DEEPFISHMAN
Management And Monitoring Of Deep-sea Fisheries And Stocks

Project number: 227390

Small or medium scale focused research action
Topic: FP7-KBBE-2008-1-4-02 (Deepsea fisheries management)

DELIVERABLE D6.1

Title: Evaluation of the relevance of commercial catch data to assess changes in the species composition of deep-water fish assemblages. Definition of indicators of fish diversity based on catch data

Due date of deliverable: M18 (September 2010)

Actual submission date: 29 November 2010

Start date of the project: April 1st, 2009 **Duration :** 36 months

Organization Name of lead coordinator: Ifremer

Dissemination Level: PU

Date: 29 November 2010

Version: 1

Research project 2009-2012 supported by the European Union,
Seventh Frame Work Programme

Evaluation of the relevance of commercial catch data to assess changes in the species composition of deep-water fish assemblages and definition of indicators of fish diversity based on catch data

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1. Introduction

Commercial catch data provide a potentially biased view of the structure and changes in the exploited fish assemblages due to the targeted nature of fishing operations. Targeting affects where, when and how fishing is carried out. As a result commercial catch data do not provide a random sample from the underlying assemblages. In statistical terms this is referred to as 'preferential sampling' (Diggle and Menezes 2010). For this reason scientific surveys have been initiated for many ecosystems which follow standardised sampling protocols. However, in the case of deep-water ecosystems, not many survey series exist currently, though for example discussions are underway for initiating a standardised deep-water bottom trawl survey in the ICES area (PGNEACS, ICES 2009). So despite the known shortcomings of commercial catch data for investigating changes in exploited fish assemblages it is essential to evaluate to what extent and under which circumstances these data might be used to inform on assemblage structure and changes.

In this study the evaluation of the relevance of commercial catch to assess changes in the species composition of deep-water fish assemblages is decomposed into several steps. The first step consists in analysing for each ecosystem (here case studies) the characteristic of the deep-water fisheries in terms of gears, fishing grounds, seasonal activity patterns, target and bycatch species with the aim to evaluate which component of the deep-water fish assemblage might be "sampled" by the fisheries and whether this sampling might be consistent in time. Any changes in the space-time allocation of fishing effort will bias time trends. As a result commercial catch data cannot be used directly but possibly once any unwanted effects have been removed using dedicated models, as for example was done by Lorance et al. (2010) for deriving blue ling population abundance indices from commercial haul-by-haul data. These authors used generalised additive models to control for vessel, depth and space-time effects.

The second step consists for each fishery to summarise the types and quantities of available commercial catch information.

In the third step for each type of commercial catch data the information content is evaluated for selected data rich case studies. The types of commercial catch data considered are: landings and logbooks, haul-by-haul data from onboard observers and haul-by-haul data from fishermen's own records (tallybooks). When possible metrics on spatial and temporal patterns of fish assemblage composition are compared to information derived from survey data.

Finally, after evaluating the information content of commercial catch data, potential indicators for monitoring changes in deep-water fish assemblages and guidelines for their calculations are be proposed.

2. Characteristics of case study fisheries

2.1. Methodology

To determine for which component of the fish assemblage commercial catch data might provide information, fisheries characteristics were collated and classified. The categories considered are fishing gears, fishing strategy, fishing area and discards.

For fishing gears, if only one type of gear with high size selectivity is employed or single species aggregations are targeted, the fishery is classified as *selective*, otherwise if either the gear used is little selective or a variety of gears are employed it is classified as *unselective* with respect to the deep-water fish assemblage. The importance of fishing gear is stressed by the results of Gordon and Bergstad (1992) who found when sampling the deep-water fish assemblage in the Rockall Trough that the number of species and their identity depended on the type of survey trawl being used.

For fishing strategies, several aspects are considered. Targeting of single species spawning aggregation or single species in certain areas or depth ranges leads to strong spatial and seasonal patterns in species composition of commercial catches. Fisheries exhibiting such space-time variability in species targeting are classified as *space-time variable,* while the others are *space-time constant*. An example for this kind of behaviour is provided by the French deep-water trawl fishery to the west of the British Isles. Up to 2009 when this practice became banned, the fishery was targeting blue ling spawning aggregations from March to April (Lorance et al. 2010).

Fishing areas determine the spatial extent of the fish assemblage for which information might be derived from commercial catch data. For each fishery the *depth range* being fished is considered.

Discards are common practice in many fisheries around the world. The reasons for discarding are diverse (Rochet and Trenkel 2005). Discards will bias the perception of fish assemblages if only certain species or size classes are discarded and most importantly only landings data are available. The two categories used are *significant* or *minor* discards.

Finally, the number of species caught are reported.

Based on the previous five categories, the fish assemblage components covered by the given catches of the given fisheries are evaluated. The fish assemblage components considered are the target species of the fishery, large non-commercial species, large vulnerable species such as sharks, rays and chimaeras and small non-commercial species. Sharks are considered to be vulnerable species because a number of sharks species have been depleted by fishing in all type of fisheries. It is amongst sharks that the highest proportion of threatened fish species are found (http://www.iucnredlist.org/). Large non-commercial species are often smoothheads, which are rarely market and therefore discarded. They are an important part of fish assemblages due to their high abundance (Gordon and Bergstad 1992). Small non-commercial species are commonly too small to be caught by commercial fishing gear but might be abundant in the ecosystem. For example, the small-bodied eel *Synaphobranchus kaupii* is the most abundant fish species in the Rockall Trough to the West of the British Isles (Gordon and Mauchline 1996) but it is generally absent from commercial catches.

2.2. Material

For determining the fish assemblage components covered by the fisheries for each of the six DEEPFISHMAN case studies, the information collected in WP2 and reported in deliverable D2.2 as well as expert knowledge were used.

2.3. Results

Table 1 provides an overview of the characteristics of the fisheries of all DEEPFISHAN case studies as well as an evaluation of the fish assemblage components most likely covered by the catch data of these fisheries. All nine sub-case studies provide information on their respective target species, five on vulnerable fish species, three on large non-commercial species and only one on small non-commercial species. The different case studies will now be discussed briefly.

Table 1. Evaluation of fish assemblage component covered by the fisheries of each DEEPFISHAN case study. Fishing strategy: s.-t. var space-time variable; s.-t. const. space-time constant. Number of fish species: number of principal fish species. Fish assemblage components: TS target species; LNC large non-commercial species, SNC small non-commercial species; VS vulnerable species.

Case study	Name	Fishing gears	Fishing strategy	Depth range	Discards	Number of fish species caught	Fish assemblage component covered by fishery
1a	Orange roughy in Namibia	Selective	s.-t. var	400-800	Minor	>10	TS (1)
1b	Orange roughy in ICES VI &VII	Unselective	s.-t. var	800-1400	Significant (selective)	>12	TS, LNC, VS
1c	Southern blue ling in ICES Vb,VI,VII, XIIb	Unselective	s.-t. var	700-1100	Unknown	Unknown	TS, ?
2	French mixed trawl fishery in ICES Vb, VI, VII	Unselective for larger species	s.-t. var	700-1500	Significant (selective)	>20	TS, LNC, VS
3a	Red seabream in the Strait of Gibraltar	Selective	s.-t const	300-700	None	1	TS
3b	Red seabream in eastern Mediterranean	Unselective	s.-t const	300-600	Minor in longlines Significant in trawls	Unknown	TS, SNC, VS
3c	Black scabbardfish in IX	Selective	s.-t const	1100-1500	Minor	>20	TS, VS
4	NE Atlantic oceanic redfish	Selective	s.-t var	600-900	Unknown	Unknown	TS, ?
5	NAFO Greenland halibut Sub-area 2 and Division 3KLMNO	Unselective	s.-t var	500-1200	Significant	?	TS, LNC, VS

(1) could be similar to case study 1b, however, orange roughy aggregations in Namibia are larger and better identified from acoustics so that the bycatch of other species is smaller. Total discards in the orange roughy fishery in ICES subaraes VI and VII was estimated to be about 50% of the total catch, i.e. similar to case study 2.
(2) there is both fishing with bottom trawl for demersal species and targeted pelagic fishing for redfish.

