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Theme Session: Bringing collaborative science – industry research data into stock assessment and fishery management: evaluating progress and future options

Deriving blue ling abundance indices from industry haul by haul data

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Abstract

A database of tallybooks, from skippers' own logbooks, provided by the French industry involved in deep-water fishing to the west of the British Isles was used to standardise blue ling Landings per Unit of Effort (LPUEs). The data covered the years 1992-2008 with more extensive data for the period 2000-2007. For each haul, landings by species, tow duration, depth and location were reported. Compared to EU logbooks, this database is on a haul by haul basis instead of being aggregated by fishing sub-trips combining hauls from the same day, ICES rectangle and gear. Moreover, it includes depth, which is a major factor for catch rates in deepwater fisheries. LPUEs were estimated from Generalised Additive Models (GAMs) with depth, vessel, statistical rectangle and zone by year as explanatory variables. Owing to the statistical distribution of landings rates, landings were modelled by a Tweedie distribution, which is a compound Poisson distribution and allows to handle data with many zeros, as it is typical for catch data. In order to investigate how to reliably track stock trends, LPUEs were estimated in five regions for different subsets including or not the spawning season, when blue ling aggregates, or considering tows where blue ling was only a bycatch. The results based on the tallybook data indicated that blue ling LPUEs have been mainly stable over the past decade. This is consistent with stable mean length in the landings. Haul by haul data are suitable to derive abundance indices for deep-water fisheries assessment.

Keywords: *Molva dypterygia*, abundance indices, fishing strategy, Tweedie distribution.

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Introduction

Accurate assessment is crucial to proper fishery management but assessment of deep-water stocks in European waters have been mostly exploratory (Basson et al., 2002; ICES, 2008; Lorance, 2008). Limitation to accurate assessment have come from a globally data poor situation of deep-water stocks where knowledge on fish populations is missing in terms of biological parameters of species and geographical distribution of population. Stock management units are delineated either based upon hypothetical considerations or upon the distribution of fisheries and may not correspond to biological populations. However, this problem is not unique to deep-water stocks.

In the case of blue ling, there is no agreed age estimation scheme, so that yearly age length-keys are not collected. Nevertheless, the species is considered recruiting to the fishery at the age of 6-8 years and to have a growth rate and natural mortality similar to typical gadoid species such as cod or saithe. ICES division Vb, and sub-areas VI and VII are considered as a stock unit for assessment and management purposes but there is not enough information to properly evaluate the stock structure (ICES, 2007). In addition to these gaps in the biological knowledge, fishery statistics are not always reported at a sufficient spatial resolution for deep-water species. Although depth is a strong structuring factor for abundance distributions and one single statistical rectangle often encompasses depths from 200 to 2000 m (Figure 1), haul depth is not reported in EC logbooks so that this factor cannot be taken into account in standard Landings Per Unit Effort (LPUEs). Therefore LPUEs based upon logbook data should be considered as very crude in most cases. Nevertheless, they are often used as a basis for assessment and advice since no more detailed data are available.

(a) **(b)**

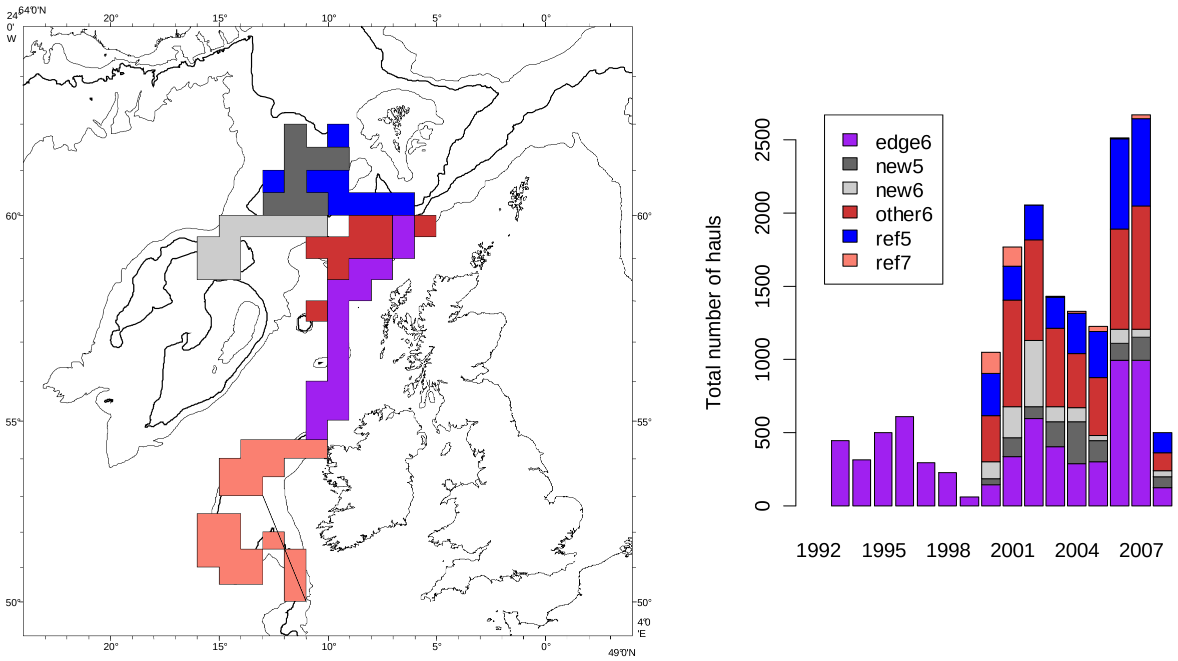


Figure 1. Reference areas (set of statistical rectangles) used to calculate French LPUEs for blue ling (a) and number of hauls per area in full data set (b). Dark grey: New grounds in V (new5), light grey: new grounds in VI (new6); red brown: others in VI (other6); purple: edge in VI (edge6); blue: reference in V (ref5); salmon: all grounds in VII (ref7). Depth contours are 200, 1000 and 2000 m.

Blue ling have been fished to the West of the British Isles at least from 1973. No archive of landings by ICES areas prior to the 1970s was found. Landings of blue ling prior to the 1970s have been reported only from Norway and Germany and are aggregated at the scale of the North East Atlantic. From 1950 to 1970 about 5 000 t of blue ling landings were reported (FAO fisheries catch statistics, http://www.fao.org/fishery/statistics/en). In these early years, catches from Norway were mainly a bycatch from longliners targeting ling and tusk and an unknown part of the catch was from the Northern North Sea and Norwegian Sea (Bergstad and Hareide, 1996). The distribution of German catches is also unknown, but the organisation of exploratory research cruises for new fishing grounds to the West of the British Isles from the mid-1970s (Ehrich, 1983) suggest that these grounds were not fished previously and that German catches of blue ling came from the North Sea and Norwegian sea areas. In the 2000s landings of blue ling from these latter areas have been about 200 to 300 t/year while they were about 10 times more in the 1980s.

In the 1970s, landings of blue ling from the Faroe Plateau, slopes of the Rockall Trough, Rockall and Hatton Banks (ICES divisions Vb and sub-areas VI and VII) increased sharply. These areas have remained the main catching area for blue ling since then (ICES, 2009). The French fleet landed more than half of the total. Up to the late 1980s, the main species in the French landings from these areas were gadoids (saithe, ling, blue ling, cod, haddock, hake and whiting). From 1987, French trawlers started to exploit roundnose grenadier (*Coryphaenoides rupestris*), black scabbardfish (*Aphanopus carbo*), orange roughy (*Hoplostethus atlanticus*) and deep-water squalid sharks (mainly the portuguese dogfish *Centroscymnus coelolepis* and the leafscale gulper shark, *Centrophorus squamosus*) at greater depths (Charuau et al., 1995). These species were reported separately in French landings from 1989 onwards (Table 1), with the exception of deepsea squalids for which individual species were not separated.

Table 1. Landings (tonnes) from French trawlers (freezer trawlers not included) in ICES-sub-areas V-VII from 1983 to 2007.

