here, these mechanisms undermine the intention to maintain a sustainable balance between harvesting capacity and resource. Other studies have suggested that directed plans of reduction in nominal capacity in combination with fleet-replacement programmes may not have the intended effect of decreasing harvesting capacity (Pascoe *et al.*, 2001a; Standal, 2007). The reason is that these management measures tend to be accompanied by technology-based increases in vessel fishing power, so confirming the more specific results and conclusions presented here of fish-finding and navigation equipment playing important roles in the process.

In a study by Pascoe *et al.* (2001b), vessel size and engine power are included in a nominal capacity expression (vessel capacity units, VCU), which is evaluated in terms of reliability by comparison with a fishing-capacity expression generated by data envelopment analysis (DEA). The evaluation demonstrated that the VCU expression reasonably approximates the effective capacity of mobile gears, but not of static gears. Another capacity expression (capacity factor), used by Standal (2007) to assess the success of the Norwegian unit quota system, includes a gear factor (single or double trawl) along with an engine-power factor and three vessel-size factors and reveals a mismatch between nominal and effective capacity in the Norwegian trawl fishery. Using such integrated capacity expressions when planning, implementing, and evaluating structural measures would take into account some of the unintended increase in harvesting capacity that often accompanies directed capacity plans. According to the model results here, the inclusion of a vessel-size factor in an integrated nominal capacity expression would most likely account for fishing-power increases resulting from the fish-finding and navigation-equipment development described, so providing an improved linkage between nominal and effective capacity.

Certainly, the development of the two above-mentioned capacity expressions, including vessel and gear size, are steps in the right direction when it comes to successfully integrating technological development in the management of fisheries capacity. However, according to the results, vessel age and possibly vessel type are also candidates to form part of an integrated nominal capacity expression. Logically, other components of technological development in fisheries, e.g. engine or gear developments, should also be examined and possibly included to approximate more closely the actual harvesting capacity.

The electronic component of technological development in commercial fisheries has been scrutinized, and relationships have been established with year, vessel type, vessel length, vessel age, and vessel region. Implications for the reliability of currently used capacity measures have been discussed and ways to improve pointed out, narrowing the gap between nominal and effective capacity. Likewise, the remaining main components of technological development in fisheries (engine and propulsion, decks machinery, and gears) should be described and understood in a fishing-power context before integrating them in a suitable nominal capacity expression, which then ultimately needs to be validated against effective capacity, possibly by econometric methods such as DEA or stochastic production frontier analyses.

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Chapter 3

Influence of fleet renewal and trawl development on landings per unit effort of the Danish northern shrimp (*Pandalus borealis*) fishery.

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(Accepted ICES Journal of Marine Science)

Influence of fleet renewal and trawl development on landings per unit effort of the Danish northern shrimp (*Pandalus borealis*) fishery

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Recent stock assessments of the *Pandalus* stock in the Skagerrak (ICES Division IIIa) and the Norwegian Deep (Division IVa East) has relied largely on a time-series of landings per unit effort (lpue) calculated from Danish logbook data. Because of fleet renewal and trawl size changes, the relationship between nominal effort data as recorded in logbooks (days fishing) and effective effort is likely to have changed, so to standardize the nominal lpue time-series, trawl size development has been taken into account using generalized linear modelling. As logbooks do not provide trawl size information, this standardization was made possible by retrieving technical trawl and vessel data from industry order books. These data demonstrated an approximately linear relationship between vessel engine power and *Pandalus* trawl size, so validated the use of vessel horsepower from the logbooks as a proxy for unknown trawl size. Standardized lpue time-series for the past 20 years indicated a lesser increase in stock size than nominal lpue, the modelling results demonstrating that vessel lpue increased by 9.5% with each 100 hp of engine power.

Keywords: cpue standardization, effort, engine power, fishing power, stock assessment, technological development, trawl size.

Introduction

The northern shrimp (*Pandalus borealis*) stock in the Skagerrak (ICES Division IIIa) and the Norwegian Deep (ICES Division IVa East) is exploited by Denmark, Norway, and Sweden (ICES, 2008). Recently, the annual stock assessment by ICES of this stock has relied largely on commercial data on landings per unit effort (lpue). Ideally there is a proportional relationship between commercial catch per unit effort (cpue) and stock size, but the conditions for such a linear relationship are rarely fulfilled (Maunder and Punt, 2004; Bordalo-Machado, 2006). The problems stem from the distribution pattern of the stocks in relation to the fisheries (Crecco and Overholtz, 1990; Rose and Kulka, 1999), and technological creep in the fisheries (Pascoe *et al*., 2001; Branch *et al*., 2006).

Commercial lpue time-series were based largely on Danish official logbook data and calculated as landings divided by days fishing. However, substantial changes in the vessel composition of the Danish *Pandalus* fleet have taken place during the past two decades, and newly acquired qualitative information from the industry suggests that an increased trawl size has enhanced the efficiency of individual vessels. Consequently, the stock assessment based on nominal effort data is probably biased. The purpose of this paper is to improve the reliability of the Danish cpue time-series as an indicator of the fishable *Pandalus* stock by incorporating the main technological developments of the fleet into the lpue calculations, using generalized linear models (GLMs). Recent technological developments in the Danish *Pandalus* fleet were obtained from three sources: (i) information on vessel number, length, and engine power in the fleet from the official Danish vessel register for the years 1987–2008; (ii) telephone interviews with net manufacturers and skippers in 2007, providing qualitative information on key technological developments; (iii) detailed characteristics of 25 trawls built between 1982 and 2007 obtained from the order books of the largest Danish net manufacturer. Two multiplicative models separating variation in the vessel composition of the *Pandalus* fleet and variation in gear size from variations in fishable *Pandalus* biomass were compared. In the second model, vessel horsepower was used as a proxy for trawl size. This assumption was validated against the order-book information as well as with the temporal development in shrimp trawl size and geometry recorded in commercial flume tank tests carried out during the same period.

Material and methods

Data

The Danish *Pandalus* fishery for the Norwegian Deep-Skagerrak shrimp stock is a single-species trawl fishery. It is usually conducted with 35-mm mesh (stretched) in the codend and yields limited bycatch or discards of other species (ICES, 2008). Landings and effort information for the fleet fishing in ICES Divisions IIIa or IVa in the period 1987–2008 was obtained from official logbooks. Corresponding technical vessel information was extracted from the Danish vessel register. A "*Pandalus* trip" was defined as any fishing trip with mesh size of 35–45 mm (stretched) where the value of *Pandalus* catches was at least 30% of the total trip value. Occasionally, more than one rectangle was fished during a trip (about 1 out of 10 trips), in which case the total landings and effort of a trip were parcelled out by rectangle. The rejection of certain fishing trips was based on (i) herring (*Clupea harengus*) fishing operations being conducted with similar mesh size, (ii) occasional Norway lobster (*Nephrops norwegicus*) operations with 35-mm half-mesh being entered in error as 35 mm stretched mesh in the logbooks, and (iii) the possibility of *Pandalus* gear having been used for *Nephrops* or mixed demersal fishery. The 30% threshold resulted in 8.3% (s.d. = 2.3) of the observations being discarded, just 1.4% (s.d. = 0.8) of annual *Pandalus* landings. The selected data came from 262 vessels carrying out 25 988 trips.

Telephone interviews with three net manufacturers and three *Pandalus* skippers were carried out in 2006 and 2007 to identify potential changes in trawl size and technology. Following the telephone screening, detailed information on the development of *Pandalus* trawls was obtained from an in-depth interview with the largest Danish manufacturer of *Pandalus* trawls (Cosmos Trawl A/S), who also provided the order-book technical details of 25 *Pandalus* trawls produced for the fishery between 1982 and 2007.

Information on the temporal development of *Pandalus* trawl size and geometry as recorded in commercial flume tank tests was also used. Three of some 15 *Pandalus* trawls tested in the SINTEF flume tank in Hirtshals (Denmark) from 1985 to 2008 were selected to typify the trawl size and corresponding engine power developments of the study period.

Modelling

Modelling fishing vessel efficiency creep from increased trawl size is not straightforward because the official Danish logbook records do not contain information on trawl size or type (e.g. twin or single trawl). However, the vessel register offers detailed information on engine power. If engine power was related to trawl size, it could be used as a proxy for trawl size, assuming that only one trawl type was used during a trip. The information in the order book from the net manufacturer (22 single and 3 twin trawls) was used to assess whether this assumption held, by plotting trawl size (40-mm half-meshes in circumference) against vessel horsepower and fitting a simple linear relationship. The two circumferences of a twin trawl were summed to give a single value for the analysis.

Log-transformed lpue data per *Pandalus* trip as defined above were analysed using multiplicative models (Gulland, 1956; Robson, 1966; Gavaris, 1980) following two approaches. Model 1 took account of developments in overall fleet fishing power related to vessel renewal of the fleet (vessels leaving and entering the *Pandalus* fleet during the period examined), using vessel identifier as explanatory factor. The model also included an area factor (ICES rectangle) and a temporal and a seasonal component modelled as a year*month interaction:

$$E[\log(\mathrm{lpue}_{ijkl})] = u + \mathrm{vessel}_i + \mathrm{area}_j + \mathrm{year}_k \times \mathrm{month}_l + \varepsilon_{ijkl}. \qquad (1)$$

In model 2, fleet fishing-power developments were modelled using an engine power factor (100–200 hp, ..., 600–700 hp, >700 hp):

$$E[\log(\mathrm{lpue}_{mjkl})] = u + \mathrm{horsepower}_m + \mathrm{area}_j + \mathrm{year}_k \times \mathrm{month}_l + \varepsilon_{mjkl}. \qquad (2)$$

Exploratory runs of both model 1 and 2 containing (i) all possible interactions, (ii) quarters instead of months, and (iii) ICES Divisions IIIa and IVa east instead of ICES rectangles, were performed but discarded based on Akaike’s Information Criterion (AIC).

Lpue was calculated as kg of shrimp landed per day fished, u is the overall mean, i denotes the 262 vessels participating in the *Pandalus* fishery at some time during the study period, j the 39 different ICES rectangles, k the years from 1987 to 2008, l the month, and m the seven horsepower categories. Vessel horsepower ranged from 110 to 1200 hp. The log-transformed lpue was assumed to be normally distributed, an assumption validated by plotting the standardized residuals against the quartiles of standard normal distribution (QQ-plot). Calculations were made using SAS software (SAS Institute Inc., 1996).

The results of model 2 were used to investigate the relationship between horsepower and *Pandalus* lpue and to test the hypothesis of engine power being a key descriptor of lpue. Biomass indices (year effects relative to 1987) for the two models (lpue–vessel index, and lpue–hp index) were derived from the back-transformed interaction estimates of models 1 and 2, as described by Maunder and Punt (2004):

$$I_k = \sum_l z_l I_{k,l}$$

$$I_{k,l} = \exp(\mathrm{year}_k * \mathrm{month}_l + 0.5\sigma^2_{k,l}), \qquad (3)$$

where I_k is the relative abundance index for year k, $I_{k,l}$ the index of abundance for year k and month l, $\sigma^2_{k,l}$ the variance of the year–month term estimate, and z_l the weighing factor for month l. As the fishery took place in all months of all years examined, the weighting factor for all months was set to 1/12.

The two standardized biomass indices were compared with the nominal index calculated as annual *Pandalus* landings divided by the number of days fishing.

Results

During the past 25 years, the *Pandalus* fishery has experienced a decline in nominal effort (annual fishing days) and a spatial effort contraction (Figures 1 and 2). The annual nominal effort (fishing days) in 2008 was just 20% of the 1987 level (Figure 2). Despite the decreasing effort, total annual landings remained stable (Figure 2). The number of participating vessels decreased dramatically, from 158 vessels in 1987 to just 11 in 2008 (Figure 3a). Mainly smaller vessels left the fishery, so average vessel length increased from 20 to 26 m and average engine power from 415 to 670 hp. However, an increase in the overall fleet fishing power caused by the increase in engine size (Figure 3b) and the larger trawls being used by the remaining *Pandalus* vessels probably compensated to some extent for the decrease in nominal effort, as discussed later.

The relationship between horsepower and trawl size (number of meshes in the trawl circumference) for 25 vessels for which this information was available was approximately linear ($r^2 = 0.46$), although twin trawls were somewhat off the line (Figure 4). Based on this relationship, it seems reasonable to use engine power as a proxy for trawl size, which is supported by the developments in trawl size and corresponding engine power requirements, as documented by the three trawls tested in commercial flume tanks during the study period (Figure 5).

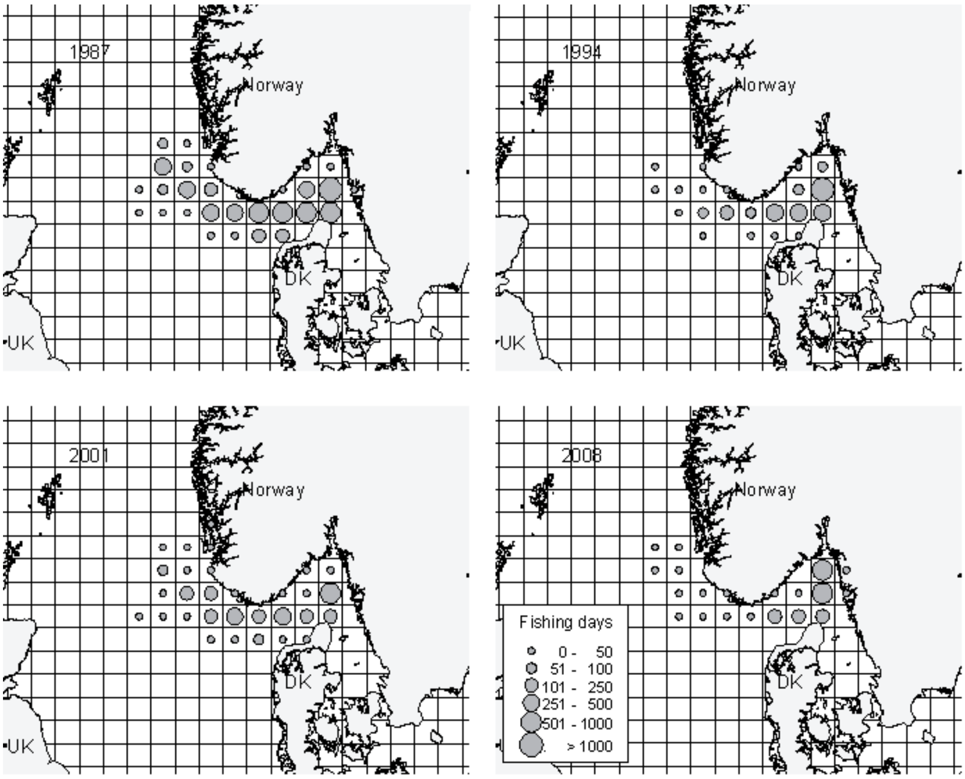

Figure 1. Effort development (annual number of fishing days per ICES rectangle) of the Danish *Pandalus* fishery for the Norwegian Deep–Skagerrak stock (IVa–IIIa stock) in selected years.

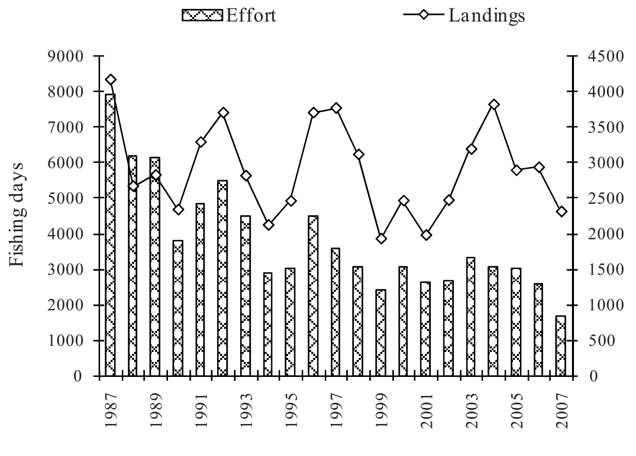

Figure 2. Annual catch and effort trends of the Danish *Pandalus* fleet in ICES Divisions IIIa and IVa.

The overall mean lpue estimate exp(u + 0.5variance) was 304.2 (s.d. = 1.4) kg per fishing day for model 1, and 399.9 (s.d. = 1.4) for model 2. None of the 39 area (ICES rectangles) estimates were significantly different in any of the models. Of the 262 vessel effects estimated in model 1, 58 were significantly different from the reference vessel ($p < 0.01$). The r^2 values of models 1 and 2 were 0.42 and 0.37, respectively, leaving unexplained lpue variability for both models. The AIC values were –11 210 (model 1) and –10813 (model 2). The estimates of the engine power factor exp(horsepower + 0.5variance) from model 2 showed that vessel lpue increased significantly ($p < 0.0001$) with increasing horsepower (Figure 6), corresponding to an average 9.5% lpue increase for each 100 hp.

The two standardized *Pandalus* biomass indices estimated from models 1 and 2 displayed similarly moderately increasing trends across the 22-year period of study. This contrasts with the nominal lpue index, which showed a much more substantial increase in *Pandalus* biomass across the period (Figure 7).

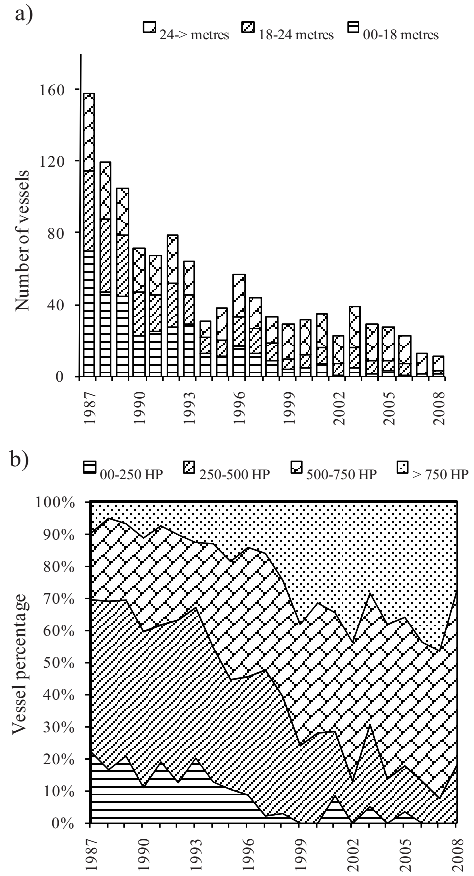

Figure 3. Number of vessels (a) per length group and (b) per engine power group of Danish trawlers participating in the *Pandalus* fishery in ICES Division IIIa and IVa in the period 1987–2008.

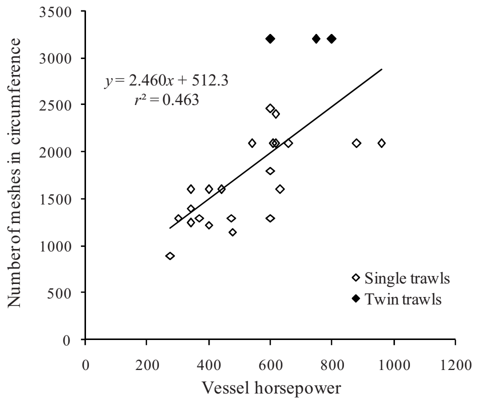

Figure 4. Trawl size (number of meshes in circumference) plotted against vessel engine power for 25 vessels equipped during the period 1982–2007. The circumference is scaled by the number of 40-mm half-meshes.

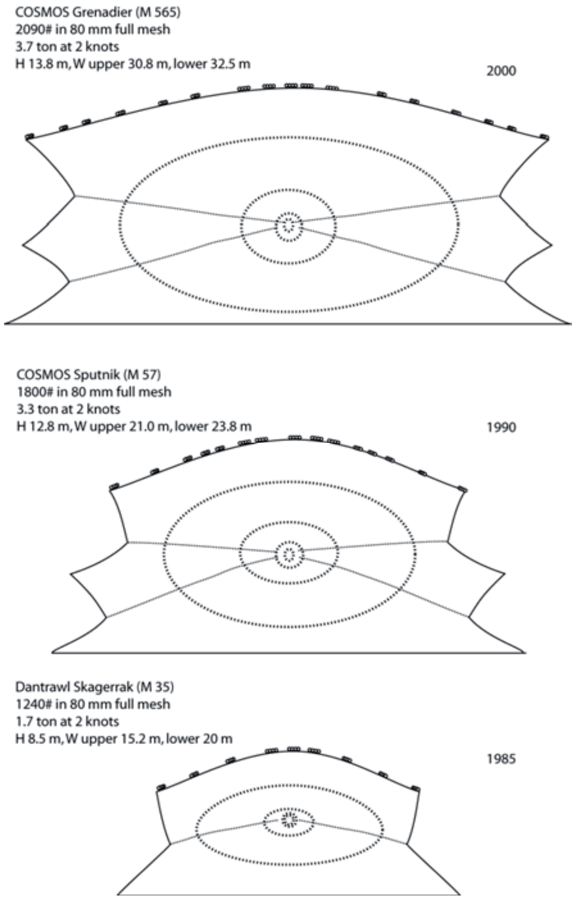

Figure 5. Developments in Skagerrak *Pandalus* trawl geometry (trawl height, spread of upper and lower wing, and cross section of the trawl mouth) as documented in flume tank trials from 1985 to 2000 (drawings courtesy SINTEF Denmark).

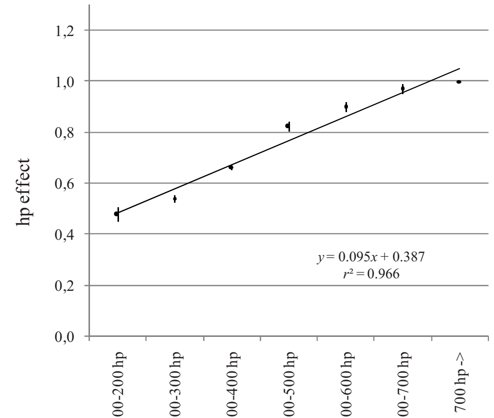

Figure 6. Model 2 estimates of horsepower effects, with 95% confidence intervals and a linear fit

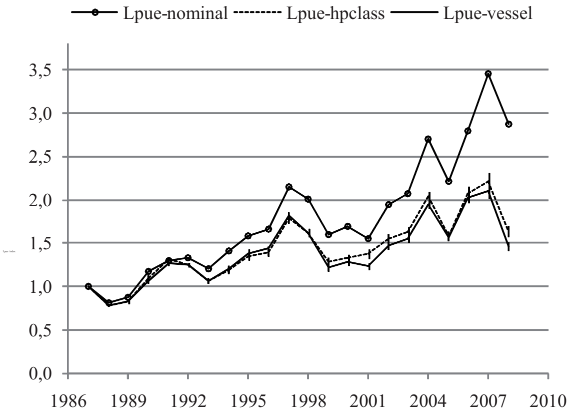

Figure 7. Comparison of GLM-standardized and nominal cpue indices, with 95% confidence intervals for standardized cpue series.

Discussion

Fleet renewal and trawl-size development in the Danish *Pandalus* fishery has reduced the reliability of the commercial lpue time-series as an indicator of stock size when based on nominal effort (days fishing). Therefore, the increasing trend in the nominal lpue index was partially the result of increases in overall fleet fishing power. The model-derived standardized biomass indices displayed only moderately increasing long-term trends. This result was not unexpected because logbook analyses of fleet renewal and industry information of trawl-gear development of individual vessels suggested substantial increases in fishing power during the period examined. Comparable improvements from lpue standardization for fleet renewal were found for the Davis Strait *Pandalus* fishery by Hvingel *et al*. (2000). It is known that individual technological uptake, e.g. of new gear designs or advances in navigation and fish-finding equipment, in the vessels exploiting a stock will result in changes in the overall fleet fishing power (Rijnsdorp *et al*., 2006; Eigaard, 2009).

The assumption of vessel engine power being a key descriptor of vessel lpue is confirmed by the results of model 2, which yielded a 9.5% increase in lpue for each increase of 100 hp (Figure 6). This is not surprising, because the coupling of engine power to gear size to increased catch rates is straightforward: the more engine power, the larger the trawl that can be dragged through the water, and the more shrimp that can be caught. This principle is confirmed by the different engine powers shown to be required for deploying different size trawls (Figure 5). Several other studies have reported a positive relationship between engine power and the catch rate of trawlers (Mahévas *et al*., 2004; O'Neill and Leigh, 2006). Further, a linear relationship between circumference and horsepower was shown to be plausible in this study. However, departures from this linearity attributable to, for example, the introduction of high-performance netting or twin trawls (as indicated in Figure 4) or the presence of some functional limitation of trawl size at higher engine power than those examined, cannot be ruled out. Clearly, it would have been preferable to treat twin trawls and single trawls individually in model 2, but these two trawl types are not distinguishable in the logbook data. Whether this is a substantial shortcoming of model 2 is difficult to assess, because twin-trawl observations from the order books are scarce. An indication can, however, be obtained from a comparison of the two standardized indices (Figure 7). Given that the standardized indices are practically identical, it seems appropriate to assume that the 9.5% lpue increase per 100 hp found here was not substantially compromised by the lack of information on trawl type.

None of the area estimates were significantly different. This was unexpected, because important area effects have been reported for other crustacean fisheries (Hvingel *et al*., 2000; Maynou *et al*., 2003; Sbrana *et al*., 2003). However, the result is in line with a historically fairly even spatial distribution of the Danish *Pandalus* fishery. Although effort contractions towards areas closer to harbours have taken place recently (Figure 1), skippers and net manufacturers believe that economic drivers (decreasing *Pandalus* prices and increasing fuel prices) are the main drivers.

Considering that fleet renewal during the study period has been dramatic, it seems reasonable to assume that renewal must have been the major mechanism behind the observed development in nominal lpue. As both models resulted in similar biomass indices, this suggests that engine power (model 2) was sufficient to explain individual vessel effects (model 1). In other words, the bulk of the vessel-renewal effect on overall fleet fishing power was related to engine power and hence to trawl size. This interpretation of annual biomass indices from the two models is backed up by both the logbook analyses of engine power trends (Figure 3b) and the information provided by the industry on trawl developments. It also implies that other factors such as global positioning systems and track plotters (Robins *et al*., 1998; O'Neill *et al*., 2003) and skipper skills (Marchal *et al*., 2006) played a secondary, if any, role in fishing-power development of Danish *Pandalus* vessels.

Both models 1 and 2 had relatively high levels of unexplained variance (r^2 = 0.42 and 0.36, respectively). This was somewhat surprising given that the *Pandalus* fishery is a targeted fishery with fairly clean catches, which in theory should limit trip-to-trip variations resulting from tactical choices of the vessels, as seen in mixed-species fisheries (Quirijns *et al*., 2008). Although many previous cpue studies with similar modelling approaches have shown unexplained variation of up to 65% (e.g. Large, 1992), it might generate concern that comparable analyses of directed crustacean fisheries in the Mediterranean (Maynou *et al*., 2003; Sbrana *et al*., 2003) resulted in up to 87% of the variance being explained. To identify the sources of variability between *Pandalus* fishing operations, the industry was contacted. The main reason given was the sensitivity of the catch process to environmental factors such as turbidity, weather, and currents, in combination with the fact that shrimp do not keep well. A *Pandalus* vessel has a limited number of fishing days from the first day of a catch. Some of these days may yield low catches as a consequence of high density of algae or poor weather, but it is impossible to make up the poor fishing days because the trip cannot be continued beyond the retention period of the shrimp (typically 4 d). Consequently, the trip-to-trip variation in lpue can be quite large.