The three fisheries making up case study 1 are targeting aggregations, thus classified space-time variable. The number of species caught are relatively small compared to other case studies. For example, the orange roughy fishery in Nambia has been described as highly targeted (Branch 2001). To illustrate this a pie chart for the average species composition in the landings is shown in Figure 1. Orange roughy make up the bulk of the landings followed by alfonsino. This landings composition may represent the fish species co-occurring on the fishing grounds. However, it is difficult to interpret these data because species caught together with orange roughy might also occur on grounds where orange roughy do not aggregate. Some species groups such as sharks, are almost absent from the catch composition. Sharks might not be caught in high numbers together with orange roughy or they might be discarded. In any case their low biomass in the catch cannot represent their relative proportion in the ecosystem. Therefore landings data where sharks do no appear while they should be abundant in the ecosystem might be regarded at poorly informative in terms of fish assemblage structure and biodiversity.

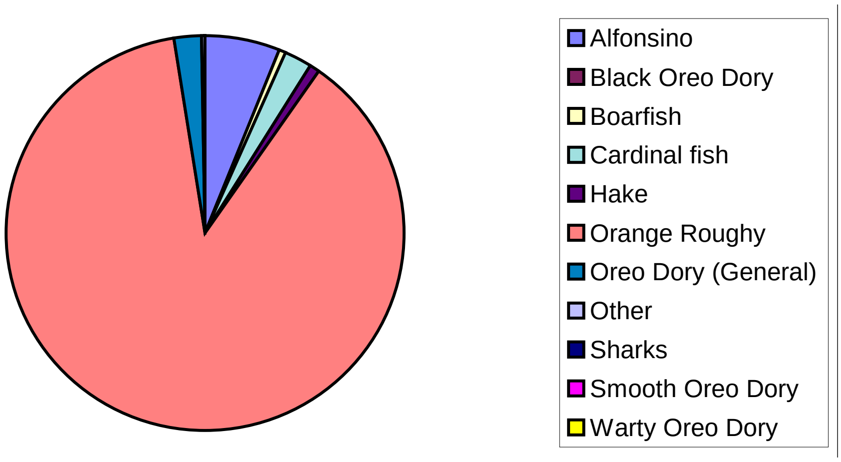


Figure 1. Case study 1a orange roughy in Namibia. Average species composition of landings in the orange roughy fishery in Namibia (1988-2001).

Case study 2 is the only mixed species trawl fishery, though target species vary in space and time (Lorance et al. 2010). About nine species make up the bulk of the catch, with several species actually consisting of a mixture of species (Figure 2a). For example, two species are recorded together as siki sharks. These are Portuguese dogfish (*Centroscymnus coelolepis*) and leafscale gulper shark (*Centrophorus squamosus*). The overall proportion of discards seems about stable with depth and time (Figure 2b).

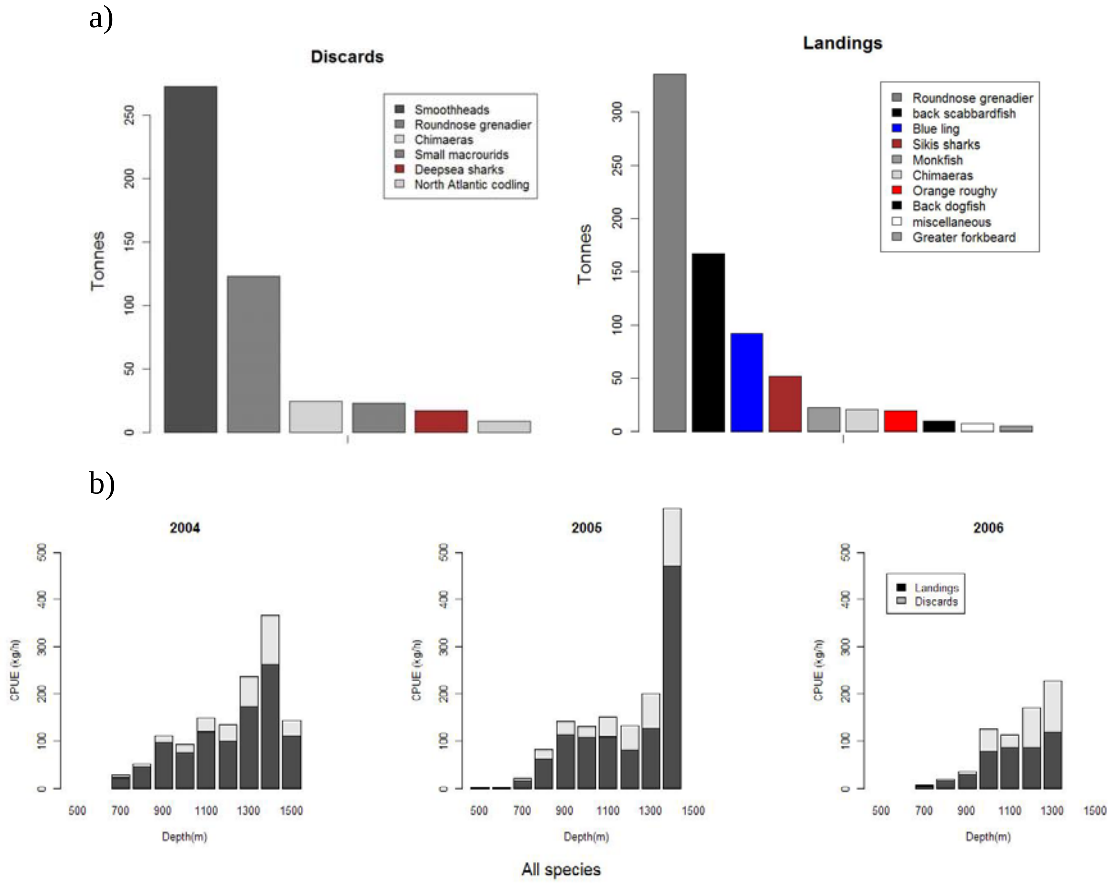


Figure 2. Case study 2 French mixed trawl fishery West of the British Iles (ICES Division Vb, VI & VII). Species composition of discards and landings and depth pattern of catch per unit effort (CPUE) for discards and landings from onboard observer data.

