

Distribution, abundance, and growth of anglerfish (*Lophius piscatorius*) on the Porcupine Bank (west of Ireland)

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This manuscript presents the first results on abundance and distribution of white anglerfish (*Lophius piscatorius*) from a series of groundfish surveys carried out on the Porcupine Bank. White anglerfish were caught in all trawlable areas, recruits and juveniles mainly from the shallower parts of the bank, around the central mound and closer to the Irish shelf. A strong cohort was manifest in 2001, and it could be tracked over time by age matrices obtained with illicia age–length keys (ALKs) collected during the surveys. However, a mismatch in the cohort analysis suggests that the growth pattern based on illicia underestimates around three of the younger age classes. Using an ALK estimated numerically from a faster growth model, this mismatch disappears, which seems to confirm faster growth. Recruits of the 0-group and adults of age 4 (with the faster growth: ca. ~57–65 cm) dominated, whereas the intermediate age groups were scarce on the bank. These results and recent findings from tag-and-recapture experiments suggest that white anglerfish move to and from the Porcupine Bank, calling into question the stock boundaries currently accepted for the species in the North Atlantic.

Keywords: anglerfish, groundfish surveys, growth, movements, Northeast Atlantic Ocean, Porcupine Bank.

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Introduction

The white anglerfish (*Lophius piscatorius*) is a bottom-living species, found from 50 to >1000 m (Whitehead *et al.*, 1986; Dardignac, 1988). They inhabit the Northeast Atlantic from the Barents Sea to the Strait of Gibraltar and also the Mediterranean and the Black Sea. The distribution overlaps considerably with that of its congener, the black anglerfish (*Lophius budegassa*), which has a more southern, shallower distribution (Whitehead *et al.*, 1986). Generally, both species are marketed as one. In bottom-trawl surveys carried out in the Porcupine Bank, white anglerfish accounted for ca. 90% of the total anglerfish catch by number, and ~92% by weight (FV, pers. obs.).

Anglerfish are a valuable component of European commercial fisheries and are taken by a mixed trawl fishery and a targeted gillnet fleet (Fariña *et al.*, 2004; ICES, 2007). Apart from anglerfish, the trawl fleets capture hake (*Merluccius merluccius*), two species of megrim (*Lepidorhombus whiffiagonis* and *Lepidorhombus boscii*), sole (*Solea solea*), cod (*Gadus morhua*), plaice (*Pleuronectes platessa*), and Norway lobster (*Nephrops norvegicus*). Because of their commercial importance, together with their particular prey luring behaviour, several scientific studies have been conducted, particularly during the past decade, covering aspects such as growth (Duarte *et al.*, 1997; Landa *et al.*, 2001, 2008; Wright *et al.*, 2002; Woodroffe *et al.*, 2003), movements and stock limits (Pereda and Landa, 1997; Fariña *et al.*, 2004; Laurenson *et al.*, 2005; Charrier *et al.*, 2006; Landa *et al.*, in press), feeding habits (Crozier, 1985; Pereda and Olosa, 1990; Azevedo, 1996; Silva *et al.*, 1997), and reproduction

(Afonso-Dias and Hislop, 1996; Quincoes *et al.*, 1998a, b; Duarte *et al.*, 2001), and stock assessment (Azevedo *et al.*, 2008b). However, much of the basic knowledge required on life history, growth, stock identification, and movements is still lacking.

In the Northeast Atlantic, ICES delimits three areas for assessment of anglerfish: (i) the southern stock of the southern shelf (Divisions VIIIc and IXa), (ii) the northern stock of the southern shelf (Divisions VIIb–k and VIIIa, b, d), and (iii) the stock on the northern shelf (Division IIIa, Subareas IV and VI). These stocks are considered to be distinct, not because of biological features but rather to facilitate the provision of management advice by ICES Division. However, the current stock or population definition of European anglerfish is questionable given the lack of basic biological knowledge mentioned above. Therefore, study of distribution and abundance is important to be able to elucidate questions on stock identity and growth rate of white anglerfish.

The Porcupine Bank lies in the Northeast Atlantic, ~200 km west of Ireland (Figure 1). Its shallowest depth is ~150 m, and the top of the bank itself is composed of a rocky non-trawlable area; trawlable areas start at depths of ~170–180 m. The north-western part of the bank is limited by steep cliffs that fall abruptly from around 450 to 1000 m. In its eastern part, the bank is connected to the Irish shelf only by the narrow Slynne Ridge (~330–340-m depth), and it is therefore relatively short of terrigenous sediment compared with the rest of the Irish margin. Finally, the southeastern part constitutes a portion of the Porcupine Sea Bight and is composed of sediment and muddy substrata along