Standardization of the Danish cpue time-series demonstrated that disregarding fleet renewal and gear developments when using commercial fisheries data for assessment purposes can seriously bias the impression of stock health. The implications for management of the North Sea shrimp stock are straightforward: although the nominal lpue values for the past 20 years indicate a substantially increasing stock size, the standardized figures indicated a more stable stock, so necessitating a change in the basis of the advice on stock size. This result underscores the necessity of addressing technological developments when making stock inferences from trends in commercial catch-and-effort data, and the more stock management relies on commercial cpue trends, the more important this issue becomes. For the Danish *Pandalus* fishery, engine-power standardization based on industry information of the link between trawl size and vessel horsepower appears to be robust. This probably applies for a number of trawl fisheries worldwide, depending on target species, so the results support the current EU initiatives towards the use of kW-days, rather than fishing days, as a standard descriptor of effort in trawl fisheries.

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Chapter 4

Effort and catchability trends of a long line fishery influenced by technological development and shifting management systems

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(Manuscript)

Effort and catchability trends of a long line fishery influenced by technological development and shifting management systems

Ole Ritzau Eigaard, Bjarti Thomsen, Holger Hovgaard, Anders Nielsen and Adriaan Rijnsdorp

During an effort regulation period from 1996 to 2002 unregistered annual increases of 0.8% in effective effort (hooks fished per day) were demonstrated for the long line fishery on the Faroe Islands with linear regression analysis of logbook data. Annual increases in hooks fished per day were, however, even higher (1.9%) during a preceding total allowable catch regulated period (1994-1995) thereby invalidating an expectation of the 1996 shift in management regime (output control to input control) to have induced significant increases in effective effort. So rather than the management system in force, an ongoing technological development of the long line fishing process seems to be the principal driver of trends in effective effort. Across the entire examined period of three different management regimes from 1986-2002 the annual increase in effective effort was estimated to 1.3%. Interview data on technology were combined with logbook data and analysed with linear regression models to demonstrate substantial haddock (*Melanogrammus aeglefinus*) catch-per-unit-effort (cpue) increases of 49% as a result of skewed hooks and swivel line being introduced on the vessels, thereby illustrating the need to address the influence of technological development on catchability when attempting to balance fishing capacity and fish resources.

Keywords: catchability, effort regulation, fishing power, long line fishery, management regimes, technological development

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Introduction

The technological development in commercial fisheries often complicates efforts to balance capacity and resources by changing vessel fishing power (e.g. Branch *et al.*, 2006; Standal, 2005). The actual technologies and mechanisms influencing vessel fishing power are numerous and depend on both the catch process and the management regime in question. Previous studies have reported of changes in vessel fishing power caused by the introduction of global positioning systems (Robins *et al.*, 1998), twin trawl technology (Mahevas *et al.*, 2004) and engine power development (Rijnsdorp *et al.*, 2006) and some of the management systems that have been challenged by technological developments are: directed capacity plans (Pascoe *et al.*, 2001), catch quota restrictions (Daan, 1997) and technical regulations (Rijnsdorp *et al.*, 2008).

Many other factors than technological development challenge the management objectives of fisheries by changing vessel fishing power. Fishermen behaviour (e.g. changed fishing practices in response to regulations, price conditions or resource availability) can have an appreciable impact on catch efficiency (Squires and Kirkley, 1999; Marchal et al., 2006). Likewise technical interactions among various fleet segments are also important to integrate in management (Rijnsdorp et al., 2000; Ulrich, et al., 2001). Although important these other aspects effort and catchability trends are, however, only treated rudimentary in the following. The main subject of this paper is the understanding of technological development in fisheries, its influence on catch efficiency of fishing vessels, and the implications for a sustainable management of fisheries and fish resources.

The catch process and the management systems investigated is the Faroese long line fishery for cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). This fishery is currently regulated by an effort quota system but was previously regulated by a set of technical measures (1986-1993) and a total allowable catch system (1994-1995). Presently effort quotas are assigned to the long line vessel group in the form of a yearly number of fishing days intended to correspond to a target share of total annual catch (and total fishing mortality) of cod and haddock in Faroese waters. Ten years of experience with the effort quota system in function on the Faroe Islands point at a number of problems in relation to safeguarding the demersal fish stocks. Jákupsstovu *et al.* (2007) conclude that the initial as well as the current number of yearly fishing days allocated to the different vessel groups is too high to ensure a cod spawning stock biomass above safe biological limits.

A critical point of an effort regulation such as the Faroese is to ensure that the relationship between intended and realized catch is reasonably close to 1. In meeting this challenge it is important to consider changes in vessel fishing power (in the following defined by the two components ‘effective effort’ and ‘catchability’) brought along by technological development (Rijnsdorp et al., 2006; Martell and Walters, 2002). With the analyses and results presented in this paper we aim to examine the effects of technological development on fishing power of the Faroese long liners across three management systems [a technical measures system (TM), a total allowable catch system (TAC), and an effort regulation system (ER)] during a 17 year period from 1986-2002. The vessel group “large long liners” has a target share of 23% and 28% of the total Faroese catch of cod and haddock, respectively, and establishment of a more accurate linkage between nominal long line effort (currently measured as fishing days) and the resulting long line fishing mortality will enhance the chances of a more sustainable management of the Faroese cod and haddock stocks in the future.

Based on interview information from the long line skippers and existing literature on long line fishing power trends (e.g. Hovgaard and Lassen, 2000; Sainsbury, 1996) we hypothesize i) that increases in effective effort (defined as number of hooks fished per day) have taken place in the Faroese long line fishery, and ii) that technologically induced catchability increases (measured as weight of fish caught per hook) have also taken place during the examined period. These hypotheses are tested by combining interview data on technology uptake in the long line fleet from 1986 to 2002 with log book data on catch and effort for the same period. The conclusions are discussed in relation to the latest ten years failure of the effort regulation to meet the target shares for the large long liner vessel group, before more general inferences are drawn.

Figure 1. Depth and extent of the two main fishing grounds for the long liners. The Faroe Plateau ground is the shallow water (< app. 200 m depth) around the Faroe Islands and is separated from the shallow water on the Faroe Bank by a channel of deep water.

Materials and Methods

Fisheries management on the Faroe Islands

On June the first 1996 the Faroe Islands introduced an effort based management system. For all vessels targeting cod, haddock and saithe the effort system was based on individually transferable effort quotas (yearly fishing days) by vessel group (defined mainly by gear type and vessel size). Prior to the introduction of the effort system the Faroese fishery was regulated by a total allowable catch (TAC) regulation from 1st of September 1994 to 31st of May 1996, and before this by a set of technical measures: license limits, area restrictions for trawl fisheries, minimum mesh sizes, measures to protect juvenile fish and others. The TAC system was introduced as a consequence of cod, haddock and saithe stock collapses in the early 1990s, but due to mainly industry resistance it was replaced by the effort regulation of the demersal fishery already in 1996.

The Faroese cod and haddock stocks

ICES operates with two distinct cod stocks within area Vb (ICES, 2008): the Faroe Plateau cod (Vb_1) and the Faroe Bank cod (Vb_2) separated by the deep waters (> 500 metres depth) of the Faroe Bank channel (Figure 1). The Faroe Plateau cod stock is the larger in terms of both stock size and landings with an estimated spawning stock biomass (SSB) averaging close to 60 000 tonnes during the latest five decades and annual landings averaging close to 25 000 tonnes. Since 2003, however, the SSB has declined steeply and the advice from ICES is no fishing and development of a rebuilding plan. The Faroe Bank cod stock has no analytical assessment or biological reference points but survey indices indicate that the stock is severely depleted. Landings have declined steeply in the last three years from 5 500 tonnes in 2003 to only 500 tonnes in 2007, while exploitation ratios (proxy for fishing mortality) remains higher than average. Only one haddock stock is defined within area Vb (Vb1+Vb2) with an estimated SSB averaging app. 60 000 tonnes during the last five decades and annual landings averaging close to 15 000 tonnes yearly. From an all time high of 100 000 tonnes in 2003 the SSB has, however, declined steeply to only 42 000 tonnes in 2008, approaching the B_{pa} of 35 000 tonnes (ICES 2008).

The Faroese long line fishery

In 2007 the vessel group 'large long liners' (LLL) consisted of 25 vessels larger than 110 gross register tons. The target share of total annual Faroese catch of cod and haddock assigned to the large long liners is 23% and 28%, respectively. The average annual landing value of cod and haddock of the vessel group is estimated by Jákupsstovu *et al.* (2007) to be roughly 13 and 8 million Euros, respectively. Other economically important species for the large long liners are ling (*Molva molva*), blue ling (*Molva dipterygia*) and tusk (*Brosme brosme*). Typically, catches of these secondary species become more dominant during the summer period, May to September, when the availability of cod and haddock is lower and the long lines are set at larger depths. Practically no other species than cod and haddock are caught at depths less than 200 m, whereas secondary species become increasingly dominant with larger depths (Figure 2).

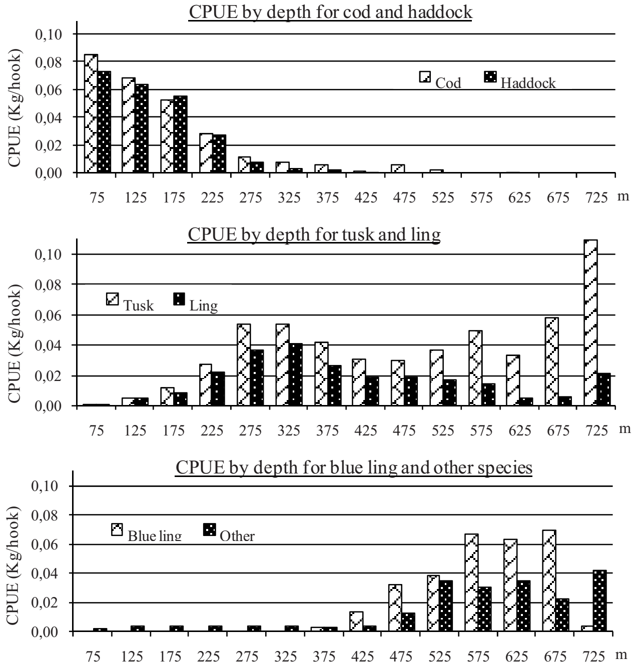

Figure 2. The average cpue (kg/hook) by species of the examined period (1986 -2002) calculated from catch and effort data from five large long liners.

Data material

The analyses and results presented are based on data from three sources. The first data source (data source 1) is a set of official catch and effort data for five large Faroese long line vessels covering the period 1986 to 2002. The five vessels, ranging from 30.7 meters to 38.6 meters in length, represent approximately 25% of the total group of large long line vessels of the period (19 licenses in 2002). This data set holds 13,688 observations of variables such as catch weight of individual species (cod, haddock, ling, blue ling and tusk), total catch weight, fishing depth, fishing area and the number of hooks set for each day fished in the 17 year period.

The second data source (data source 2) is the information from an interview program conducted by the Faroese Fisheries laboratory in 1997. This program aimed at retrospectively identifying technology acquired by vessels of the LLL group, and in particular technologies with marked effect on the catch efficiency in the long line fishery. The reports from interviews with the skippers of the five long line vessels described above were kindly made available to this analysis by the Faroese Fisheries Laboratory. The five vessels were picked out for the interviews based on their history of reliable and unbroken time series of logbook reportings (data source 1). The identified technological innovations, time span of introduction and their estimated effect on catchability are listed below, together with changes in gear deployment or fishing practice expected to affect the reliability of fishing days as a descriptor of effective effort (Table 1).

Table 1. Technological innovations, their prevalence, and estimated effect on catchability for five vessels belonging to the LLL group as informed in skippers interviews in 1997.

Innovation	Prevalence	Introduction	Catchability effect			Comments
			+	-	Blank	
Loran C	80%	1974-1978	2		2	
Auto baiter	100%	1978-1986			5	
Plotter	100%	1983-1989	1	1	3	
Skewed hooks	100%	1991-1995	4		1	Haddock
Swivel line	100%	1992-1995	4		1	Haddock
GPS	80%	1992-1994	1	2	1	
Stability tanks	40%	1995-1997		2		
Lines per day	100%	1976-1994			5	
Hooks per line	80%	1976-1994			4	

The third data source is the information from a questionnaire survey conducted by the Faroese Fisheries Laboratory in 2000 addressing catch efficiency change of the entire Faroese fleet. More than 200 skippers from a variety of vessel types such as trawlers, seiners, gillnetters and long liners responded to the questionnaire. The answers give an overview of when technological changes have been made to vessels and gears as well as the related efficiency change as estimated by the individual skippers. Technological innovations, time span of introduction and estimated catch improvements from skippers in the large long liner vessel group are listed below (Table 2).

Table 2. Technological innovations and their estimated effect on catch rates for vessels in the LLL group from a 2000 questionnaire survey covering the entire Faroese fleet.

Innovation	Answers (*)	Introduction	Range catch improvement	Mean catch improvement	Comments
Auto baiter	18 (9)	1978 - 1993	0 - 30%	16%	
Skewed hooks	17 (14)	1990 -1996	5 - 50%	21%	
Stability tanks	10 (5)	1991 - 1999	5 - 30%	13%	
Swivel line	17 (14)	1992 - 1996	10 - 50%	34%	Haddock
Snood line	5 (3)	1992 - 1996	10 - 20%	13%	
Line tec	3 (0)	1997 - 1999			
Others	1 (0)	1991			

(*) The numbers in brackets indicate the responders that gave an estimate of catch improvement. Some skippers said it was impossible to give a percentage as the fishery is affected by too many factors.

Key technologies affecting catchability and effort

The skipper interviews pointed at the swivel line and the skewed hooks as the most important innovations of the examined period (Figure 3). Four out of the five vessels estimated both innovations to have had positive effect on catchability. This evaluation was strongly backed by the questionnaire survey, where fourteen out of seventeen vessels having acquired skewed hooks and swivel line estimated the catch improvements to be on average 21% and 34%, respectively (Table 2). Both sources of information also pointed at haddock catch rates being influenced most by the two innovations.

Figure 3. The key long line developments of the study period: the transition from a straight to a skewed hook and from a fixed ganglion line attachment to a fully flexible swivel line.

Other widespread innovations identified from interviews and questionnaires are the Loran C navigation system, automatic baiters, global positioning systems (GPS), plotters and stability tanks. However, none of these technologies are broadly assessed across both sources to result in catch improvements (Table 1 and 2). Therefore we have focused the following analyses on identifying the cpue influence from the introduction of the swivel line and skewed hooks in the Faroese long line fishery.

In addition to identifying the key technologies expected to influence catchability, the interviews also established that all five vessels had implemented changes in gear deployment, which might have influenced the reliability of fishing days as a descriptor of effective effort (Table 1). This had taken place by either setting more - in some cases less - lines per day, by changing the ganglion distance and thereby the number of hooks on the lines, or by deploying longer or shorter lines. The motives behind the changes were not clearly stated in the interviews and no estimates of catch influence were given. It was, however, clear from the interviews that effective effort (hooks fished per day) had varied substantially during the period prior to the interviews.

Modelling variations in effective effort

The variation in average number of hooks fished per day of the five large long liners (data source 1) was analysed using a standard linear regression model (McCullagh and Nelder, 2005). Only trips to the two main fishing areas grounds of the large Faroese long liners, Vb1 and Vb2 (Figure 1), were included in the analysis. To exclude irregular fishing days, due to e.g. weather conditions or material break down, 106 fishing days with less than 10.000 hooks set were excluded from the data set (1.15% of the observations). To estimate the year to year changes in effective effort, the hook number fished per day (*E*) was modelled in response to a year factor (*Y)* as well as a vessel (*V*), and a depth (*D*) factor:

$$E_{ijk} = \beta_0 + Y_i + V_j + D_k + \varepsilon_{ijk} \qquad (1)$$

The model was parameterised on the basis of 1728 trips and 9,065 days of fishing. The number of hooks fished per day (*E*) varied from 10,000 to 57,000, *i* denotes the years from 1986-2002, *j* denotes the id-number of the five vessels and *k* denotes the depth fished ('<200m' and '>= 200m'). The error term (ε) is assumed to be normally distributed, N (0, σ^2/n), where n is the number of observations and σ^2 is the variance. The assumption of normality was validated by plotting the standardised residuals against the quartiles of standard normal distribution (QQ-plot). Homogeneity and independence were verified with plots of residuals versus fitted values and explanatory variables. The calculations were made using SAS software (SAS Institute Inc., 1996).

Modelling technological influence on catchability

To estimate how the key technologies of the examined period had influenced cod and haddock catchability the interview data on technological acquirements of the five long line vessels (data source 2) were merged with their log book data on catch and effort for the period 1986 to 2002 (data source 1).

It proved difficult to separately estimate the catchability influences from the two identified key technologies, swivel line (SL) and skewed hooks (SH), as they were introduced almost simultaneously, and in some cases together, on the individual vessels. We therefore decided to treat SL and SH as one joint technological acquirement (SL-SH) when merging the interview information on technology to the logbook information of catch and effort. Furthermore SL and SH were not purchased as single discrete events but gradually replaced existing lines and hooks during typically a 1-2 year period. To cover the time period where we were uncertain of whether (and to what degree) the individual vessels had introduced SL-SH we introduced of a category for transience "per" (perhaps) in addition to the two categories "yes" and "no" for the variable SL-SH in the merged data set. This approach resulted in the following categories being applied to each observation in the logbook data set depending on observation year: observations before any introduction of SL-SH were assigned a "no", years after 100% introduction were assigned a "yes", and years in between were assigned a "per".

To ensure that cod and haddock was the main target species of the trips modelled only observations with the lines set at maximum 200 metres depth were included (Figure 2). Furthermore all catch observations from ICES squares outside the Faroe Plateau and the Faroe Bank were excluded as were all observations without a specified hook number.

The combined data set was used for analysing variation in cpue values [kilo/hook/day (C)] in response to five factors: key technologies [SL-SH (*K*)], year (*Y*), area (*A*), vessel (*V*) and month (*M*) using multiplicative modelling (McCullagh and Nelder, 2005).

Industry information pointed at the vessels being able, to some extent, to target either cod or haddock in the individual sets through choice of bait and location. To take into account possible cpue bias from sets where the "other" species was the main target, cod and haddock cpue's were treated separately in two models (cod in model 2a and haddock in model 2b) and catch weight of the "other" species was included in the models as a continuous variable (*O*), resulting in the following generic model:

$$\text{Log } C_{ijklmn} = \beta_0 + K_i + Y_j + A_k + V_l + M_m + \alpha O_n + \varepsilon_{ijklmn} \quad (2)$$

The models were parameterised on the basis of 6343 and 6233 cod and haddock catch reportings, respectively. The cpue values ranged from 0.001 to 0.529 kg/hook (cod) and 0.001 to 0.371 kg/hook (haddock). β_0 is the common fixed intercept and *i* denotes the three categories "yes", "per" and "no". Observation year varied from 1986 to 2002 (*j*), *k* denotes area (Vb_1 and Vb_2), *l* denotes the id-numbers of the five different vessels, *m* denotes the twelve months of a year and *n* denotes the catch weight of the "other" species ranging from 0 to 16 tonnes (cod) and 0 to 13 tonnes (haddock). The error term (ε) is assumed to be normally distributed, N (0, σ^2/n), where n is the number of observations and σ^2 is the variance. The assumption of normality was validated by plotting the standardised residuals against the quartiles of standard normal distribution (QQ-plot). Homogeneity and independence were verified with plots of residuals versus fitted values and explanatory variables. The calculations were made using the SAS software (SAS Institute Inc., 1996). As a further model control the antilog of the year factor estimates (assumed to reflect mainly the yearly stock variations) were plotted with the yearly ICES assessed Faroe Plateau Spawning Stock Biomass (SSB) of cod and haddock of the period (ICES 2008).

Results

Variance analysis of effective effort

The average number of hooks fished per day across the entire study period was 31 096 (Table 3) and there were significant differences (P<0.0001) between 10 of the 17 year factors estimated and plotted relative to 1986 (Figure 4). A linear fit to the individual year estimates resulted in a 1.3% annual average increase ($R^2 = 0.91$). This annual increase appears to occur gradually across the entire study-period and no obvious differences exist between the different management regimes (Figure 4). Possibly there is a flattening of the index curve towards the end of the ER-period but for this period as a whole there is an average annual increase of app. 0.8%. For the TAC-period the increase is app. 1.9%. Observing that there is also a four year period of zero growth in the beginning of the TM-period (app. 1.5% increase across entire period) it is doubtful whether the rates of increase can be said to differ significantly between the three management regimes.

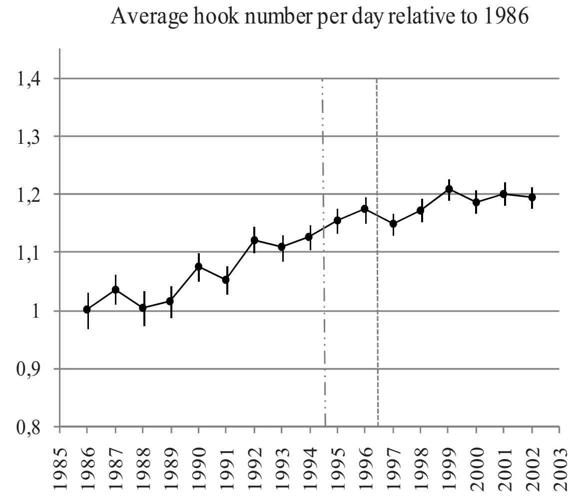

Figure 4. Estimates of year factors from model 1 indexed relative to 1986. The first vertical line (long dash dot dot) indicates introduction year of the TAC system and the second vertical line (dotted) indicates introduction of the effort regulation.

Only one vessel, vessel#3, set a significantly (P<0.0001) higher number of hooks per day (5.9%) compared to the others vessels, but in general the vessel group appears rather homogeneous with respect to the number of hooks fished per day (Table 3).

Almost 20% more hooks per day were set in the cod and haddock directed fishery (Depth < 200 m) than in the fishery for the secondary target species (Depth >= 200 m) (Table 3).

Table 3. Estimates of model 1 vessel and depth parameters and statistical test values (R-Square = 0.21).

Parameters	Estimate	Std. error	Pr < |t|
Intercept	31096	550	<.0001
VESSEL#1	-506	368	0.1696
VESSEL#2	-64	381	0.8669
VESSEL#3	1848	386	<.0001
VESSEL#4	1201	389	0.0021
VESSEL#5	0		
Depth < 200 m	2745	258	<.0001
Depth >= 200 m	0		

Variance analysis of cod and haddock cpue

Haddock cpue increased with 49% following full introduction of swivel line and skewed hooks (SL-SH) and 33% following partial introduction (Table 4), whereas cod cpue was not significantly influenced by either the partial or the full introduction of SL-SH (Table 5).

Table 4. Estimates of model 2b (Haddock) parameters and statistical test values (R=0.43). Estimates of year and month factors from the model are not included in the table but indexed relative to 2002 and graphed (Figure 5).

Parameter	Estimate	Std. Error (-)	Std. Error (+)	Pr > |t|
Intercept	0.10	0.00	0.00	<.0001
SL+SH - (No)	0.67	0.06	0.06	<.0001
SL+SH - (Per)	0.75	0.05	0.06	<.0001
SL+SH - (Yes)	1			
Faroe Plateau	1.09	0.02	0.03	<.0001
Faroe Bank	1			
Cod-tonnes	0.93	0.01	0.01	<.0001
VESSEL#1	0.79	0.02	0.02	<.0001
VESSEL#2	0.85	0.02	0.02	<.0001
VESSEL#3	1.19	0.04	0.04	<.0001
VESSEL#4	0.94	0.03	0.03	0.0356
VESSEL#5	1			

Table 5. Estimates of model 2a (Cod) parameters and statistical test values (R=0.42). Estimates of year and month factors from the model are not included in the table but indexed relative to 2002 and graphed (Figure 5).

Parameter	Estimate	Std. Error (-)	Std. Error (+)	Pr > |t|
Intercept	0.08	0.00	0.00	<.0001
SL+SH - (No)	1.05	0.10	0.11	0.6177
SL+SH - (Per)	1.13	0.08	0.09	0.1083
SL+SH - (Yes)	1			
Faroe Plateau	1.46	0.04	0.04	<.0001
Faroe Bank	1			
Haddock-tonnes	0.94	0.01	0.01	<.0001
VESSEL#1	0.90	0.03	0.03	0.0008
VESSEL#2	0.74	0.02	0.02	<.0001
VESSEL#3	1.12	0.04	0.04	0.0006
VESSEL#4	0.84	0.03	0.03	<.0001
VESSEL#5	1			

Cpue's were significantly higher on the Faroe Plateau compared to the Faroe Bank for both cod (46%) and haddock (9%). In both models catch weight of the "other" species had significant negative influence on cpue. Cod cpue was 6% lower with each 1 tonne increase in haddock catch of a trip and haddock cpue was 7% lower with each 1 tonne increase in cod catch (Table 4). There were cpue differences between most vessels with the largest difference being 33% for both species. Estimates of year and month factors from the models are not included in the table but indexed relative to 2002 and graphed (Figure 4 and 5).

The haddock cpue index, based on the antilog of the year factor estimates from model 2b, has an almost identical trajectory with the haddock SSB index, based on the annual ICES assessments (Figure 5, top), whereas the equivalent cod cpue and SSB indices show some divergence (Figure 5, bottom).

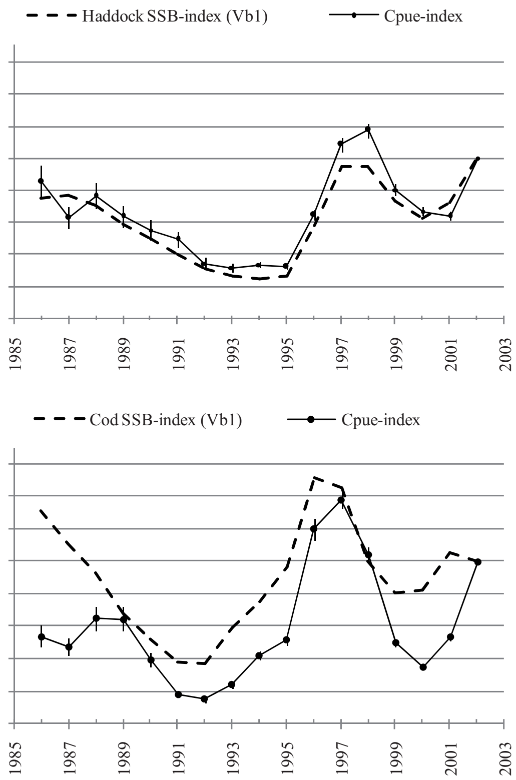

Figure. 5. Comparison of the estimated cpue year factors (Cpue-index) and the ICES assessed Faroe Plateau spawning stock biomass (SSB) of haddock (top) and cod (bottom).

Only moderate seasonal differences in cod and haddock cpue's exist, with a little higher haddock cpue's in the early spring and a little lower haddock cpue's in the early summer being estimated (Figure 6).

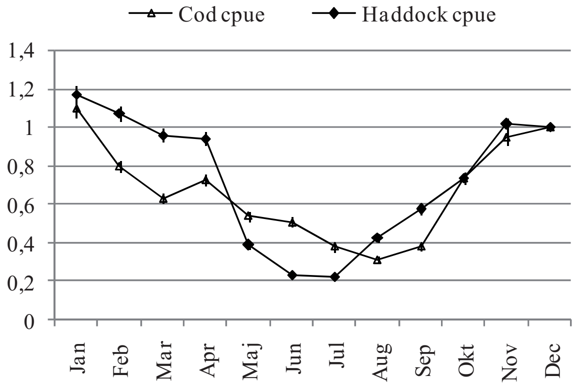

Figure. 6. Estimates of monthly cpue factors for cod and haddock.

Discussion

The state of the Faroese cod and haddock stocks has deteriorated during the last twenty-five years and the present effort regulation system, introduced in 1996, has not been able to change this development. We reasoned that in the case of the large long liners insufficient incorporation of increases in vessel fishing power brought along by technological development might be a shortcoming of the effort regulation system.