The two red seabream fisheries in case study 3 are quite different in terms of fisheries characteristics and fish assemblage components covered. In case study 3a, red seabream in the Strait of Gibraltar, only one species is caught, which is the target species. In case study 3b, red seabream in the eastern Mediterranean Sea, the fishery is seasonal and mainly a summer activity. The weather condition being unsuitable for small vessels in winter. There is little data on the spatial distribution but fishing in understood to occur every year in the same locations. It was then categorised as s.-t const although there is a clear seasonal pattern. In case study 3c, black scabbardfish fishery, the level of discards is low (<15%), deep-water sharks contribute most to the discards. A high number of sharks species, although in small quantities, was identified in scientific observations.

There is both fishing with bottom trawls for demersal species and targeted pelagic fishing for redfish in the NE Atlantic redfish, case study 4. Bycatch of redfish in bottom trawl demersal fishing is subject to regulation but these fisheries catch and discards several species. The pelagic fisheries for redfish have small bycatch of other fish species. Therefore, the fish assemblage component covered by the redfish fishery is most likely primarily the target species.

The Greenland halibut fishery, case study 5, is deploying bottom trawls which sample a range of fish assemblage components except small species.

3. Evaluation of the available commercial catch information

3.1. Material and Methods

For each DEEPFISHMAN case study the type and extent of available commercial catch data was evaluated based on the data compilation carried out in WP1 (D1.3) and summarised in the case study reports in WP2.

3.2. Results

Commercial landings data are available for all case studies and logbooks for most (Table 2). Onboard observations of landings and in many cases also discards exist for six sub-case studies. In many cases fishery independent information also exist to a certain degree, not always as time series.

Table 2. Overview of commercial catch and other data available for each case study (LO: landings only).

Case study	Name	Landings	Logbooks	Onboard observations	Tallybooks	Surveys
1a	Orange roughy in Namibia	Y	Y	Y, LO	No	Acoustic
1b	Orange roughy in ICES VI &VII	Y	Y	Y	No	Acoustic (1)
1c	Southern blue ling	Y	Y	Y	Y	Trawl (1)
2	French mixed trawl fishery	Y	Y	Y	Y	Trawls (2)
3a	Red seabream in the Strait of Gibraltar and ICES VIII	Y	N	N	N	None
3b	Red seabream fishery in eastern Mediterranean Sea	Y	N	N	N	Trawl
3c	Black scabbardfish in ICES IX	Y	Y	Y	N	None
4	NE Atlantic oceanic redfish	Y	Y		N	Acoustic & trawl
5	NAFO Greenland halibut	Y	Y	Y, LO	N	Trawl

(1) one-off surveys; (2) in literature

4. Evaluation of the information content of commercial catch data

4.1. Introduction

In this section the information content of different types of commercial catch data is evaluated. The underlying question is to what extent commercial data do allow to obtain a representative view of fish assemblages and their spatio-temporal patterns. It can be expected that assemblage properties might be more robust to trawl type and sampling issues compared to single species abundance indices. For example, Trenkel et al. (2004) compared abundance and fish assemblage indices for two different scientific trawl surveys in the Celtic Sea. The surveys differed in terms of the trawl used and also season (summer versus autumn). The results showed while for certain single species there was no clear positive relationship between the two time series indicating different time trends, average individual weight, proportion of benthic species, proportion of piscivores and proportion of non-commercial species were not significantly different. In contrast the size spectra differed as a result of different size selectivity. Another example is the study by Trenkel et al. (2008) in which diel changes in Nephrops densities where compared between video observations and onboard fishing vessels observer data. These authors found that due to varying fishing strategies during the course of the day, in particular decreasing haul duration, commercial catches did not contain the well known diel activity pattern of Nephrops and hence do not allow to study individual behavioural. Here we will evaluate to what extent community attributes might be representative in commercial catch data.

4.2. Case study: French mixed species trawl fishery

Several catch data types are available for the French mixed species fishery operating to the west off the British Isles (Table2, Figure 3). In addition, a rich literature exists on this area. Species compositions and depth patterns in species richness and abundance have been described for Rockall Trough (see X on Figure 3a) by Gordon and co-authors based on scientific trawl data (Gordon and Duncan, 1985, Gordon and Berstad, 1992). More recently, Francis and Neat (2010) explored the depth distribution of macrourids and time trends in survey population abundance indices and Campbell et al. (2010) used the same data to investigate biodiversity changes (see Figure 3right for location of survey hauls).

a) b)

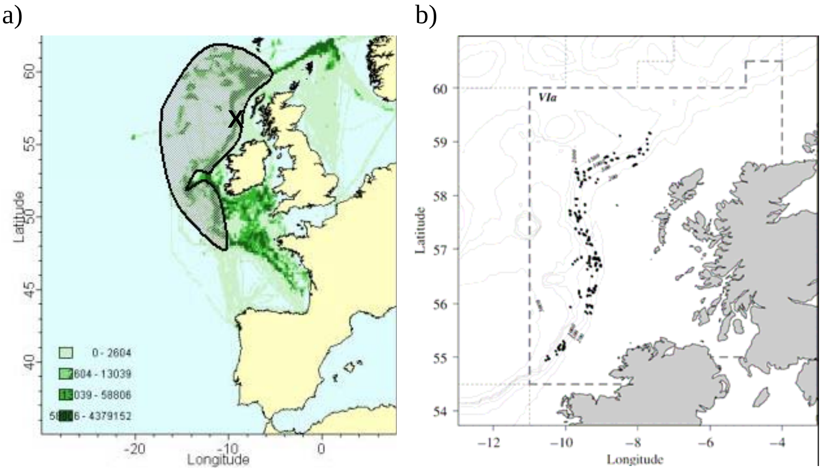


Figure 3. Fishing locations of French vessels with deep-water licences (left). The grey area indicates the fishing zone for the mixed trawl fishery to the west of the British Isles. X indicates location of "Rockall Trough" study area. Location of survey hauls in Scottish survey reproduced from Campbell et al (2010) (right).

Given the variety of available commercial catch information, the French mixed species trawl case study was selected for exploring the information content and the determining factors in different types of commercial catch data.

4.3. Landings and logbooks

4.3.1. Material

The landings of the French deep-water trawlers provide information for 16 fish species (Table 3). Of these only three species belong to the top ten of most abundant species found in survey trawls in the same area (Gordon and Duncan 1985). The others are either not caught by the commercial gear as too small or discarded.

Table 3. Species landed by French mixed species trawl fisheries to the west of the British Isles. Top ten refers to the top ten species in abundance found in at least one 250 m depth stratum between 375 and 1125 m in at least one of three survey trawls reported in Gordon and Duncan (1985).