Year	Blue ling	Saithe	Roundnose grenadier	Black scabbardfish	Deepsea squalids	Orange roughy
1983	5141	21795				
1984	6140	16451				
1985	12787	23520				
1986	12109	33019				
1987	12072	27168				
1988	9863	26033				
1989	9380	24807	2597	308	140	
1990	6358	18191	6770	1448	1288	
1991	6423	13649	9019	2538	3104	3361
1992	4030	8441	8714	3541	3468	3995
1993	4682	11580	8570	3512	3812	2099
1994	3112	11315	8051	3103	3186	1905
1995	3489	7852	8351	3440	3630	988
1996	3450	6465	7421	3775	3095	1031
1997	4249	4662	7396	2806	3177	1016
1998	3487	3635	5214	1303	3079	289
1999	5572	3467	8677	2110	3519	1330
2000	5696	3583	10118	3745	3684	1140
2001	3582	6091	8738	5007	2103	1228
2002	3077	3669	8527	4621	1454	465
2003	3650	3869	6888	3422	1189	516
2004	3958	3200	7501	3091	866	469
2005	3067	3575	4480	2878	744	250
2006	3037	6097	3139	2209	855	497
2007	2721	4064	2240	2066	802	155

Blue ling LPUEs derived from aggregated logbook data of the French fishing fleet display a declining trend from 1985 to about 1995 and then stabilize (Lorance and Dupouy, 2001). Depending on the method used to calculate them: directed LPUEs taking into account only the hauls targeting the species or total LPUEs for all or a subset of vessels, the stabilization is estimated to have started somewhere between 1995 and 2000 (Figure 2a). Although, there is no doubt that blue ling and other gadoid stock abundance declined in the 1980s and that this was a reason for French vessels to move to other resources (Charruau et al. 1995), several issues compromise the use of logbook data for calculating LPUE for blue ling. The issues are i) changing fishing strategies, ii) imprecise effort data, and iii) lack of information on haul depth.

Blue ling seasonally aggregate for spawning, while its distribution is considered to be mainly scattered during the rest of the year. In the 1980s, the fishery was mainly operating on aggregations and was particularly active at spawning time, from March to May. When the exploitation of other deep-water species started, trawlers changed their fishing strategy. They fished deeper, some blue ling fishing ground were no longer exploited and, in addition to a target species, blue ling became also a bycatch of fishing operations for mid-slope species. In addition, the catch became much less seasonal (Lorance and Dupouy, 2001). In other words, the proportion of effort targeting blue ling, but also saithe varied over time and space.

Logbook data do not always permit to estimate accurately which proportion of effort is directed to each species because each record combines several fishing operations during the same day in the same statistical rectangle. In addition to this, effort data might be less reliable than catch data, because accurate effort reporting would require very explicit guidelines while catch reporting is more straightforward. Reporting rules may have varied between skippers and over time. For example, due to long shooting and hauling times, there are significant differences between the total time of one trawl haul and the duration during which the trawl is actually fishing on the seabed. The relation between effort as available in logbooks and catch may also be modified by regulation, as fleets change their strategies to comply with regulation. From 1995 deep-water fishing effort was regulated (Council regulation (EC) No 2027/95) and a licensing system was introduced in 2003 (Council regulation (EC) No 2347/2002). TACs for blue ling in ICES division Vb and sub-areas VI and VII were introduced in 2003 and reduced in 2005 and 2007. Additionally, technical measures were introduced and fishing companies also set some rules for their vessels in order to comply with annual quotas. From 2007, landings by EU vessels where limited to 25 tonnes per fishing trip (council regulation (EC) No 2015/2006). One of the ship owning companies reduced further the landings per trip to 20 tonnes in 2006 and 2007 and 15 tonnes in 2008 in order to avoid quota overrun (in relation to decreasing TAC). Although, in the 2000s the French fishery statistics database included two effort variables (vessel fishing time and gear fishing time), for the 1990s only vessel fishing time is available. Therefore, for consistency the times series of logbook based LPUEs was computed using vessel fishing time, which includes steaming time.

Fishing depth is not available from logbooks although it is a major explanatory factor of blue ling catches. Average fishing depth increased when exploitation of roundnose grenadier and other mid-slope species started and then varied over time. The species composition of the landings reflects the move towards deeper waters from the late 1980S (Table1). Finally, previous LPUE series (ICES, 2008) have been calculated using a reference fleet of similar high-sea trawlers. Unfortunately, these vessels have been progressively decommissioned and are no longer in the fleet in 2009 so that new indices are required.

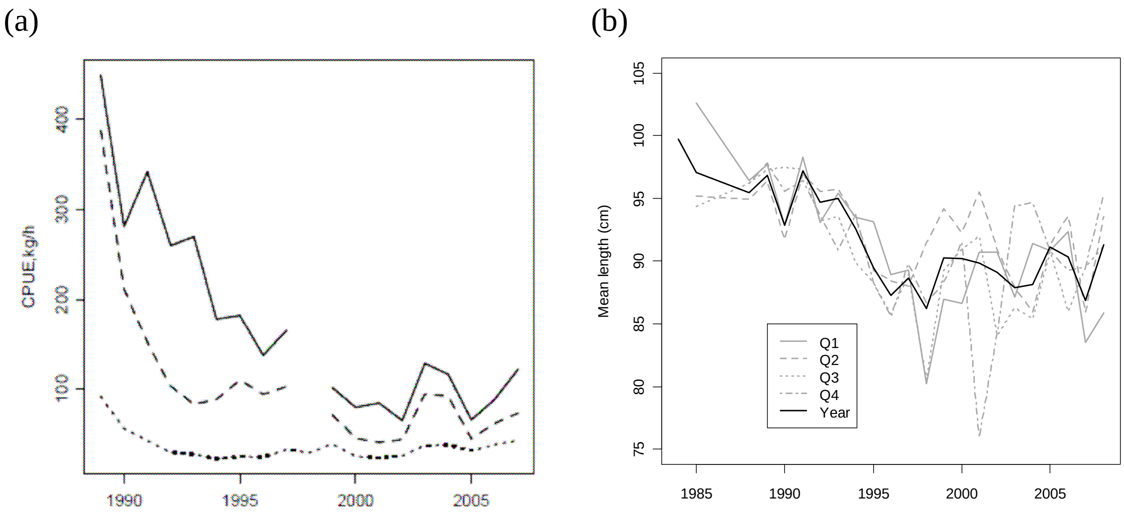


Figure 2. a) Blue ling LPUEs for French trawlers fishing in ICES Division Vb and sub-areas VI and VII. Dotted line: all vessels; dashed line: reference fleet of large high-sea trawlers; solid line directed LPUE of the reference fleet (landings for fishing trips where blue ling represents >10% of total landings). Redrawn from ICES (2008). b) Mean length of French landings by quarter and year, 1985-2008.

Collaboration with the fishing industry has led to the use of tallybook data for deriving standardised LPUEs (e.g. Dobby et al., 2008). A partnership between the French fishing industry involved in the deep-sea fishery and Ifremer was initiated several years ago. The Industry (PROMA/PMA, a producers organisation and EURONOR, a ship owner) has created a database with landings per species and haul information including fishing depth of a panel of volunteer trawlers since the late 1990s. Some Skippers ' personal logbooks have been retrieved back to 1992, so that a database from 1992 to 2008 is now available. Several workshops with the industry have been organised to assemble the database and check the data. Preliminary analysis showed that several factors had an effect on deepwater fish LPUEs (Biseau, 2008).

Here further statistical modelling was carried out to calculate standardised blue ling LPUEs. General Additive Models (GAMs) where fitted to extract the main factors and identify trends over time. Landings or catches data are often characterised by a large number of zero observations. A common way for handling this problem in CPUE standardisation is to use the delta-approach in which presence-absence and quantity when present are modelled separately. Less often both zero and non-zero observations have been modelled together. In certain cases the Poisson distribution (e.g. Dobby et al., 2008) or the inflated Poisson is an option. The Tweedie distribution, also called Poisson-Gamma distribution, offers a family of distributions with the Poisson distribution as a special case. It has a positive mass at zero and a continuous distribution for positive values. The Tweedie distribution has successfully been used to model LPUE data for yellowfin tuna and silky shark (Shono, 2008) and Patagonian toothfish (Candy, 2004).

Material and Methods

Data

The DeepWater TallyBook database (DWTB) contains information on hauls and vessels from 30 French deep-sea trawlers operating in the Northeast Atlantic for the period 1992-2008

(Figure 3). For each haul location, mean fishing depth, effort (tow duration...) and landings (biomass) by species are reported. For the purpose of this work, location was treated as statistical rectangle. Vessels are identified with a numeric code and engine power is available. The data come from volunteer vessels for which information for all tows during a given period was provided. The participation of vessels varied over the years as some were decommissioned or moved to other fisheries and new vessels were built. No framework for dedicated staff and data protocol existed, so that the data collection was mainly opportunistic.