It was hypothesized that, owing to the poor quality of fishing days as descriptor of fishing effort, unregistered increases in effective effort (number of hooks fished per day) had taken place in the long line fishery. Modelling results confirmed unregistered annual effort increases of ca. 0.9% in the cod and haddock directed long line fishery during the ER period, thus explaining some of this regulations failure to achieve agreement between intended and realized cod catches. However, annual increases were higher during both the earlier management regimes, averaging ca. 1.9% in the TAC-period and ca. 1.5% in the TM period, and the general impressions is a rather gradual increase across the entire examined period (Figure 4). So, although undermining the intentions of the ER-system the annual increases in effective effort of the period are probably only to a limited degree a result of introducing the system. The observed increases in effective long line effort are rather a result of a continuous technological development in commercial fisheries (Hilborn and Sibert, 1988; Whitmarsh, 1990), and only to a lesser degree a result of the shifting Faroese management systems.

Catchability increases brought along by technological development were also hypothesized to have taken place during the examined period. Skipper interviews and questionnaires identified swivel line and skewed hooks as key technologies of the period in terms of influencing catch efficiency. Subsequent GLM modelling of single set cod and haddock cpue variations demonstrated that haddock cpue increased with 49% following full introduction of the swivel line and skewed hooks (Table 6), whereas cod cpue was not significantly altered. Such an estimate of cpue increase seems drastic and its reliability might be questioned. The questionnaire survey, however, informed of a 34% increase in haddock catchability from the swivel line and a non-species specific catchability increase of 21% from the skewed hooks, thereby supporting the 49% increase in haddock catchability estimated from the catch and effort data. Other investigations have also found significant increases from hook designs (e.g. Quinn et al., 1985; Skeide at al., 1986) and swivel line (Bjordal, 1989) and Sainsbury (1996) estimates a general 30-40% catchability increase in long line fisheries from improvements in hook design and swivel line.

A species specific effect was anticipated as skippers in both interview schemes had informed that haddock catchability was particularly affected (Table 1 and Table 2), but even so it was a little surprising that no effect at all could be observed for cod. It is, however, shown that cod and haddock behave differently when taking the bait. Haddock is characterized by biting repeatedly and carefully at parts of the bait, whereas cod completely ingests the bait thereby increasing the probability of being hooked (Løkkeborg *et al.,* 1989). It is therefore not unlikely that the skewness of the hooks in combination with the easy mobility of the swivel line significantly increased the hooking success for the carefully biting haddock, but only had very limited effect on the hooking success for the much more aggressively biting cod.

Although the analysed key technologies did not influence cod catchability, the significant result for haddock gives credibility to the general concept of catchability increases from technological development in commercial fisheries - also for cod catches of the Faroese long liners -, which is demonstrated in other studies (e.g. Eigaard, 2009; Marchal *et al.,* 2007). Possibly some of the technologies not consistently informed across both interview schemes (and therefore not subject to analyses) might very well also have increased target species catchability. GPS and plotters could be such technologies and have been demonstrated to bring along catchability increases in e.g. the Northern Prawn fishery in Australia (O'Neill *et al.*, 2006; Robins et al. 1998).

Vessel, year and season effects

Cpue values varied up to 33% between vessels for both species, which was a little unexpected as many vessel differences (e.g. vessel size and number of hooks set per day) in theory are ruled out by calculating the catch weight by each hook. Possibly, differences in main fishing area of the boats result in different size composition of the cod and haddock catches, thus explaining cpue differences when measured in weight. Any variations in bait choice (type and size) between the vessels can also lead to differences in size composition of the cod and haddock caught (Lokkeborg 1990). Another explanation might be variations in skipper skills and crew experience, which has been shown to significantly influence efficiency in other fisheries (e.g. Branch *et al.*, 2006; Marchal *et al.*, 2006). Confirmation of this mechanism also influencing long line vessel catchability was obtained from the skipper interviews, where one skipper considered the transition to a different rotation system of the crew to have increased catches. An expansion of the associated crew from 12 to 15 and a shift from 12 days fishing and 6 days home to 6 days fishing and 6 days home, had improved the crew performance, which ultimately had lead to a an increase in catch per hook explained by more careful treatment of machinery, lines, hooks, baits and catch.

The estimated cod cpue index of the period showed relatively poor agreement with the cod SSB index (Figure 5, bottom), whereas for haddock the cpue index and the SSB index had almost identical trajectories (Figure 5 top). Possibly the overlap between the length sizes included in the SSB and the length sizes of the commercial landings is less for cod than for haddock. If for instance the smaller mature cod are discarded and therefore omitted from the catch data, or if they have very low availability due to e.g. environmental conditions or bait size, the cpue-index would have lower values than the SSB index as observed for cod (Figure 5, bottom). Another explanation for the cod cpue index falling somewhat lower than the SSB index could be under- and misreporting of cod landings which is known to have taken place in certain periods of the index time span (Jákupsstovu *et al.*, 2007). In any case the index discrepancies for cod are not severe enough to discredit model 2 and the almost identical index trajectories for haddock support the validity of the model formulation.

Some seasonal differences in cod and haddock cpue's were found indicating that the vessels might separately target either of the two species. It is possible to some degree by choice of bait to more specifically target either cod or haddock (Løkkeborg 1992) and the estimation of a significant negative "other" species effect puts doubt to the assumption that the Faroese vessels in general conduct a combined cod and haddock fishery and indicate that the two species are targeted separately.

Management implications

According to the results described great care should be taken when defining the metric with which to manage fishing effort in an effort regulated system. We found a substantial discrepancy in the temporal development of the presently used Faroese effort descriptor, fishing days, and the number of hooks fished per day, which is more directly linked to the fishing mortality. This discrepancy between nominal and effective effort development no doubt explains part of the mismatch between intended and realized fishing mortality of the Faroese effort regulation.

Technologically induced catchability increases of the Faroese long liners is another mechanism, which appears to have played a very significant role in the decline of particularly the Faroese haddock stocks. Accepting that the estimated 49% percent catchability increase is in the right order of magnitude, this substantial result of two rather insignificant changes in line and hook design puts serious doubts to the ability of effort regulation to control fishing mortality.

It was, however, a little surprising that the mechanisms anticipated – and demonstrated - to have undermined the intentions of the Faroese effort regulation only to a limited degree were induced by the introduction of the system. The mechanisms were already in progress during previous management regimes and at a higher speed. So, although compromising the intentions of the effort regulation none of these mechanisms appear to be a direct reaction to the regime shift. More likely the effective effort and the catchability increases are results of a continuous process of technological development in commercial fisheries - a development which is presumably driven mainly by economic and technological processes and only to a lesser degree by whatever management system in force.

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Chapter 5

Refining capacity and effort descriptors: Engine power, trawl geometry, target species and trawl size of five European demersal fleets

Ole Ritzau Eigaard

(Manuscript)

Refining capacity and effort descriptors: Engine power, trawl geometry, target species and trawl size of five European demersal fleets

Ole Ritzau Eigaard

Based on information from an international inventory of gears currently deployed by trawlers in five EU countries, the relationship between vessel engine power and trawl size is quantified for different trawl types and trawling techniques. Using multiplicative modelling it is estimated that the circumference of pelagic trawl types targeting species such as blue whiting (*Micromesistius poutassou*) and sand eel (*Ammodytes marinus*) increases app. 44 meters with each 100 hp increase, whereas the increase for demersal trawl types targeting Nephrops (*Nephrops norvegicus*) and monkfish (*Lophius piscatorius*) is only app. 13 meters per 100 hp. The trawls used for pair trawling have a significantly ($P<0.001$) lower rate of circumference increase with horsepower of a factor 0.52 of that of both twin and single trawls. Underlying these results is the definition of four geometrically different trawl typologies and corresponding target species groups, driven by the assumption that the fishing mortality of a trawl gear is proportional to both the size and geometry of the trawl gear, and based on existing knowledge of the interactions between various target species and trawl gears during fishing.

Keywords: capacity, effort, engine power, fishing mortality, kilowatt days, trawl size, trawl type

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Introduction

Fleet or vessel fishing capacity is typically defined by a physical attribute such as total gross tonnage or engine power, but the harvesting potential of a vessel is also highly dependent on many other factors, including the gears deployed and on-board electronic equipment (e.g. Standal 2005; Eigaard 2009). These technological factors have often been ignored, but the refinement of fishing capacity and fishing effort descriptors is receiving growing scientific (e.g. Marchal *et al.*, 2007; Eigaard, 2010) and political attention (e.g. current EU initiatives towards the use of kilowatt days, rather than fishing days, as a standard descriptor of effort in trawl fisheries).

This study investigates the relationship between vessel engine power and vessel trawl size with the overall objective to enhance the understanding of how fishing mortality of different target species can be linked to standard measures of capacity and effort in European trawl fisheries. More precisely, we define four trawl typologies and four corresponding target species groups (pelagic, semi-pelagic, semi-demersal and demersal) and establish the relationship between vessel capacity (in terms of engine power) and vessel trawl size (in terms of circumference) depending on these four typologies. Furthermore the influence of three trawling techniques (single trawling, twin trawling and pair trawling) on this relationship is examined.

The analyses and results presented are driven by the assumption that the species specific fishing mortality of a trawl gear is closely linked to both the size and geometry of the trawl gear, and the definition of trawl typologies is based on existing knowledge of the interactions between various target species and trawl gears during fishing. These interactions have been subject to some research and most of the work so far has focused on fish behaviour behind the fishing line of the trawl (e.g. Thomsen, 1993; Ferro *et al.*, 2007; Krag, 2009), but some attention has also been given to fish behaviour at the fishing line (Engås and Godø, 1989; Ingólfsson and Jørgensen 2006) and ahead of the fishing line (Main and Sangster, 1981; Dickson, 1992). In this paper mainly results on gear/species interactions from the doors and to the trawl circumference, both included, have been considered in the definition of the four trawl typologies and corresponding target species groups.

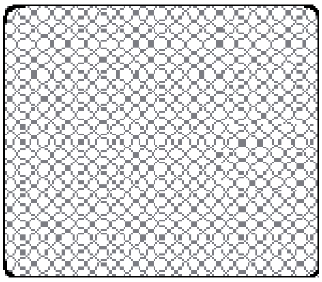
Materials and methods

Interview data

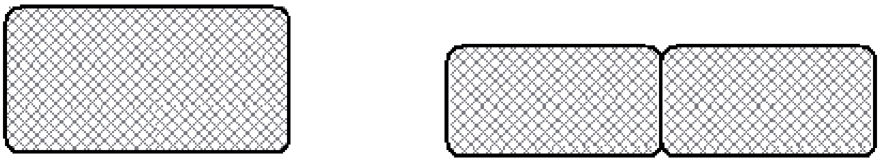
The data set used is the result of an initial benchmarking exercise in the EU-FP6-Project DEGREE (Development of Fishing Gears with Reduced Effects on the Environment). The project partners used harbour interviews to create an inventory of gears being deployed in their respective trawl fisheries. More than 350 interviews were made but only 206 observations from five countries (Norway [8], Ireland [50], Denmark [35], Faroe Islands [80] and Italy [33]) had sufficiently detailed information of: i) target species, ii) vessel horsepower, iii) trawling technique and iv) trawl circumference, to make them usable for this study. Despite the reduction of observation number, the final inventory data cover a broad selection of European trawl fishery in the North East Atlantic, the Mediterranean and the Baltic Sea. Vessel sizes ranged from 150 to 8000 hp and trawl sizes from 12 to 1232 metres in circumference.

Definition of trawl typologies and corresponding target species groups trawl geometries

The rationale behind the definition of the following four trawl typologies and corresponding target species groups is that the fishing mortality exerted by a trawl gear is very closely linked to trawl geometry as well as trawl size. Mesh number and mesh size in the circumference of a trawl is typically used to describe trawl size (e.g. Rahikainen and Kuikka, 2002; Eigaard, 2010), but the size of the circumference can be transferred differently into geometrical components such as height or width of the trawl mouth. Based on personal communications with net makers and fishermen and reflections on how trawl geometry, ground gear and mesh sizes are best matched to the behaviour and size of target species, four trawl types were defined: 1) Pelagic trawls with focus on trawl mouth area and no limitations on the applicability of large mesh sizes in the trawl body [pelagic and semi-pelagic species, which are herded by the large meshes of wings and front trawl body such as blue whiting (*Micromesistius poutassou*) and sand eel (*Ammodytes marinus*)], 2) Semi-pelagic trawls with focus on mouth area, but restricted by the necessity of small meshes in the trawl body [semi-pelagic and pelagic species, which are not herded such as shrimp (*Pandalus Borealis*)], 3) Semi-demersal trawls with main focus on door spread and some on trawl height [demersal species, herded by doors and sweeps such as cod (*Gadus Morhua*) and haddock (*Melanogrammus Aeglefinus*)], and 4) Demersal trawls with focus on wingend spread [demersal species, which are not herded such as Nephrops (*Nephrops norvegicus*)].

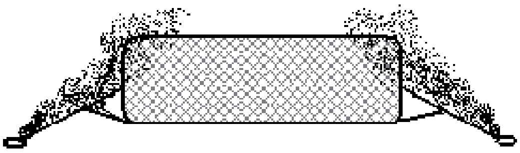


1. (PE) Pelagic trawl

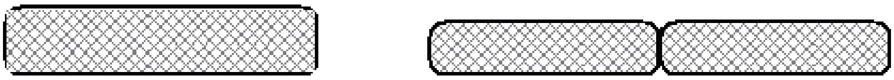


2. (SP) Semi-pelagic trawl

Semi-pelagic twin trawl



3. (SD) Semi-demersal trawl (herding)



4. (DE) Demersal trawl

Demersal twin trawl

Figure 1. Trawl types defined: Pelagic (PE), Semi-pelagic (SP), Semi-demersal (SD) and Demersal (DE). Where relevant both single and twin trawls are depicted.

Assignment of observations to the four trawl typologies by target species informed

Table 1. Target species and groups as assigned to the four trawl types by country.

Trawl type	Target species	Denmark	Faroe Islands	Ireland	Italy	Norway
Pelagic	Blue Whiting					1
	Sand eel	6				3
Semi-pelagic	Pandalus	2	4			
Semi-demersal	Cod	13				
	Cod-Saithe-Haddock		27			
	Norway pout	1				2
	Saithe					
	Scabbard Fish		3			
	Whitefish			10		
	Whitefish-Deepwaterfish			2		
	MixDemersal		11			
	Mixdemersal-Flatfish		32			
	Mixdemersal-Flatfish-NN				33	
	Monkfish-Whitefish			3		
	Greenland Halibut		3			
	Plaice	3				
	Monkfish			1		
Demersal	Nephrops	10		14		2
	Nephrops-Monkfish			17		
	Nephrops-Whitefish			3		
		35	80	50	33	8

Based on available literature (e.g. Fernö an Olsen. 1994; Bublitz, 1996; Sangster and Breen, 1998) and contemplations within the group of gear technologists on the species specific interactions between fish/crustaceans and trawl gear during the capture process, each inventory observation was assigned to one of the four conceptual trawl types according to target species informed (Table 1). The available trawl data were distributed a little uneven in relation to the four trawl typologies, as the demersal and semi-demersal trawl types made up app. 90 % of the data set and pelagic and semi-pelagic trawls only app. 10%.

Verification of trawl types and target species assignment

The feasibility of how the inventory observations were assigned to the four trawl typologies by the target species informed (Table 1) was evaluated by calculating the ratio of the circumference to ground gear length for each trawl and plotting these values by trawl type. Only 132 observations had sufficiently detailed ground gear information to allow this exercise, but the impression from the plot (Figure 2), that a categorisation based on conceptual geometric differences is reasonable for these 132 observations, is extrapolated to the additional 74 observations of the data set. The pelagic trawl types display a substantially higher ratio of circumference/ground-gear ratio (5.4-5.7), whereas the difference in ratio values between the other three trawl types is more subtle and values slightly overlapping: demersal (0.3-1.4), semi-demersal (0.7-3.5), semipelagic (3.4-3.7).

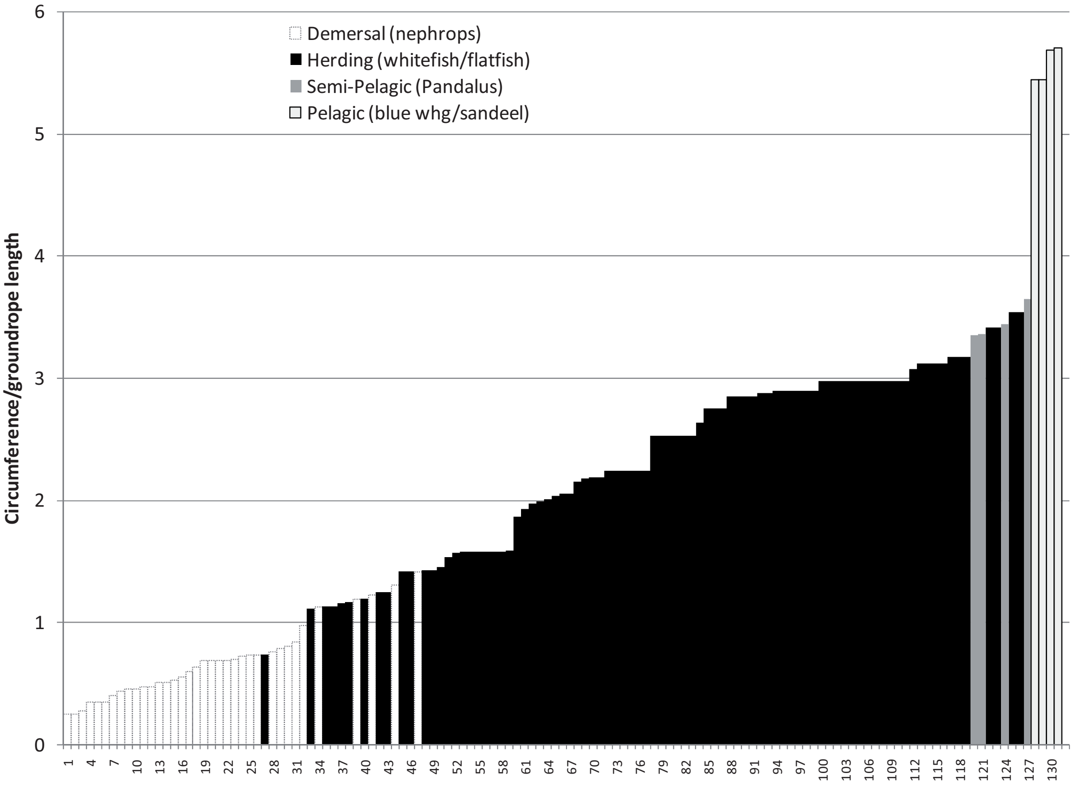


Figure 2. The ratio of the circumference to ground gear length by target species group for 130 trawl observations of the inventory.

Trawling techniques

The *single trawl* technique is the most widespread demersal trawling technique of the data set (136 of the observations) and is often used for demersal fish species, which react to the sand and mud clouds from the doors and the presence of the sweeps and bridles (can be herded). In such fisheries the door spread (and only to a lesser degree, the wing end spread of the trawl itself) is an important parameter affecting catchability, but also trawl height can be important as some fish species are believed to have an upwards escapement behaviour when approaching the fishing line. Single trawls are also well suited for semi-pelagic and pelagic trawls, where focus is on both trawl width and height (Sainsbury, 1996).

The main benefit from using the *twin trawl* technique (47 of the observations) is the ability to increase the wing end distance/swept area of the trawl deployed without proportionally enlarging the posterior of the gear, in which case the drag resistance would become inconveniently large. This is done by deploying two juxtaposed smaller trawls rather than one wider (and also higher and longer and heavier to drag) trawl. In other words twin trawls enable you to increase trawl width (with app. one third) without also increasing height and length and towing resistance (Sainsbury, 1996). This exercise is most useful in trawl fisheries targeting species closely associated to the bottom, which are not herded by the sweeps, and which are not liable to escape above the headline of the trawl. Species such as Nephrops and monkfish fall into this category (Sangster and Breen, 1998). Occasionally semipelagic shrimp trawls are also fished as twin rigs by Irish, Danish and British fishermen (Sainsbury, 1996; Eigaard 2010).

The *pair trawling* technique (23 of the observations) supposedly increases catchability compared to single trawling with the same gear under certain conditions. This is the case when fishing at low depths for demersal species, or when schools of pelagic species are located close to the surface. A single vessel directly in front of the trawl risks scaring the fish, whereas two vessels on each side of the trawl are believed to herd the fish (Sainsbury, 1996). This is also the case when fishing at larger depths where it is possible to increase the swept area by deploying very long sweeps, but of course this advantage only goes for target species which respond to sweeps and bridles ("herdable" species). Fuel savings can also be expected as a result of avoiding the drag resistance from the doors as well as a lower optimal trawling speed when pair trawling. In some cases the trawl deployed during pair trawling is up scaled to match the combined engine power of the two vessels (Sainsbury, 1996).

Modelling of circumference per hp depending on trawl type, trawling technique and country

To statistically analyse the influence of trawl type and trawling technique on the relationship between vessel horsepower and trawl circumference multiplicative modelling - traditionally used for cpue estimation and standardisation (Robson 1966; Large 1992; Maunder and Punt 2004) - was applied. The circumference observations were standardised by horsepower. The length of circumference in metres per vessel horsepower (mchp) was calculated for each observation (for pair trawls the circumference was divided by the combined horsepower of the two vessels) and the following log transformed multiplicative model was parameterised on the basis of the 206 inventory observations:

$$E[\mathrm{Log}(\mathrm{mchp}_{ijk})] = u + \mathit{trawl\text{-}type}_i + \mathit{trawl\text{-}technique}_j + \mathit{country}_k + \varepsilon_{ijk} \qquad (1)$$

The meters of circumference per vessel horsepower (mchp) varied from 0.01 to 0.45, u is the overall mean circumference per horsepower, i denotes the four defined trawl types [pelagic (PE), semi-pelagic (SP), semi-demersal (SD) and demersal (DE)), j denotes the three trawling techniques (pair trawl (Tp), single trawl (Ts) and twin trawl (Tt)] and k denotes the five countries of the data set (Denmark (DK), Faroe Islands (FI), Italy (I), Ireland (IR) and Norway (NO)]. The error term ε is assumed to be normally distributed N $(0, \sigma^2/n)$, where n is the number of observations and σ^2 is the variance. The assumption of normality was validated by plotting the standardised residuals against the quartiles of standard normal distribution (QQ-plot). Homogeneity and independence were verified with plots of residuals versus fitted values and explanatory variables. The calculations were made using SAS software (SAS Institute Inc., 1996).The R-square value of the model run was 0.35.

Results

A plot of trawl circumference against vessel horsepower by trawl type indicates that, within the range of vessel horsepower observations examined, a linear increase by trawl type fits the data reasonably well (Figure 3). The plot also shows that pelagic trawl circumference has a substantially higher rate of increase with increasing horsepower than the three other trawl types. Possibly semi-pelagic trawl circumference increases at a slightly higher rate than demersal and semi-demersal trawl circumference, but this difference is less pronounced.

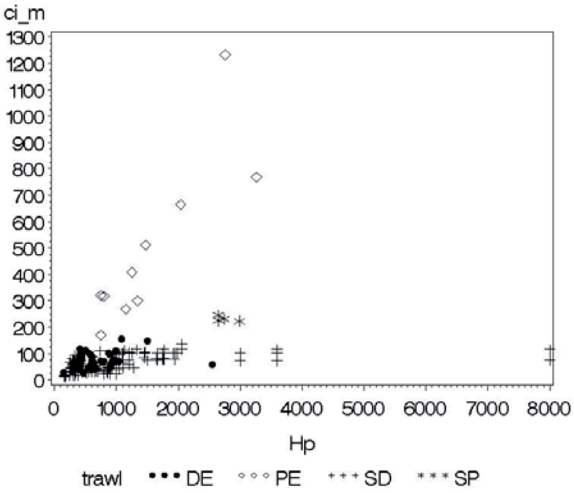


Figure 3. Trawl circumference against vessel horsepower by trawl type: demersal (dots), pelagic (diamonds), semi-demersal (plusses) and semi-pelagic (stars).

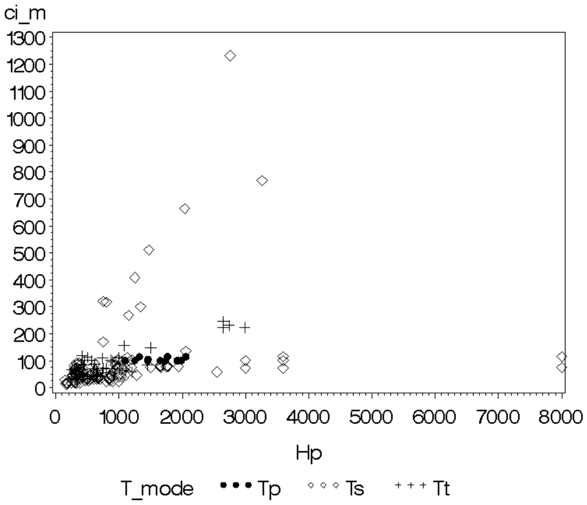


Figure 4. Trawl circumference against vessel horsepower by trawling technique (pair trawling (dots), single trawling (diamonds) and twin trawling (plusses).

A plot of trawl circumference against vessel horsepower by trawling technique (Figure 4) indicates that, within the range of vessel horsepower observations examined, a linear increase fits the data reasonably well for twin and pair trawls, whereas the single trawls clearly display two separate - reasonably linear - relationships, presumably one for the pelagic and one for the none-pelagic single trawls. It seems twin trawl circumference increases at a slightly higher rate than pair trawl circumference, but any difference is not pronounced. For the pair trawling observations the combined horsepower of the two vessels are used.

Modelling results

The overall mean circumference per horsepower (mchp) was estimated to 0.13 meters and the circumference of the pelagic trawls was estimated to be a factor 3.37 (P<0.01) higher than the three other trawl types, which were not significantly different from each other (Table 2). Trawling technique had significant influence (P<0.01) on the circumference per horsepower in that the effect of pair trawls was a factor 0.51 of the twin trawl effect. The model run also indicated (P=0.02) that the single trawl effect (0.76) was lower than the twin trawl but higher than the pair trawl effect. The country estimates were not significantly different from each other although there are indications (P= 0.02) that Italian trawls have slightly less circumference per horsepower than the other four countries (0.57).

Table 2. Model (1) parameter estimates and statistical test values (R-Square = 0.35).

Parameter		Estimate	(+) Std. Error	(-) Std. Error	Pr > |t|
Intercept		0.13	0.05	0.04	<0.01
Country	DK	0.87	0.22	0.18	0.535
Country	FI	1.08	0.30	0.23	0.751
Country	I	0.57	0.16	0.13	0.025
Country	IR	1.13	0.31	0.24	0.618
Country	NO	1.00			
trawl	DE	0.86	0.26	0.20	0.58
trawl	PE	3.37	1.30	0.94	<.001
trawl	SD	0.89	0.25	0.19	0.64
trawl	SP	1.00			
T_mode	Tp	0.52	0.10	0.09	<.001
T_mode	Ts	0.77	0.10	0.09	0.034
T_mode	Tt	1.00			

Discussion

Trawl types in relation to circumference and catchability

The ‘pelagic’ trawl type had a significantly larger effect on the mchp value (a factor 3.37) when compared to the other three types (Table 2). This result was anticipated from the plot in Figure 2 and also from considerations of species-gear interactions of the four defined trawl types. Logically trawl circumference and trawl catchability are closely linked for the ‘pelagic’ trawls, and it seems reasonable to assume that the larger water volume you can trawl – the more catch of e.g. herring (*Clupea Harengus*) or mackerel (*Scomber scombrus*) schools you get. However, this linkage between trawl size and catch quantity presumably has some upper trawl size limit given by school sizes and distributions, fish behaviour, and some physical restrictions of vessel loading capacity or gear handling capacity. Equally important is, that the herding behaviour of many pelagic species (Wardle, 1993) allows for the use of very large meshes in the front part of a pelagic trawl without losing potential catch. This enables the construction of trawls with a very large circumference but without a proportionally large drag resistance of the netting material (Rahikainen and Kuikka, 2002).