Scientific name	Common name	Status in French landings	Top ten
Aphanopus carbo	Black scabbardfish	Major species	
Argentina silus	Greater silver smelt	Small landings	x
Beryx spp.	Alfonsinos	Small landing (ca 30 tonnes per year), mainly from ICES subarea VIII (i.e. not the deep-water fishery)	
Centrophorus granulosus	Gulper shark	Minor landings	
Centrophorus squamosus	Leafscale gulper shark	Major species (before TAC closure)	
Centroscyllium fabricii	Black dogfish	Significant landing in the 2000s	
Centroscymnus coelolepis	Portuguese dogfish	Major species (before TAC closure)	
Coryphaenoides rupestris	Roundnose grenadier	Major species	x
Dalatias licha	Kitefin shark	Minor landings	
Galeus melastomus	Blackmouth dogfish	Minor landings	
Galeus murinus	Mouse catshark	Minor landings	
Hexanchus griseus	Six-gilled shark	Minor landing	
Hoplostethus atlanticus	Orange roughy	Major species (before TAC closure)	
Molva dypterygia	Blue ling	Major species	
Phycis blennoides	Forkbeards	Major species	x
Scymnodon ringens	Knifetooth dogfish	Minor landings	

4.3.2. Methods

Total landings per unit effort might be indicative of underlying assemblage changes. Hence landings per unit effort is the first indictor of fish assemblage state to be investigated. Due to their life history, species differ in their sensitivity to fisheries. Sharks are sensitive to fishing impacts while black scabbardfish is less sensitive and roundnose grenadier intermediate. Black scabbardfish and roundnose grenadier are found in the same depth range. The proportions of shark species and roundnose grenadier in the fish assemblage are therefore important indicators for the health of the deep-water fish community. Further the ratio roundnose grenadier to black scabbardfish would indicate a change in assemblage structure, in particular as roundnose grenadier is among the most abundant species in this area (Table 3). All four indicators were calculated from commercial landings (in weight) for different data subsets. The first data set consists of all international landings in ICES Division VI and VII and was compiled from ICES (2010a) and ICES (2010b) for sharks. The second data set, referred to as French landings, consists of landings of French vessels having landed more than 5t of a given species in a given year. For the French landings two denominators were used: total landings for deep-water species and total landings for all species. The later data include landings for saithe, monkfish, megrim, hake and some other species. For fishing effort the number of days at sea was divided by vessel power (in 1000kW) to account for differences in fishing power which is necessary as the vessels involved in the fishery changed over time (Lorance et al. 2010).

4.3.3. Results

French deep-water species landings per unit effort were rather stable for the period 1989-2008 while total landings per unit effort decreased over most of the period with a slight increase at the end (Figure 4).

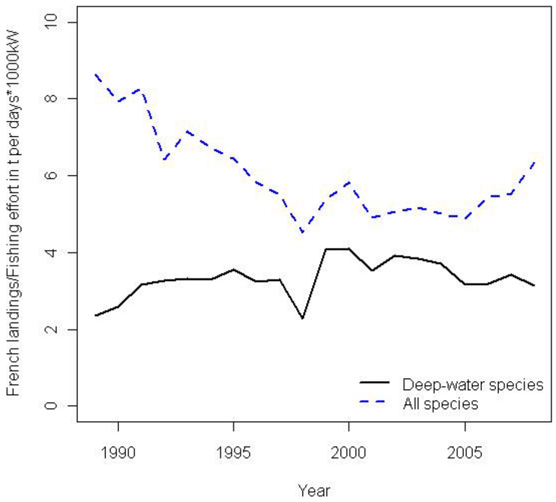
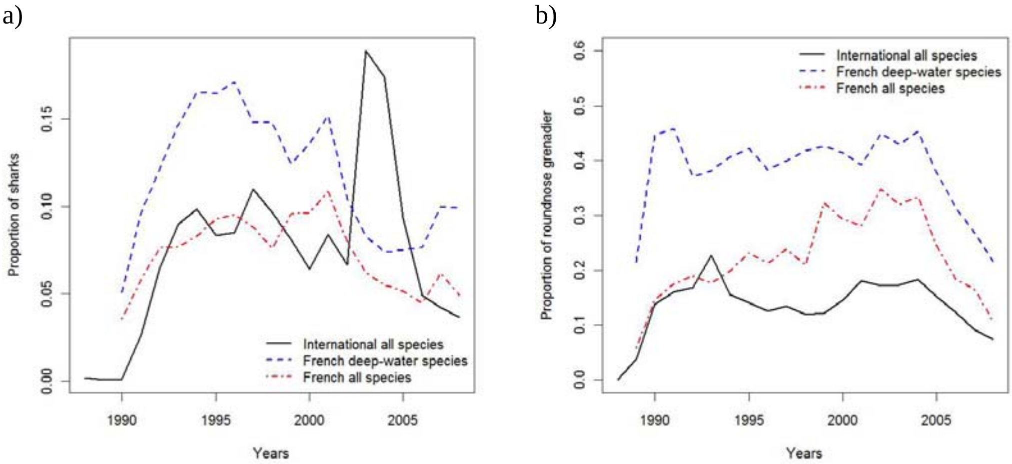
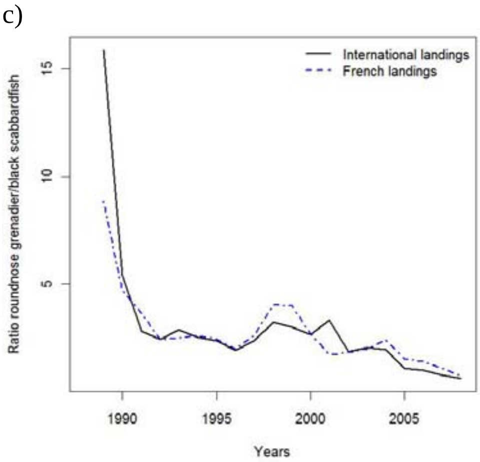


Figure 4. French landings per unit effort for deep-water species and all species on continental slope to the west of the British Isles.

The proportion of sharks in commercial landings varied somewhat over time and between data sets and calculation methods (Figure 5a). After an initial period, it decreased steadily in the French landings. There was a peak in international landings in 2003 and 2004. The proportion of roundnose grenadier in French deep-water and international landings remained stable until about 2004 and decreased thereafter (Figure 5b). In contrast, the proportion of roundnose grenadier increased in total French landings before 2004 but also declined thereafter. The ratio between roundnose grenadier and black scabbardfish landings decreased sharply at the beginning and slowly thereafter over the whole study period (Figure 5c).

Both the proportion of sharks and roundnose grenadier in landings showed initial increases in all subsets which most likely reflect changes in fishing strategy rather than the underlying assemblage structure changes. Further all indicators decreased at the end of the study period. For roundnose grenadier Neat and Burn (2010) published abundance index (in numbers and weight) time series for the period 2000 to 2008 for part of the area covered by the commercial fisheries (Figure 5d). Both series were first stable and then slightly increasing from 2006. Hence, in absolute terms roundnose grenadier did probably not decrease though it might still have in relative terms.





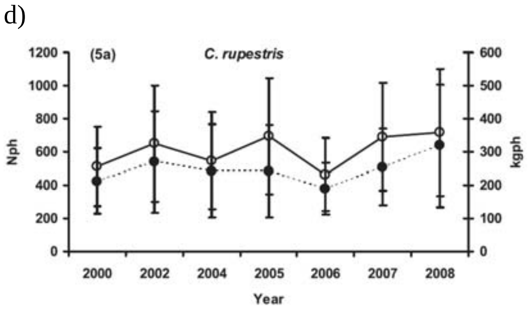


Figure 5. Fish assemblage indicators derived from commercial landings (a-c) and abundance index derived from scientific bottom trawl survey (d) by Neat and Burn (2010) on the continental slope to the west of the British Isles. In d) open circles are in weight and closed symbols in numbers.

4.3.4. Conclusions

The derived indicators seemed to present spurious temporal trends and were sensitive to the data set being used. Thus, based on the examples in this section it is not evident that commercial landings can inform on changes in exploited fish assemblages beyond changes in fishing strategies and management measures such as variations in TAC. However, more comparisons with independent survey data are required to conclude. One important short coming of commercial landings and logbooks is that no depth information is available.