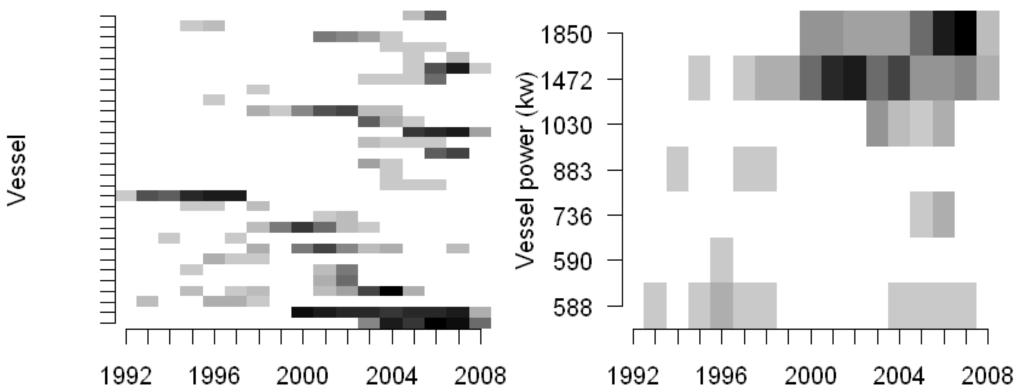


Figure 3. Number of hauls in tallybooks by vessel and vessel power category.

Several data sets were created for the analysis. The full data set contains a selection of hauls with haul duration between 30 and 600 mins and haul depth between 200 and 1100m. The “outside spawning season” data set, is a subset of the full data set excluding the spawning months March to May while the spawning season data set only includes the months March to May. Finally, several blue ling bycatch data sets were created by selecting hauls were blue ling was not a target species, corresponding to hauls with less than 20, 30, 40 or 50% of total landings belonging to blue ling.

Six fishing areas were defined (Figure 1) based on the logbook data analysis for the period 1989-2005 by Biseau (2006). From this analysis it appeared that some fishing grounds were not exploited in the 1990s and only started to be fished by French vessels in the 2000s. However these areas were exploited previously by other fleets and possibly by French vessels prior to 1989. As average LPUE levels differed between areas, the extension of the fishing grounds in the 2000s had an effect on LPUEs based upon EU logbooks. Therefore LPUE were estimated at the scale of the smaller areas. Here, we took the same approach. Reference fishing grounds, exploited since the 1990s where defined in ICES Sub-areas V, VI and VII (ref5, ref6 and ref7) and new fishing grounds, exploited in the 2000s were defined in subareas V and VI (new5 and new6). Moreover, ref6 was further split between statistical rectangles from the slope to the west of Scotland, along the Rockall Trough here referred to as edge6 and other rectangles, referred to as other6 (Biseau, 2006 and Figure 1a). The number of hauls per fishing area for the full data set are shown in figure 1b. Most hauls in the DWTB data base come from the edge6 area. Finally, because there were fewer hauls in the DWTB data base for the years prior to 2000 (Figure 1) and the fleet composition changed with no vessel participating throughout the whole period (Figure 3), the data sets used for model fitting were restricted to the years 2000-2008.

Modelling

For creating LPUE (Landings Per Unit of Effort) indices per area, generalised additive models (GAM) were fitted to the blue ling landings per haul for each data subset. All models include (i) a smooth term of haul duration, (ii) an interaction for year and area (i.e. a different year effect was fitted per area with no general year or area effect), (iii) depth as a smooth function, (iv) a factor for vessel id and (v) a factor for rectangle.

The models have the form
log(E[landings]) = s(haul duration) + s(depth) + vessel.id +rectangle+ year:area

where s() indicates a smooth non-linear function (cubic regression spline).

All models were fitted assuming a Tweedie distribution with a log-link function using the mgcv package in R. The Tweedie distribution has mean μ and variance $\varphi\mu^p$, where φ is a dispersion parameter and p called the index ($1<p<2$). The index p cannot be estimated simultaneously with the model parameters, hence a detailed study was carried out for one subset. Subsequently $p=1.3$ was fixed for all analyses as this value led to the largest likelihood of the fitted model for the tested data set. Model fit and assumptions were judged by visual inspection of residual plots.

To obtain predictions on the scale of the landings (not the log-scale of the predictor) for each area and year, predictions were carried out for a given rectangle in the first month of the data set (January or March), a haul duration of 300 mins at 700m depth and a vessel that fished in most areas and during the whole study period. Given this selection model predictions in each area are relative not absolute. Therefore, for each area annual LPUE estimates were standardised by dividing them by the predicted value of the first year. Confidence intervals for these predictions were obtained assuming normal distributions. As blue ling are not discarded, trends in LPUE correspond to trends in CPUE and thus represent actual trends in the quantities of fish caught.

Results

Representativness of tallybook data

The spatial distribution of effort for hauls in the DWTB data base seems quite representative of the spatial distribution of total French fishing effort of deep-water fisheries west of Scotland for most years (Figure 4). Blue ling catches in the data base are concentrated in the Northern part. Thus the effort in the South-West of Ireland is dedicated to other species.

Raw tallybook LPUE

The proportion of tows with blue ling present (positive tows) display quite similar trends for the data sets full data, outside spawning season and blueling bycatch (Figure 5). In particular, area edge6 shows an increasing proportion of hauls catching blue ling from about 20% in 1993 to about 80% in 2006-2008. The trend is mainly stable but increases slightly in area other6 for the dataset spawning season and bycatch. There is no trend in the new grounds in V and VI (new5 and new6) where the proportion of tows with blue ling have been close to one in all years. The trend in ref7 may not be reliable because it is based upon small numbers of tows (annexe1). The proportion of positive tows during the spawning season (Figure 5c left) is high and almost stable over time.

The highest LPUEs for positive tows (Figure 5, right panels) are found in new fishing grounds (new5, new6) in some years. Interannual variations are large in these areas, probably as a result of the small numbers of tows in some years (Annexe 1). LPUEs show increasing trends in edge6 for the data sets full data and outside spawning season. No clear trend appears for spawning season and blue ling bycatch. Bycatch LPUEs, are much lower than for any other data. The bycatch data set includes roughly half the total number of tows of the total dataset and more than the spawning season dataset (Annexe 1). In the bycatch data set high values observed in 2008 in edge6 and other6 should be regarded with caution due to small tow numbers in these years. In other6, the 2007 value is however the highest in the time series (1998-2008) and is derived from more than 500 hauls (Annexe 1). There is no clear trend for any other area/dataset.