In theory the pelagic principle of how trawl circumference/swept volume is linked to catch quantity also applies to the trawl type we have defined as 'semi-pelagic', where aggregations of species such as shrimp are targeted. The principles of pelagic trawl design cannot, however, be directly transferred, because the semi-pelagic target species are not herded by large meshes in the front part of the trawl. This necessitates the use of relatively small meshes throughout the semi-pelagic trawl, which imposes high drag resistance on the gear. This fact constrains the rate of circumference increase with horsepower, as demonstrated by the modelling results where the rate of increase is significantly lower for semi-pelagic than for pelagic trawls (Table 2).

The linkage between trawl circumference and catch quantity becomes less straight forward when moving from pelagic and semi-pelagic trawls to 'semi-demersal' trawls, because focus shifts from fished volume to swept area. Demersal fish species which live at, or close to, the bottom such as cod, haddock, saithe and many flatfish are targeted with this trawl type and therefore trawl width becomes more, and height less, important in the design of semi-demersal trawls. Height cannot, however be completely ignored as some target species such as haddock are liable to escape above the headline of the trawl (Main and Sangster, 1981; Engås *et al.*, 1998). Furthermore it is not only the dimensions of the trawl mouth that control catch quantity, also the doors, sweeps and bridles become important by virtue of their herding abilities. For many demersal species the sand and mud clouds from the doors (Figure 1), and the physical presence and disturbance of the sweeps, herd fish from the doors to the centre of the trawl (Main and Sangster, 1981; Sangster and Breen, 1998). In theory, if the herding effect is significant, the trawl size itself becomes almost insignificant compared to the area swept (between the doors) and the length of the sweeps and based on this we would actually expect a lower rate of increase for this trawl type. The model (1) estimates are in fact lower (0.90) for semi-demersal trawls compared to semi-pelagic trawls, but this difference is far from significant (P=0.67). Probably this is a result of many fisheries being mixed, so that both demersal (Nephrops) and semi-demersal (roundfish/flatfish) species are fished with hybrid trawls that are not optimal for either target species group.

For the 'demersal' trawls the main target species is Nephrops. No significant herding from either doors/sweeps or the front meshes of the trawl takes place, which means that the focus of trawl design is on obtaining as much trawl width/wingend spread as possible (Sainsbury, 1996; Sangster and Breen, 1998). The most straight forward means to achieve this objective is to make as large and flat a trawl as possible. Based on this, the rate of circumference increase with horsepower was expected to be lower than for the pelagic trawls and comparable to the semi-pelagic trawls, which is in fact what the model parameterisation showed (Table 2).

Trawling techniques in relation to circumference and catchability

The principles for the interactions between target species and trawl types described above are based on the single trawl technique. The influence from the twin and pair trawling techniques on the circumference-horsepower relationship, should be viewed as a means of modifying/improving the single trawl technique towards the gear features in focus, such as increased trawl width or door spread, depending on trawl type and target species.

The main potential benefit from twin trawling is that it enables an increase of trawl width, without proportionally increasing trawl height and length and consequently trawl drag resistance (Sainsbury, 1996). In theory twin trawling should also bring along some enlargement of the total trawl circumference without proportionally enlarging trawl drag resistance, which might then be translated into a higher mchp value for twin than for single trawls. The parameter estimates of the two techniques were, however, not significantly different (Table 2), although the model results strongly indicate (P=0.02) that that the single trawl mchp value is smaller than of that of twin trawls (a factor 0.76). This not quite s ignificant result might be explained by the twin trawl technique imposing increases in gear drag resistance from the clump between the twin trawls and from the more comprehensive rigging requirements.

It was a little surprising that the circumference per hp of the pair trawlers was much lower (0.52) than that of the other trawling techniques. The expectation was that in many cases the trawls deployed during pair trawling would be up scaled to match the combined engine power of the two vessels (Sainsbury, 1996), but apparently the other benefits of the technique (e.g. herding from longer sweeps and fuels savings) have been solely in focus for the vessels in the data set.

Management implications

The quantification of trawl circumference increase with horsepower across trawl types, trawling techniques and EU countries gives support to the introduction of kilowatt days, rather than fishing days, as standard effort descriptor in fisheries management. The results do, however, also point at the need to explore this measure further, as clearly the linkage between vessel horsepower, trawl circumference and trawl catchability is not uniform across the four target species groups analysed (e.g. app. 44

metres circumference increase for each 100 hp for pelagic trawls and app. 14 metres for none-pelagic trawls). As discussed above pure trawl size (trawl circumference) is not the only key measure for establishing the gear catchability – geometry is equally important, and other gear components such as door spread and ground gear design can also play a significant role for catchability. This does not necessarily imply any serious flaws of kilowatt days as descriptor of effective effort, in that many of these other gear components, e.g. trawl door size, are also linked to horsepower. It does, however, put emphasis to the need of further investigations of the coupling of engine power to trawl gear size to fishing mortality, before any comprehensive effort management program can be expected to result in a sustainable European fishery.

Further research

A linear relationship between trawl circumference and horsepower seems feasible within the range of engine power observations available to this study. However, departures from this linearity due to e.g. the introduction of high performance netting or the presence of some functional limitation of trawl size at higher engine powers than the ones examined cannot be ruled out. Exploration of trawlsize-enginepower relations from various Scottish and Irish trawl fisheries showed very mixed results (ICES, 2009). The analyses suggested that a relationship exists for smaller vessels but that this breaks down for larger vessels and that a logarithmic fit is better than a linear.

Furthermore, the engine power-trawl circumference relationship is an integrated expression of many other gear components such as optimal trawling speed, door and ground gear drag resistance, netting resistance, and more (Sainsbury, 1996). Flume tank experiments with thirteen different trawls have shown that the drag resistance of wires varied from 2-8% of total gear resistance; doors from 11-27%; groundgear from 2-24%; netting from 39-95%; and floats from 1-7% (personal communication, Ulrik Jes Hansen, SINTEF, Denmark). Consequently an uniform enginepower-circumference relationship for all trawlfisheries is difficult to imagine. Therefore the definition and parameterisation of a mechanistic model of the relationship between engine power and circumference, depending on trawl type, which includes these gear components would certainly be valuable and worth pursuing. Analyses of historical flume tank data on the linkage between hp, trawl size, geometry and drag requirements from other parts of the gear could enable the definition of a predictive model of species specific fishing mortality of trawl gears, but unfortunately such work is beyond the scope of the present study.

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Chapter 6

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

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

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

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Introduction

Commercial fishers continuously adapt their activities to prevailing conditions by changing the physical inputs of production (technological development) and the way these inputs are used to harvest target species (tactical adaptation). There is evidence that the efficiency of fishing vessels has increased through technological creep. Quantifying the importance of fishers' reactions relies on an ability to define appropriate standardized effort measures, which itself depends on the detail of data available on fishing effort. Fishing effort is traditionally estimated by combining available physical measurements of fishing capacity (fixed production inputs) and fishing activity (variable production inputs). Fishing capacity is frequently approached by some physical attribute of the operating vessel (engine power, gross tonnage), but is also dependent on other factors, including gear technology and on-board equipment, which are often ignored. The introduction of new gear and technology includes both larger marked technological investments (e.g. acoustic fish-finding equipment, electronic navigation tools) and smaller stepwise improvements to the gear (e.g. stronger netting, changes in the design of trawl panels), which in themselves do not result in marked changes in a vessel's capacity but in combination cause a noticeable increase in capacity over time. Fishing activity is typically estimated by the duration of fishing trips. Such a definition ignores factors that potentially may impact fishing pressure, including the number and the sizes of gear deployed, or the effective time used for fishing.

A number of studies have been carried out to evaluate time variations in fishing efficiency (Cook and Armstrong, 1985; Millischer *et al.*, 1999; Marchal *et al.*, 2001, 2002). However, those studies did not investigate the extent to which such variations could be attributed to the technological development of fishing fleets. A number of other studies aimed to gain more insight into the key processes of technological creep. Such investigations were often based on the analysis of variations in either catch per unit effort (cpue) or catch value per unit effort (vpue), or profit, using a variety of modelling approaches ranging from simple general linearized models (GLMs) (Robson, 1966; Gavaris, 1980; Kimura, 1981; Hilborn, 1985) to more complex stochastic production frontier (Pascoe *et al.*, 2001) or multi-output distance functions (Squires, 1987; Squires and Kirkley, 1996). However, the scope of such approaches was generally restricted by vessel information available from logbooks, which typically includes engine power, vessel length, and/or gross tonnage.

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

Material and methods

Data

Collection of data on the evolution of fishing effort was carried out between April and October 2004 for the French fleets, between March 2004 and April 2005 for the Danish fleets, and

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

Type	Variable	Unit
General characteristics (hull, equipment)	Date of construction	DD/MM/YYYY
	Date of acquisition	DD/MM/YYYY
	Date of sale	DD/MM/YYYY or NA
	Overall length	m
	Tonnage	grt
	Main engine power	Hp
	Number of revolutions per minute	rpm
	Date of acquisition of engine	DD/MM/YYYY
	Maximum speed	Knots
	Bollard pull	Tonnes
	Crew size	Number
	Hull type (displacement, surfing, catamaran)	D/S/C
	Hull material (steel/aluminium/GRP/wood)	S/A/G/W
	Bulb	Yes/no
	Kort nozzle	Yes/no
	Storage room capacity	m^3
	Freezer room capacity	m^3
	Ice-making machine	Y/N
	Deck surface	m^2
	Variable pitch propeller	Yes/no
	Winch (or net hauler) capacity (power)	kW
	Winch (loading) capacity	m (of cable)
	Winch speed (or net hauler)	$m\ s^{-1}$ or rpm
	Number of winch drums	Number
	Number of net drums	Number
	Net-disentangling machine	Yes/no
	Net-washing machine	Yes/no
Electronics	GPS	Yes/no
	Facsimile	Yes/no
	Radar	Yes/no
	Shore/ship confidential communication	Yes/no
	Computer	Yes/no
	Charting software (dedicated plotter or computer)	Yes/no
	Number of sounders	Number
	Sounder 1 frequency	kHz
	Computer interface of sounder 1	Yes/no
	Sounder 2 frequency	kHz
	Computer interface of sounder 2	Yes/no
	Number of sonars	Number
	Sonar frequency	kHz
	Computer interface of sonar	Yes/no
Catch handling	Conveyor	Yes/no
	RSW system	Yes/no
	Container/Boxes on board	Yes/no
	Deck crane	Yes/no

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

Type	Variable	Unit
All gears	Gear unit	
	Number of fishing trips per year	number
	Number of days per fishing trip	days
	Number of fishing days per fishing trip	days
Trawls	Number of warps	2, 3, or NA if not trawl
	Number of panels	2, 4, 6, or NA if not trawl
	Yarn material	
	Yarn diameter in codend	mm
	Vertical opening	m or NA if not trawl
	Horizontal opening	m or NA if not trawl
	Mesh size of codend	mm or NA if not trawl
	Mesh size of wings	mm or NA if not trawl
	Length of headline	m or NA if not trawl
	Length of groundrope	m or NA if not trawl
	Type of groundrope	
	Rigging	
	Scanmar sensors	Y/N or NA if not trawl
	Trawleye (or netsonde)	Y/N or NA if not trawl
	Number of otter boards	0, 2, 4, or NA if not trawl
	Weight of otter boards	kg or NA if not trawl
	Average trawling speed	knots or NA if not trawl
	Selectivity device	
	Volume of water filtered per time unit	$m^3 s^{-1}$
	Number of hauls per fishing day	number or NA if not trawl
	Mean duration of a haul	h or NA if not trawl
Nets	Number of panels	number
	Smallest stretched mesh size	mm or NA if not net
	Stretched mesh size of the external panel	mm or NA if not net
	Net material	
	Total length of net set per fishing trip	m or NA if not net
	Total length of net set per fishing day	m or NA if not net
	Total height of net	m or NA if not net
	Soak time of nets	h or NA if not net
Seines	Diameter of seine rope	mm or NA if not seine
	Length of seine rope	m or NA if not seine
	Number of panels	2, 4, 6, or NA if not seine
	Yarn material	
	Yarn diameter in codend	mm
	Vertical opening	m or NA if not seine
	Horizontal opening	m or NA if not seine
	Mesh size of codend	mm or NA if not seine
	Mesh size of wings	mm or NA if not seine
	Length of headline	m or NA if not seine
	Length of groundrope	m or NA if not seine
	Type of groundrope	
	Rigging	
	Tickler chain	Y/N or NA if not seine
	Selectivity device	
	Number of hauls per fishing day	number or NA if not seine
	Mean duration of one haul	h or NA if not seine

Table 3. Details of the sampling procedure for the harbour enquiries for the French, Danish, and Basque fleets.

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

between June 2003 and February 2005 for the Spanish fleets. In France, the survey was conducted by seven technicians who interviewed a pre-selected sample of fishers located on the English Channel and Atlantic coasts, from Dunkerque to Bayonne. In Denmark, the survey was conducted by student employees and aimed at complete geographical coverage within the three vessel groups: demersal trawlers, gillnetters, and Danish seiners. In Spain, the survey was conducted in two harbours of the Basque Country, Ondarroa and Pasaia.

Generally, the first contact with fishers was by telephone, by which an appointment was arranged after obtaining his consent to answer the questionnaire. Interviews lasted between 30 min and

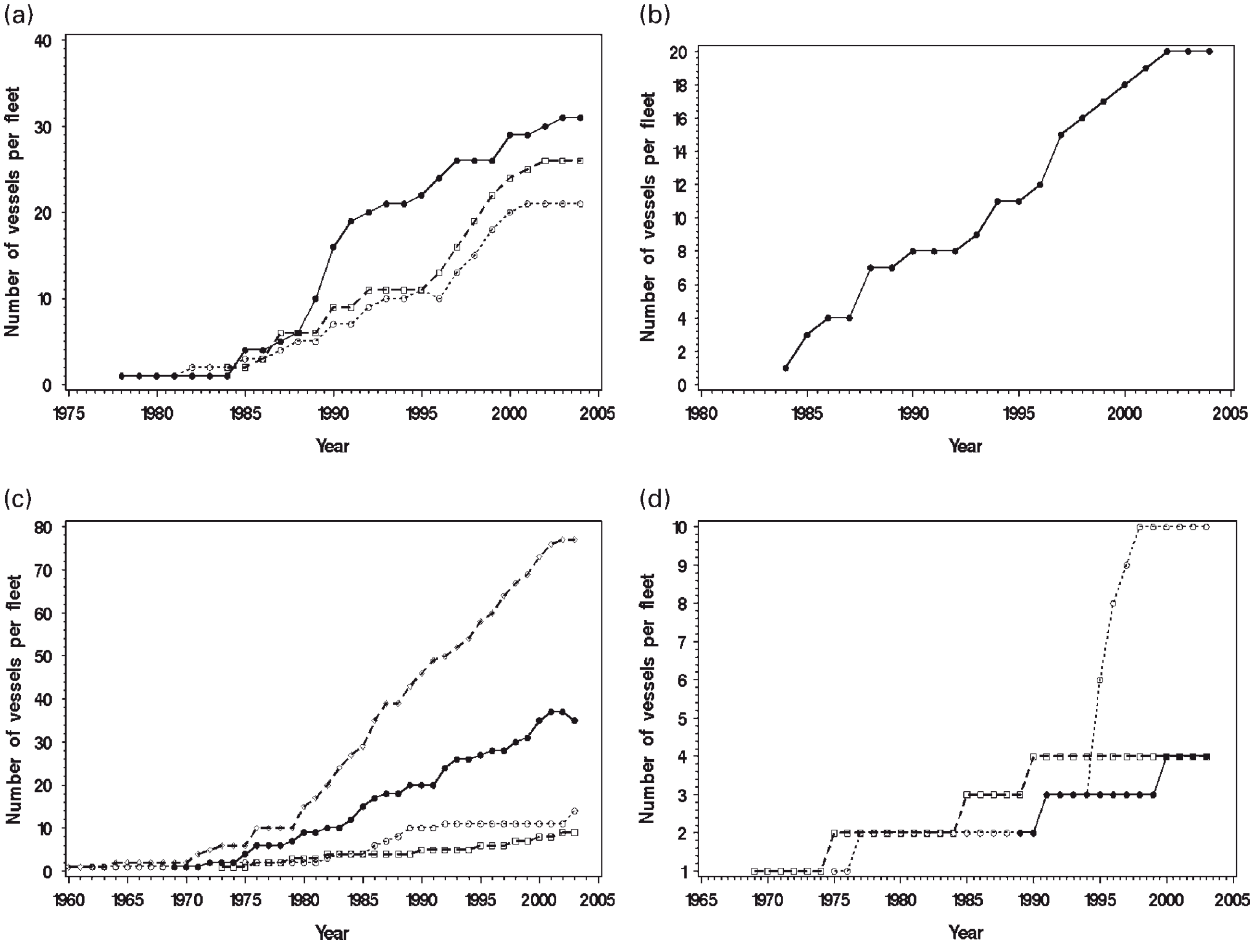

Figure 1. Number of vessels, by year, for which fishing effort data were recorded. (a) French otter trawlers (black dot, 12–16 m; circle, 16–20 m; square, 20–24 m), (b) French gillnetters, (c) Danish fleets (black dot, gillnetters; square, Danish seiners; diamond, trawlers; circle, others), and (d) Basque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

1 h. On rare occasions, contacts and interviews were done on return of the vessel to harbour after a fishing trip. The questionnaires were divided into three main sections. The first part concerned the vessel owner surveyed, evolution of his career, of previously owned vessels, and the different métiers practiced since 1985. The second part concerned the current vessel owned, and the evolution of key variables such as hull, engine, deck equipment, electronics, handling, and conservation of catches on-board, crew size and, for trawlers only, electronic devices used for monitoring the gear. Finally, the questionnaire collected information on the fishing gears, their evolution, and the fishing effort deployed. The study builds on the technological data collected through the second and the third parts of the questionnaires. The key variables fishers were asked to document are listed in Tables 1 (vessel attributes) and 2 (gear attributes).

In France, the best questionnaire returns were achieved for vessels registered in Bay of Biscay harbours and belonging to four fleet segments. These fleets are otter trawlers (12–16 m, 16–20 m, and 20–24 m) targeting Norway lobster (*Nephrops norvegicus*) and hake (*Merluccius merluccius*), and gillnetters (>12 m) targeting sole (*Solea solea*), hake, and anglerfish (*Lophius* spp.). In Denmark and Spain, the questionnaires were designed in a manner similar to the French ones, but minor adjustments were made to accommodate differences in vessel characteristic and target species among the fleets and countries. In Denmark, the return quality of the questionnaires was best for Danish otter trawlers, and all subsequent analyses have been based on that vessel group. The main targets of Danish otter trawlers were cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), and Norway lobster. In Spain, three Basque fleets were targeted: bottom trawlers of length 20–30 m registered in Ondarroa, bottom trawlers of length 30–40 m registered in Ondarroa, and bottom trawlers of length 30–40 m registered in Pasaia. The main target species of these three fleets were hake and anglerfish. However, as a consequence of relatively limited sampling during the surveys, the 20–30 m bottom trawlers registered in Ondarroa and the Pasaia bottom trawlers were excluded from further analyses. Table 3 and Figure 1 provide some details on sampling levels for the French, Danish, and Spanish fleets under investigation. Effort data for the French fleets could be traced back to the early 1980s, for the Spanish fleets to the early 1970s, and for the Danish fleets to the late 1950s.

In the fishing effort data set, each observation was a combination of one vessel and 1 year. A number of vessels used several gears during 1 year. For the French fleets, it was possible to identify which was the main gear used by each vessel throughout the year. For this fleet, therefore, the fishing-effort data set included the technological characteristics of both the fishing vessel and the

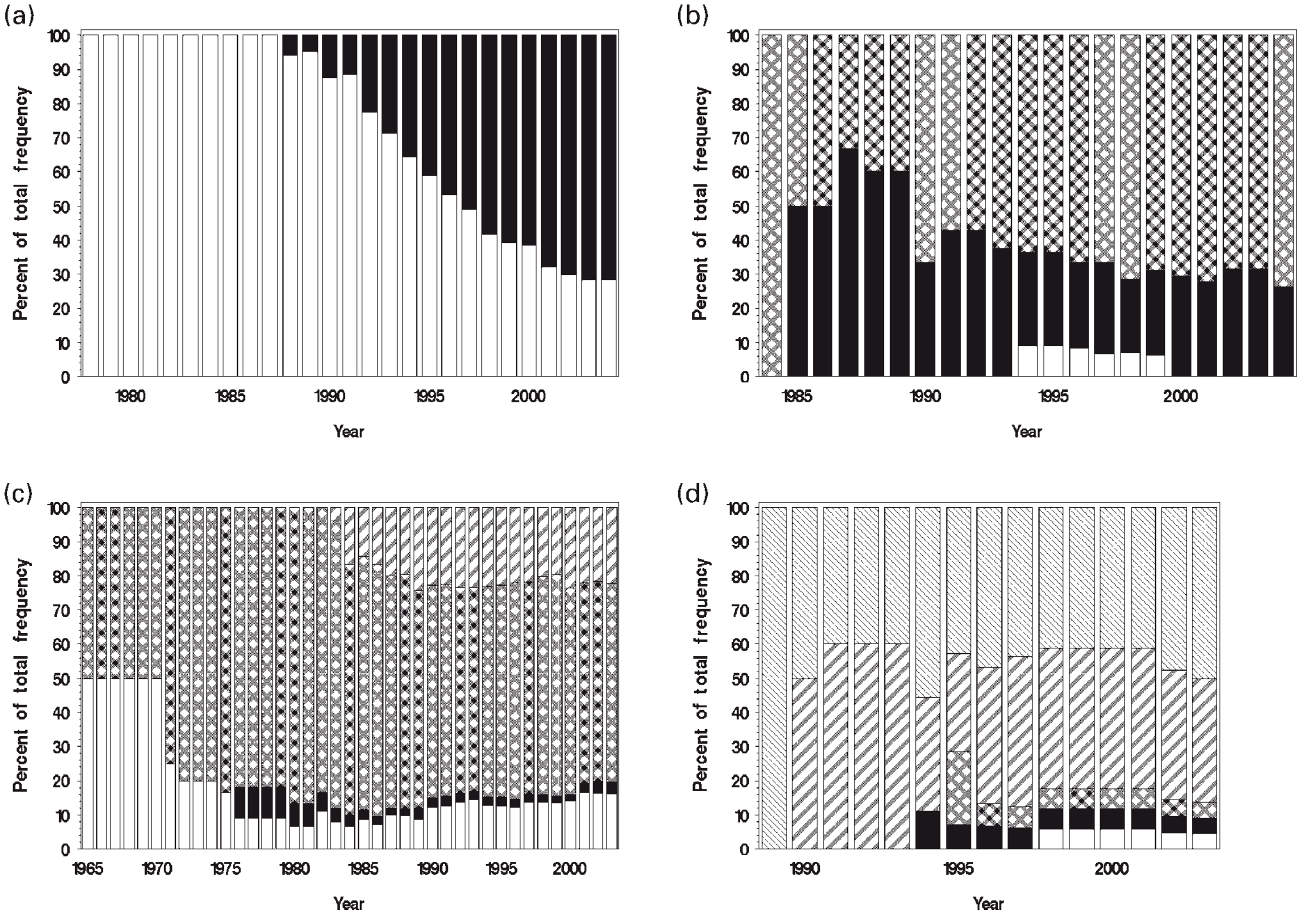

Figure 2. Annual changes in gear types for (a) French otter trawlers, all length classes (white, single otter trawls; black, twin trawls), (b) French gillnetters (white, drift nets; black, fixed nets; double-hatched, trammel-nets), (c) Danish otter trawlers (white, multi-rig trawls; black, pelagic trawls; double-hatched, single trawls; single-hatched, twin trawls), and (d) Basque bottom trawlers 30–40 m long registered in Ondarroa in 2003 (white, fixed nets; black, longlines; double-hatched, "Bou" otter trawls; thick single-hatched, single otter trawls; thin single-hatched, very high vertical opening bottom trawls).

main gear used. For the Danish and the Basque fleets, it was not possible to determine the gear most used, so only the vessel characteristics were included in the fishing effort data set.

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

Total international landings and estimated fishing mortality (*F*) by stock were derived from ICES advisory documents (ICES, 2003). The stocks investigated are Celtic Sea and Bay of Biscay anglerfish, North Sea cod, northern hake, Bay of Biscay Norway lobster, Celtic Sea Norway lobster, North Sea plaice, Bay of Biscay sole, Celtic Sea sole, and North Sea sole. Separate estimates of *F* were available for the two anglerfish species (*L. budegassa* and *L. piscatorius*), so a combined anglerfish fishing mortality was calculated by averaging the landings-weighted *F* of each species.

Data exploration and modelling

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

Catch rates (cpue), calculated for each vessel and each year, are modelled using GLMs (McCullagh and Nelder, 1989). Two models were considered. In model 1, the explained variable is cpue, which is assumed to follow a gamma distribution, and in model 2, the explained variable is ln(cpue), which is assumed to follow a normal distribution. To choose between these two models, the distribution of cpue was tested visually against a gamma distribution, using QQ plots, and the distribution of ln(cpue) was similarly tested against a normal distribution. The most appropriate combination of explained variable and probability distribution (cpue/gamma distribution, model type 1, or log-transformed cpue/normal distribution, model type 2) was selected. The link function was either Logarithm (model type 1) or Identity (model type 2).