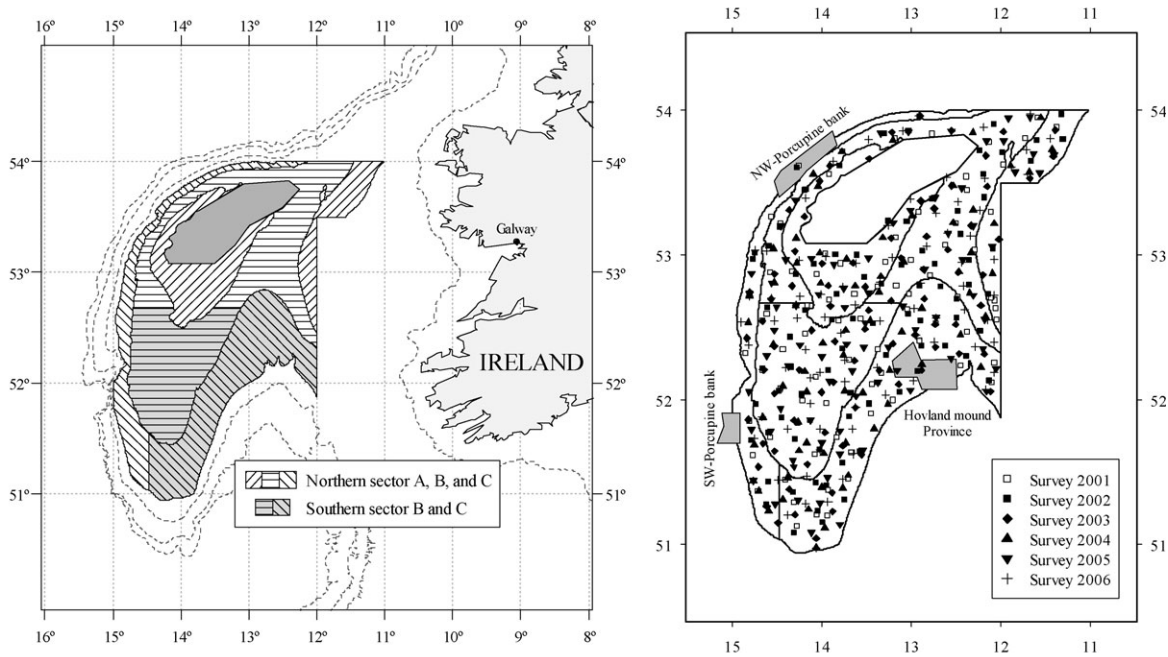


Figure 1. (Left panel) Sampling design of Porcupine Bank groundfish surveys (depth strata: A, <300 m; B, 301–450 m; C, 451–800 m) showing the 100, 1000, 1500, and 2000 m isobaths (dashed lines). (Right panel) Hauls performed during the time-series showing the three special areas of cold-water coral protection established in 2006.

a gentle slope. With this configuration, the bank forms a structure similar to seamounts with their related anticyclonic structures (White *et al.*, 1998; Mohn *et al.*, 2002). These conditions might become a barrier for organisms moving off the bank, but the structures could be broken down by storms and strong meteorological phenomena, so could have more effect on eggs and larvae than on juveniles or adult fish.

White anglerfish inhabiting the Porcupine bank (ICES Subareas VIIc, k) belong to the so-called northern stock and are, as elsewhere, fished by trawl and gillnet. Landings of white anglerfish from Subarea VII since 1986, as estimated by the Working Group on the Assessment of Southern Stocks of Hake, Monk, and Megrin (WGHMM; ICES, 2007), have fluctuated between 11 500 and 23 000 t, with peaks >20 500 t since 2003. The northern stocks of the southern shelf of both species of anglerfish are managed by a common total allowable catch (TAC) and quota system, and their state of exploitation is assessed annually. Nevertheless, an analytical assessment was not carried out in 2007 owing to the poor quality of the catch data, and especially to the absence of discard estimates and problems with age determination (ICES, 2007). Consequently, surveys (though not the Porcupine Groundfish Survey) were considered only from a qualitative point of view as indicators of recruitment and overall trends.

The results from research trawl surveys are widely used in constructing fisheries-independent indices of relative abundance for a number of commercially important fish stocks (Smith and Gavaris, 1993; Pelletier, 1998). Bottom-trawl surveys are nowadays one of the most important methods for assessing commercial fish stocks, because they provide information independent of the fishery and unlikely to be affected by misreporting (Beare *et al.*, 2003). Often, survey data play an important role in calibrating single-species assessment models, used as a tool for fisheries management. Survey abundance indices are particularly important

for tracking recruitment strength. Such information cannot usually be obtained from fisheries owing to minimum landing size/weight constraints, although recent work has proposed the use of discard estimates to track recruitment strength, correlating recruit abundances in surveys and discard estimates (Díaz *et al.*, 2008).

Studies on the growth of white anglerfish have focused on age estimation using different calcified structures, such as illicia (Dupouy *et al.*, 1986; Peronnet *et al.*, 1992; Duarte *et al.*, 1997; Landa *et al.*, 2001) and otoliths (Tsimenidis and Ondrias, 1980; Crozier, 1989; Wright *et al.*, 2002; Woodroffe *et al.*, 2003). The northern stock was assessed until 2007 using an age-structured model, with age information derived from illicia (ICES, 2007). Recently, however, inconsistencies in white anglerfish cohort tracking have been found within the southern stock fishery data time-series (Azevedo *et al.*, 2008a). Despite the use of standardized reading criteria and the fact that the precision, relative accuracy, and agreement between readers were good after several workshops on age determination (Landa *et al.*, 2002; Duarte *et al.*, 2005), it has been concluded that the current anglerfish growth rate might be underestimated (Azevedo *et al.*, 2008a). A lack of discard data and problems in catch estimates for some years were also identified as other sources of inconsistencies in the catch matrix, which impeded the acceptance of an assessment based on an age-structured model (ICES, 2007).

Landa *et al.* (2008) studied the growth patterns of white anglerfish in Atlantic waters with techniques alternative to the common age estimates from hard parts, i.e. tag-recapture, length frequency of the catches, and microstructural analysis of hard parts. Estimates of growth rate based on those variables were higher than estimates based on illicia (Duarte *et al.*, 1997, 2005; Quincoces *et al.*, 1998a; Landa *et al.*, 2001, 2002), which are used currently in assessments of the northern European white

anglerfish stock. The results of Landa *et al.* (2008) showed that three increments counted from illicia were not true annual ones, in particular for lengths <60 cm (ages <7 years), although for lengths >60 cm, the growth rate calculated appears to match that from illicia studies.