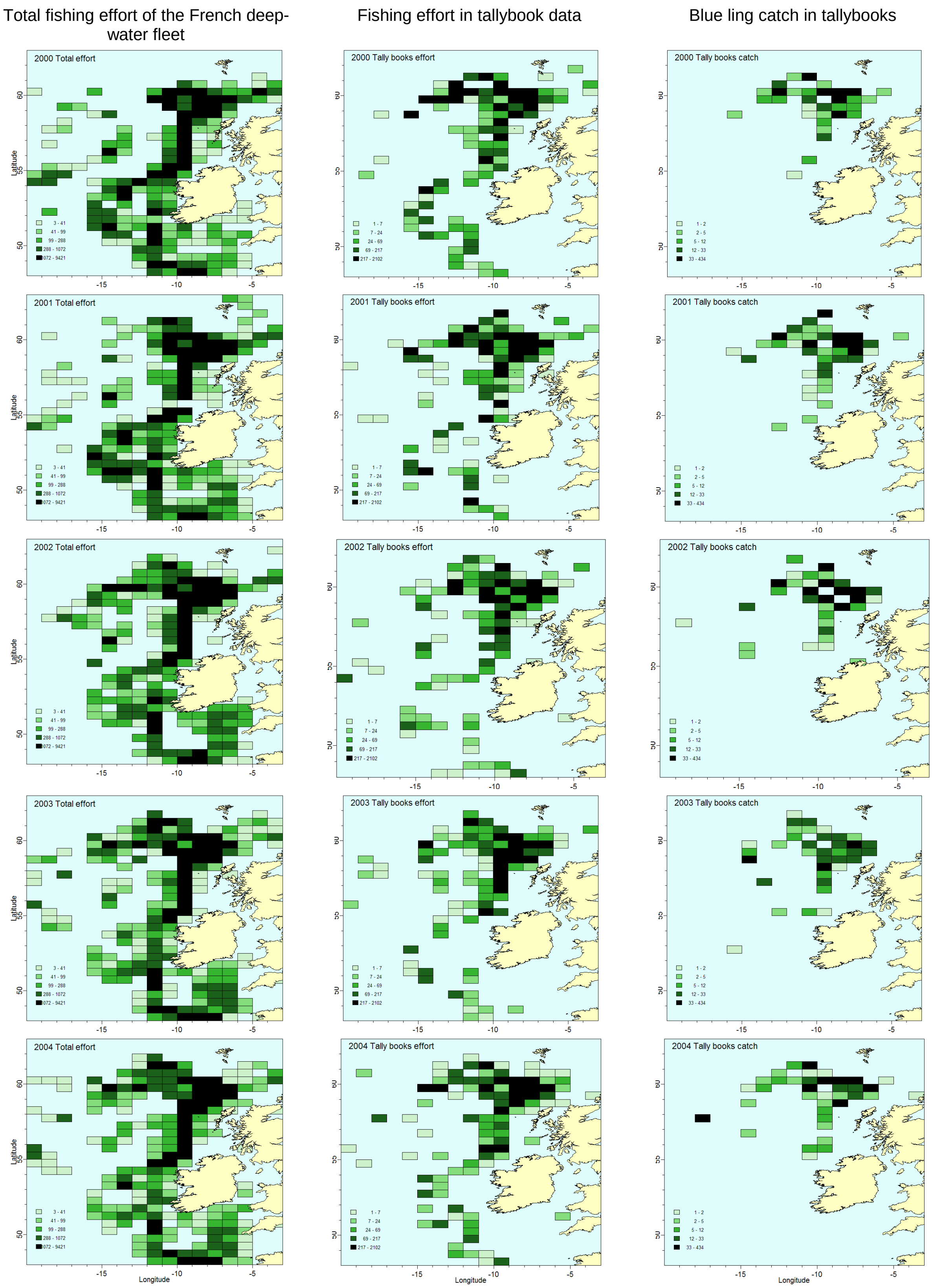
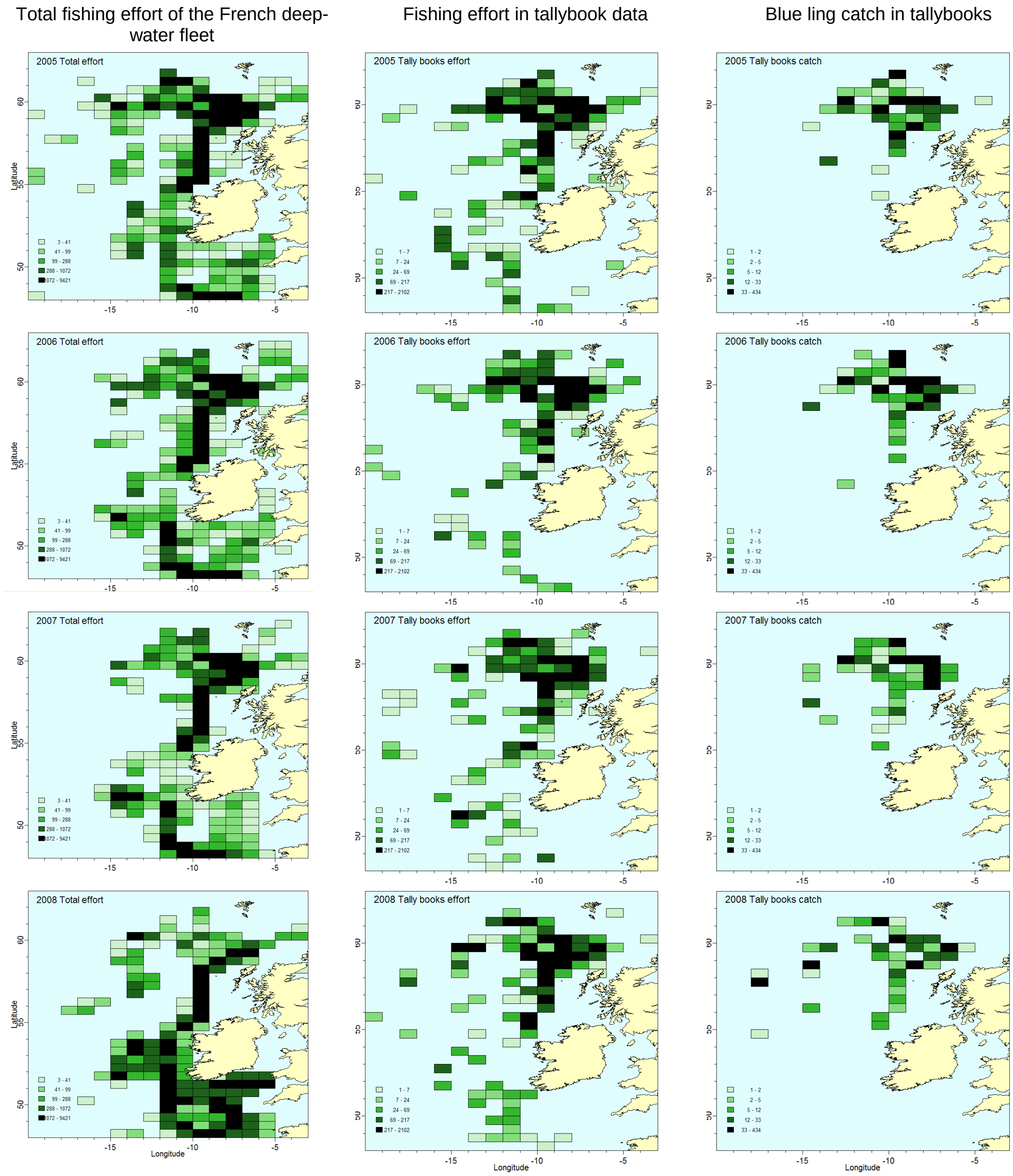


Figure 4. Geographical distribution of total effort of the French deep-water licensed fleet (left column, hours), total effort reported in tallybooks (central column, hours fishing), blue ling catch reported in tallybooks (right column, tonnes) in 2000-2004.



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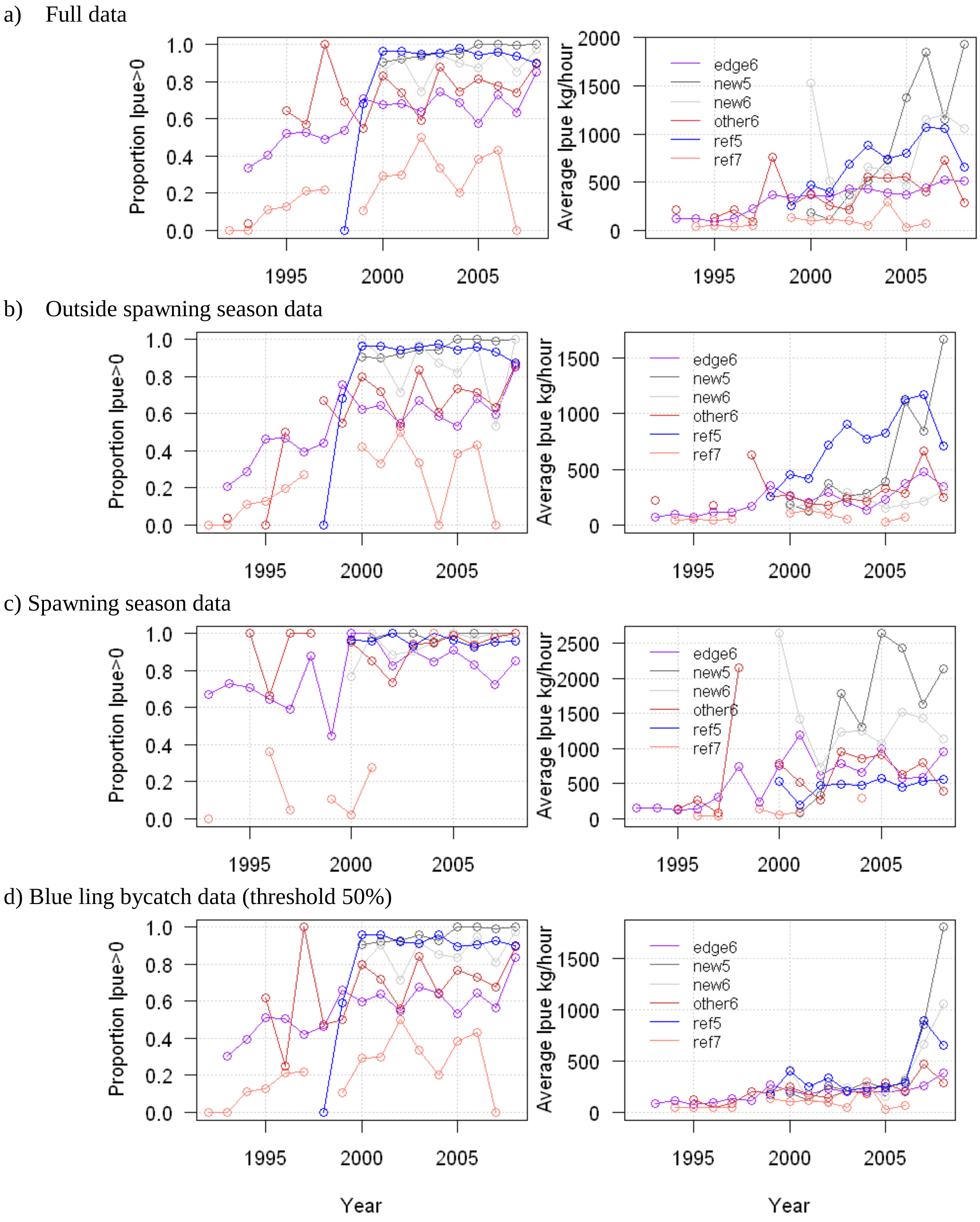

Figure 5 Left: Proportion of positive (blue ling catch >0) hauls and Right: average blue ling lpue for positive hauls for the different data sets.