The explanatory variables were year and the different descriptors of fishing effort. Some descriptors are discrete factors (e.g. gear unit), others are continuous variables (e.g. soak time). Assuming that technological creep is described by fishing effort variables, the "Year" effect may indicate annual abundance changes for the species (or combination of species) under

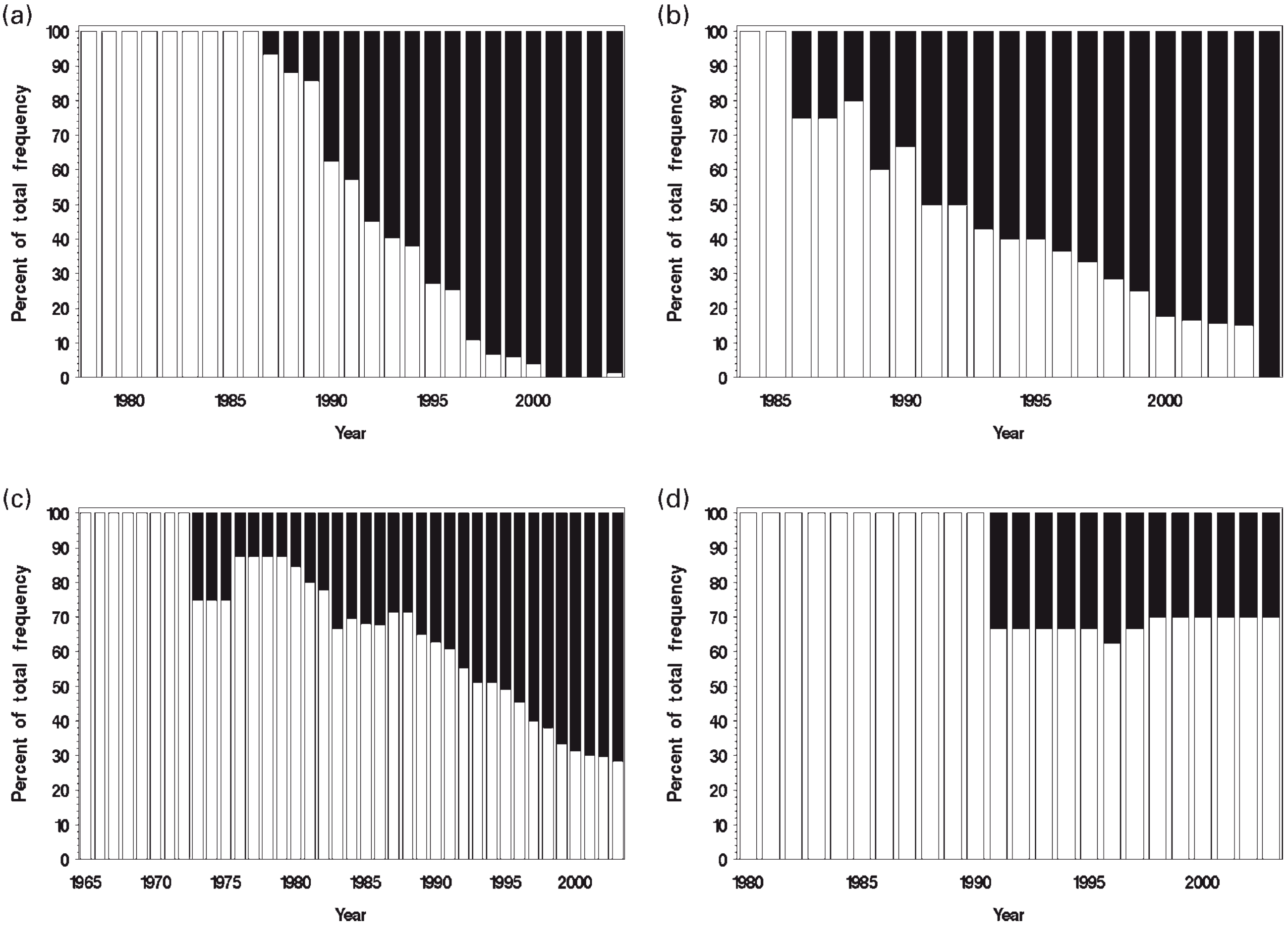

Figure 3. Annual changes in (a–c) GPS availability, and (d) computer availability for (a) French otter trawlers, all length classes combined, (b) French gillnetters (white, driftnets; black, fixed nets; double-hatched, trammel-nets), (c) Danish otter trawlers, and (d) Basque bottom trawlers 30–40 m long registered in Ondarroa. White bars represent the absence of electronic devices (GPS or computers) and black bars their presence.

consideration. Each observation cell is a combination of vessel and year. A general formulation of the models is:

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

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

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

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

Adjusting fishing effort and evaluating its benefits

The method used for this analysis was adapted from the traditional approach of Kimura (1981). The adjustment factors were the effects of the different variables characterizing fishing effort, estimated by either Equation (1a) or Equation (1b). If ε_* is the effect of the reference effort factor, the relationship between the adjusted (or effective) log of the fishing effort (ln Ee) and the nominal (or untransformed) log fishing effort ln En may be expressed as

$$\ln \mathrm{E}e_{v,y} = \ln \mathrm{E}n_{v,y} + (\hat{\varepsilon}_h - \hat{\varepsilon}*) + \sum_{k=1}^{NI} \hat{\theta}_k e_{k,v,i}. \qquad (2)$$

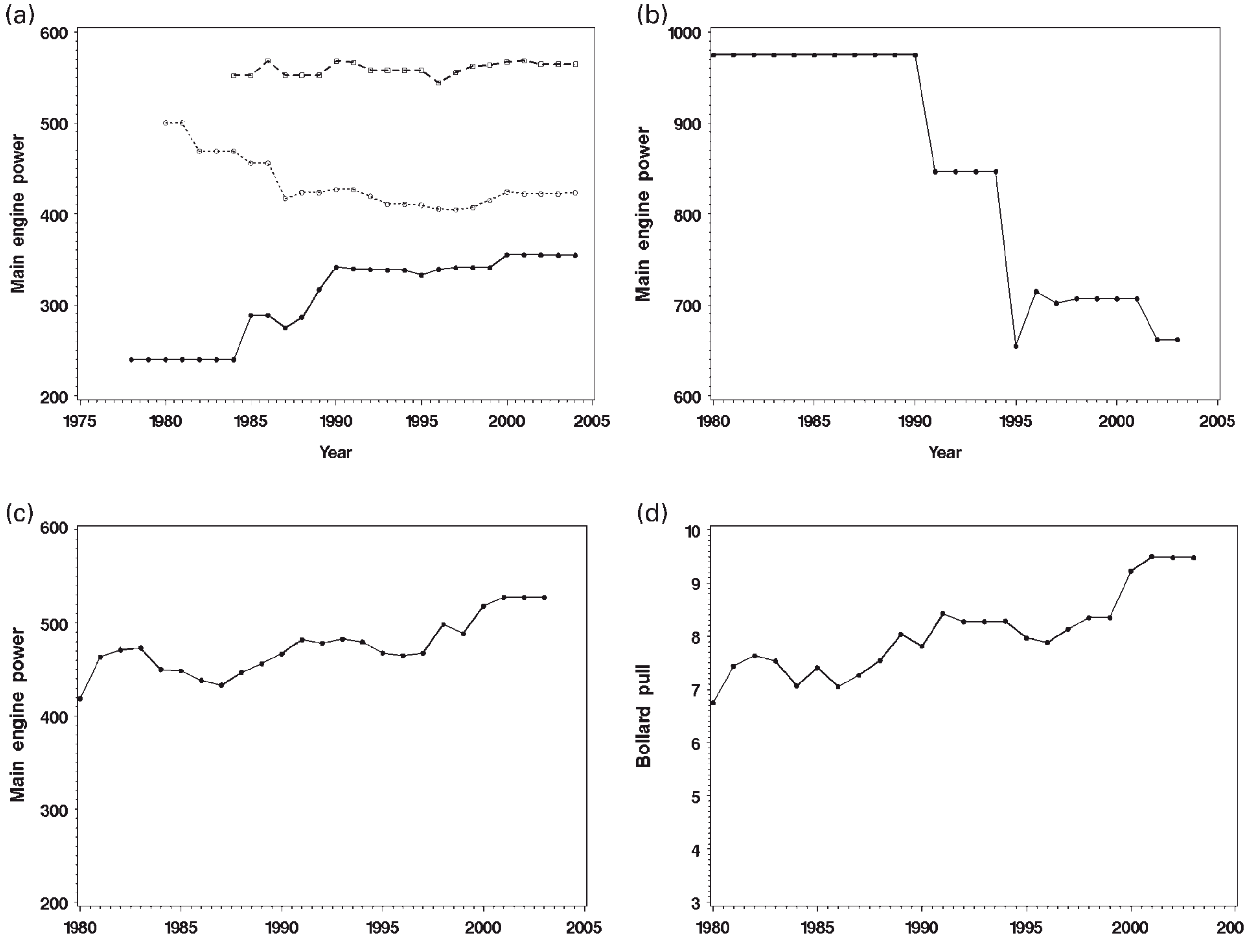

Figure 4. Annual changes in average (a–c) horse power, and (d) bollard pull (t) for (a) French otter trawlers (black dot, 12–16 m; circle, 16–20 m; square, 20–24 m), (b) Basque bottom trawlers 30–40 m long registered in Ondarroa, and (c and d) Danish otter trawlers.

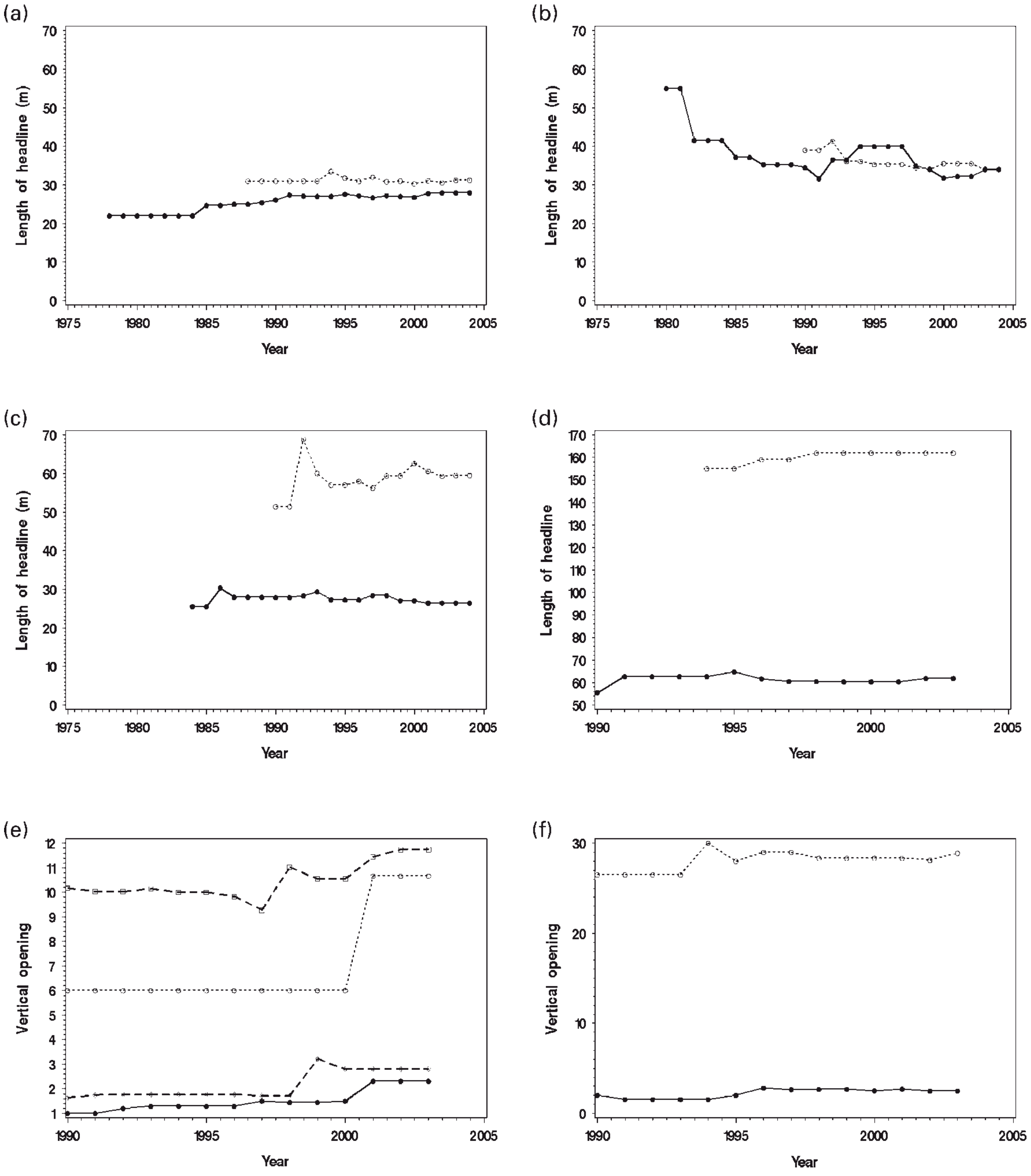

Figure 5. Annual changes in (a–d) headline length, and (e and f) vertical opening (m) for (a) French otter trawlers 12–16 m long (black dot, single trawls; circle, twin trawls), (b) French otter trawlers 16–20 m long (black dot, single trawls; circle, twin trawls), (c) French otter trawlers 20–24 m long (black dot, single trawls; circle, twin trawls), (d and f) Basque bottom trawlers 30–40 m long registered in Ondarroa (black dot, single trawls; circle, very high vertical opening trawls), and (e) Danish otter trawlers (black dot, multi-rig trawls; circle, pelagic trawls; square, single trawls; diamond, twin trawls).

Table 4. Summary of the results of the analysis of cpue by GLMs for French gillnetters targeting hake, sole, and anglerfish

Species	d.f.	SCC/d.f.	Gear type		Net length	Soak time	Vessel length
			GNS	GTR			
Hake	136	1.04	2.15	0.00	0.04	−0.05	0.001
Sole	113	1.04	−3.06	0.00	0.04	0.04	–
Anglerfish*	137	1.02	−0.78	0.00	–	–	–

The statistics include the degrees of freedom (d.f.), the ratio of the scaled Pearson chi-square to d.f. (SCC/d.f.), and the values of the coefficients associated with the significant fishing effort descriptors ($p < 0.05$). Gear types are fixed nets (GNS) or trammel-nets (GTR).

* indicates that the hypothesis that residuals are normally distributed is not rejected on the basis of a Kolmogorov–Smirnov test ($p < 0.05$).

Table 5. Summary of the results of the analysis of cpue by GLMs for French otter trawlers targeting hake and Norway lobster.

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

The statistics include d.f., the ratio of the scaled Pearson chi-square to d.f. (SCC/d.f.), and the values of the coefficients associated with the significant fishing effort descriptors ($p < 0.05$). Gear types are single trawls (OTB) or twin trawls (TTB), combined with different groundropes: diabolo (1), chains (3), spheres (4), rubber (5), plain wire (6).

* indicates that the hypothesis that residuals are normally distributed is not rejected on the basis of a Kolmogorov–Smirnov test ($p < 0.05$).

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

Implementation

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

Results

Data exploration

Gear types have varied considerably over time for most of the fleets under investigation (Figure 2). For the French (Figure 2a) and Danish trawlers (Figure 2c), the main feature was the emergence of twin trawls in the 1980s, which was associated with fishing for *Nephrops*. For French gillnetters (Figure 2b), the main feature was the increasing importance of trammel-nets for fishing sole. Trammel-nets have been the main gear since 1996. For Basque trawlers registered in Ondarroa of length 30–40 m (Figure 2d), the proportion of the two main gear types (single otter trawls and pair trawls with a very high vertical opening, VHVO) remained stable over the period 1990–2003, but since 1995, the fleet appeared to be increasingly polyvalent, as reflected by the emergence of another trawl type (the so-called "Bou" otter trawls) and the increasing use of static gears (fixed nets and longlines).

On-board electronics (GPS or computers) emerged for all fleets over time. In particular, GPS appeared in the 1960s and 1970s in the Danish fleet (Figure 3c), and in the 1980s in the French fleets (Figure 3a and b). All Basque trawlers were equipped with GPS and on-board computers around 1990. In 2004, all French and Basque vessels were equipped with GPS, but 10–30% of Danish vessels were not equipped with the device.

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

For both small and large French otter trawlers (Figure 5a and c), the headline length increased slightly over the study period. Otter

Table 6. Summary of the results of the analysis of cpue by generalized linear models for Danish otter trawlers targeting cod, Norway lobster, and plaice.

Species	d.f.	SCC/d.f.	Date of construction	Crew size	Vessel length	Number of winch drums	Number of net drums	Number of sounders
Cod	208	1.09	–	0.70	−0.27	1.00	–	–
Norway lobster	180	1.11	-5.0×10^{-4}	–	−0.25	2.55	1.87	–
Plaice*	178	1.12	-3.0×10^{-4}	0.77	−0.31	1.38	1.38	0.74

The statistics include degrees of freedom (d.f.), the ratio of the scaled Pearson chi-square to d.f. (SCC/d.f.), and the values of the coefficients associated with the significant fishing effort descriptors ($p < 0.05$).

* indicates that the hypothesis that residuals are normally distributed is not rejected on the basis of a Kolmogorov–Smirnov test ($p < 0.05$).

Table 7. Summary of the results of the analysis of cpue by generalized linear models for Basque bottom trawlers, registered in Ondarroa, of length 30–40 m, targeting hake and anglerfish.

Species	d.f.	SCC/d.f.	Variable pitch propeller		Number of net drums
			Yes	No	
Hake	114	1.10	0.86	0.00	−0.37
Anglerfish	114	1.10	0.83	0.00	0.79

The statistics include d.f., the ratio of the scaled Pearson chi-square to d.f. (SCC/d.f.), and the values of the coefficients associated with the significant fishing effort descriptors ($p < 0.05$).

trawlers equipped with twin trawls had a longer headline than those equipped with single trawls. For the medium-sized French otter trawlers (Figure 5b), the headline length decreased over time. Headline length of otter trawlers equipped with twin trawls was similar to that of those equipped with single trawls. For the Basque fleet, both headline length (Figure 5d) and vertical opening (Figure 5f) increased over time. Trawlers equipped with VHVO trawls had longer headlines and higher vertical openings than those equipped with single trawls. The vertical opening of Danish trawlers (Figure 5e) increased over time. Danish trawlers equipped with single trawls had the highest vertical opening, and those equipped with multi-rig trawls had the smallest.

Modelling catch rates and adjusting fishing effort

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

Results of the GLM are summarized in Tables 4–7 and Figures 7 and 8. For French gillnetters, the greatest catch rates of hake were achieved with fixed nets and the greatest catch rates of sole and anglerfish with trammel-nets (Table 4, Figure 7). Net length had a positive effect on catch rates of hake and sole, but the effect of soaking time was unclear. Vessel length had an effect on catch rates for hake only.

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

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

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

Evaluating the benefits of adjusting fishing effort

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

Discussion

An important feature revealed by the data exploration was the gradual appearance of twin trawls since the early 1980s, in both Danish and French trawler fleets, a development clearly associated with the gradual emergence of Norway lobster as target species.

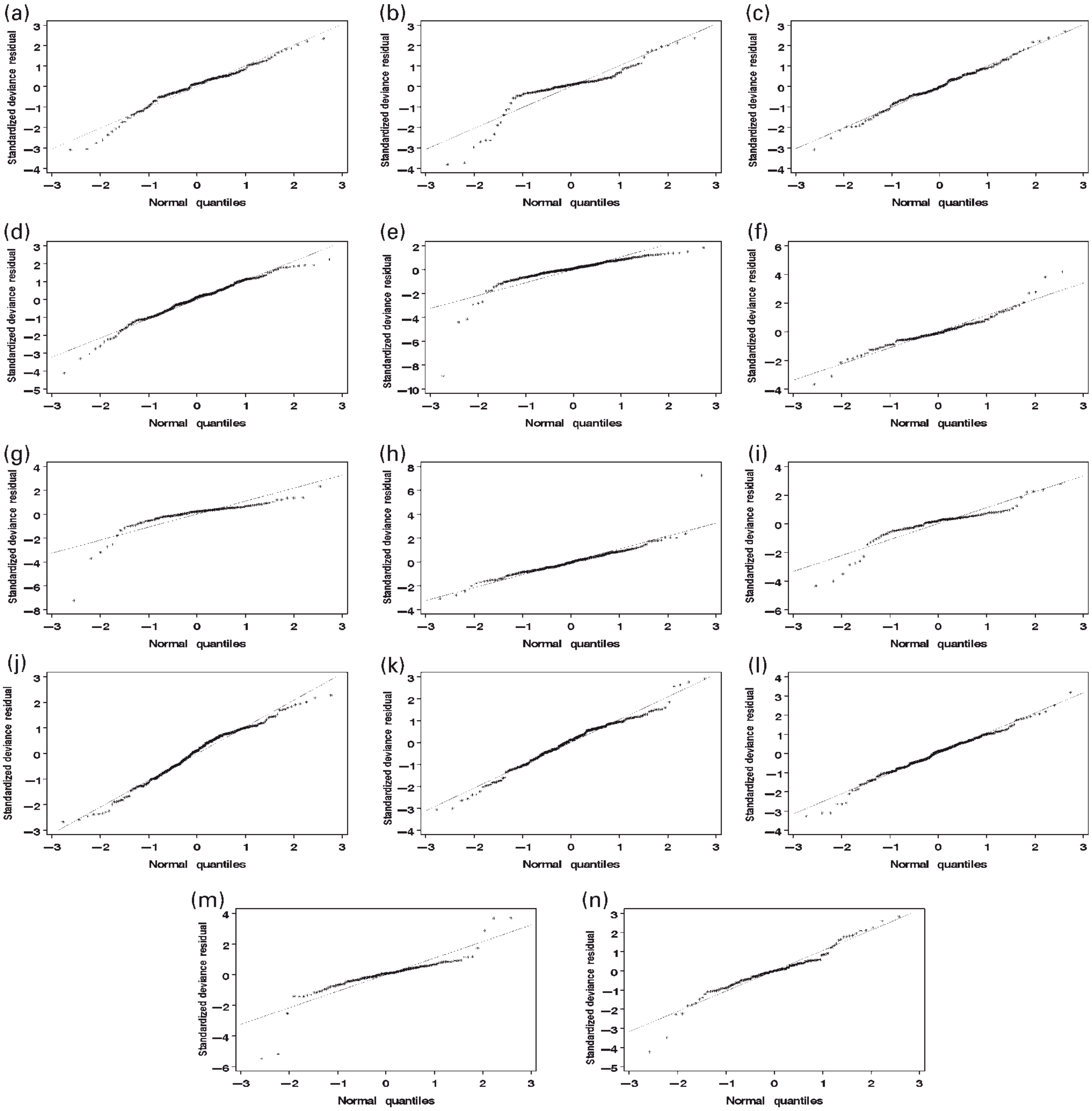

Figure 6. GLM residuals inspection through QQ plots. French gillnetters harvesting (a) hake, (b) sole, (c) anglerfish; French otter trawlers (12–16 m) harvesting (d) hake, (e) Norway lobster; French otter trawlers (16–20 m) harvesting (f) hake, (g) Norway lobster; French otter trawlers (20–24 m) harvesting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

For French trawlers, the emergence of twin trawls was accompanied by the appearance of new groundropes (diabolos, metallic spheres), which allow fishing on harder grounds, areas that could scarcely be exploited before. A similar change in fishing technologies was observed for the French gillnetters, for which the increased importance of trammel-nets was associated with sole becoming the dominant target species. These shifts are likely to be due to both Norway lobster and sole having a high market value, and by the diminished abundance of hake, the traditional target of both fleets. For the Basque bottom trawlers, the main feature was the increased polyvalence of fishing vessels, which may reflect the greater opportunism of skippers in recent years.

Analysis of the effects of vessel and gear properties on fishing efficiency for the six fleets clearly shows that collecting non-trivial information on fine-scale technological change allows more insight into the factors affecting fishing power. For the four

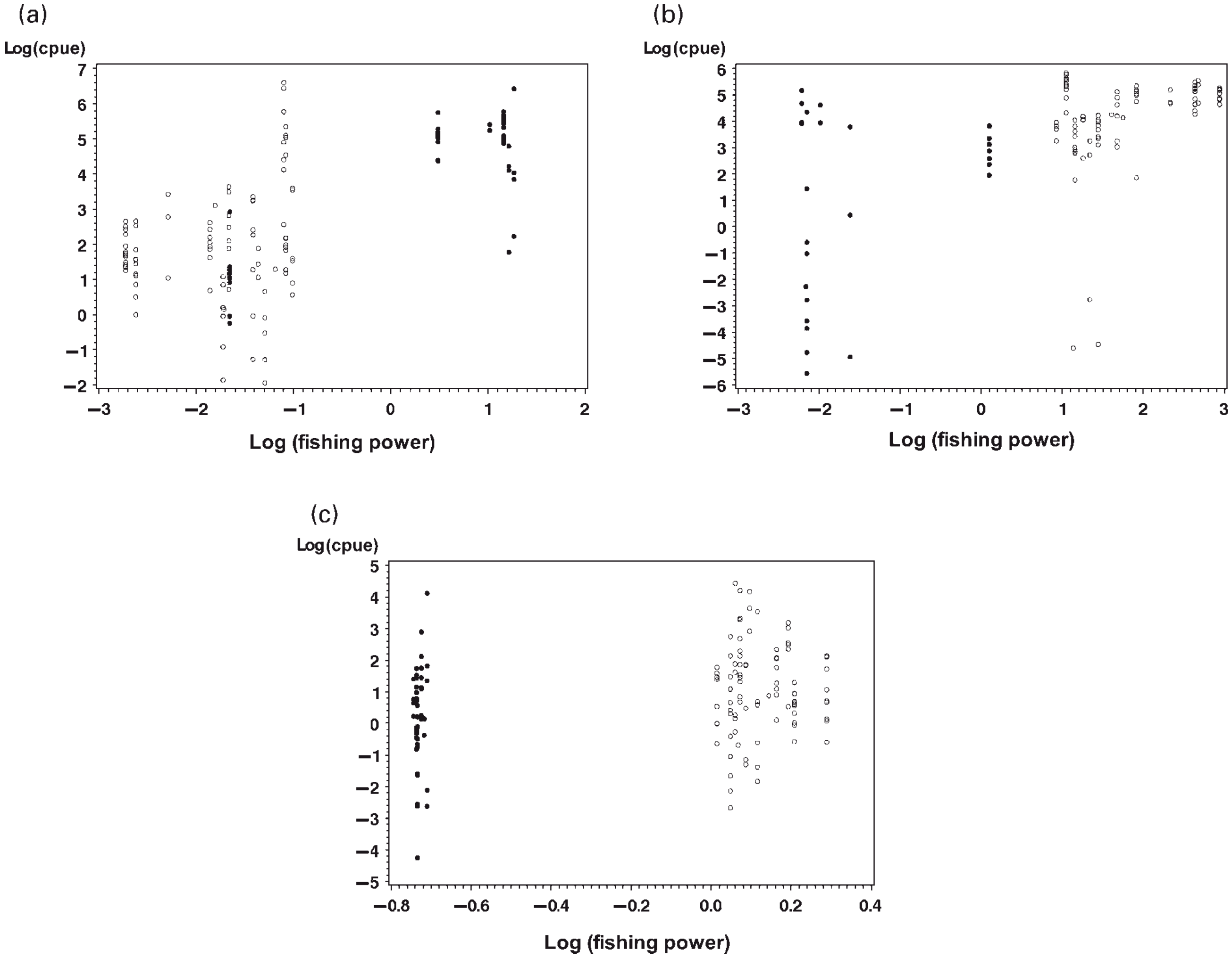

Figure 7. Relationships between log-transformed cpue and fishing power by net type (black dot, fixed nets; circle, trammel-nets), as derived from generalized linear models. French gillnetters harvesting (a) hake, (b) sole, and (c) anglerfish.

French fleets, where both vessel and gear information were compiled in the fishing effort data set, the gear effect appeared to be dominant over the vessel effect, bearing out the great plasticity of these fleets' fishing strategies. For French gillnetters, trammel-nets were clearly utilized to target sole by night, when the fish rise in the water column, and fixed nets were traditionally used to target hake. Therefore, it would be anticipated that vessels equipped with trammel- and fixed nets would be more efficient with regard to sole and hake fishing, respectively. Other characteristics of gillnets, such as twine thickness, are thought to have a substantial effect on fishing power (Holst *et al.*, 2002), but information on such attributes was not consistently available from the questionnaires. Also, the length of net towed had a positive effect on fishing efficiency for the main target species (sole and hake), and could from now on be considered as a useful measure of fishing capacity. Soak time, sometimes evoked as a measure of the fishing activity of gillnetters (Marchal *et al.*, 2001, 2002), did not have a clear effect on catch rates. It could be anticipated that an increasing soak time would allow more fish to be caught, but discussion with skippers who participated in the survey indicated that leaving fish more than 24 h in the net would adversely impact the quality of the fish flesh, making it unmarketable. Therefore, it is likely that soak time has a non-linear effect on catching efficiency, but this requires further investigation.