4.4. Haul-by-haul data from onboard observations

4.4.1. Material

Under the European data collection framework sampling onboard fishing vessels is carried out regularly since 2004. Additional sampling of deep-water fleets carried out under EU regulation 2382 (2002). The main objective is to obtain discard estimates. Here we use the onboard sampling data from the French mixed species trawler fishery for the period 2004 to early 2010. For each haul, the data consist of haul depth, duration and geographic position, target species, numbers per species caught, weight per species caught and for a subsample for some species numbers per length class.

The data were restricted to hauls deeper than 625m to focus on the deep-water fish assemblage. Further, only hauls for which both discards and landings and all species were sampled were retained and any unidentified biomass was removed (recorded as “rest”, “unidentified”, “pisces”) from each haul. Vessel engin powers were checked against the fleet registry and corrected in one case. Overall 856 hauls were available, with unequal distribution between depth categories, quarters and vessel engin categories (Table 4). The depth categories correspond to those used by Gordon and Duncan (1985). Depth is an important structuring factor for deep-water fish assemblages as species composition changes with depth (e.g. Gordon and Dunction 1985; Cambell et al. 2010), Vessels were catgorised by engin power. The engin power of vessels having been sampled increased somewhat over the study period.

Table 4. Number of hauls sampled onboard of French fishing vessels belonging to the deep-water mixed species trawl fishery operating to the west of the British Isles. Midpoints of 250m-depth categories are given.

Category	2004	2005	2006	2008	2009	2010
Total	244	154	81	19	182	30
Depth (m)						
750	16	20	43	8	65	10
1000	99	61	16	7	73	16
1250	91	70	22	2	25	1
1500	38	3	0	2	19	3
Quarter						
1	0	0	50	0	44	30
2	90	0	10	0	81	0
3	99	99	14	0	31	0
4	55	55	7	19	26	0
Power (kW)						
<500	0	9	21	0	3	0
500-1000	91	41	29	6	38	0
1000-1500	111	44	21	0	0	0
>1500	42	60	10	13	141	30

4.4.2. Methods

First, a small study was carried out to investigate the impact of vessel engin power on vessel fishing efficiency and a correction factor was derived. For obtaining standardised fishing effort, fishing time (in hours) was multiplied by this correction factor.

Second, seven fish assemblage indicators were calculated by depth range by year: total catch weight per standardised unit effort, total catch numbers per standardised unit effort, species richness, proportion of shark (in weight), ratio roundnose grenadier to blackscabbardfish (in weight), mean weight and mean length. Abundance and mean weight could only be estimated in the case where the species was measured in a given haul as otherwise no counts were available. Length subsamples were raised to the haul level before use.

Third, a small simulation study was carried out to investigate the impact of sample size (number of hauls) on total species richness and compare it to published results from scientific surveys. For this study hauls (across years and depth strata) were randomly resampled with replacement and the total number of species were counted.

4.4.3. Results

For studying fishing efficiency, total catch per haul divided by haul duration was plotted against engin power by depth stratum (Figure 6). It is apparent from this figure that there is no linear relationship between relative fishing power and engin power in this fishery. In particular, vessels between about 600kW and 1500kW had similar fishing powers while smaller and larger vessels differed. Further there was large inter-haul variability. It was decided to created three vessel groups and use the average value within each group as correction factor for standardising fishing effort (see horizontal line in Figure 6).

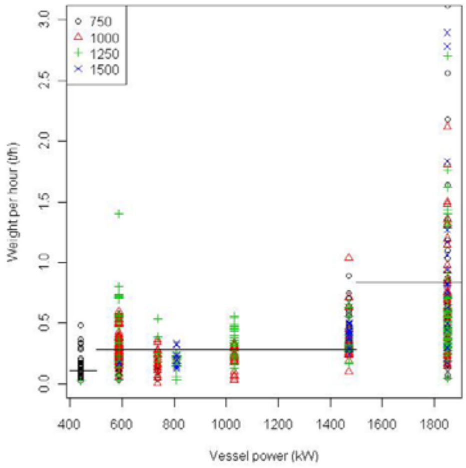


Figure 6. Catch per haul standardised per hour fishing by depth strata. Horizontal lines indicate fishing power correction factors that were used for assemblage indicators.

Most fish assemblage indicators did not show any strong time trends over the study period 2004 to 2010 (Figure 7). Inter-annual variations were strong for all indicators, probably as a results of low sample sizes. For some indicators there was a clear difference between depth strata. For example, mean length decreased with depth while the proportion of shark increased with depth. The time trend of species richness deserves a special comment. Mean species richness per haul increased at the end of the period for the two most shallow depth strata (625 – 1125 m) while it decreased deeper down. These divergent species richness trends seem odd and might be due to species identification problems.

The ratio of roundnose grenadier to blackscabbard fish decreased slightly in all depth strata (Figure 8a) while standardised total weight per haul showed no strong pattern with depth (Figure 8b).

The resampling study revealed the relationship between observed species richness (total number of species observed) and the number of hauls available (Figure 9). It clearly showed that at least 100 hauls would be required to stabilise richness estimates. In contrast Gordon and Bergstad (1982) observed the same number of species in only 10 survey hauls. Thus using onboard observations means that larger sample sizes are required compared to a designed scientific survey to determine species richness and detect changes.

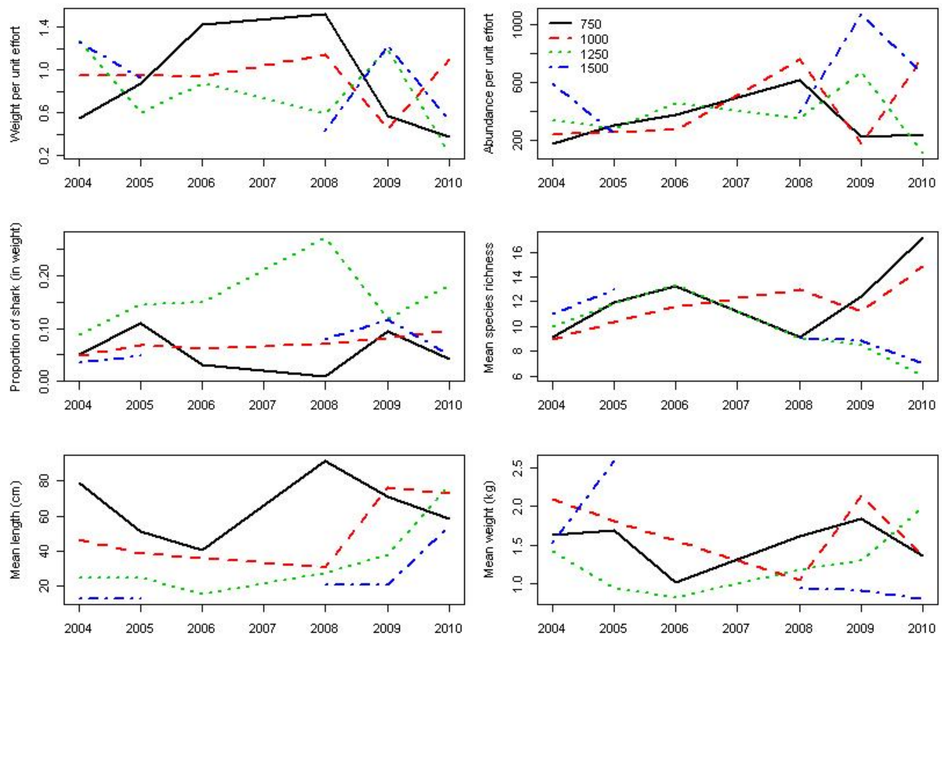


Figure 7. Fish assemblage indicators by depth stratum derived from onboard observations.