Standardised tallybook LPUEs

Predicted trends in standardised LPUEs varied over data sets and areas (Figure 6). Diagnostics and full information for model fits are provided in appendix 2. The full and the outside spawning season data sets display very similar patterns over time with peaks and troughs in predicted LPUEs in the same years. The spawning season and outside spawning season datasets are non-overlapping and together make up the full data set. As there are more tows outside the spawning season, the trend for the full data is mainly driven by hauls from the outside spawning season data. Hence the similarity between the predictions of the two data sets are not surprising. The spawning season and the blue ling bycatch data set have similar time trends as the other two for area new5 and other6 and somewhat distinct trends for the other three areas.

In area edge6, no clear time trend appears outside the spawning season and in the bycatch data set, while there is a decline during the spawning season which is also visible in the full data set with an increase at the end. In area new5, all data sets show a more ore less steady increase after the lowest values were reached in 2001. In area new6, the four data sets show different patterns. Blue ling bycatch shows an increase, in particular at the end of the time series. The predictions from the different data sets are more consistent for area other6 with high levels in 2000 and 2003 and a low level in 2002, but overall no clear trend. In area ref5, predicted LPUEs have wide confident interval during the spawning season, due to the small number of tows. For the other data sets no clear time trends in predictions are visible.

Overall the results suggest increasing trends in new5 over the period 2000-2008 and stability in the four other areas. The trends from the spawning season data set different from the other four data sets for most areas except new5. There is no consistency in the years of high and low LPUE across areas which might indicate a meta-population structure of the blue ling stock.

The results for the bycatch data set presented above were obtained assuming a threshold value of less than 50% blue ling in total landings. The sensitivity to the threshold value was tested by varying it from 20 to 50% (Figure 7). The trends in most areas were insensitive. For area ref5, when lowering the threshold value, a decreasing trend appeared. Note that at a threshold of 20% the number of hauls is very small.

Discussion

Without modelling, calculating LPUEs for each tow is done by dividing the catch by tow duration (Figure 5). For the two most fished areas, edge6 and other6, there was an increase in the proportion of positive tows over time. This proportion was always close to 1 in ref5, new5 and new6 and data are insufficient in ref7. Average LPUE for positive tows showed consistent increases over time in all data sets.

Modelling allows assessing trends for the combined proportion of positive tows and LPUE of positive tows and taking account of changes in fishing strategy over time. Thus account is taken for (i) a non linear effect of depth and fishing time and (ii) a vessel and rectangle effect. Unlike in the raw LPUEs, no trends were found in all areas with the exception of new5 and LPUEs were mostly stable over the 9 years (2000-2008). Therefore the trends seen in the raw LPUEs might be primarily due to factors accounted for in the models.

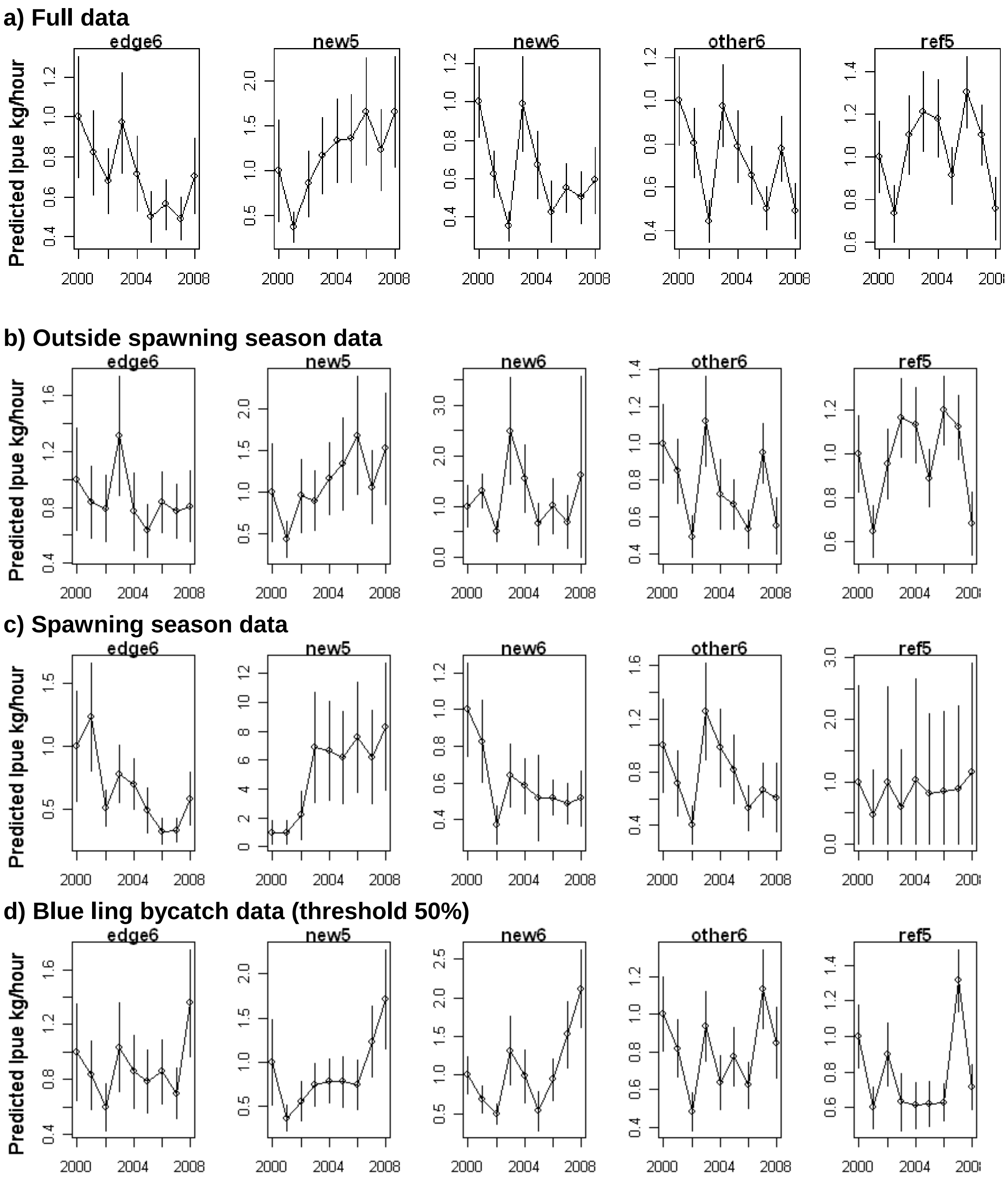

Figure 6. Predicted standardised relative blue ling LPUE per data set and area. Predictions are made for one vessel in January (March for c), 300 mins fishing time and 700 depth.