We had anticipated that, within each groundrope category, French otter trawlers using twin trawls would have a greater efficiency than single trawls when fishing Norway lobster, but a lesser efficiency when fishing hake (Sangster and Breen, 1998). This expectation was fulfilled for small (12–16 m) and large (20–24 m) otter trawlers, but not for medium-sized vessels (16–20 m). The reason why medium-sized trawlers did not have the expected efficiency when fishing for Norway lobster and hake could be the result of those vessels targeting other benthic (e.g. flatfish, anglerfish) or demersal species (e.g. cod, whiting), which were not included in this analysis. French trawlers chose different groundropes depending on the type of ground visited. For 8 of 12 combinations of fleet, species, and gear type categories, vessels equipped with hard bottom groundropes (diabolos, metallic spheres) had a greater efficiency than those equipped with soft bottom groundropes (plain wires, chains, rubber), irrespective of the target species. Before the advent of diabolos and metallic spheres for fishing, operating on hard bottom was very risky

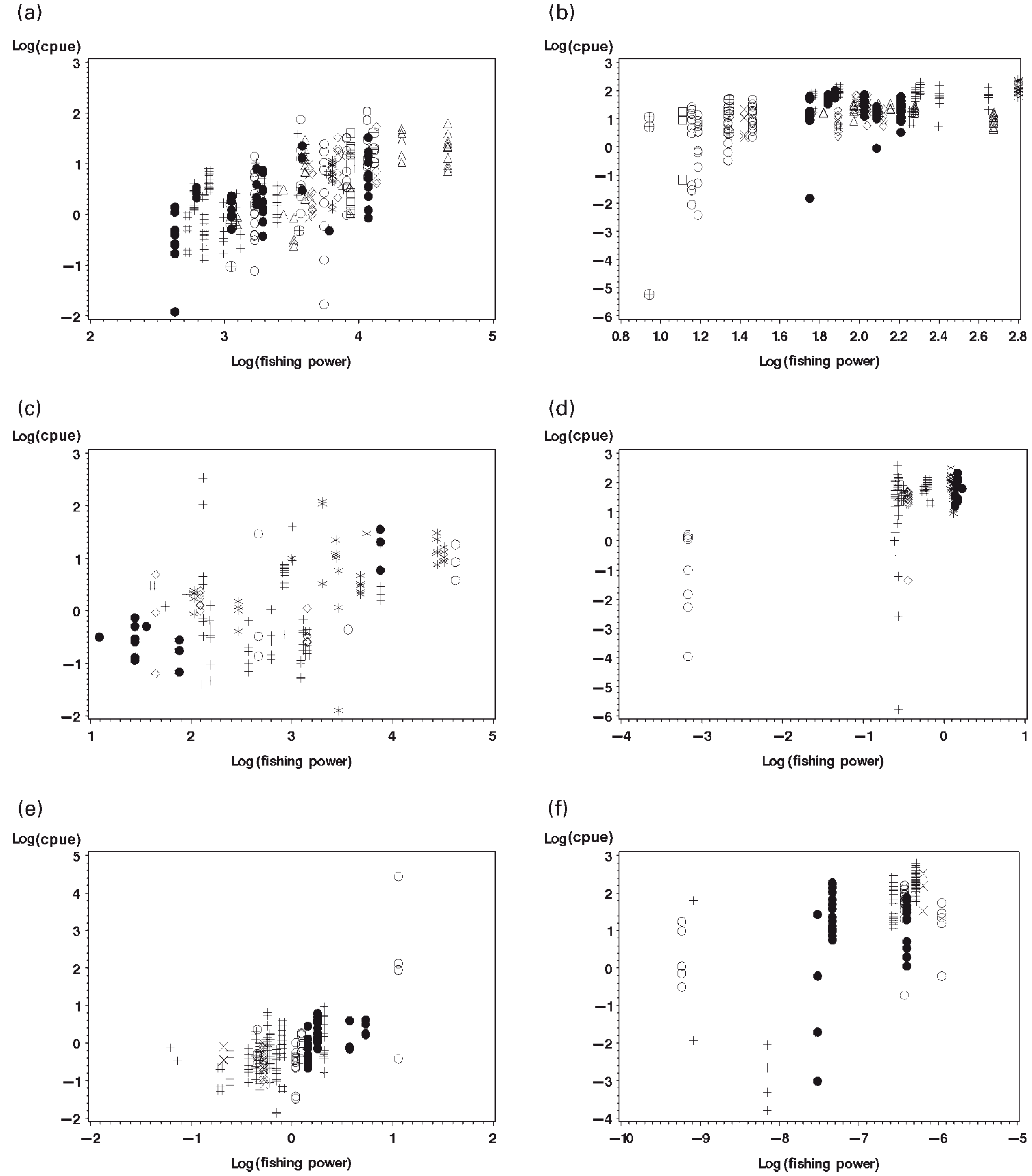

Figure 8. Relationships between log-transformed cpue and fishing power by trawl type and groundrope type: single trawl equipped with diabolos (dot), chains (circle), metallic spheres (square), rubber (diamond), plain wire (triangle); twin trawl equipped with diabolos (plus sign), chains (cross), metallic spheres (star), rubber (hash), plain wire (encircled plus), as derived from generalized linear models. French otter trawlers of length range (a, b) 12–16 m, (c and d) 16–20 m, (e and f) 20–24 m harvesting (a, c, and e) hake and (b, d, and f) Norway lobster.

(gear breakage, etc.). The emergence of such devices made it possible for vessels to have greater access to alternative fishing grounds, perhaps less exploited than the traditional ones. This greater local stock density could be the reason why efficiency was higher when trawls were equipped with diabolos and metallic spheres.

The effect of gear size on trawl selectivity and catching efficiency has been investigated before (e.g. Rose and Nunnallee, 1998; Dahm *et al.*, 2002). One might expect that increasing the trawl opening would enhance its efficiency, but Rose and Nunnallee (1998) found that restricting the trawl opening did not

Table 8. Outputs comparison of (model a) the regression between log fishing mortality ($\ln F$) and log nominal fishing effort ($\ln \mathrm{En}$), and (model b) the regression between log fishing mortality ($\ln F$) and log-adjusted fishing effort ($\ln \mathrm{Ee}$).

Fleet	**Stock**	***n***	**r^2 (a)**	**r^2 (b)**	**Standard error of slope (b)**	**Equation (b)**
French otter trawlers (12–16 m)	Hake	246	0.29	0.39	0.05	$\ln F = -23.73 + 0.59 \ln \mathrm{Ee}$
French otter trawlers (16–20 m)	Hake	246	0.63	0.31	0.07	$\ln F = -25.46 + 0.76 \ln \mathrm{Ee}$
French otter trawlers (20–24 m)	Hake	246	0.00	0.07	0.05	$\ln F = -19.38 + 0.22 \ln \mathrm{Ee}$
French gillnetters	Hake	194	0.00	0.43	0.07*	$\ln F = -21.51 + 0.90 \ln \mathrm{Ee}$
	Bay of Biscay sole	49	0.21	0.03	0.21	Not significant
	Bay of Biscay and Celtic Sea anglerfish	130	0.01	0.01	0.29	Not significant
	North Sea and Western Scotland anglerfish	45	0.00	0.09	0.50*	$\ln F = -23.45 + 1.06 \ln \mathrm{Ee}$
Danish otter trawlers	North Sea cod	64	0.03	0.51	0.14*	$\ln F = -13.92 + 1.14 \ln \mathrm{Ee}$
	North Sea plaice	73	0.06	0.79	0.07*	$\ln F = -22.11 + 1.14 \ln \mathrm{Ee}$
Basque bottom trawlers (30–40 m)	Hake	170	0.11	0.19	0.17*	$\ln F = -14.76 + 1.06 \ln \mathrm{Ee}$
	Bay of Biscay and Celtic Sea anglerfish	95	0.03	0.35	0.14*	$\ln F = -18.35 + 0.98 \ln \mathrm{Ee}$
	North Sea and Western Scotland anglerfish	47	0.01	0.35	0.24*	$\ln F = -19.03 + 1.16 \ln \mathrm{Ee}$

The standard error of the slope of model regression (b) is provided, and marked with an asterisk (*) when the slope is not significantly different from 1 ($p < 0.05$).

necessarily lead to decreased catch rates. In our study, we found that trawl size, as reflected by the headline length, had a positive effect on catch rates of hake by all French trawlers and on catch rates of Norway lobster by the small trawlers. Such results seem to be in accord with expectations, but it is difficult to compare our results, which are based on interviews, with those of Rose and Nunnallee (1998), which were based on field experiments.

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

For the Danish and Basque trawling fleets, gear information could not be used to adjust fishing effort, and only vessel characteristics were examined in relation to fishing efficiency. Small, old Danish trawlers generally appeared to be more efficient than large, new ones, an unexpected result. About the vessel size effect on catch rates, a plausible explanation could be that larger vessels periodically targeted other species (e.g. pelagic fish) than those included in the analysis here. The negative effect of the date of construction on fishing efficiency may indicate that vintage is a misleading descriptor of fishing effort. Because these days vessels are continuously rebuilt, older vessels may in fact have more up-to-date equipment and technology, and hence be more efficient, than the newer ones. Also, although it cannot be shown with the data available here, one cannot exclude the possibility that more experienced skippers fish with older vessels.

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

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

The cpue analysis has been carried out using a GLM. Although it is a standard procedure in that field of research (Robson, 1966; Kimura, 1981; Hilborn, 1985; Marchal *et al.*, 2002), it has a number of limitations. First, the data set used in this investigation is unbalanced (not all vessels are present over all time-series). Not explicitly accounting for the vessel effect by a fixed or a random effects model may lead to biased and inconsistent parameter estimates. A fixed or random effect specification could help to explain unobserved heterogeneity between vessels, including the skipper effect. In such a context, one may consider the use of generalized

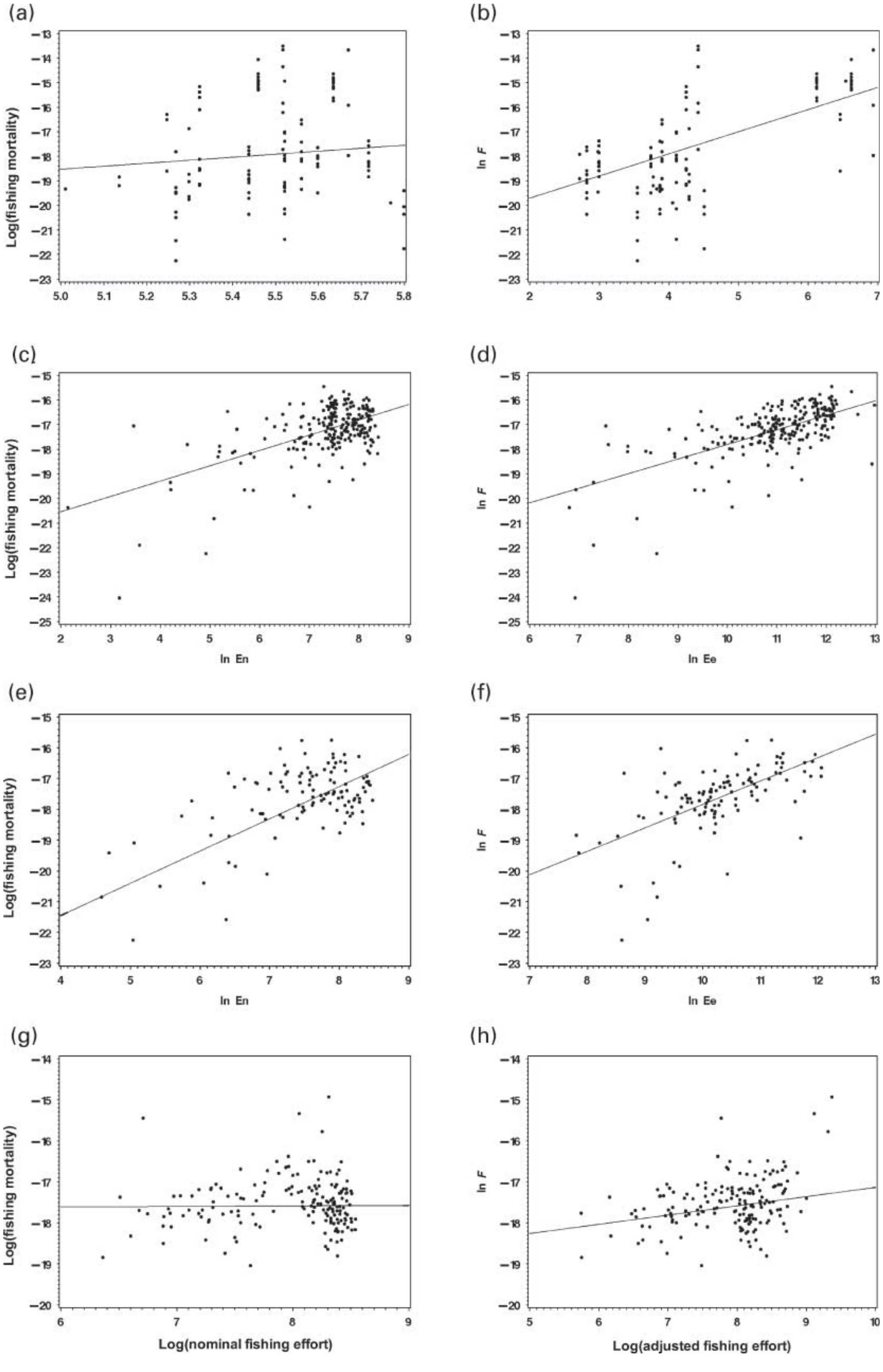

Figure 9. Relationships between log-transformed (a, c, e, g) partial fishing mortality, log(*F*), and nominal fishing effort, log(En); (b, d, f, and h) partial fishing mortality, log(*F*), and adjusted fishing effort, log(Ee). French (a and b) gillnetters, (c and d) otter trawlers (12 – 16 m), (e and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

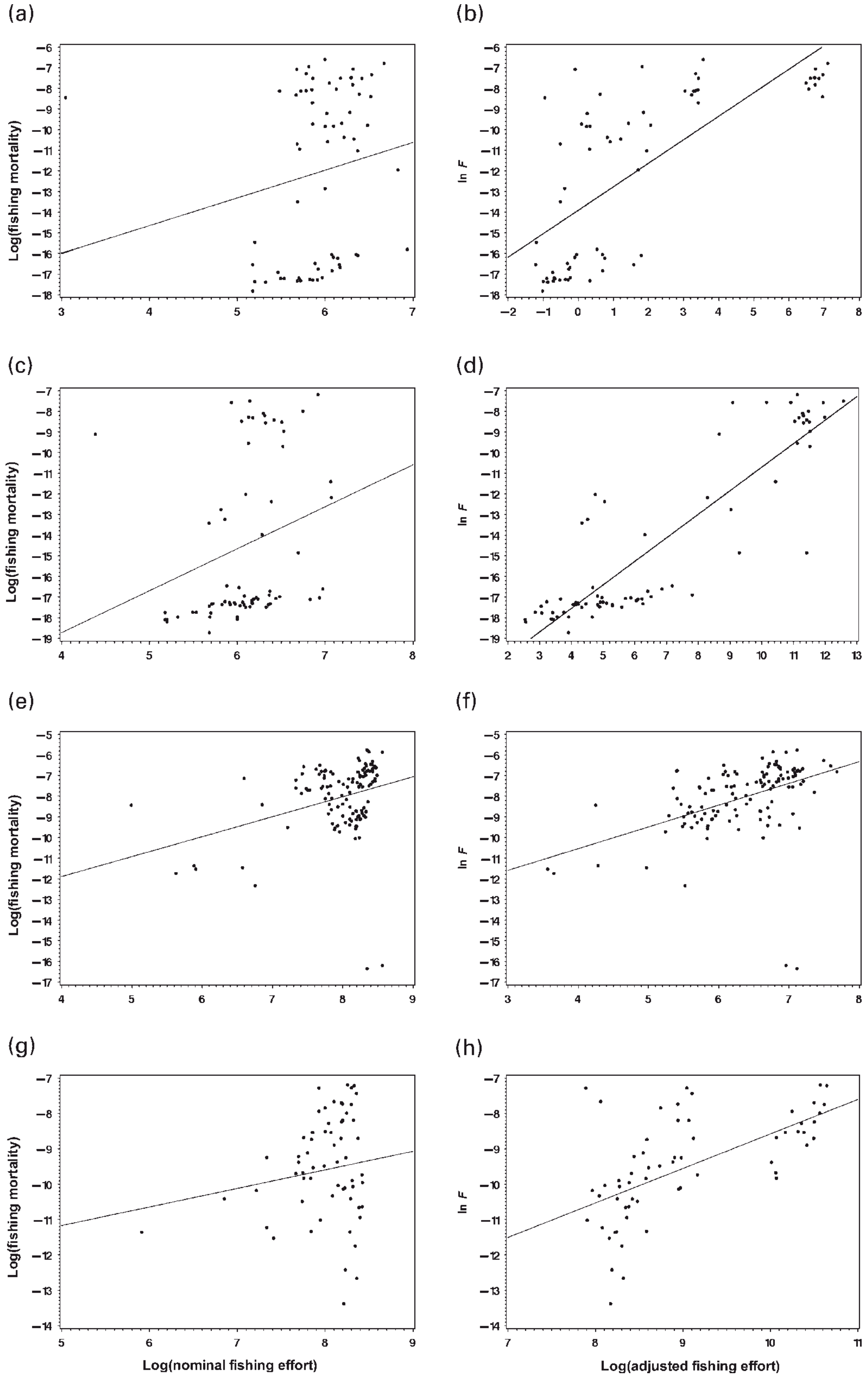

Figure 10. Relationships between log-transformed (a, c, e, and g) partial fishing mortality, log(*F*), and nominal fishing effort, log(En); (b, d, f, and h) partial fishing mortality, log(*F*), and adjusted fishing effort, log(Ee). (a and b) Danish otter trawlers harvesting North Sea cod, (c and d) Danish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

linear mixed models (GLMMs) as an alternative to GLMs (Venables and Dichmont, 2004). GLMMs make it possible to include both fixed and random terms in the linear predictor. Although still a research topic, this method has been applied to the field of fisheries research (Squires and Kirkley, 1999). Second, the model used here is entirely linear. To allow for a broader use of the approach, more general models could be contemplated. For instance, the GLM model used in this study is consistent with the Cobb–Douglas function used by fisheries economists to model production in relation to economic inputs (capital, labour, fuel) and various dummy variables (e.g. accounting for spatial and annual effects). A Cobb–Douglas function has therefore been used by Kirkley *et al.* (2004) to evaluate the technological effects on the production of the Sète trawl fishery. The Cobb–Douglas function is in fact a simplification of the trans-log production function which includes, in addition to linear explanatory variables, a quadratic functional term. This quadratic term could in principle be used to account for elasticities of substitution between the fishing effort descriptors and also, to some extent, the non-linear effects of the explanatory variables. However, given the relatively large number of explanatory variables, a quadratic functional form might be intractable because of multi-collinearity. A more general approach could be to account for non-linear effects of explanatory variables (e.g. the effect of soak time on the catch rates of gillnetters) using generalized additive models (GAMs). GAMs may extend the scope of GLMs by substituting the linear predictor by a generalized additive (and possibly non-linear) predictor (Maunder and Punt, 2004). Overall, although the GLM may oversimplify the processes underlying the dynamics of fishing effort, the diagnostics and analyses of residuals suggest that, for our case studies, the main outcomes of the investigation are reasonably robust to the assumptions made.

The link between fishing mortality and effort was investigated for a number of combinations of fleets and stocks. In most case studies, adjusting fishing effort led to (i) a gain in the precision of the relationship between fishing mortality and fishing effort (10 of 12 case studies) and (ii) fishing mortality being directly proportional to fishing effort (7 of 12 case studies). However, the results also indicated that the linkage between fishing mortality and effort could still be enhanced. This could be done by both revisiting some of the assumptions and refining the scale of the investigation. First, it has been assumed in the GLMs that the "Year" effect is indicative of changes in annual abundance of the stocks, whereas technological creep is embodied in the different fishing-effort descriptors. This assumption could be violated for several reasons. Therefore, there may be factors contributing to improved technological efficiency that have not been captured by the survey. In particular, gear-related factors of the Danish and the Basque fleets could not be used for this study. In such cases, the annual effect may reflect a combination of both stock fluctuations and improved gear efficiency. Additionally, an implicit assumption made in this study was that the skipper effect is captured by the different fishing effort descriptors in the GLM. It has been demonstrated that skipper skill is an important determinant in explaining catch rates (e.g. Houghton, 1977; Hilborn, 1985; Hilborn and Ledbetter, 1985; Squires and Kirkley, 1999). Skipper skill may be reflected by, for instance, choice of fishing ground (Marchal *et al.*, 2006) and experience and education levels (Kirkley *et al.*, 1998). Shifts in target species observed for the fleets under investigation have required an adaptation of technologies, but also of skippers' skills from year to year. Moreover, it is likely that vessel skippers have changed over time during the period examined. Not accounting for the skipper effect can likely lead to an omitted variable bias for the parameter estimates. Information on skippers' skill and on comings and goings of skippers on different vessels over time was not available to us. It is therefore likely that part of the skipper effect has been embedded in the "Year" effect. Finally, the "Year" effect may pick up other excluded factors that are correlated with time, including changes in the environment, along with changes in institutions and markets (Pascoe *et al.*, 2001). Second, an improvement in our results could be expected with more appropriate estimates of *F*. Such estimates from stock assessments have great uncertainty, and estimates for the most recent years of VPAs (Virtual Population Analysis) assessments may not have converged. Third, the linkage between fishing effort and fishing mortality could be enhanced by refining both the time (month or fishing trip, instead of year) and spatial scales of this analysis.

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

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

Acknowledgements

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Chapter 7

General Discussion

Management challenges from overfishing and over-capacity

Many of the world's fisheries are suffering from declining resources caused by overfishing and over-capacity (FAO, 2009; EC, 2008). To solve these problems the institutions managing the fisheries have a variety of tools at their disposal, which have been deployed globally with mixed success (Hilborn et al., 2004). The applicability of these regulation tools (e.g. individual transferable quotas [ITQs], marine protected areas [MPA] and community-based management [CBM]) is highly sensitive to the complexity of the fisheries and management system in question (Stefansson and Rosenberg, 2005; Degnbol et al., 2006). According to Degnbol et al. (2006) the pending discussion of more or less effective regulation types, e.g. effort quotas versus landing quotas, should rather be focused on appreciating the complexity of the fisheries system and responding accordingly (e.g. by using community-based tailor-made regional or local regulations on a regular basis) if management is to be substantially improved. Keeping in mind the need for carefully choosing the right tools to apply on a fishery basis, it is, however, still possible to make generalisations on the advantages and disadvantages (including the ability to integrate technological development) of the major regulation types available. Two main types of marine resource management policies can be identified from the various regulations in force globally, one output-based (Total allowable catches [TACs] and individual landing quotas) and one input-based (capacity control [long-term] and effort quotas [short-term]). Both of these overall management strategies can be enforced separately or with varying degrees of concurrency and both are usually accompanied by a suite of additional regulations and technical measures intended to fine tune the effect of fishery activities on the resources (Catchpole et al. 2005; Christensen and Raakjær, 2006; Rijnsdorp et al., 2007).

Output versus input control as regulatory tools in fisheries

The obvious advantage of output control is a seemingly inevitable agreement between intended and realized fishing mortality: when the TAC of a species is reached the fishing for this species is stopped. The main weakness of output control is its inability to cope with discards and misreported catches, which undermine the idea of controlling fishing mortality through control of fishermen landings and complicates stock assessment (Raakjær and Mathiesen, 2003; Catchpole et al., 2005; Branch et al., 2006). In the short term perspective discarding occurs if the fishermen catch unintended species or sizes of fish, if the catch is damaged, if the species quota is reached, or if high grading is practiced. The underlying explanation of discards and illegal landings is management failure to restrict capacity and effort, resulting in over-capacity and overfishing, and the use of unselective gears (Rossiter and Stead, 2003; Catchpole et al., 2005). As a consequence of discards and misreporting, stock assessment and thus the basis of setting TACs can be substantially biased (Daan, 1997; Rijnsdorp et al., 2007). The setting of appropriate TAC levels can also be seriously hampered from catchability changes owing to i) technological development (Salthaug, 2001; Marchal et al., 2002), ii) fishermen behaviour such as improved skipper skills, targeting behaviour and technical interactions (Ulrich et al., 2002; Marchal et al. 2006; Quirijns et al., 2008) and iii) biological factors such as stock contractions and changed availability of target species due to environmental conditions (Horwood and Millner, 1998; Rose and Kulka, 1999). Logically the above mentioned discard problems of output controlled fisheries are higher in mixed fisheries with low-selectivity gears than in single species high-selectivity fisheries (Rijnsdorp et al., 2007; Poos et al., 2010).

The main advantages of short-term input control (e.g. a yearly effort quota of days at sea) are argued to be easy enforcement and monitoring, improved regulation legitimacy and compliance among fishermen, and limited incentives to discard, high grade or misreport (Murawski and Finn, 1986; Rossiter and Stead, 2003; Shepherd, 2003). Consequently, the basis for scientific stock assessments (the officially reported catch and effort data) will be reliable, dumping and waste of caught fish will be minimized, and improved accordance between intended and realized fishing mortality will be obtained. The main shortcoming of short-term input control as fisheries management strategy is its vulnerability to technological development and the resulting efficiency changes of vessels (Stefansson and Rosenberg 2005; Jákupsstovu et al., 2007). Temporal technological development makes it inevitable to somehow meet efficiency increases with compensating reductions in allocated fishing days or any other chosen measures of effort with regular intervals (Rossiter and Stead, 2003; Catchpole et al., 2005). Projecting efficiency increases and predicting the patterns of catchability, which are prerequisites of any input control system, are by no means trivial tasks in mixed species fisheries (Rijnsdorp et al. 2006; Rijnsdorp et al. 2007) and neither is obtaining a sufficiently accurate relationship between intended and realized fishing mortality to meet management objectives. Great care should be taken when defining the metric with which to manage fishing effort, as technological advances can result in nominal effort becoming more and more decoupled from effective effort (Ulrich et al., 2003; Stefansson and Rosenberg, 2005; chapter 4). Other factors affecting catchability and thereby the ability of nominal effort to reflect effective effort are those informed in the section above: a) fishermen behaviour such as improved skipper skills, targeting behaviour and technical interactions and b) biological factors such as stock contractions and changing availability of target species. Another problematic aspect of input control in mixed fisheries is the ability of fishermen to target any species of fish they wish, including high-value species with low stock levels, which in theory could be fished to extinction (Rossiter and Stead, 2003). These complexities of short-term input control, particularly in mixed fisheries, require substantial additional regulation initiatives as well as the identification and quantification of appropriate nominal effort descriptors and efficiency projections for a set of very heterogeneous fisheries. Consequently a choice of either short-term input control or output control might well be a question of choosing between two different but equally complex and imperfect management strategies.

Long-term input control should in theory be suited for eliminating over-capacity and thus be able to better balance the harvesting capacity to the resource size in the long run. However, the examples of long-term input control so far (e.g. buy back schemes and multi annual guidance plans under the CFP), have suffered from some of the same shortcomings that characterize short-term input control (i.e. the inability to capture fishing power increases from temporal technological development) as well as being vulnerable to efficiency increases from structural (vessel composition) changes of fleets. Such structural technological development can take place without being instigated by management initiatives, but most frequently occurs during the course of buy back schemes, where older, smaller vessels of a fleet often become replaced with newer, larger vessels within a fixed or reduced nominal capacity limit (e.g. total fleet tonnage or total fleet kilowatt). However, nominal capacity reduction in fleet level may very well be undermined by increases in individual fishing power of the newer and larger vessels of the restructured fleet (Hilborn, 1985, Pascoe and Coglan, 2000; Pascoe et al., 2001). Consequently, some projection of efficiency increases with time is needed to account for these effects of technological development on long-term input control, as also pointed out by the European Union Commission (EC, 2008).