Considering the above, it is important that we test the compliance of these new faster growth parameters (Landa *et al.*, 2008) with real fishery-independent data. Survey data do not have many of the shortcomings of commercial data (e.g. in terms of discard estimates and anomalies in the estimates from commercial catches in some years), because they are standardized.

The aim of the present study is therefore twofold; first to analyse the distribution and abundance of white anglerfish on the Porcupine Bank using the results of bottom-trawl surveys carried out by the Spanish Institute of Oceanography (IEO) between 2001 and 2006; and second to compare and analyse the catch-at-age matrices using the two growth models listed above: the illicia readings used in the assessments and the new faster model of Landa *et al.* (2008).

Material and methods

The surveys were carried out on the Porcupine Bank from 12 to 15°W and from 51 to 54°N, covering a depth range of 180–800 m. The cruises were carried out annually each September on the RV “Vizconde de Eza”, a stern trawler of 53 m and 1800 kW, and the survey was coordinated by the ICES International Bottom Trawl Survey Working Group (ICES, 2002).

A random stratified proportional-to-strata area sampling design was used on the survey. Strata were initially defined from data on catches of commercial hauls carried out in the area of the Porcupine Bank, collected within an IEO Discard Sampling project. In 2003, the structure and distribution of the bottom-trawl faunal assemblages in the Porcupine area were studied using the data from the two first surveys, combined in terms of the most abundant and commercially important demersal species, and available environmental information (depth, latitude, longitude, bottom temperature, and salinity) which could influence the distribution (Velasco and Serrano, 2003). The results of those analyses, in combination with bathymetric information provided by the National Geological Survey of Ireland, were used to develop a new stratified sampling design more suited for the main species under study (including anglerfish).

The stratified sampling design adopted from the 2003 survey is shown in Figure 1, with two geographic sectors (referred to as northern and southern) and three depth strata delimited by the 300, 450, and 800 m isobaths. This resulted in the establishment of five strata, because there are no trawlable grounds shallower than 300 m in the southern sector. The area surveyed was divided into rectangles of 5 × 5 nautical miles, and the total number of hauls per survey was set to 80, resulting in one out of seven squares being sampled. This number did vary slightly in some years, however, owing to adverse weather conditions. Before 2005, the allocation of samples within strata was undertaken randomly, but when adjacent squares were selected, one was moved to the closest gap within the same strata. From 2005 on, the allocation of the samples was performed with a buffered random sampling procedure (as proposed by Kingsley *et al.*, 2004) to avoid the selection of adjacent 5 × 5 mile rectangles. Only when there were no trawlable areas within the selected rectangle was it moved to the closest trawlable rectangle within the

same stratum. The allocation algorithm was implemented in R 2.5 (R Development Core Team, 2007).

The fishing gear used in the sampling surveys was the Porcupine boca 40/52, an otter trawl gear described in ICES (2003), with 250 m sweeps and 850 kg doors. The mean vertical opening of the trawl during the survey was ca. 3 m, and the doors spread ca. 135 m, allowing the net to have a horizontal opening of ~23 m. Net mesh size was 90 mm throughout the gear, and a 20-mm liner covered the codend inner portion to retain small specimens. Towing time was set at 30 min between the end of wire deployment and starting to re-haul it, and the towing speed was set at 3.5 knots. From every catch, all the white anglerfish were weighed, measured, and the sex determined, except for fish that were tagged and released after measuring and weighing (see Landa *et al.*, in press).

Given the uncertainty about true anglerfish growth rate, and to test the validity of the faster growth model developed by Landa *et al.* (2008), two catch-at-age matrices were estimated for each survey:

- (i) Applying the age–length keys (ALK) obtained from illicia readings to the respective stratified length distributions. For this purpose, the illicia from three fish per 1-cm length group were collected in each survey. Illicia were mounted and sectioned following the methodology of Duarte *et al.* (1997). Interpretation of growth rings followed the standardized reading criteria set by an international ageing workshop (Duarte *et al.*, 2002). ALKs by survey were built using the respective age estimates for 2004–2006. A combined ALK from these years was used for the years 2001–2003, because even where the illicia of those years were collected, they have not been read yet owing to a lack of manpower.
- (ii) Applying a slicing method (Kimura and Chikuni, 1987) to the stratified length compositions using the growth parameters corresponding to the faster growth hypothesis of Landa *et al.* (2008): $L_{\infty} = 140$ cm; $k = 0.11$ year⁻¹. In this case, the parameter t_0 was not defined, because the Fabens model used by Landa *et al.* (2008) does not allow its estimation. Therefore, for this work, different values of t_0 between 1 and -1 were tested, and the results were analysed after the slicing procedure. Finally, t_0 was set at -0.7, because this value provided modal sizes more in line with the length distributions observed during the surveys. This value is also similar to those estimated in recent work on white anglerfish growth (Quincoces *et al.*, 1998a; Landa *et al.*, 2001).

To compare the abundance between years, variability was studied by two different methods: by the parametric standard error derived from random stratified sampling (Grosslein and Laurec, 1982), and by a non-parametric bootstrap procedure. The bootstrap method was implemented in R 2.5 (R Development Core Team, 2007), resampling randomly with replacement stations within each stratum, to obtain the same number of stations per stratum as in the original sample. Sampling intensity in each stratum, which was proportional to the stratum area, was therefore maintained. In all, 1000 resamples were performed for each survey, and 90% bootstrap confidence intervals were estimated using the 0.05 and 0.95 quantiles of the resultant distribution of bootstrap replicates (Efron and Tibshirani, 1993).

Within-survey consistency, i.e. the ability of the survey to track year groups, was analysed using correlation coefficients estimated

Table 1. Number of hauls carried out during Porcupine Bank surveys by depth and geographic stratum (northern and southern) by year.