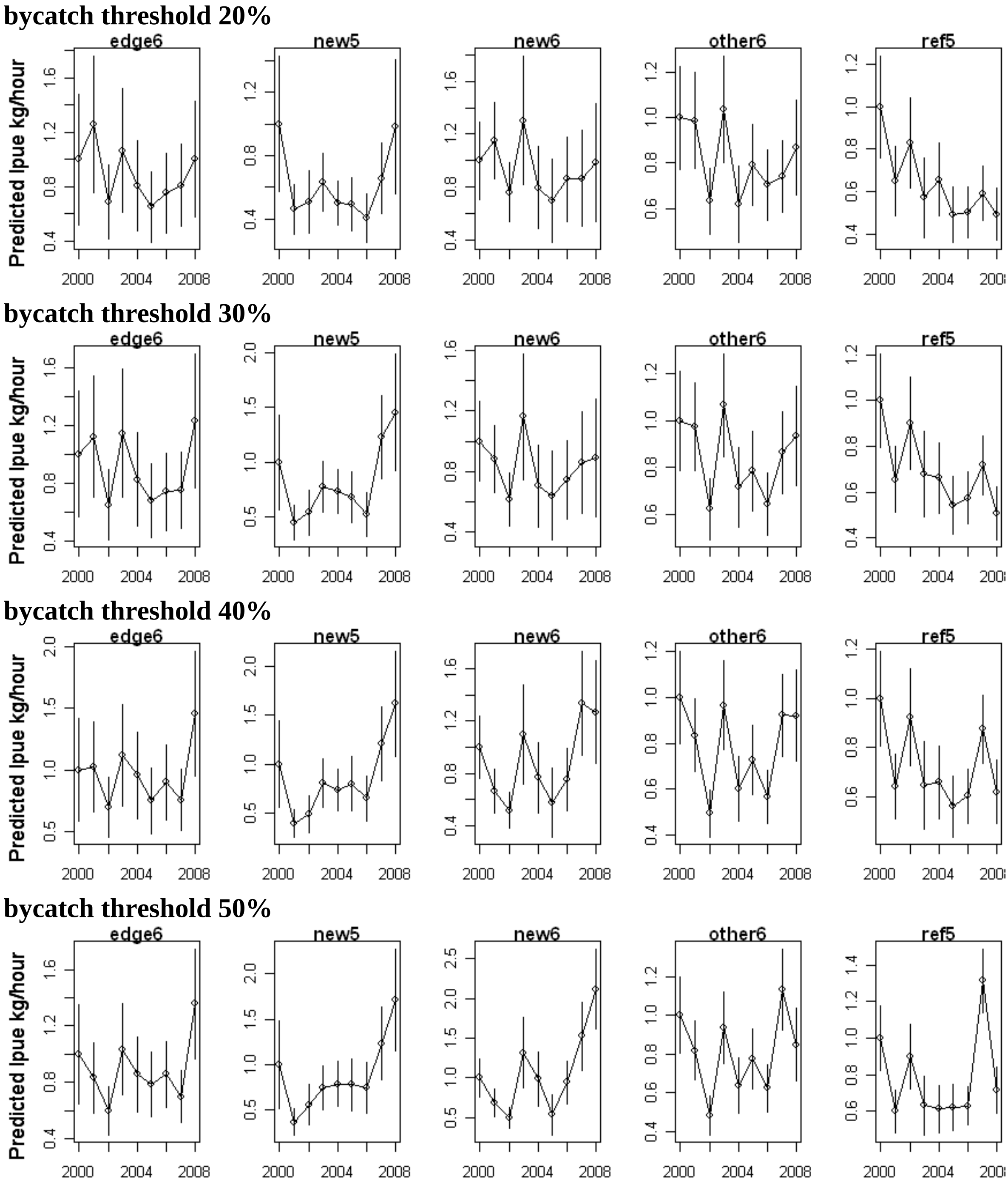

Figure 7. Impact of threshold value for bycatch data set (p=1.3) on predictions.

The bycatch data set might be the most reliable to assess variations in blue ling density. As blue ling aggregates at spawning time, using LPUEs from the spawning season as abundance indices might lead to biased estimates. Problems with CPUEs of aggregating species are well known. LPUEs from commercial fishing may also be impacted by fishing strategies and regulations. Management measures have an effect on fleet fishing strategies and therefore on the LPUE indices calculated based on landings and effort data. For blue ling, TACs where introduced in 2003 and were reduced in 2005 and 2007. From 2007, blue ling landings per fishing trip were limited by EU regulation and fishing companies. This might have impacted targeted blue ling fishing in several ways: vessels may no longer steam to fishing grounds where blue ling is the main catch and in the fished areas the fishing depth/location might be chosen to match the allowed landings. Our LPUE model accounts for this by including terms for fishing rectangle and depth.

In term of population abundance, although blue ling in the study area is considered to represent a single population unit, our study showed different trends in the five defined areas. Separate trends were already observed based on logbooks data (Biseau, 2006). This suggests that there might be spatial heterogeneity in population dynamics. If this is the case, caution is required when using blue ling LPUEs from a single large area as an abundance index for stock assessment. Differences in trends between areas might be related to bio-ecological factors or to the effects of fishing. The total effort from the French fleet, which catch most of the blue ling in the study area shows strong spatial heterogeneity (Figure 4). Effort decreased since 2003 and a larger proportion is now expended on shelf areas of the Porcupine Bank and the Celtic Sea (Figure 4). The effort in areas where blue ling is caught decreased and is more concentrated in our edge6 area. Areas to the North and West of the Hatton bank were not fished in recent years.

The risk of local depletion has been an additional reason to restrict the fishery for blue ling. One case of depletion of a spawning aggregation has been reported south of Iceland (Magnússon and Magnússon, 1995). Our study shows no sign of local depletion over the period 2000-2008: (i) standardised LPUEs were stable in edge6, which is the most intensively fished area; (ii) new fishing grounds (new5 and new6) started to be exploited by the French fleet in the 2000s, but blue ling continued to be fished in previously exploited areas ref5, edge6, other6; and (iii) the distribution of catches per rectangles does not indicate a shift in the underlying distribution of blue ling. Therefore, if local depletion occurred, it might have been at spatial scale inferior to the size of statistical rectangles as catches have continued to be obtained from all fished rectangles.

The present work does not contradict the consensus view that the blue ling stock declined since the 1980s. The decline of the catches in Icelandic waters, the Norwegian Sea, the North Sea and the Skagerrak in the late 1980s-early 1990s (ICES, 2008) are enough evidence that stocks can easily be overfished. Nevertheless, in the light of the results found here, blue ling in Vb, VI and VII can hardly be regarded as a stock that is still on the downward trend. Our standardised LPUEs are rather stable in 4 out of 5 areas and increasing in the fifth. This can be regarded as a positive outcome of deep-water fisheries management since 2003. Unlike for other deep-water species, the gadoid-like life history of the species might allow for a rapid dynamic reaction to changes in fishing mortality. Blue ling catch are not longer driven by fleet capacity and strategy but capped by the TAC. Management by TAC might be efficient for a species whose largest catches come from targeted tows, under a TAC management vessels have no reason to go for these targeted tows.

Past assessments of the blue ling stock have been mainly driven by aggregated LPUEs from the French fleet (Figure 2a), which show a declining trend in the early part and stability in recent years. Length distributions of the landings (Figure 2b) have been little used for assessment purposes. However, they might convey some information on stock status. The mean length at the start of the time series is similar to that in exploratory cruises from 1973-74; i.e. at the onset of the major exploitation (Bridger, 1978). This may suggest that in 1984 the fishery was still fishing unexploited grounds with a "pristine" size distribution.

No yearly age composition of the landings of blue ling is estimated but some growth parameters are available from the literature. These were used to calculate the level of fishing mortality required to reduce the mean length in the landings by 10 cm from 99 cm at the start of the time series in 1984 to 89 cm on average during 2000 to 2008. Growth parameters for male and female were used considering that they should represented limits for the likely values for the total stock. Relative numbers at age were calculated as in a yield per recruit model with constant recruitment and assuming a natural mortality of M=0.17 (Table 2). Under these assumptions, a 10 cm reduction in mean size of a blue ling stock is obtained with fishing mortality between 0.15 and 0.3. If such a mortality was generated by the landings reported in the 2000s (6 600 t on average in 2000-2007), the current TAC (2 009 t) and the landings from the Faroe Islands and Norway (roughly 2 000 t in recent years) might represent a smaller mortality, something in the range 0.1-0.2. The F values would be higher if recruitment decreased.

Table 2. Fishing mortality required reducing the mean length in the stock a 10 cm for a set of bleu ling growth parameters, a natural mortality M=0.17 and fishing mortality beginning at age 7.