Improving management by integrating technological development

From the above it is evident that technological development is a key factor when it comes to improving the current fisheries management to reduce problems of overfishing and over-capacity. The major objective of this PhD synthesis has been to throw light on the role of technological development in fisheries management by documenting and quantifying how the propagation of new technology in fisheries can complicate efforts to balance capacity and fish resources. In the previous six chapters it was demonstrated, how technological development can complicate output control by adding uncertainty to standard stock assessment procedures (chapter 3), how short-term input control (in terms of effort quotas) can be undermined by technologically induced efficiency increases, which decouple nominal effort from effective effort (chapter 4; chapter 5; chapter 6), and how long-term input control (in terms of buy back schemes and other capacity control measures) are also challenged by efficiency changes from both temporal and structural technological development (chapter 2). In the following it will further be explored, i) how the main instruments of current European fisheries management are best applied and supplemented in order to mitigate the efficiency increases from technological development in commercial fisheries, and ii) whether operational and valid descriptors and projections of effective capacity and effort, based on standard capacity and activity data from logbooks, can be developed for aggregate vessel groups.

Capacity management and technological development

The biological sustainability of a fisheries policy based on long-term input control (capacity management) of total fleet tonnage or total fleet engine power is highly vulnerable to the efficiency changes resulting from technological development. Technological development can result in effective capacity becoming more and more decoupled from nominal capacity and this is particularly the case when long term capacity targets are accompanied by fleet modernisation programmes. In the course of such combined structural management plans, older, smaller vessels of a fleet are often replaced with newer, larger vessels within a fixed or reduced nominal capacity limit (e.g. total fleet tonnage), but nominal capacity reduction in fleet level is often undermined by increases in individual vessel efficiency (chapter 2; Pascoe and Coglan, 2000; Pascoe et al., 2001; Standal, 2007). In chapter 2 it was demonstrated that the level of technological equipment on board Danish trawlers and gillnetters increases with vessel length and with decreasing vessel age as well as with time, so underpinning the two main mechanisms of technologically driven decoupling of effective capacity from nominal capacity: 1) structural technological development in fleet level (small, old vessels being replaced with newer larger and more technological ones) and 2) temporal technological development in vessel and fleet level (the introduction and improvement of vessel technology with time). Both mechanisms are documented to increase fleet efficiency in other studies (Pascoe *et al.*, 2001; Rijnsdorp *et al.*, 2006) and the need to explicitly address efficiency changes from technological development when launching modernization programs and setting long term capacity targets seems evident.

Integrating structural technological development in capacity management

As broadly realized (FAO, 2009; EC, 2008) the currently deployed measures of nominal capacity in commercial fisheries do not sufficiently reflect the actual harvesting capacity (effective capacity) of the fleets. Clearly, better descriptors are needed to capture efficiency increases from structural change. In a study by Pascoe et al. (2001) vessel size and engine power are included in a nominal capacity expression (vessel capacity units, VCU), which is evaluated in terms of reliability by comparison with a comprehensive fishing-capacity expression generated by data envelopment analysis (DEA). The evaluation demonstrated that the VCU expression reasonably approximates the effective capacity of mobile gears, but not of static gears. Another capacity expression (a capacity factor), used by Standal (2007) to assess the success of the Norwegian unit quota system, includes a gear factor (single or double trawl) along with an engine-power factor and three vessel-size factors and reveals a substantial mismatch between nominal and effective capacity in the Norwegian trawl fishery. Using such integrated capacity expressions when planning, implementing, and evaluating structural measures would take into account some of the unintended increases in harvesting capacity that often accompanies directed capacity plans. According to the model results in chapter 2, the inclusion of vessel size and vessel age in an integrated nominal capacity expression would most likely account for fishing power increases resulting from technological development of fish-finding and navigation-equipment. In chapter 6 the importance of gear factors (single/twin trawl and ground gear type) in describing efficiency is confirmed.

Based on the above referred experiences vessel length, vessel hp and vessel age in combination with some gear factor, depending on fishery type, are candidates for inclusion in a nominal capacity expression, which reasonably reflects the effective capacity of most fishing vessels. However, two shortcomings of such an integrated expression are also obvious from the experiences so far: i) that an appropriate gear factor is not only gear type dependent but also target species dependent (chapter 4; chapter 5 and chapter 6), and ii) that kilowatts are not very good descriptors of effective capacity in fisheries with static gears (Pascoe et al., 2001; Marchal et al., 2002). Therefore a single capacity expression covering all vessel groups of the commercial fishery is difficult to imagine and a tradeoff is inevitable between the level of accuracy in reflecting effective capacity of very heterogeneous fisheries (here fisheries are conceived as a combination of gear type and target species) and the need for such an expression to be operational in terms of its identification, its applicability and the routine monitoring of its constituents. Different tradeoffs and suggestions for operational integrated capacity expressions for some main groupings of vessels are explored further and summarized below in the section on technological challenges to effort management.

Even if integrated capacity factors, which more accurately reflect effective harvesting capacity, are successfully identified and implemented, they will only mitigate the effect of structural technological developments from non-stimulated vessel renewal or directed modernisation schemes (mechanism 1, defined above). The temporal technological development (mechanism 2), and thus the future efficiency changes from e.g. increased gear catchability or development of improved fish finding and navigation equipment, cannot be sufficiently captured no matter what the complexity and accuracy of the capacity expressions of the present. Consequently, additional measures to counteract temporal change in fishing power are needed.

Integrating temporal technological development in capacity management

One option to mitigate the effects of temporal technological development in capacity management of commercial fisheries is to include a projection of annual efficiency increase, when setting long term capacity targets. Such an approach has recently been considered by the European Commission, who has estimated an annual efficiency increase in the range of 2 to 4% in many fisheries (EC, 2008). Disregarding technological efficiency influence in structural management of European fleets will most likely result in excess fishing capacity from a mismatch between development in nominal and effective capacity as illustrated by the EU commission in figure 1, chapter 1. Assuming that a projection of a 3% annual increase in efficiency from technological development is a serious consideration in the pending revision of the CFP, two questions immediately arise in relation to the complex technology dissemination patterns and effects established in chapter 1: i) is a linear projection in accordance with the bifurcate process of radical and gradual technology development and the differentiated spread in fleet level?, and ii) if so, is a 3% annual increase in efficiency in the right order of magnitude?

To answer the first question, regarding the linearity of efficiency increases, some literature on estimates of individual annual change in fishing power or productivity for longer time periods exists (e.g., Marchal et al., 2002, Banks et al. 2002). Most of this literature takes a top-down approach and estimates annual changes in overall fleet efficiency relative to reference points such as stock indices, reference fleets (vessels that have changed little over time) or production frontiers (vessels that have been the most efficient over time). Marchal et al. (2002) investigates the annual change in an efficiency expression, integrating all vessel attributes other than engine power, for 39 different North Sea fisheries as defined by gear types and target species. Most of the fleets display an increasing efficiency trend over the study period (1987-1998) but only very few of these trends are reasonably linear (Figure 1).

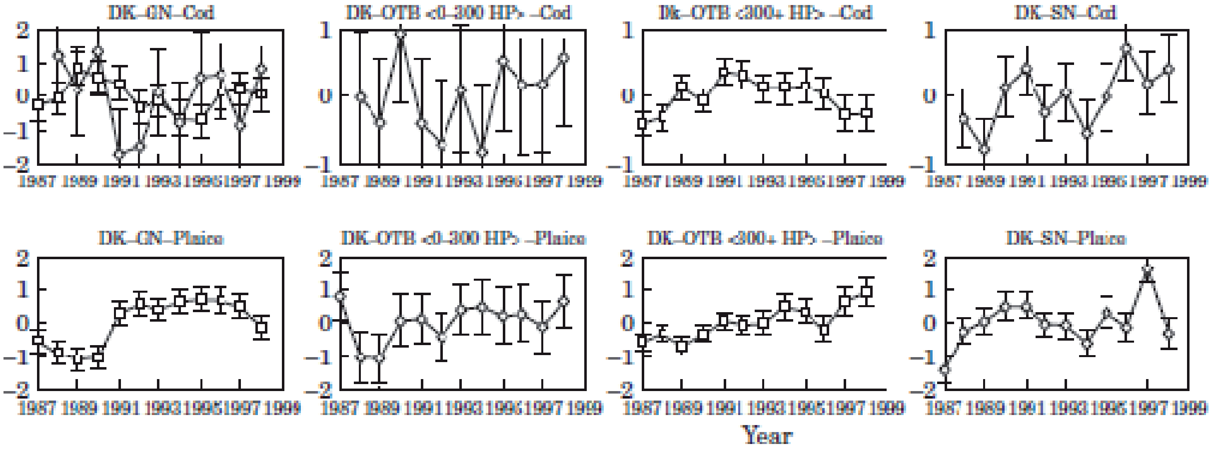

Figure 1. Annual variations in an index of fishing power for 8 of 39 North Sea fleets analysed by Marchal et al., 2002. (GN=Gill netters, OTB=Otter board trawlers, SN=Danish seine)

The most frequent pattern seems to be shorter relatively stable periods with moderate trends interrupted by one or two large year to year changes, but in general the pattern of efficiency change with time is very heterogeneous (Figure 1). However, the estimated overall efficiency development from Marchal et al. (2002) includes changes resulting from both technological development and from fishermen behaviour, as well as the effects of various regulations and other drivers. Consequently, such estimates are not very usable for identifying the course or patterns of efficiency development resulting explicitly from technological development, as the other effects are not separable.

One paper takes a more bottom-up oriented approach to identifying efficiency changes from both temporal and structural technological developments. O'Neill and Leigh (2007) relate comprehensive technological vessel data from interviews to logbook catch data on a fine temporal scale allowing estimation of fishing power changes arisen explicitly from technological development in the period 1988 to 2004. The authors separate fishing power trends into those resulting from temporal technological change (fixed terms) and those resulting from structural technological development (random terms). The fixed terms fishing power trajectories of the six investigated fleets are in principle estimates of efficiency change from temporal technological development and consequently usable for assessing the reliability of a linear projection. The trajectories display reasonably gradually increasing trends and although a few year to year changes deviate somewhat, linearity of the technological efficiency trends (dotted line, Figure 2) is more feasible than for the overall efficiency trends estimated by Marchal et al. (2002) (Figure 1).

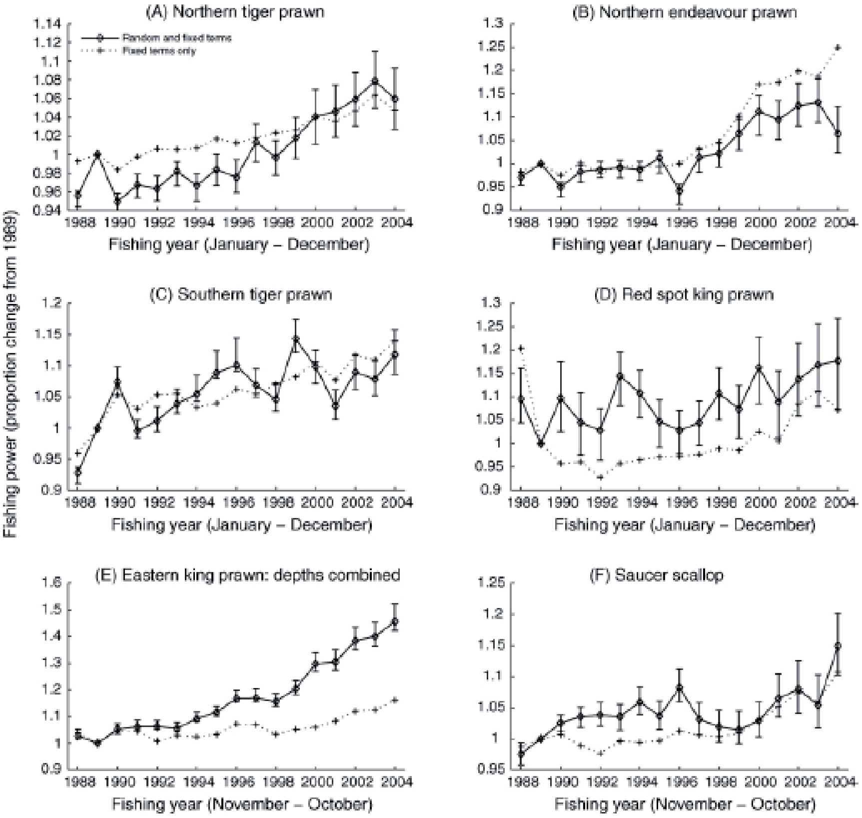

Figure 2. The technologically induced development in fishing power of six Australian trawler fleets relative to 1989. The fixed terms trajectories (dotted lines) represent the fishing power change resulting from technological vessel development (temporal technological development) and the solid lines represent the overall change from both temporal and structural (vessel renewal in the fleets) technological development. (O'Neill and Leigh, 2007).

A few additional investigations include descriptions of technology dissemination within commercial fisheries. One result questioning the validity of a linear projection is the very rapid uptake of the GPS technology seen for French bottom trawlers of South Brittany, where a fleet dissemination level of 80% was reached in three years from 1988-1990

(Mahevas et al. 2003). On the other hand the spread of this particular technology was much slower and more gradual in several other French and Danish fleets (Marchal et al., 2007; Eigaard et al., 2009). Considering also the more gradual dissemination patterns for a number of other technologies described in these two papers (e.g. twin trawls, sonars, and trawl sensors), very steep introduction slopes of larger vessel groups appear to be the exception rather than the rule. This is confirmed by the dissemination patterns of five trawler and gill net technologies within the Danish fleet (Figure 3), where the combined technology introduction (the dissemination fraction of each technology in fleet level summed) seems to be a fairly gradual progress across the 25 year study period for all three vessel groups examined.

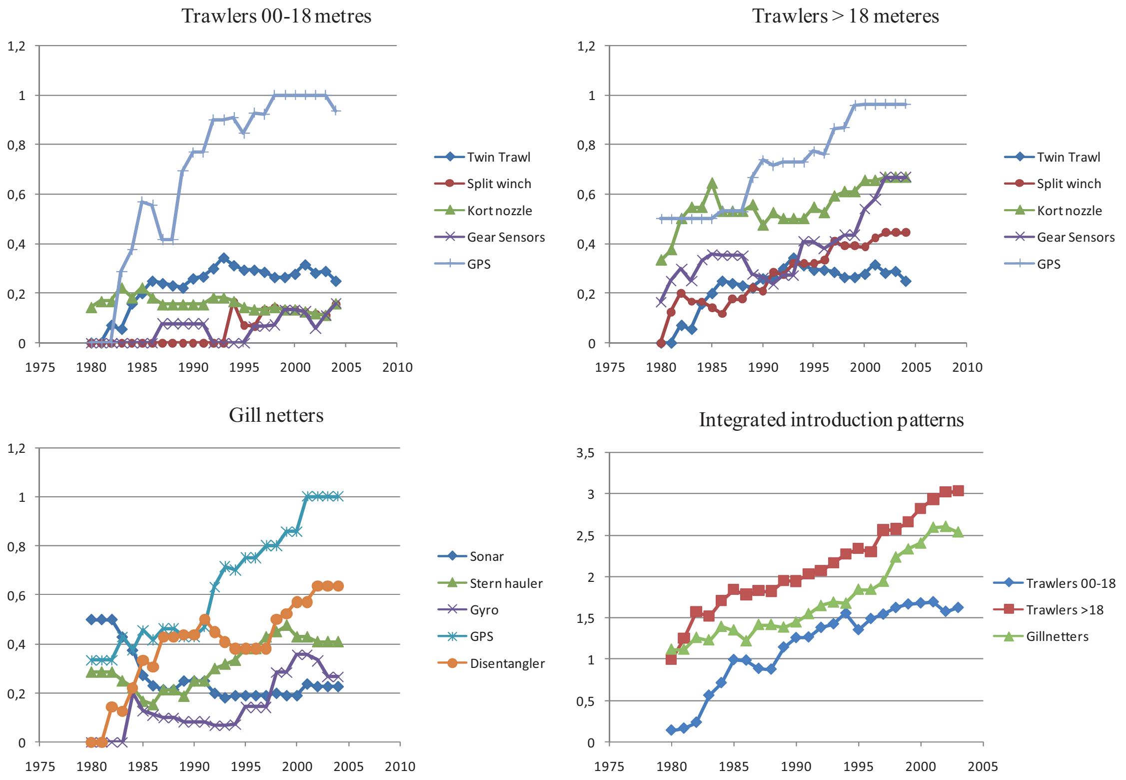

Figure 3. Individual (top-left, top-right and bottom-left) and combined (bottom-right) dissemination patterns of five trawler and five gill netter technologies in three Danish vessel groups from 1980 to 2005. The figure is based on interview data from a ~10% subsample of the demersal trawler and gill netter fleet

It does however appear that the combined introduction of twin trawl, gps and kort-nozzle on board the trawlers was quite rapid in the early eighties, thereby distorting somewhat the impression of a smooth temporal technology development across the period. However, the technology dissemination in fleet level is only an indicator of the resulting efficiency change, and bearing in mind the adverse and occasionally contradictory effects of technology introductions (chapter 1) and the time lag of full vessel fishing power benefits from e.g. GPS and plotter introduction (Bishop et al., 1998) a linear long term projection of fleet efficiency increases from technological development, seems reasonable based on the trajectories of technology introduction in Demersal Danish fleets (Figure 3) and the technological efficiency change in the Australian prawn and scallop fleet (Figure 2).

To assess whether a linear projection of fleet efficiency increase of 3% annually is in the right order of magnitude the relevant literature on quantifying efficiency change has been scrutinized and summarized (Table 1).

Table 1. A summary of global estimates of annual efficiency changes in commercial fisheries. Some of the entries by vessel type are aggregate estimates (the mean of two or three individual estimates by species, as specified in the Case study column). The estimates represent a variety of methods, models, variables and outcomes, and are as such not directly comparable, but a crude grouping in technology related estimates and overall estimates (technology, behavioural and regulation influenced efficiency change) is made to allow the extraction of average figures.

Vessel type	Reference	Outcome	Methodology	Case study	Time period	specifi tech-variables	Annual tech-related efficiency change	Annual overall efficiency change
Trawlers	Banks et al., 2002	Technical efficiency	Econometric	DK Baltic cod trawlers	1987-1999	Comprehensive tech	1.8	0
Trawlers	Kirkley et al., 2004	Technical efficiency	Econometric	Séte trawler fleet	1985-1999	Comprehensive tech	1	-3
Trawlers	Marchal, 2001	Fishing Power	GLM	Baltic cod trawlers	1987-1999	None		2
Trawlers	Marchal, 2002	Fishing power	GLM	DK-North Sea trawlers (cod, plaice) 0-300HP	1987-1998	Engine power		0
Trawlers	Marchal, 2002	Fishing power	GLM	DK-North Sea trawlers (cod, plaice) > 300HP	1987-1998	Engine power		8
Trawlers	Marchal, 2002	Fishing power	GLM	NO-North Sea trawlers (cod, haddock, saithe) 0-1000HP	1980-1998	Engine power		6.8
Trawlers	Marchal, 2002	Fishing power	GLM	NO-North Sea trawlers (cod, haddock, saithe) 1000-2000HP	1980-1998	Engine power		6.8
Trawlers	Marchal, 2002	Fishing power	GLM	NO-North Sea trawlers (cod, haddock, saithe) 2000-3000HP	1980-1998	Engine power		2.0
Trawlers	O'Neill, 2007	Fishing power	GLMM	Queensland - Northern tiger prawn	1988-2004	Comprehensive tech	0.3	
Trawlers	O'Neill, 2007	Fishing power	GLMM	Queensland - Northern endeavour prawn	1988-2004	Comprehensive tech	1.7	
Trawlers	O'Neill, 2007	Fishing power	GLMM	Queensland - Southern tiger prawn	1988-2004	Comprehensive tech	0.9	
Trawlers	O'Neill, 2007	Fishing power	GLMM	Queensland - Red spot king prawn	1988-2004	Comprehensive tech	0.5	
Trawlers	O'Neill, 2007	Fishing power	GLMM	Queensland - Eastern king prawn	1988-2004	Comprehensive tech	0.8	
Trawlers	O'Neill, 2007	Fishing power	GLMM	Queensland - Saucer scallop	1988-2004	Comprehensive tech		
Trawlers	Fitzpatrick, 1996	Technology coefficient	Engineering	Super trawlers - global estimate	1980-1995	All tech	10	
Trawlers	Fitzpatrick, 1996	Technology coefficient	Engineering	Freeze trawlers - global estimate	1980-1995	All tech	6.7	
Trawlers	Fitzpatrick, 1996	Technology coefficient	Engineering	Stern trawler - global estimate	1980-1995	All tech	6	
Trawlers	Fitzpatrick, 1996	Technology coefficient	Engineering	Shrimp trawler - global estimate	1980-1995	All tech	8	
Trawlers	Fitzpatrick, 1996	Technology coefficient	Engineering	Trawler - global estimate	1980-1995	All tech	5.3	
Trawler average							**3.6**	**2.8**
Beam trawlers	Banks et al., 2002	Technical efficiency	Econometric	Dutch Beam trawlers (sole and place)	1983-1998	Engine power, length, crew		0.8
Beam trawlers	Marchal, 2002	Fishing power	GLM	UK-North Sea beam trawlers (cod, plaice, sole)	1989-1998	Engine power		-2.1
Beam trawlers	Marchal, 2002	Fishing power	GLM	NL-North Sea beam trawlers (cod, plaice) 0-300HP	1991-1998	Engine power		3
Beam trawlers	Marchal, 2002	Fishing power	GLM	NL-North Sea beam trawlers (cod, plaice, sole) > 300HP	1991-1998	Engine power		4.7
Beam trawlers	Rijnsdorp, 2006	Partial F per unit of effort	GLM	NL-North Sea beam trawlers (plaice, sole)	1990-2003	Engine power, vintage, vessel age	2	2.2
Beam trawler average							**2**	**1.7**
Gill netters	Marchal, 2001	Fishing Power	GLM	Baltic cod gill netters	1987-1999	None		6
Gill netters	Marchal, 2002	Fishing power	GLM	DK-North Sea gill netters (cod, plaice, sole)	1987-1998	Engine power		9.5
Gill netters	Marchal, 2002	Fishing power	GLM	UK-North Sea gill netters (cod, plaice)	1989-1998	Engine power		-4.4
Gill netters	Marchal, 2002	Fishing power	GLM	NO-North Sea gill netters (cod, haddock, saithe)	1980-1998	Engine power		4
Gill netters	Fitzpatrick, 1996	Technology coefficient	Engineering	Gill netters - global estimate	1980-1995	All tech	3.3	
Gill netter average							**3.3**	**3.8**
Long liners	Fitzpatrick, 1996	Technology coefficient	Engineering	Long liner - global estimate	1980-1995	All tech	12	
Long liners	Fitzpatrick, 1996	Technology coefficient	Engineering	Tuna long liner - global estimate	1980-1995	All tech	8.7	
Long liners	Marchal, 2002	Fishing power	GLM	NO-North Sea long liners (cod, haddock, saithe)	1980-1998	Engine power		16
long liner average							**10**	**16**
Seiners	Fitzpatrick, 1996	Technology coefficient	Engineering	Purse seiner - global estimate	1980-1995	All tech	6.7	
Seiners	Fitzpatrick, 1996	Technology coefficient	Engineering	Tuna seiner - global estimate	1980-1995	All tech	4	
Seiners	Marchal, 2002	Fishing power	GLM	DK-North Sea seiners (cod, plaice)	1987-1998	Engine power		11
Seiner average							5.3	11.0
Overall Average							**4.4**	**3.9**

As discussed above, most of the literature on temporal efficiency increases in fisheries take a top-down approach to estimating annual changes in overall efficiency of various fleet segments based on analyses of landings and effort data kept in national databases. These data, from which expressions of vessel performance (economic or biological) may be calculated and analysed over time, generally reflect three types of signals: (i) the variation in stock abundance, (ii) changes in fishermen behaviour, and (iii) technological development. The signal from variations in resource abundance can in theory be separated out from the two others by using independent stock data from assessments and surveys (e.g. Marchal et al., 2002; Banks et al., 2002) but unless sufficient external technology or behaviour data are brought into the analyses of landings and effort data, as done by O'Neill and Leigh (2007) only the combined effect of these two factors can be estimated – if the resource variation is accounted for.

The problem of separating the factors resulting in overall efficiency change of commercial fleets is also reflected in the summary of quantitative efficiency estimates produced so far (Table 1). The estimates represent a variety of methods, models, variables and outcomes, and are as such not directly comparable. To evade this problem the outcomes are grouped in two categories of efficiency estimates: i) those directly attributable to technology specified in the analysis/model, and ii) those attributable to all that is not explicitly analysed/modelled - typically fishermen behaviour/skipper skills, regulatory constraints and varying subsets of vessel technology (frequently in the form of a year effect in the models). This grouping is, however, far from sharp cut, but the separation allows the extraction of average figures by vessel types, which can be used for assessing the order of magnitude of annual efficiency increases from technological development. Having said that, it is worth underpinning that these average figures should be treated with caution; a weakness of practically all the investigations, apart from those of O'Neill and Leigh (2007) and Fitzpatrick (1996), is the applicability and the reliability of the data used for separating out the influence of resource variation with time. In several studies, this aspect of uncertainty is informed by the authors as a reason for treating their results only as indicative (e.g. Kirkley et al., 2004). Even so, the figures in Table 1 are currently the only quantitative data available for assessing the magnitude of catch efficiency increases with time in fisheries.

Well aware of the uncertainty involved (e.g. from the aggregation of some entries through averaging two or three individual estimates by species), the main picture taken from the summary is that temporal technological development has enabled an annual efficiency increase of 3.6% in demersal trawl fisheries, 2.0% in beam trawl fisheries, 3.3% in gill net fisheries, 10% in long line fisheries, and 5% in seine fisheries, leading to an overall average of 4.4% (Table 1). It is also interesting to observe that the average overall efficiency increase estimates for trawlers and beam trawlers are lower than the average technology efficiency increase estimates. This implies that regulations and constraints on these two fishery types are heavier or easier to enforce than in the three other fisheries (long line, gill net, and seine fishing) where the overall efficiency increase is higher than the technological efficiency increase alone.

In conclusion, attempts to integrate the effects of temporal technological development in long term capacity management by projecting a general annual efficiency increase of 3% in the total EU fleet, should not be rejected based on the scientific results so far (Table 1). Apparently there are, however, different rates of efficiency increases between vessel types, e.g. long liners 10% and beam trawlers 2%, and it might be worthwhile considering different annual percentages for the main vessel groups (Table 1). For this purpose, however, the currently available data are insufficient and an extension of the input basis for table 1 needs to be made.