Year	180–300 m			301–450 m			451–800 m			Total		
	North	South	Total	North	South	Total	North	South	Total	North	South	Total
2001	16	–	16	16	18	34	8	22	30	40	40	80
2002	18	–	18	18	18	36	7	25	32	43	43	86
2003	16	–	16	20	17	37	8	19	27	44	36	80
2004	15	–	15	16	15	31	6	18	24	37	33	70
2005	14	–	14	18	17	35	7	20	27	39	37	76
2006	15	–	15	19	17	36	8	20	28	42	37	79
Total	94	–	94	107	102	209	44	124	168	245	226	471

Table 2. White anglerfish total abundance indices by biomass and number, with standard errors (in parenthesis) during sampling surveys.

Year	Biomass (kg haul ⁻¹)	Number (ind. haul ⁻¹)
2001	6.81 (0.93)	4.75 (0.53)
2002	6.29 (0.94)	2.69 (0.33)
2003	9.86 (0.88)	4.13 (0.32)
2004	12.80 (1.65)	4.63 (0.54)
2005	8.56 (0.90)	2.55 (0.25)
2006	8.46 (1.33)	2.42 (0.28)

over years between two ages from the same cohorts [$\log(U_{ay})$ vs. $\log(U_{a+1, y+1})$, where U is the abundance index, a the age, and y the year]. This offers a first indication of the ability of the survey to track year-group strength (Beare *et al.*, 2003).

Results

In all, 471 hauls were carried out during the six Porcupine bottom-trawl surveys performed between 2001 and 2006 (Table 1), their geographical distribution being shown in Figure 1.

Anglerfish abundance indices recorded during the sampling surveys are shown in Table 2 and Figure 2. White anglerfish were relatively abundant in 2001 and in 2004, with a drop in abundance in 2002 and in 2005/2006. The same pattern was found for biomass values except for 2001, when biomass was low, though the large number then was attributable to the abundance of recruits. The increase in 2003 and 2004 (Figure 2) was beyond the bootstrap confidence intervals (90%) and also the s.e. with respect to 2001 and 2002 (for those years only in number), and so was the decrease in 2005 and 2006, but the abundances remained at similar levels at the beginning and the end of the series.

The mean stratified length distributions of white anglerfish (Figure 3) reveal distinct recruitment peaks between 2001 and 2004, with a remarkable one in 2001. In contrast, recruitment in 2005 and 2006 was lower than for the rest of the series.

Table 3 and Figure 4 depict the abundance indices by age group of white anglerfish calculated using each of the two growth models under study. Two major conclusions can be drawn from the catch-at-age matrix obtained by ALKs from illicia readings (Table 3, Figure 4a and b): (i) the most abundant or scarce cohorts cannot be followed over time, and (ii) groups of consecutive cohorts seem to have behaved as would be expected of a single year class. When studying the standardized proportions at age through the time-series (Figure 4b), there is an obvious mismatch

between age groups, compared with the theoretical follow-up (the rectangle in Figure 4b).

These problems do not occur in the catch-at-age matrix obtained using slicing from the faster growth parameters (Landa *et al.*, 2008; Table 3, Figure 4c and d). The abundant 2001 cohort can be followed through the years up to age 5 in 2006; additionally, a small cohort for 2000 can be tracked. Therefore, the faster growth rate hypothesis seems to match better the results obtained from sampling surveys than the illicia ALKs. On the other hand, both growth models result in a very high abundance of fish of intermediate age groups (ages 7–8 with illicia ALKs, or ages 4–5 with the faster growth model; Figure 4a and c). As a consequence, the bulk of the white anglerfish catch obtained during the survey is of age groups 0 and 4–5.

Correlation coefficients between age abundance indices for both growth models were not statistically significant (Table 4), but the correlation indicated that the faster growth model has better consistency up to ages 3 and 4, whereas at older ages, the illicia readings correlate better, although the differences in correlation between both models were not statistically significant.

The geographical distribution by age group is shown in Figure 5 only for the faster growth hypothesis, and up to age group 6 given the scarcity of older fish. The 0-group was distributed in the shallower part of the survey area, and also over the Irish shelf in years of good recruitment (2001 and 2003/2004). Age groups 1 and 2 were scarce in the area, appearing mainly related to the strong recruitment of 2001 (i.e. in 2002 and 2003, respectively) and also in the shallower part of the central bank. Age group 3 was relatively abundant only in 2004 in relation to the 2001 cohort mainly in the centre of the bank, though it also appeared in small quantities over the Irish shelf. Finally, age groups 4–6 (55–80 cm) occupied the whole study area, including the deepest grounds where smaller fish were absent.

The evolution of the cohorts with the faster growth model, shown in Figure 6, initially has a remarkable decrease in log abundance from age 0 to age 2. From age 2 to age 3, there was a small decrease in abundance for most cohorts, but for age 4, in almost all the cohorts sampled, there was an increase in abundance that could only be the result of immigration from other areas or grounds with reduced catchability on the bank. For ages of 4+, there was a steady decrease in abundance up to age 8+, for which the apparent increase was simply because of the grouping of the older ages within that 8+ age group.

Discussion

The results of this study have provided new information on the distribution and abundance of white anglerfish in the Porcupine

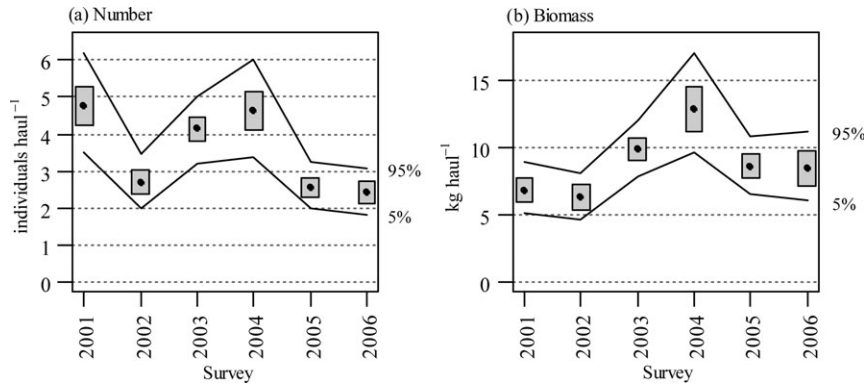


Figure 2. Stratified abundance indices of white anglerfish by (a) number, and (b) biomass for research surveys.