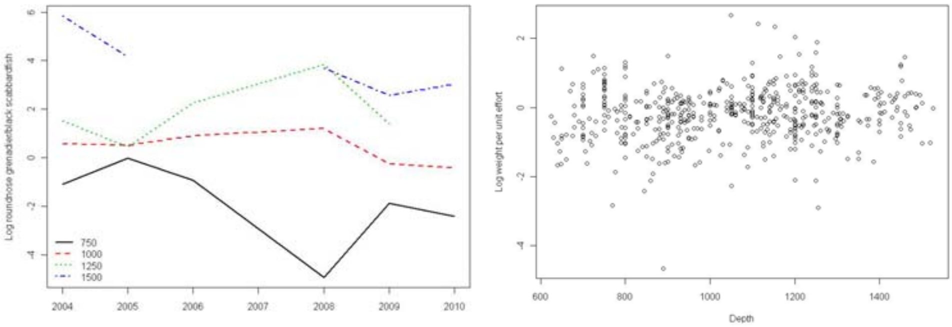


Figure 8. Ratio roundnose grenadier to black scabbardfish derived from onboard observations (a) and distribution of fish assemblage biomass (total biomass per unit effort per haul) with depth (b) derived from onboard observations of French demersal trawl fishery.

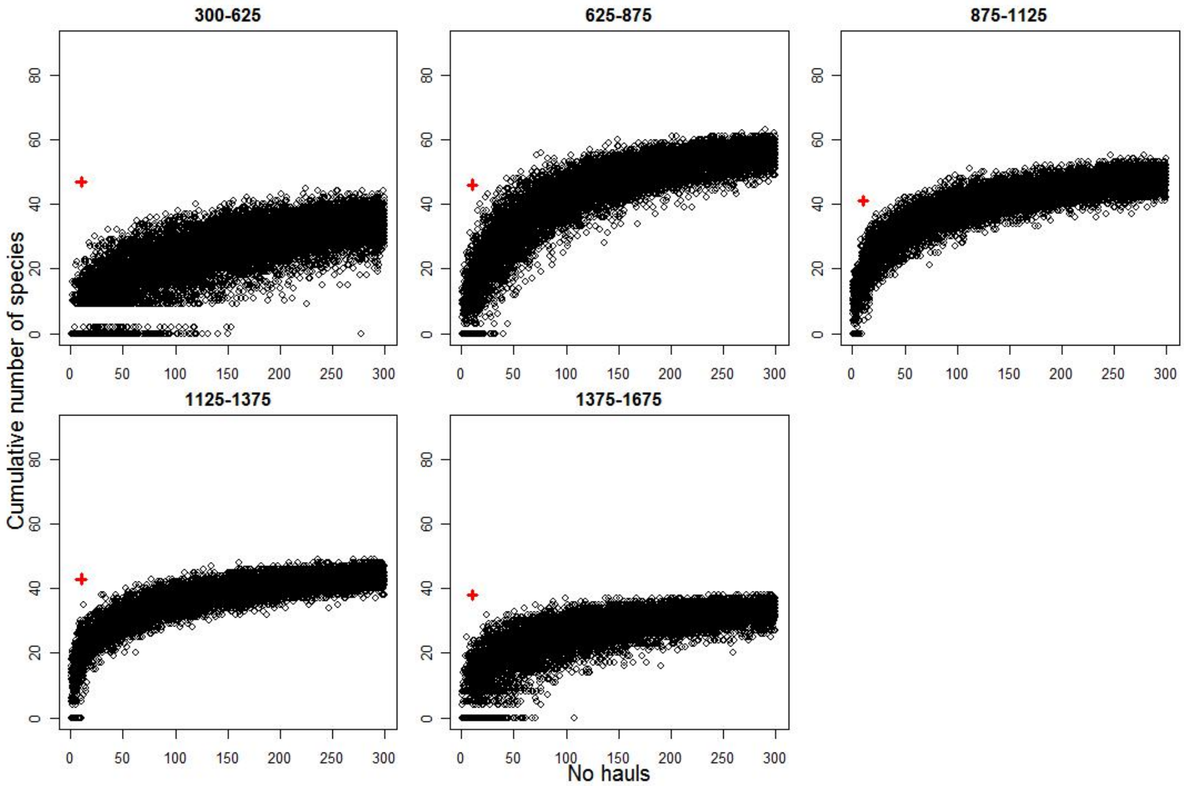


Figure 9. Total number of species (richness) as a function of the number of hauls from onboard observations. The red cross indicates the number of species obtained by Gordon and Bergstad (1982).

4.4.4. Conclusion

Although much richer than landings, onboard observations have a number of short comings as well. First of all species identification is not always reliable. Second, due to logistic constraints not all species can be measured on board, which means that under the current data registration scheme numbers are not available for species which were not measured. Third, differences in vessel power and haul duration make it tricky to standardise observations as it is not obvious how to define a standard unit of effort. Fourth, seasonality probably also affects catch quantities and composition, but these could not be investigated here due to too small sample sizes. As result of all these short comings in addition to low sample sizes assemblage indicators showed strong interannual variations but generally no clear time trends. Thus it seems that the exploited fish assemblage (not necessarily all species) to the west of the British isles might have been rather stable during the period 2004 to early 2010.

4.5. Haul-by-haul data from fishermen's own records (tallybooks)

4.5.1. Introduction

Deep-sea fisheries in the West of the British Isles have experienced in only two decades many changes regarding the size of the fleets, engine power and fishing gears, fishing grounds and depth while signs of depletion of deepwater stocks and damages to the ocean floor have led to an increasing number of management rules aiming at ecosystem conservation and at protecting stocks from unsustainable fishing pressure (see description in Lorance et al 210). As deepwater scientific surveys are scarce, abundance indices have been lately estimated using a database containing the catch composition of 29 000 hauls and provided by two organizations from the French fishing industry through a science-industry partnership (Lorance et al 2010, Lorance et al. submitted).

Catch composition reflects the combination of the influence of various fisheries related factors and the “true” species distribution, itself depending on environmental factors varying in space and time. It is therefore impossible to treat haul by haul dataset by standard analyses as they generally require independent observations and normal distributions of continuous variables. Various multivariate analyses and clustering methods were applied in an attempt to characterize the spatio-temporal variability in species abundance and to identify structuring factors and species associations in the landings.

4.5.2. Material and Methods

The information on landings associated with single trawl hauls in the tallybook data base spans a period of ten years, from 2000 to 2009. Landings of six deep-sea species have been reported: roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish (*Aphanopus carbo*), blue ling (*Molva dypterygia*), black dogfish (*Squalus acanthias*), as well as Portuguese dogfish (*Centroscymnus coelolepis*) and leafscale gulper shark (*Centrophorus squamosus*). Due to uncertainty associated with the identification of the last two species, the landings of these have been summed up under the denomination "sikis". In addition, landings of other species frequently landed by deep-sea French trawlers appear in the data base, namely saithe (*Pollachius virens*) and anglerfish (monkfish *Lophius piscatorius* and blackbellied angler (*Lophius budegassa*).