Effort management and technological development

The fishing effort term can be considered an elaboration of the fishing capacity term with a fishing activity component, or possibly better; a function of capacity and activity, as in some cases nominal fishing effort is managed and described purely with activity (.e.g. in the Faroese effort regulation, chapter 4). This definition of fishing effort is easily comprehended from figure 2, chapter 1, and it is also appreciable from the same figure that most of the mismatch problems of nominal and effective fishing capacity discussed above are directly transferable to effort management, in that capacity is a constituent of effort. This also implies that the technological creep solutions of capacity management, in terms of improved capacity descriptors and projections of efficiency increase, are a part of the technological creep solutions or for effort management. This contemplation is of course also the reason that specific suggestions for appropriate integrated capacity descriptors by vessel type was not made previously, in the section on technological challenges to capacity management, but postponed to be dealt with in more detail in an effort regulation context. If capacity related mismatch is one constituent of effective and nominal effort mismatch, the other is activity related mismatch. Activity related mismatch can be conceived as the ability of any nominal activity descriptors to reflect effective fishing activity. In the terminology established in chapter 1, effective fishing activity translates to effort utilization at sea, which is strongly influenced by technological development and can have substantial effect on catch efficiency of e.g. seiners pair trawlers and beam trawlers (Figure 8, chapter 1; Thomsen, 2005; Rijnsdorp at al., 2008). With reference to i) the technological framework established in chapter 1, ii) the analyses and results of chapter 4, chapter 5 and chapter 6, and iii) the available relevant literature, considerations of valid descriptors of effective capacity, activity and effort by seven main types of fishing vessels/gears are summarized (table 2). The suggestions for optimal effective effort descriptors and additional logbook variables (third and second last column, Table 2) have been established with the objective of most accurately reflecting the main motive of fisheries: to increase catches through optimizing q, density and effort utilization (page 7, chapter 1) in a capacity, activity and effort context. As expressed for each vessel group in the last column (Table 2) no effort descriptor, regardless of accuracy, can capture the influence of temporal technological development on the catchability of the gears deployed in the future. Therefore a projection of increases in gear catchability with time seems inevitable - at least for the five non-pelagic vessel types, where the catch process is more important compared to the search process. The magnitude of such a projection of gear catchability increases would need to be identified by each vessel/gear type (table 2) and lies in immediate continuation of the future research need for quantification of efficiency increase projections for capacity management (previous section). The suggestions for accurate effort descriptors (second last column, Table 2) have been made under the assumption of full compliance from fishermen and no technical data handling problems. This is of course a simplification and if for instance the activity descriptors on a fine scale (e.g. number of seine hauls per trip) are considered to be poorly operational, another option could be to incorporate expected increases from improved effort utilization with time in the projection of improved catchability with time. Such an approach would enable using a more operational activity descriptor, e.g. days at sea, but it would also reduce the ability of nominal effort descriptors to accurately reflect effective effort – and it would require an intensive effort to quantify valid integrated projections by vessel group.

Table 2. Suggestions for improved effective effort descriptors by vessel type based on the definition of effort as a function of capacity and activity and the concept of technological influence on efficiency through either, Q, density or effort utilisation.

Vessel/gear type	Catch principle	Principal technology	Optimal effort measure	Optimal capacity measure	Optimal activity measure	Main shortcomings of optimal measure	Available logbook Proxy for capacity	Available logbook Proxy for activity	Additional shortcomings of Log book proxies	new logbook variables	Suggested effort descriptor	Remaining shortcoming
Demersal seiners	"blind fishing"	Gear size	M2 fished	Seine rope length	Haul number	q (e.g. groundgear, seine design) and density trends	Kilowatt, boat size (Loa, GRT)	Days of fishing	Trends in effort utilisation	i) Seine rope length ii) number of hauls	Loa * rope-length* haul number	Temporal trends in q
Pelagic/purse seiners	Searching	Sonar range	M2 searched	Sonar range	Distance searched	q (e.g. seine design)	Kilowatt, boat size (Loa, GRT)	Days of fishing	None	i) Sonar range ii) loading capacity	Sonar range* loading capacity* distance searched	Temporal trends in q
Demersal trawlers	"blind fishing"	Gear size	i) M2 fished ii) M2 fished iii) M3 fished*	i) door spread ii) ground gear length iii) trawl mouth area	Distance trawled	q (e.g. groundgear, trawl design) and density trends	Kilowatt, boat size (Loa, GRT)	Days of fishing	Trends in effort utilisation	i) Door spread/ ground gear length/ trawl mouth area ii) trawling speed iii) trawling time	Loa* Door spread/ ground gear length/ trawl mouth area * trawled distance	Temporal trends in q
Pelagic trawlers	Searching	Sonar range	M2 searched	Sonar range	Distance searched	q (e.g. trawl design)	Kilowatt, boat size (Loa, GRT)	Days of fishing	None	i) Sonar range ii) loading capacity	Sonar range* loading capacity* distance searched	Temporal trends in q
Beam trawlers	"blind fishing"	Gear size	M2 fished	Total beam width	Distance trawled	q (e.g. ticklers, schafers) and density trends	Kilowatt, boat size (Loa, GRT)	Days of fishing	Trends in effort utilisation	Trawling speed and time	Loa* Beam width* trawled distance	Temporal trends in q
Gill netters	"blind fishing"	Gear size	M1 fished	Length of nets set	Number of sets	q (e.g. netting material, diameter) and density trends	Kilowatt, boat size (Loa, GRT)	Days of fishing	Trends in effort utilisation	i) Meters of net set ii) sets per trip	Loa* Length of nets* number of sets	Temporal trends in q
Long liners	"blind fishing"	Gear size	Hooks fished	number of hooks set	Number of sets	q (e.g. hook and line design, bait used) and density trends	Kilowatt, boat size (Loa, GRT)	Days of fishing	Trends in effort utilisation	i) Hooks per set ii) sets per trip	Loa* Number of hooks* number of sets	Temporal trends in q

* In some demersal trawl fisheries trawl height is important component gear efficiency, e.g. the *Pandalus* fishery with semi pelagic trawls and Sand eel fishery with pelagic trawls (chapter 3 and chapter 5).

In this discussion the increasing amount of VMS (Vessel Monitoring System) data being generated and explored should also be brought forward and these data point in the direction of effort descriptors on a finer temporal scale being more feasible to deploy. Another argument supporting the feasibility of a fine scale effort management is that precise effort and activity descriptors have a more "fair" nature, in that e.g. material break down or bad weather interruptions are accounted for, and effort quotas thus a larger probability to be accepted as meaningful and therefore complied with by the fishermen (Raakjær and Mathiesen, 2003; Christensen and Raakjær, 2007).

With the vessel groupings and the effective capacity and activity summary of Table 2 the basis for identifying valid effort descriptors for aggregate vessel groups is certainly improved. The suggestions for effort descriptors, however, represent a tradeoff between the accuracy in reflecting adverse biological effects of very heterogeneous fisheries and the need for the effort descriptors to be operational in terms of applicability and routine monitoring. Therefore one main concern remains: whether such aggregate descriptors are sufficiently robust to the species specific effects of many technologies (chapter 4; chapter 5) and e.g. the targeting behavior options of fisheries (Branch and Hilborn, 2008; Quirijns et al., 2008), when it comes to defining effort quotas that reasonably correspond to the intended level of fishing mortality. This is a key issue and a potential problem of any effort regulation (Martell and Walters, 2002; Shepherd, 2003; Rijnsdorp et al., 2006) and the consequences of inaccurate effort descriptors and quotas have recently been demonstrated by the overfished Faroese cod and haddock stocks (Jákupsstovu et al., 2007).

TACs and technological development

Whenever time series of commercial cpue data are employed for stock assessment purposes, either directly as an indicator of fishable biomass or indirectly for tuning age-based stock assessment models, bias from technological development is to be expected (Marchal et al., 2001; Branch et al., 2006). If this bias is not corrected for, the result is inaccurate or incorrect stock assessments and consequently a wrongful basis of advice, including the setting of TACs.

The more direct the influence of commercial cpue in the scientific stock assessments, the more important cpue correction is. The annual assessment of the northern shrimp (*Pandalus Borealis*) stock in the North Sea has largely relied on a commercial cpue time series calculated from Danish logbook data. In chapter 3 it is demonstrated how a 2008 cpue correction for 22 years of technological development, in terms of fleet renewal and trawl size development, has altered the basis of advice substantially, from a strongly increasing stock size of the period to a stable to slightly increasing stock size. Similar results on the importance of correcting commercial cpue indices used in stock assessments are demonstrated for a number of prawn and scallop fisheries in Greenland and Queensland, Australia (Hvingel et al., 2000; O'Neill et al., 2003; O'Neill and Leigh, 2007). In the cases where commercial cpue time series are used only indirectly for tuning age-based stock assessment models, the technological bias of the times series has of course lesser impact on the final assessment of the stock status. Presumably this is also the reason why very few scientific investigations dedicated technological standardisation of such indirectly used time series exists. However, even cpue time series of commercial tuning fleets can substantially influence the final assessment result and if such tuning series are deployed, they should be scrutinized on a regular basis for potential bias from efficiency trends. Well-founded suspicions of any radical or gradual technology development of the period with substantial efficiency influence should be analysed in detail and if necessary the time series should be corrected accordingly.

Another, more theoretical, challenge to TAC managed fisheries from technological development is the influence from increased efficiency on discards and high grading. In fisheries that are managed through output control such as TACs, discard and high grading behaviour is practically impossible to avoid (Daan, 1997; Catchpole, et al., 2005; Poos et al., 2010) and it is conceivable that higher catches from e.g. larger or more efficient gears will also result in larger discards or more high grading. It is, however, more likely that the main effects of technological development in TAC managed fisheries will be cost reduction oriented in terms of catching the allowed quantity of fish with less effort (e.g. in fewer fishing days or using less fuel) and consequently the biological effect in output controlled fisheries will be limited (Thomsen, 2005). In conclusion, the challenges from technological development are likely to be of less concern in an output-based fisheries policy, although the complications imposed on the use of commercial effort data in stock assessments should be recognized, as should the potential risk of increased discards and high grading behaviour.

Conclusion

Whatever the management system in force technological development in commercial fisheries will take place, with catch efficiency increases as the main driver and the main effect (chapter 1). Even though the radical and gradual development of technology is inevitable and almost indifferent to the regulations in force (Whitmarsh, 1990; Stefansson and Rosenberg, 2005; chapter 4) the sensitivity of the different management strategies to the effects of technological development are far from uniform.

Direct control of fishing effort (short-term input control) is expected to have certain advantages over TACs such as decreased enforcement costs and reduced discards (Murawski and Finn, 1986; Catchpole, et al., 2005;; Rijnsdorp et al, 2007). However, the success of effort control as fisheries management strategy is highly sensitive to technological development and the resulting efficiency changes of commercial fishing vessels (Rossiter and Stead, 2003; Stefansson and Rosenberg, 2005; Jákupsstovu et al., 2007), whereas in an output controlled system these effects are in theory self adjusting (Charles, 1995; Thomsen, 2005; chapter 4).

Accepting that both discards and technological creep are serious threats to a sustainable fisheries management, the currently available regulation tools leave the management in a catch 22 situation: output control and discard and misreporting problems or input control and continuously increasing and potentially excess resource harvesting capacity. What choice to make is in the nature of the case difficult to decide? Well aware that the problems of discard and misreporting are not treated in detail in this thesis and consequently difficult to assess precisely, the demonstrated management challenges from technological development to input-oriented fisheries policies seem the more comprehensive. Considering the heterogeneity of the biological effects the task of achieving agreement between intended (effort quotas set) and realized fishing mortality appears difficult. The heterogeneity of the technological challenges is not only restricted to the development of different technologies in different fisheries, or different use of the same technologies in different fisheries (e.g. the use of sonar technology for fish finding in pelagics and for small scale navigation in wreck fishing with gill nets), but also to species specific effects of the same technology development in the same fishery (e.g. the development of skewed hooks and swivel line in the Faroese long line fishery, which in combination resulted in a 49% increase in haddock catchability but only marginally affected cod catchability [chapter 4]). Bearing this complexity in mind, and adding to it the need to also identify and predict catchability changes from factors such as targeting behavior, skipper skills, technical interactions, compliance, contraction of the stocks and environmental conditions, the pendulum of this PhD synthesis swings towards favouring output control - and coping somehow with discards and misreporting - rather than attempting to manage fishing mortality levels through expected matching levels of fishing effort. In this consideration recent successful experiments with fully documented fisheries enabling the transition from landing quotas to actual catch quotas (Dalskov et al., 2009) have played a part.

If, however, the benefits of reduced discards, misreporting and enforcement costs of short-term input control are assessed more important than the relative insensitiveness of TAC management to the effects of technological creep (and the other factors influencing catchability), it is crucial to equip such a system with tools to mitigate the unintended biological effects of technological development (as well as catchability trends related to e.g. fishermen behavior and environmental conditions). Accurate and operational nominal descriptors of effective capacity and effort are prerequisites of long- and short-term input control systems and need to be supplemented with realistic long- and short-term projections of efficiency increases from technological development.

One of the objectives of this thesis was to assess whether such descriptors and projections can be developed for aggregate vessel groups. With respect to the descriptors of effective capacity and effort, the conclusion is positive and the foundation for identifying suitable nominal descriptors by major vessel groups seems feasible (Table 2, chapter 7). Based on the analyses and reviews in this thesis identification of a linear long-term projection suited for integrating in capacity management plans also appears realistic. Furthermore the tentative overall 2-4% annual efficiency increase presented by the Commission (EC, 2008) is assessed to be in the right order of magnitude, although a differentiation by major vessel groups is recommendable (Table 1, chapter 7). When it comes to deploying short-term projections of catchability changes from technological development, which are inevitable to integrate if effort quotas are to correspond reasonably to the intended level of fishing mortality, the feasibility is more questionable. As discussed above the complexity of the biological - often species specific - effects of technological development makes the task very comprehensive. Considering the need also to integrate other catchability effects related to e.g. fishermen behavior and environmental conditions, the task of achieving a reasonable correspondence between assigned effort quotas and realized fishing mortality on a broad basis seems unrealistic.

In conclusion, the undesired effects of technological development are limited in output controlled fisheries and almost solely restricted to complicate the setting of appropriate TACs, if time series of commercial effort data are part of the underlying stock assessments. When this is the case, assessment procedures should be scrutinized for bias from efficiency trends on a regular basis and the time series should be corrected accordingly. However, although relatively insensitive to technological development, the inability of output control to cope with discards and misreporting are serious flaws, which in many fisheries have resulted in failure to achieve management objectives.

The undesired effects of technological development are comprehensive and difficult to counter in short-term input control systems (effort management). The problem of mismatch between nominal and effective effort can only be solved partly with the improved descriptors and the remaining task of predicting and mitigating catchability trends in a system as complex as the commercial fishery is not feasible on a broad basis. Other factors such as targeting behaviour and skipper skills can also contribute substantially to decoupling of nominal and effective effort and an unbalance between intended and realized fishing mortality. A great advantage of direct effort control as a sole regulation in force is that it gives very little incentive to discard or misreport.

Fishing power increases from technological development also substantially undermine long-term input control (capacity management), but counteracting these effects with improved capacity descriptors and long-term efficiency projections by major vessel groups is relatively straight forward. However, the long-term perspective of capacity management does not fit well with the changeable character of biological systems and supplementing short-term regulations are therefore required.

Consequently, integration of technological development in fisheries management – and of other factors undermining policy objectives - is not a question of either input or output control, but of understanding the complexity of the fisheries system and of tailor making solutions from the mixed input- and output regulation toolbox on as fine a scale as possible.

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Summary

The major objective of this synthesis has been to throw light on how technological development in fisheries can complicate efforts to balance harvesting capacity and fish resources. The basis of achieving this objective has been the compilation of technological data from a selection of European fisheries, which cover some main principles of how technological development influences catch rates and fishing mortality. This work has been based largely on sociological approaches in the form of interviews with fishermen, gear manufacturers, ship yards, suppliers of electronic equipment, etc., as well as exploration of historical and commercial data from the same type of sources. That is, retrieval of technological data in very incompatible formats from a broad and heterogeneous set of sources and structuring the data in an operational manner.

Building on this empirical material a bottom-up analytical framework embracing technical, economical, sociological and biological aspects was established, in which to understand the technological development in fisheries and its effects on the marine resources. Using this framework the concept of technological development was related to the main components and mechanisms of the European fisheries system. It was established i) how new fishing technology is developed in a bifurcated process of either radical or gradual nature, ii) how the speed and extent of technology spread is very uneven among the different vessel groups of the commercial fleet, iii) how catch increase is the main driver of technology uptake on board the vessels, iv) how this objective can be achieved through technologically mediated improvements of gear catchability, fish finding and navigation, and effort utilisation at sea, and v) how both input and output oriented fisheries management is challenged by these bearings of technological development in commercial fisheries.

The main message from this bottom-up approach was that irrespective of the management system in force technological development in commercial fisheries will take place with catch efficiency increases as the main driver and the main effect.

Even though radical and gradual development of technology in fisheries is inevitable, and almost indifferent to the regulations in force, the sensitivity of the main management principles to the effects of technological development are far from uniform. This became evident as analyses of five European case study fleets demonstrated i) how technological development can complicate output control by adding uncertainty to standard stock assessment procedures, ii) how short-term input control (in terms of effort quotas) can be undermined by technologically induced efficiency increases, which decouple nominal effort from effective effort, and iii) how long-term input control (in terms of buy back schemes and other capacity control measures) are also undermined by efficiency changes from both temporal and structural technological development.

The main shortcomings of both output and input oriented management strategies were explored further in relation to the undesired effects from technological development, as well as a multitude of other factors, which have been shown to influence catchability and the reliability of official catch and effort data (e.g. targeting behaviour, discards, high-grading, and environmental conditions). Following this exploration of advantages and disadvantages of the main type of management strategies available, the possibilities of integrating technological

development to improve biological sustainability and achieve better agreement with policy objectives were identified and summarized as follows:

i) The undesired effects of technological development are limited in output controlled fisheries and almost solely restricted to complicating the setting of appropriate TACs, if time series of commercial effort data are part of the underlying stock assessments. When this is the case, assessment procedures should be scrutinized for bias from efficiency trends on a regular basis and time series should be corrected accordingly. However, although insensitive to technological development, the inability of output control to cope with discards and misreporting are serious shortcomings, which in many fisheries have resulted in failure to meet management objectives.

ii) In contrary, the undesired effects of technological development are comprehensive and difficult to counter in short-term input control systems (effort management). The problem of mismatch between nominal and effective effort can only be solved partly with improved descriptors and the remaining task of predicting and mitigating catchability trends in a system as complex as the commercial fishery is not feasible on a broad basis. Other factors such as targeting behaviour and skipper skills can also contribute substantially to a decoupling of nominal effort from effective effort and with that a mismatch between intended and realized fishing mortality. A great advantage of direct effort control as sole regulation in force is that it gives very little incentive to discard or misreport.

iii) Fishing power increases from technological development also substantially undermine long-term input control (capacity management), but counteracting these effects with improved capacity descriptors and long-term efficiency projections by major vessel groups is relatively straight forward. However, the long-term perspective of capacity management does not fit well with the changeable character of biological systems, for which reason supplementing short-term regulations (i.e. elements of (i) or (ii) above) are required.

Consequently, integration of technological development in fisheries management - and of other factors undermining policy objectives - is not a question of either input or output control, but of understanding the complexity of the fisheries system and of tailor making solutions from the mixed input and output regulation toolbox on as fine a scale as possible.

Samenvatting

Het doel van dit proefschrift is om inzicht te verkrijgen in de vraag hoe technologische ontwikkelingen het vinden van een balans tussen vangstcapaciteit en productiviteit van visstapels kan bemoeilijken. Op basis van een compilatie van technologische gegevens van verschillende Europese visserijen worden de belangrijkste principes behandeld die de relatie tussen visserijtechnologie en de vangst en visserijsterfte bepalen. Het onderzoek combineert een sociologische benadering waarbij vissers, toeleveranciers van vistuigen en elektronische hulpmiddelen, scheepswerven e.d. worden geïnterviewd, met de ontsluiting en analyse van historische gegevens. Een belangrijk uitdaging hierbij is het structureren van een breed scala aan diverse gegevens die vaak op een niet uniforme manier waren opgeslagen.

Op basis van deze empirische gegevens is een analytisch raamwerk ontwikkeld, waarin technische, economische, sociologische en biologische aspecten zijn samengebracht, waarmee het concept van technologische ontwikkeling gerelateerd wordt aan de belangrijkste componenten en mechanismen van het Europese visserijsysteem. Aangetoond wordt dat (i) visserijtechnologie zich volgens een bifurcatie proces ontwikkelt van geleidelijke of plotselinge aard; (ii) verschillende groepen van schepen sterk verschillen in de snelheid en mate waarin nieuwe technologie wordt opgenomen; (iii) de belangrijkste drijfveer voor het toepassen van nieuwe technologie is de toename van de vangst; (iv) de vangsttoename kan worden gerealiseerd door technologische verbeteringen van het vistuig, de visopsporing methodiek, de navigatie methodiek en effectieve vistijd op zee, en v) technologische ontwikkelingen implicaties heeft voor zowel 'input' als 'output' gericht visserijbeheer.

De belangrijkste conclusie van de gevolgde 'bottom-up' benadering is dat ongeacht het beheerssysteem zich technologische ontwikkelingen voordoen waarbij de verbetering van de vangstefficiëntie zowel de belangrijkste drijfveer si als het belangrijkste effect.

Alhoewel snelle of geleidelijke ontwikkelingen in visserijtechnologie onvermijdelijk zijn, en bijna ongevoelig zijn voor management maatregelen, zijn de effecten ervan op het beheer verre van uniform. De analyse van vijf verschillende Europese visserijen toonde aan dat: (i) technologische ontwikkelingen het beheer door middel van vangstbeperkingen ('output control') bemoeilijken door toename in onzekerheid in de toestandsbeoordelingen; (ii) technologische ontwikkelingen kunnen de korte termijn visserijinspanningbeperkingen ('input control') teniet doen door het verhogen van de vangstefficiëntie (ontkoppeling van nominale visserijinspanning van de effectieve visserijinspanning); (iii) lange termijn beperkingen van de visserijinspanning (door het terugkopen van visserijcapaciteit of andere maatregelen om de visserijcapaciteit te beheersen) kunnen worden teniet gedaan door zowel temporele als structurele technische ontwikkeling.

De belangrijkste tekortkomingen in het beheer door middel van inspanningbeperking en vangstbeperking werden verder onderzocht in relatie tot de ongewenste effecten van technologische ontwikkeling en een groot aantal andere factoren die de vangstefficiëntie en de betrouwbaarheid van de vangst en inspanningsgegevens (zoals veranderingen in de gerichtheid van de visserij op meerdere doelsoorten, de bijvangst van ondermaatse vis (discards), het opwaarderen van de besomming door het overboord zetten van de goedkopere sorteringen van marktwaardige vis of van het deel van de vangst waarvoor de visser geen vangstrechten heeft en

omgevingsfactoren). Teneinde de biologische duurzaamheid te verbeteren en om een betere overeenstemming te verkrijgen met de gestelde politieke doelstellingen kunnen, op basis van de analyse van voor- en nadelen van de twee visserijbeheerssystemen (vangstbeperking, inspanningsbeperking), de mogelijkheden voor het integreren van informatie over technologische ontwikkeling in het beheersysteem als volgt worden samengevat:

(i) binnen het beheersysteem van vangstbeperking blijven de ongewenste effecten van technologische ontwikkeling beperkt tot het bemoeilijken van het vaststellen van de TAC (Total Allowable Catch) wanneer althans in de toestandbeoordeling gebruik wordt maakt van commerciële vangst en inspanningsgegevens. Indien dit het geval is moeten de commerciële gegevens nauwkeurig worden geanalyseerd op de mogelijkheid van efficiëntie veranderingen en indien nodig hiervoor worden gecorrigeerd. Het vangstbeperkingbeheer is ongevoelig voor technologische ontwikkeling maar wel gevoelig voor bijvangst (discards) en misrapportage die in verschillende visserijen hebben geleid tot het falen van het visserijbeheer.

ii) binnen het beheersysteem van inspanningbeperkingen (korte termijn) zijn de ongewenste effecten van technologische ontwikkeling moeilijk te pareren. Het probleem van de ontkoppeling van de nominale en de effectieve visserijinspanning kan deels worden opgelost door de ontwikkeling van betere indicatoren voor effectieve visserijinspanning. Het voorspellen of mitigeren van het effect van technologische ontwikkeling op de vangstefficiëntie lijkt echter niet haalbaar. Ook andere factoren, zoals de gerichtheid waarmee een schipper een doelsoort bevist en de vaardigheden van de visser, kunnen tot een ontkoppeling van de nominale en effectieve visserijinspanning leiden en zodoende tot een verstoring van de relatie tussen nominale visserijinspanning en visserijsterfte. Een groot voordeel van inspanningsbeperking is dat het de prikkel tot misrapportage of marktwaardige vis overboord te gooien (discards, over-quota vis, opwaarderen van de vangst) wegneemt.

iii) de toename van het vangstvermogen (‘fishing power’) ten gevolge van de technologische ontwikkeling in de visserij ondermijnt het capaciteitbeheer (lange termijn), maar dit effect kan worden ondervangen door de ontwikkeling van indicatoren van de vangstcapaciteit en vangstefficiëntie en het projecteren van ontwikkelingen in de vangstefficiëntie van verschillende groepen van schepen. Het lange termijn perspectief van het capaciteitbeheer botst echter met de variabiliteit in het biologische system waardoor korte termijn maatregelen (elementen van (i) en (ii)) nodig zijn.

De integratie van technologische ontwikkelingen in het visserijbeheer – en van andere factoren die de beheerdoelstellingen kunnen ondermijnen - heeft niet zozeer te maken met een keuze voor het beheersysteem (vangst- of inspanningsbeperking) maar met het begrijpen van de complexiteit van het visserijsysteem op basis waarvan vervolgens pasklare oplossingen kunnen worden ontwikkeld waarbij gebruik kan worden gemaakt van elementen uit zowel de vangstbeperking als inspanningsbeperking systeem op een zo klein mogelijke schaal.

Curriculum Vitae

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Education

- Training course in advanced fish stock assessment techniques (ICES-WKAFAT), 2005
- PhD course in bio-economic modelling, FAME, 2003
- Course in Regression analysis, Royal Danish Veterinary and Agricultural University, 2003
- International training course in trawl technology, SINTEF-Denmark, 2002
- Master of Science in biology, University of Copenhagen, 1999

Positions held

- Academic employee at DTU Aqua, Charlottenlund, 2004-present. Research focus: gear technology, fisheries technology and fisheries management
- Research assistant, DIFRES, Hirtshals, 2000-2004. Research focus: gear technology
- Research assistant, University of Lund, 1999-2000. Research focus: nutrient flow to the Baltic Sea
- Assistant lecturer in freshwater biology courses, University of Copenhagen, 1999

Scientific focus and experience

Research

- Participation in about 10 international EU funded research projects on gear technology and fisheries management (e.g. ISDBITS, TECTAC, CAFE, DEGREE)
- International project leader of the EU funded project (EU-study project No. 98/002: Development and testing of a grid system to reduce by catches in Norway Pout trawls).
- Project leader of three externally funded national research projects conducted in close collaboration with the fishing industry (two projects on by-catch reduction of fish through improved trawl selectivity and one project on reducing harbour porpoise by-catch through improved gill net selectivity)
- Participation in about 10 national externally funded research projects with focus on gear technology, monitoring and managing of human consumption and industrial fisheries (e.g. TEMAS, FISHSELECT, ETOMTOBIS, Fehmern Belt)
- Project lead and participation in several national internally funded research projects
- Referee for international journals (Fisheries Research, Aquatic Living resources, Journal of Cetacean Research)
- Comprehensive sailing experience on board both commercial and research vessels in relation to research projects

Advice and public information

- Member of the NAFO/ICES *Pandalus* Assessment Group, *Pandalus* stock in IIIa and IVa East
- Member of the ICES Fishing Technology and Fish Behaviour Working Group
- Member of the ICES study group on combining gear parameters into effort and capacity metrics
- Member of the ICES study group on survey trawl standardisation, 2005-2007
- Member of the ICES Baltic Fisheries Assessment Working Group, 2003, cod stock in Kattegat
- Several notes for the Danish Ministry and text for use in DK legislation
- Several presentations of scientific results on fishing gear for the industry and the ministry
- Presentation of scientific results in local radio stations and newspapers

Teaching and dissemination of research results

- Assistant lecturer in freshwater biology at the University of Copenhagen
- Guest lecturer on fisheries management at the Danish Fisheries Training Centre
- Supervision of bachelor project in fisheries technology at University of Copenhagen
- Frequent oral presentations in English at symposia, study groups and workshops
- Production of peer reviewed papers (7), conference proceedings (9) and scientific reports (9) as detailed in the attached list of publications

Publications

Peer reviewed articles in scientific journals

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