L_∞ (cm)	K (year^{-1})	Sex	Reference	Mean size in unexploited stock	F for a 10 cm reduction
160	0.11	Combined	Magnussen, 2007	111	0.18
112.5	0.16	Male		91	0.28
165.8	0.084	Female	Moguedet, 1988	97	0.16
125	0.15	Combined	Ehrich and Reinsch,1985	99	0.28
145.2	0.155	Female	Ehrich and Reinsch,1985	116	0.24

The time trends estimated here have to be confirmed in future years. The purpose of the management of deep-water fisheries, including blue ling, in the 2000s has been to halt over exploitation. Assessments of deep-water stock have been undermined by several sources of uncertainties, short times series and a situation of a "one-way trip", which are assumed to contain little information on population dynamics. Nevertheless, a sustainable catch level exists also for deep-water species. Starting from a level of overexploitation, management now faces the difficulty to detect changes in stocks status over time.

The proportion of positive tows in the bycatch data set might allow assessing habitat occupancy. The increase of the proportion of blue ling in non targeted tows in several areas (Figure 5) suggests that blue ling was caught at more locations in the late 2000s. Thus area occupancy of the population might have slightly expanded over the period 2000-2008.

This work provides a basis for developing abundance indices of blue ling in ICES sub-areas VI and VII and division Vb. The reliability of a LPUE index from blue ling taken as a bycatch will become essential because fishing on spawning aggregation is regulated from 2009 so that a component of the past fishery will disappear. Further addition of data to the currently available tally books could allow to assess trends on longer time period.

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Annexe 1

Number of hauls for different data sets

All data

	All tows						Tows with blue ling catch					
Year	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**
1992	0	0	0	0	0	43	0	0	0	0	0	0
1993	448	0	0	27	0	15	149	0	0	1	0	0
1994	319	0	0	0	0	18	129	0	0	0	0	2
1995	499	0	0	14	0	55	261	0	0	9	0	7
1996	614	0	0	7	0	157	324	0	0	4	0	33
1997	299	0	0	1	0	362	147	0	0	1	0	78
1998	224	0	0	165	11	0	120	0	0	114	0	0
1999	62	0	0	42	22	19	44	0	0	23	15	2
2000	145	43	117	311	290	144	98	39	100	258	279	42
2001	334	134	212	723	234	130	227	123	197	535	225	39
2002	599	78	456	682	240	4	383	73	339	402	227	2
2003	407	167	106	535	214	6	304	159	100	470	204	2
2004	290	284	98	373	274	10	199	269	88	278	268	2
2005	302	142	40	395	313	34	173	142	35	322	295	13
2006	992	121	97	679	621	7	723	121	94	527	593	3
2007	993	157	54	847	591	27	629	156	46	628	552	0
2008	122	81	35	124	139	0	104	81	34	111	125	0

All data out of spawning season (months 3-5 excluded)

	All tows						Tows with blue ling catch					
Year	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**
	0	0	0	0	0	43	0	0	0	0	0	0
1993	329	0	0	27	0	10	69	0	0	1	0	0
1994	235	0	0	0	0	18	68	0	0	0	0	2
1995	375	0	0	5	0	55	173	0	0	0	0	7
1996	411	0	0	4	0	146	193	0	0	2	0	29
1997	154	0	0	0	0	275	61	0	0	0	0	74
1998	175	0	0	155	11	0	77	0	0	104	0	0
1999	53	0	0	42	22	0	40	0	0	23	15	0
2000	124	43	45	250	233	98	77	39	45	200	224	41
2001	300	99	161	610	210	61	193	89	146	439	202	20
2002	404	64	371	489	218	4	222	59	264	260	205	2
2003	278	140	63	313	200	6	187	132	61	261	191	2
2004	178	160	62	221	250	8	104	151	54	134	244	0
2005	268	80	28	270	286	34	142	80	23	198	269	13
2006	684	53	27	487	566	7	467	53	26	347	542	3
2007	692	97	17	584	491	27	412	96	9	370	457	0
2008	88	36	3	94	93	0	75	36	3	81	81	0

All data spawning season only (months 3-5 only)

	All tows						Tows with blue ling catch					
Year	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**
1993	119	0	0	0	0	5	80	0	0	0	0	0
1994	84	0	0	0	0	0	61	0	0	0	0	0
1995	124	0	0	9	0	0	88	0	0	9	0	0
1996	203	0	0	3	0	11	131	0	0	2	0	4
1997	145	0	0	1	0	87	86	0	0	1	0	4
1998	49	0	0	10	0	0	43	0	0	10	0	0
1999	9	0	0	0	0	19	4	0	0	0	0	2
2000	21	0	72	61	57	46	21	0	55	58	55	1
2001	34	35	51	113	24	69	34	34	51	96	23	1
2002	195	14	85	193	22	0	161	14	75	142	22	19
2003	129	27	43	222	14	0	117	27	39	209	13	0
2004	112	124	36	152	24	2	95	118	34	144	24	0
2005	34	62	12	125	27	0	31	62	12	124	26	2
2006	308	68	70	192	55	0	256	68	68	180	51	0
2007	301	60	37	263	100	0	217	60	37	258	95	0
2008	34	45	32	30	46	0	29	45	31	30	44	0

All data tows not targeting blue ling (<50% blue ling in total catch)

	All tows						Tows with blue ling catch					
Year	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**	**edge6**	**new5**	**new6**	**other6**	**ref5**	**ref7**
1992	0	0	0	0	0	43	0	0	0	0	0	10
1993	430	0	0	26	0	15	131	0	0	0	0	0
1994	312	0	0	0	0	18	122	0	0	0	0	2
1995	488	0	0	13	0	55	250	0	0	8	0	7
1996	584	0	0	4	0	157	294	0	0	1	0	33
1997	262	0	0	1	0	362	110	0	0	1	0	78
1998	194	0	0	97	11	0	90	0	0	46	0	0
1999	53	0	0	38	17	19	35	0	0	19	10	2
2000	117	43	82	264	248	144	70	39	65	211	237	42
2001	296	134	158	666	188	130	189	123	143	478	180	39
2002	475	67	409	637	158	4	259	62	292	357	145	2
2003	318	136	70	402	89	6	215	130	64	337	81	2
2004	254	204	66	261	146	10	163	189	56	166	140	2
2005	275	74	30	305	169	34	146	74	25	233	151	13
2006	760	49	54	560	285	7	491	49	51	408	257	3
2007	839	119	42	672	515	27	475	118	34	453	476	0
2008	109	77	35	124	138	0	91	77	34	111	124	0

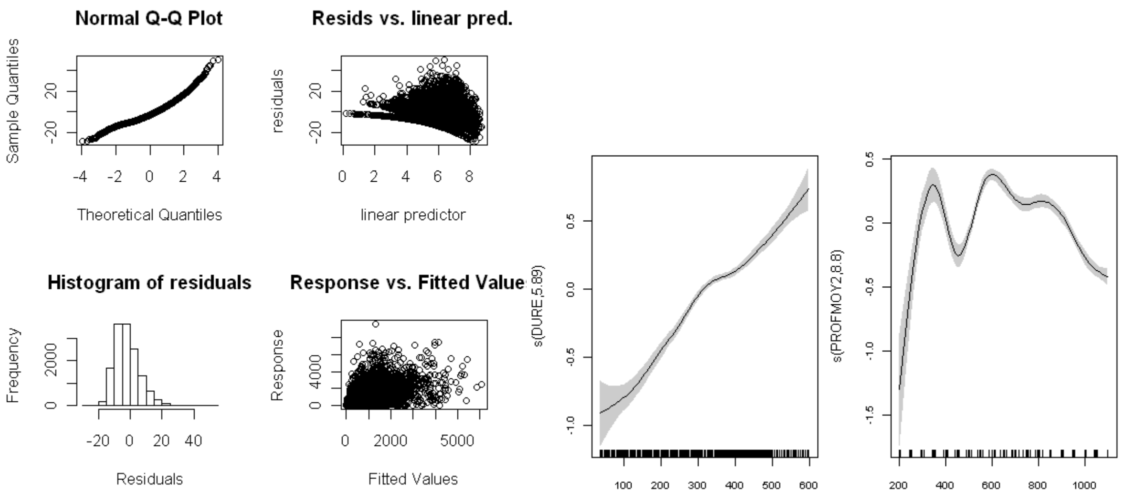
Annexe 2: Modelling

Model

Blueling ~ s(duration, bs = "cr") + factor(vessel id) + s(depth, bs = "cr") + factor(month) + factor(rectangle) + year:area