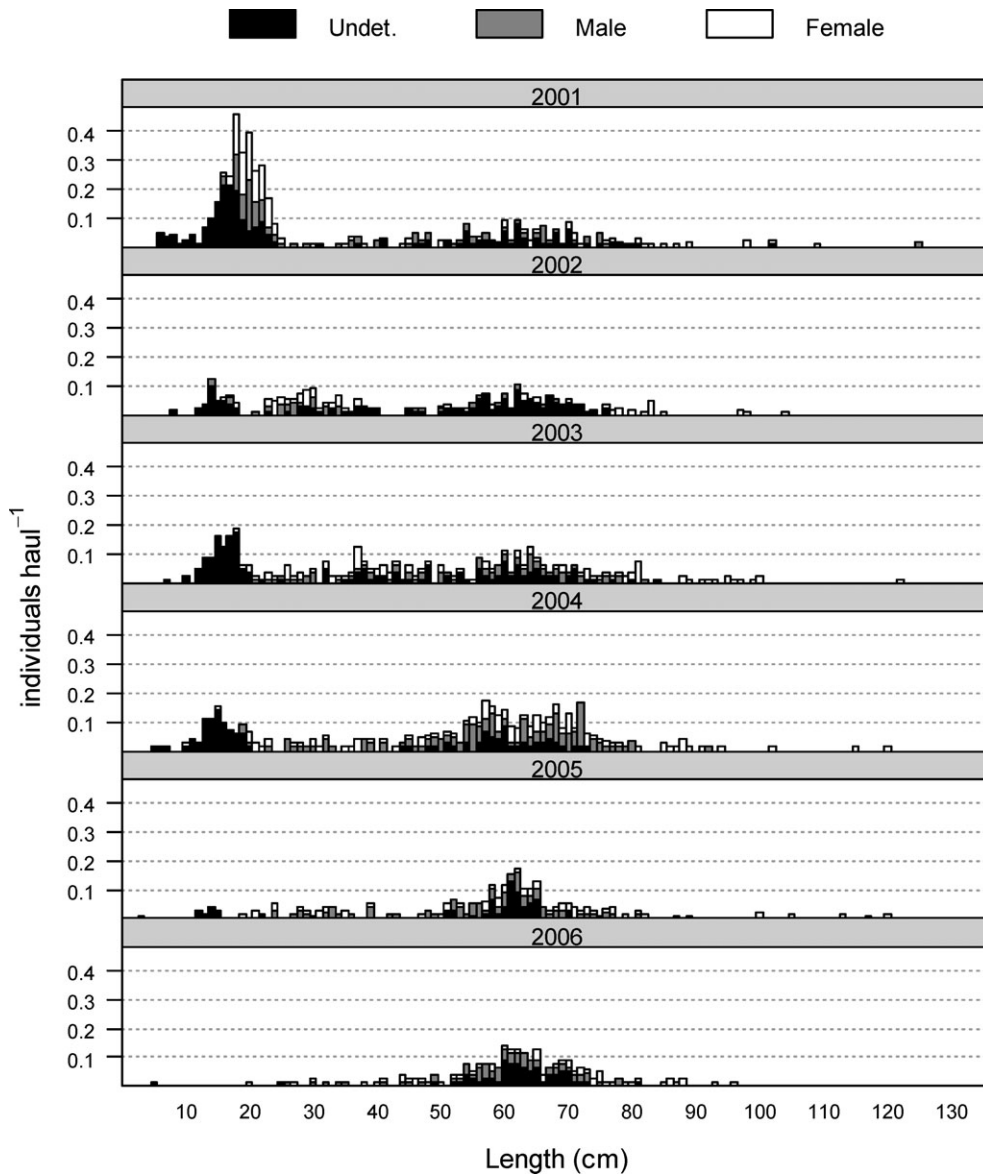


Figure 3. Stratified length distribution of white anglerfish in the research survey time-series.

Bank area, which is managed as part of the northern stock of the species. The good recruitment in 2001 was also detected by the EVHOE survey of the Celtic Sea, and the poor recruitment of

2005 and 2006 was also detected by EVHOE (although that survey shows values for all except 2001 much lower than the current surveys) and Irish surveys, both used as indicators of

Table 3. White anglerfish abundance indices (individuals 30 min haul⁻¹) by age group, 2001–2006: (top panel) growth according to illicia readings ALKs; (bottom panel) faster growth model, after Landa *et al.* (2008).