A principal component analysis (PCA) was first performed in order to identify the main factors associated with variability in the landings. Depth strata, vessel engine power as well as year and season of collection were included in the analysis as illustrative variables.

In order to assess changes in species composition of deep-sea trawl hauls both in space and time, "pseudo-stations" were determined, in which hauls were carried out repeatedly over the entire period covered by the study. This led to a substantial reduction of the area covered by the analyses, the pseudo-stations regularly fished during 2000-2009 being located in ICES Division V and in the northern part of Division VI (Figure 10). The outcome of the preliminary PCA was used to identify variables to define relevant stations. Thus, stations were here defined as the combination of an area (7.5' latitude by 12' longitude rectangle, corresponding to 1/20 of an ICES statistical rectangle), a depth stratum (500-700m, 700-900m, 1100-1300m or below 1300m), and a season (winter: from October to March, or summer: from April to September).

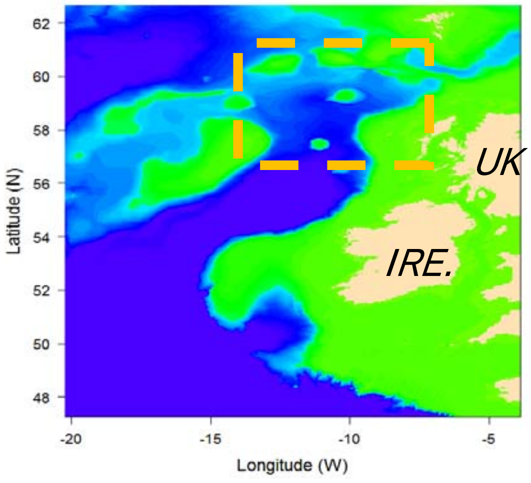


Figure 10. Study area for analysis of species association from commercial haul-by-haul landings data. The region delimited by the dashed orange lines is the area encompassing the stations common to all time periods.

A multi-table analysis (STATIS) was performed on the data subset to evaluate temporal changes during the study period. In order to avoid small sample sizes, years were grouped into four periods: 2000-2002, 2003-2005, 2006-2007, 2008-2009. Each period has a separate data table. PCA and STATIS analyses were performed on the relative composition of trawl hauls realised in the West of the British Isles, meaning that the quantities landed did not influence the results. Proportions were cosine transformed.

Following this global comparison of the structure of the period tables, cluster analyses were carried out to identify groups of pseudo-stations depending on the relative composition of landings. For each period, three or four groups of pseudo-stations were identified, depending on the best group discrimination appearing on the dendrogram.

4.5.3. Results

In the PCA, depth clearly appeared as the main structuring factor, while season and engine power seemed to have a limited influence on the composition of landings (Figure 11). The distribution of the modalities of the year variable on the first two components of the PCA suggests a gradual change in species composition from the beginning to the end of the data series, the first years being located on the right side of the origin while the latest appear on the left side. The circle of correlations between the active variables (proportion of each species or group of species in a haul) indicates that the three most important species in terms of landings, namely roundnose grenadier, blue ling and black scabbardfish are the ones best discriminating groups of hauls.

a) b)

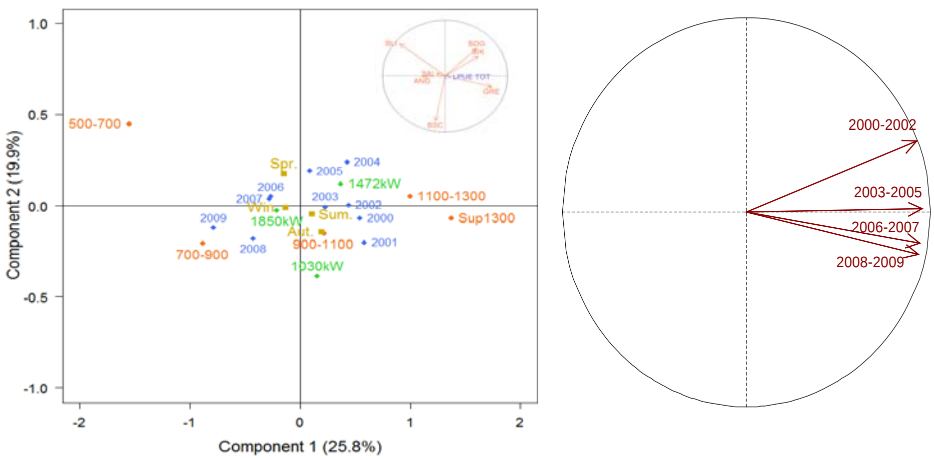


Figure 11. PCA and Statis results. Projection of illustrative variables on the first two components in PCA (a) and of years in Statis analysis (b).

The STATIS analysis was primarily used to evaluate the relative proximity of structure between the four data tables. The results suggested a progressive change from the first to the last period, arrows illustrating each period being ordered along the second axis of the PCA (Figure 11b). The change appears to have been faster at the beginning of the study period than towards the end, the structure of the 2000-2002 period being the most dissimilar.

Using cluster analysis three or four groups were identified for the four data periods (Figure 12). For the first period, 2000-2002, landings in the first two groups were dominated by roundnose grenadier, but the second group appeared more as a "mixed group" with higher proportions of blue ling and black scabbardfish than the first one. These two groups are those containing the highest number of pseudo-stations. Note that the average proportion of sikis was highest in these two groups. The third group identified was also the smallest one. The composition of landings in this group was largely dominated by blue ling. Landings in the fourth and last groups were dominated by black scabbardfish. Pseudo-stations constituting this group were mainly fished during winter. For the other time periods, the targeting of roundnose grenadier, blue ling, and black scabbardfish determined the segregation of pseudo-stations into groups. The other species had a limited influence on the determination of these groups.

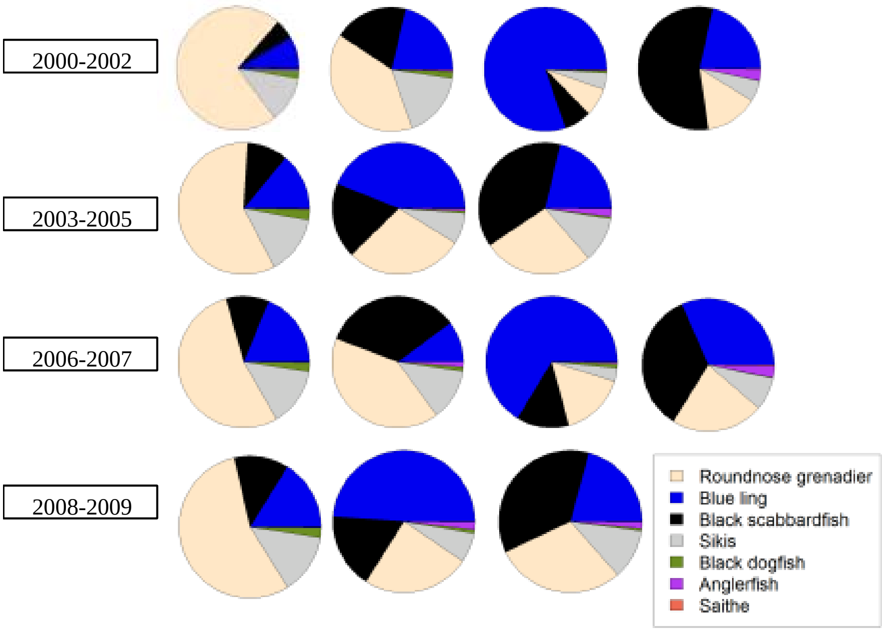


Figure 12. Average species composition of the landings realised in groups of pseudo-stations identified from cluster analyses for each period.