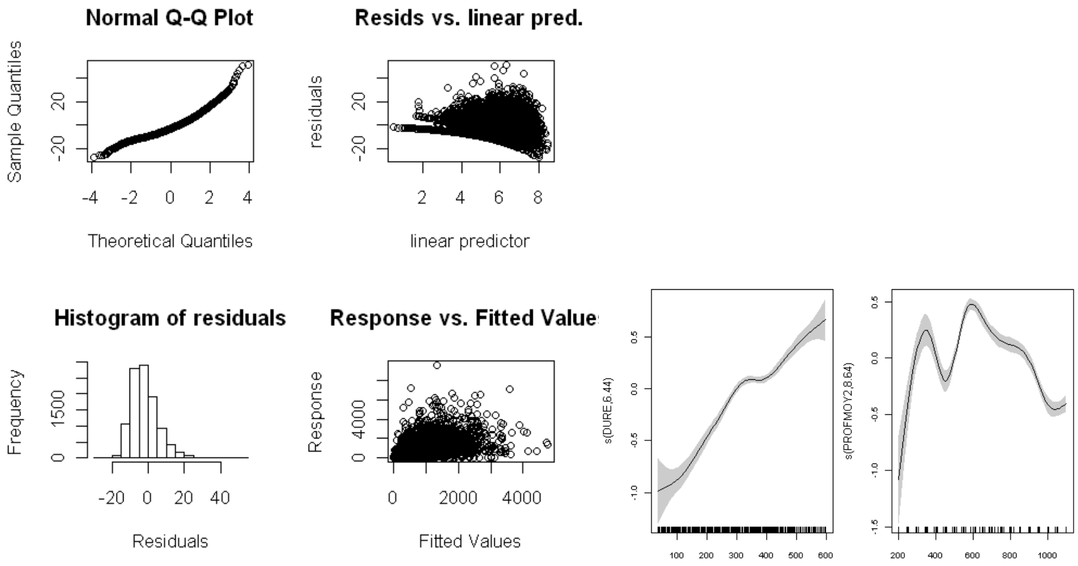
Model fits

Annexe 2.1 All data (p=1.3)



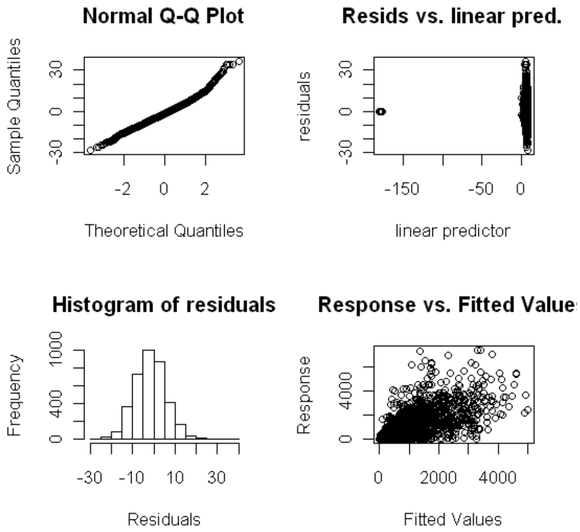

```
R-sq.(adj) =  0.413   Deviance explained = 52.3%
REML score =  87310  Scale est. = 67.719    n = 14191

Family: Tweedie(1.3)
Link function: log

Formula:
Zvar ~ s(DURE, bs = "cr") + factor(nom) + s(PROFMOY2, bs = "cr") +
    factor(mois) + factor(RECT) + an:ZONE

Parametric Terms:
             df      F p-value
factor(nom)  20  32.76  <2e-16
factor(mois) 11 200.66  <2e-16
factor(RECT) 46  51.55  <2e-16
an:ZONE      43  15.46  <2e-16

Approximate significance of smooth terms:
              edf Ref.df      F p-value
s(DURE)     5.891  5.891 130.02  <2e-16
s(PROFMOY2) 8.796  8.796  58.53  <2e-16
'log Lik.' -87787.61 (df=135.6872)
```

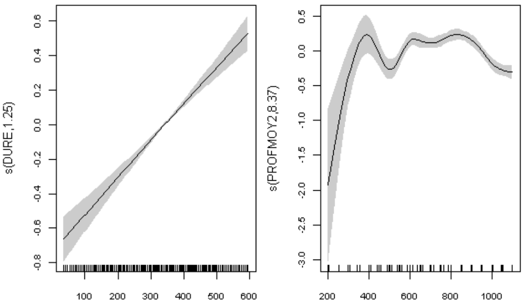
Annexe 2.2 Outside spawning season (months 3-5 excluded)




```
R-sq.(adj) =  0.397   Deviance explained = 53.2%
REML score =  60037  Scale est. = 61.187    n = 10430

Family: Tweedie(1.3)
Link function: log

Formula:
Zvar ~ s(DURE, bs = "cr") + factor(nom) + s(PROFMOY2, bs = "cr") +
    factor(mois) + factor(RECT) + an:ZONE

Parametric Terms:
             df     F p-value
factor(nom)  20 24.50  <2e-16
factor(mois)  8 66.07  <2e-16
factor(RECT) 46 27.31  <2e-16
an:ZONE      43 10.81  <2e-16

Approximate significance of smooth terms:
              edf Ref.df     F p-value
s(DURE)     6.442  6.442 91.03  <2e-16
s(PROFMOY2) 8.638  8.638 57.66  <2e-16

'log Lik.' -60225.4 (df=133.0801)
```

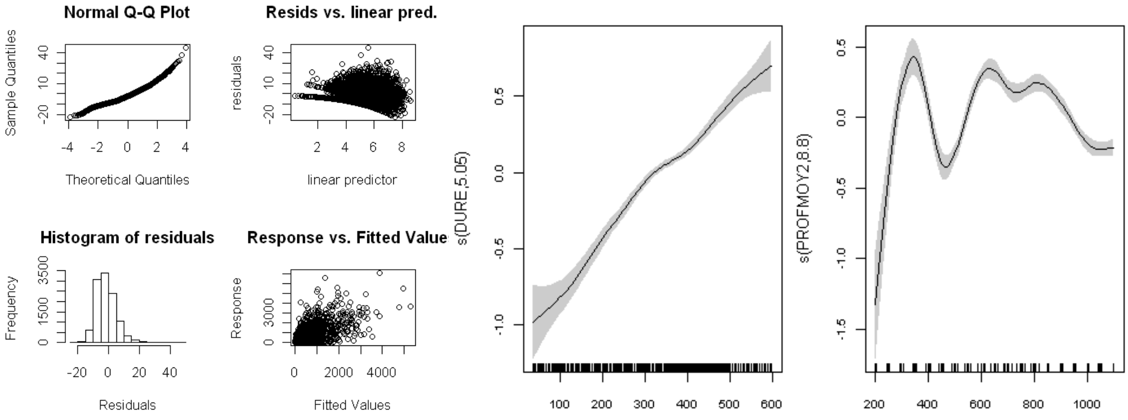
Annexe 2.3 Spawning season (months 3-5)






```
R-sq.(adj) =  0.474   Deviance explained = 54.6%
REML score =  26589  Scale est. = 63.018    n = 3761

Family: Tweedie(1.3)
Link function: log

Formula:
Zvar ~ s(DURE, bs = "cr") + factor(nom) + s(PROFMOY2, bs = "cr") +
    factor(mois) + factor(RECT) + an:ZONE

Parametric Terms:
             df        F p-value
factor(nom)  19   12.825  <2e-16
factor(mois)  2   93.822  <2e-16
factor(RECT)  3 1.94e-08       1
an:ZONE      42    8.826  <2e-16

Approximate significance of smooth terms:
              edf Ref.df      F p-value
s(DURE)     1.245  1.245 123.03  <2e-16
s(PROFMOY2) 8.373  8.373  12.93  <2e-16
'log Lik.' -26291.1 (df=118.6179)
```

Annexe 2.4 hauls with blue ling as a bycatch (<50% blue ling in total catch)




```
R-sq.(adj) =  0.473   Deviance explained = 49.5%
REML score =  59014  Scale est. = 44.346    n = 11119

Family: Tweedie(1.3)
Link function: log

Formula:
Zvar ~ s(DURE, bs = "cr") + factor(nom) + s(PROFMOY2, bs = "cr") +
    factor(mois) + factor(RECT) + an:ZONE

Parametric Terms:
             df      F p-value
factor(nom)  20  24.34  <2e-16
factor(mois) 11 126.92  <2e-16
factor(RECT) 46  23.53  <2e-16
an:ZONE      43  18.11  <2e-16

Approximate significance of smooth terms:
              edf Ref.df      F p-value
s(DURE)     5.054  5.054 118.98  <2e-16
s(PROFMOY2) 8.797  8.797  42.34  <2e-16
'log Lik.' -58771.77 (df=134.8508)
```

ANNEXE 3 Impact of Tweedie index parameter *p* on loglikelihood

bycatch (<50% blue ling in total catch) data set