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+	Total
2001	1.938	0.874	0.265	0.103	0.081	0.192	0.160	0.258	0.396	0.155	0.334	4.754
2002	0.421	0.084	0.470	0.230	0.102	0.099	0.160	0.351	0.383	0.162	0.227	2.688
2003	0.971	0.158	0.241	0.307	0.360	0.248	0.167	0.415	0.521	0.243	0.504	4.134
2004	0.867	0.131	0.132	0.229	0.170	0.187	0.713	0.792	0.584	0.332	0.495	4.632
2005	0.122	0.056	0.181	0.100	0.110	0.131	0.227	0.462	0.655	0.180	0.326	2.551
2006	0.026	0.013	0.065	0.013	0.078	0.137	0.205	0.474	0.685	0.419	0.301	2.415
	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8+	Total		
2001	2.923	0.193	0.206	0.311	0.438	0.363	0.154	0.070	0.097	4.754		
2002	0.486	0.670	0.183	0.239	0.554	0.344	0.095	0.080	0.038	2.688		
2003	1.092	0.410	0.621	0.352	0.738	0.412	0.242	0.093	0.174	4.134		
2004	0.985	0.258	0.282	0.653	1.079	0.926	0.237	0.033	0.178	4.632		
2005	0.178	0.303	0.089	0.329	1.044	0.327	0.156	0.030	0.096	2.551		
2006	0.026	0.104	0.138	0.339	0.958	0.561	0.165	0.046	0.078	2.415		

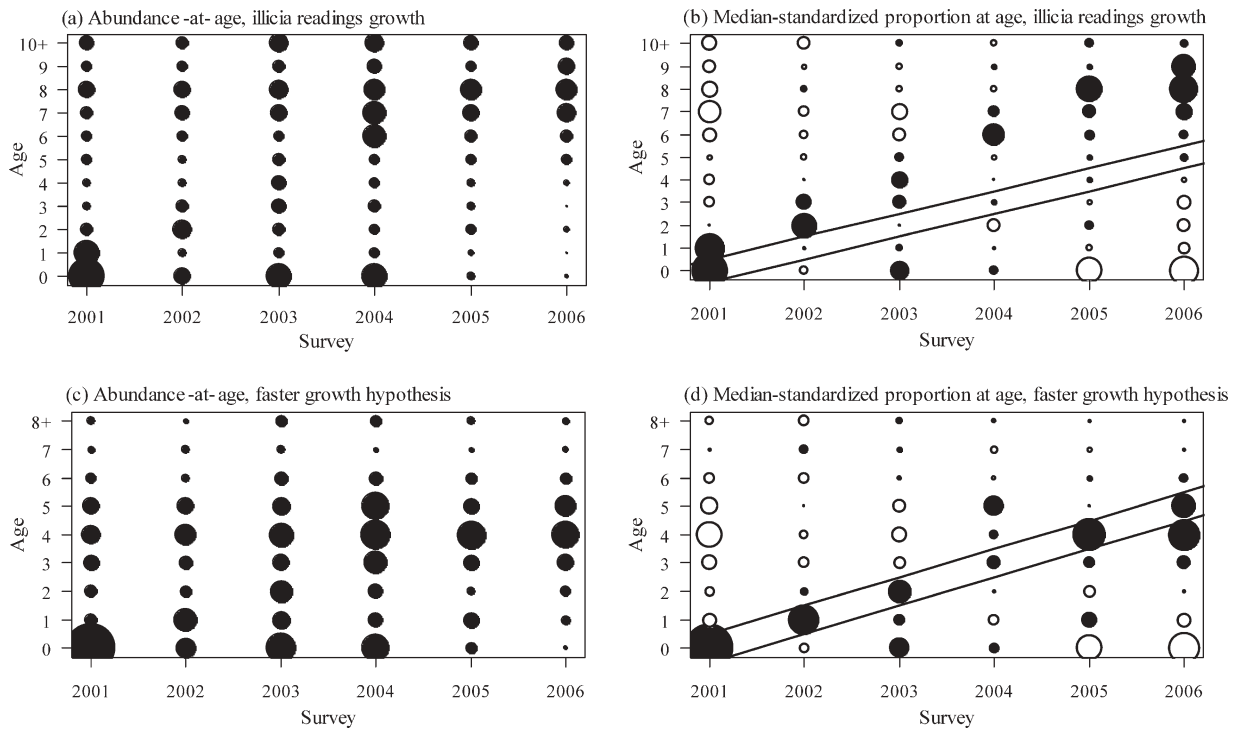


Figure 4. Bubble plots of white anglerfish: (a) abundance-at-age from estimates based on illicia readings and (c) from the faster growth hypothesis; (b) median standardized proportion-at-age (year – median years) in the Porcupine Bank bottom-trawl survey time-series from estimates based on illicia readings and (d) from the faster growth hypothesis. Black bubbles are above the median value, empty ones are below it. The diagonal lines encompasses the 2001 year class.

recruitment strength by the WGHMM (ICES, 2007). These results indicate a consistency among surveys, although the areas do not necessarily overlap and correspond to different subareas of the northern stock.

In terms of following up on the abundance of cohorts, the mismatch between age groups when using the illicia ALKs, together with the length distribution observed in 2001, suggest that the age groups estimated as 0 and 1 in 2001 belong to a single age group and therefore that the large mode appearing in the length distribution of recruits for 2001 is probably 0-group, as suggested

by Wright *et al.* (2002), who found that most fish <27 cm belonged to the 0-group. Likewise, age groups 2 and 3 in 2002 behave as a single year class and could correspond to age group 1, and age groups 3 and 4 in 2003 seem to belong to what would then be age group 2. For older ages, age groups 6/7 in 2004, 7/8 in 2005, and 7/8/9 in 2006 all behave as would a single cohort, so perhaps should be interpreted as age groups 3, 4, and 5 of the 2001 cohort, respectively. However, for the older ages the mismatch seems to be smaller or non-existent, because in 3 years there is an increase of 3 age groups (Figure 4b).

Table 4. Correlation coefficients between ages of the same cohort for white anglerfish taken during Porcupine Bank surveys.