To assess the stability of the identified species associations in time, the assignment of pseudo-stations belonging to the four groups identified for the period 2000-2002 in the subsequent periods was analysed (Figure 13). The group constituted of pseudo-stations where landings were dominated by roundnose grenadier appeared as the most stable in time, whereas the mixed group (group 2 in 2000-2002) was the least stable. Groups where landings were dominated by blue ling and black scabbardfish exhibit intermediate stability.

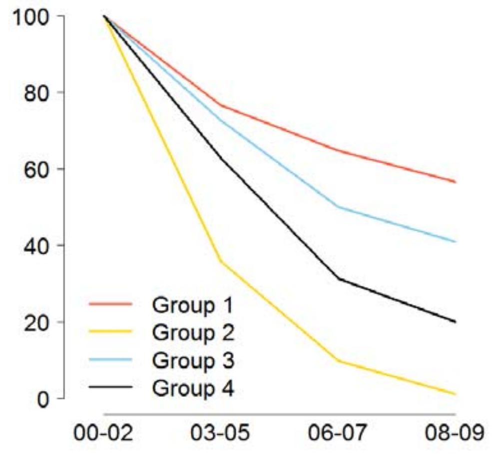


Figure 13. Progressive decrease (in percents) of stations in groups defined for 2000-2002 successively present together in subsequent periods. Ex.: 56.5% of the pseudo-stations assigned to group 1 in 2000-2002 were assigned to a group dominated by roundnose grenadier for the period 2008-2009.

The analysis of descriptors of pseudo-stations in the outcome of the cluster analyses allowed assessing the segregation of groups along the depth gradient. In pseudo-stations allocated to the "roundnose grenadier group" (group 1 in 2000-2002), trawl hauls were mostly carried out in the lower part of the depth range covered by the French deep-sea fleet (700-1300m). In contrast, hauls for which landings were dominated by blue ling were realised in relatively shallow waters (500-700m), while hauls targeting black scabbardfish were mostly realised at intermediate depth (700-900m). The mapping of pseudo-stations associated to the different groups indicated a relative spatial segregation (Figure 14), with pseudo-stations associated with high proportions of roundnose grenadier in the landings located more on the western part of the study area. This segregation is most likely a reflection of the depth gradient.

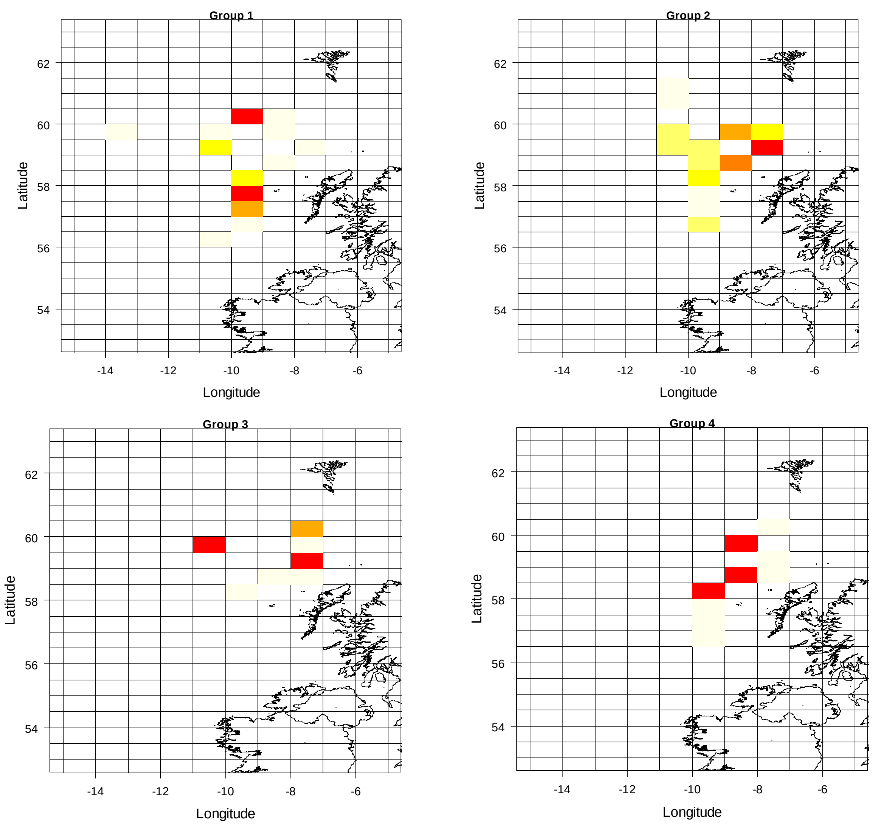


Figure 14. Relative abundance per ICES statistical rectangle of the stations corresponding to depth stratum 900-1100m for each of the groups of stations obtained from a cluster analysis of the data for the period 2000-2002. Red color indicates high relative abundance (for each group).

4.5.4. Discussion and conclusion

The analyses led to the identification of the main factors governing the variability in the species composition of the French deep-sea trawlers operating off the British Isles. As expected, depth appeared as the most prominent of the tested sources of variability. Both the preliminary PCA and the multi-table analyses suggested the existence of a progressive modification of the relative composition of landings, but only a detailed examination of the haul-by-haul data base will permit the description of its nature and the quantification of its importance. A quick look at the data seems to indicate that modifications in the seasonality of the targeting of black scabbardfish over the study period were responsible of part of this progressive change. A major limitation pertains to the nature of the data, not allowing disentangling the relative influences of changes in species abundances and distribution, and modifications in fishing strategies in time and space.

5. Definition of indicators of fish diversity based on commercial catch data

As show in the previous sections several simple fish assemblages indicators can be derived from commercial catch data. Table 5 summarises the seven indicators tested here and lists the suitable catch data types. Because of strong depth patterns in both species and density patterns, the indicators might be difficult to interpret without taking account of depth.

More research, in particular for other case studies would be required to conclude regarding their general usefulness beyond the deep-water fish assemblage to the west of the British isles exploited by the French trawler fleet for which these indicators were evaluated.

Table 5. List of proposed indicators for deep-water commercial catch data and suitable data types.

Indicator	**Description**	**Landings & logbooks**	**Onboard observations**	**Tallybooks**
B	total biomass per unit effort	Y (landings)	Y	Y (landings)
N	total numbers per unit effort	N	Y	N
PropShark	proportion of shark (in weight)	Y (landings)	Y	Y (landings)
RatioGrenScab	ratio roundnose grenadier to black scabbardfish	Y	Y	Y
Lbar	mean individual length	N	Y	N
Wbar	mean individual weight	N	Y	N
S	species richness	N	Y	N

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