Illicia readings growth model			Faster growth model		
Age group	Pearson's <i>t</i>	<i>p</i> -value	Age group	Pearson's <i>t</i>	<i>p</i> -value
0–1	0.678	0.209	0–1	0.851	0.068
1–2	0.814	0.094	1–2	0.818	0.091
2–3	0.588	0.297	2–3	0.659	0.227
3–4	0.649	0.236	3–4	0.541	0.346
4–5	0.328	0.590	4–5	0.186	0.764
5–6	0.676	0.210	5–6	–0.080	0.898
6–7	–0.047	0.940	6–7	–0.908	0.033
7–8	0.826	0.085	8+	–	–
8–9	0.549	0.338			
10+	–	–			

Note that age 10+ in the illicia readings growth model and age 8+ in the fast growth model are not considered because they include different ages and cohorts.

Therefore, from 2001 to 2006, we found a mismatch of up to 3 age groups, but it was concentrated in the younger age groups, from age group 0 to age group 6.

If an exceptionally good or weak year class can be followed over a long period through the age composition, this provides a strong indication that the age-reading method is accurate (Panfili *et al.*, 2002). The evolution of the apparently strong 2001 year class in the Porcupine Bank surveys helps to evaluate the current age estimation criteria based on illicia. In the present study, the standardized illicia criteria of Duarte *et al.* (2002) have been used to estimate the ages, and our results also show an underestimation of the growth rate, prompting us to test the faster growth rate suggested by Landa *et al.* (2008) with the data from our survey series. The faster growth rate model seems to be corroborated by the results we obtained, especially for age groups 0–3/4.

Similar problems in cohort tracking, using ALKs based on illicia readings, were found by Azevedo *et al.* (2008a), who analysed the commercial catch-at-age matrix for the 1996–2006 southern stock time-series: (i) the large or small cohorts could not be tracked through the years, and (ii) groups of consecutive cohorts seemed to behave as a unique age group. On the other hand, in an ICES (2007) workshop report, it was also stated that the lack of discard data and misreporting in the landings/catches could explain such inconsistencies to some extent; although the results obtained here do not show these uncertainties, suggesting that the problems in cohort tracking are mainly related to the illicia reading criteria. At the same time, the faster growth hypothesis proposed by Landa *et al.* (2008) seems to fit better the data found for Porcupine Bank white anglerfish, providing reasonable tracking of large or small cohorts during the first 4–5 age groups. The survey results for the next few years of the 2001 year class, and specially in respect of the poor recruitment in 2005 and 2006, will likely provide important insight into the growth of white anglerfish.

Considering only the faster growth hypothesis of Landa *et al.* (2008), the consistent pattern of relatively large recruit abundance, and the steady decreases in abundance of ages 1 and 2, could be explained partly by the combination of natural and fishing mortality, because white anglerfish recruit to the fishery at age 1, and age group 2 (36–46 cm with the faster growth rate), is an

important component of the landings. Nevertheless, a scarcity of these groups and the subsequent increases in abundance of age groups 3 and 4 can only be explained by movement out of the area or reduced catchability of post-recruits and juveniles, along with immigration of adults into the survey area. The immigration of age groups 3–4 and older from other areas, probably driven by factors different from those driving recruitment-at-age 0 on the Porcupine Bank, can also explain the poor correlations of the 4–8 age groups (Table 4).

The length at first maturity of white anglerfish for both sexes combined in the northern stock was estimated by Quinoces (2002) to be 58.6 cm (age 4 in the hypothesis of faster growth). Therefore, most of the anglerfish older than 4 years would be adult. The movements of these adults could be related to feeding and/or reproductive behaviour, although the scarcity of information on environmental factors, feeding habits, seasonality of spawning (November–June, according to Afonso-Dias and Hislop, 1996), or spawning grounds in the area precludes confirmation of such hypotheses.

Figure 5 shows age 0 recruits mainly around the central bank, in shallower water, and close to the Irish shelf, although the few fish aged 1 and 2 were not common in the area close to the Irish shelf; fish of age groups 3–4 were again more abundant on the Irish shelf, and the oldest age groups studied had a wide dispersion pattern, occupying the whole area and most likely also grounds deeper than those surveyed (Whitehead *et al.*, 1986). Hislop *et al.* (2001) analysed the early stages of white anglerfish and the spawning grounds in northern waters of the British Isles, and concluded that spawning takes place in deep water, but that post-larvae can be transported long distances by currents before settling. These conclusions are in agreement with the overall pattern discussed here.

The differential abundance seems to be related to migration. Although the morphology of anglerfish suggests that they are weak swimmers (Wheeler, 1969), movements of white anglerfish have been described for several areas of the European Atlantic (Pereda and Landa, 1997; Hislop *et al.*, 2000; Arkhipov and Mylnikov, 2002; Laurenson *et al.*, 2005; Landa *et al.*, in press). Arkhipov and Mylnikov (2002) showed that juvenile white anglerfish have a pelagic behaviour, which promotes wider dispersal and expansion of their natural habitat. Hislop *et al.* (2000) suggested that, in the Northeast Atlantic, some near-surface catches were post-juvenile white anglerfish undertaking short migrations. Pereda and Landa (1997), Laurenson *et al.* (2005), and Landa *et al.* (in press) demonstrated significant geographical movement after tagging anglerfish, with distances as long as 876 km, from the Shetland Islands to Iceland, being recorded.

The only movement known from the Porcupine Bank is a fish recaptured in Division VIa (northern shelf stock), 117 km north of where it was tagged (Division VIIb, northern stock) (Landa *et al.*, in press), and although it is a single case, it disproves the hypothesis of the Porcupine Bank being an isolated area for the white anglerfish population, and confirms movements to and from the area. Moreover, the relative changes in abundance by age also suggest movements to other areas such as the Irish shelf, or from other areas to the Porcupine Bank, as the most logical explanation for the results. Our results also suggest that even if the destination and origin of the displacements are unclear, major migrations of white anglerfish do take place.

It is important to remember that the Porcupine Bank and the surveys addressed here cover only part of the distribution of the

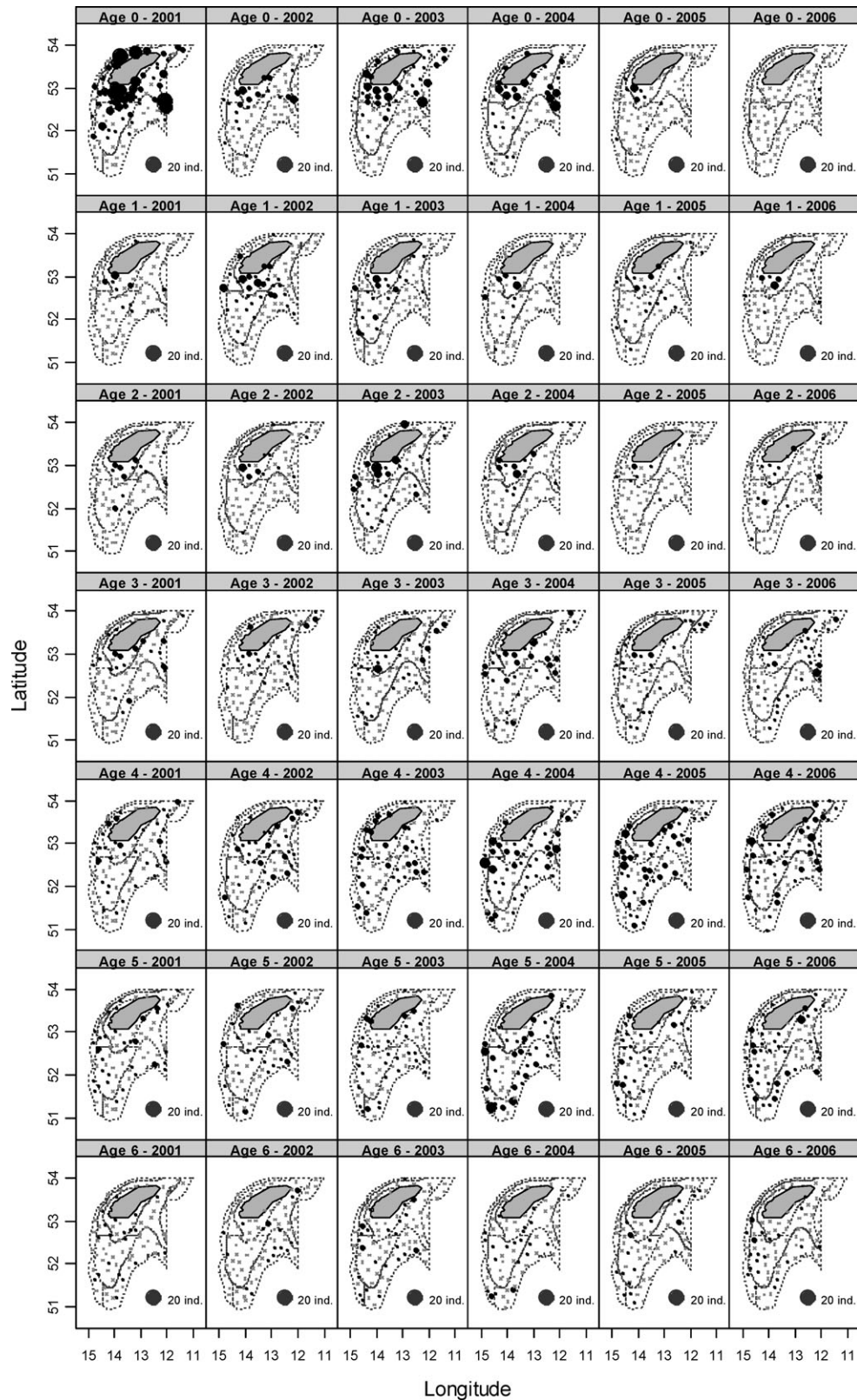


Figure 5. White anglerfish geographic distribution during the sampling surveys, by age group.

white anglerfish northern stock and were carried out over a relatively short time frame, and migration patterns may also vary seasonally. However, the bank is close to the usually accepted

boundary between the northern stock and the northern shelf stock, and the single anglerfish tagging result mentioned above was of a migration to the northern shelf area. This result, together

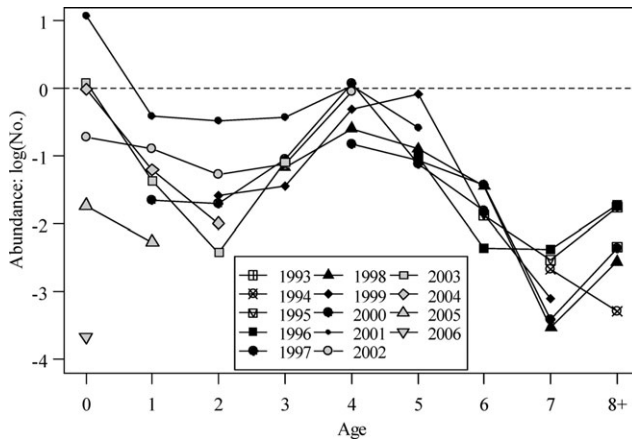


Figure 6. White anglerfish abundance (individuals 30 min haul⁻¹) evolution on a logarithmic scale through each cohort sampled.

with other cases of interactions between stocks described by Laurenson *et al.* (2005) and Landa *et al.* (in press), and documented stock identification results (Fariña *et al.*, 2004; O'Sullivan *et al.*, 2005) cast doubts on the biological basis of the current definition of these stocks (Landa *et al.*, in press).

Our study has, we believe, provided new information on the distribution and abundance of white anglerfish in the Porcupine Bank area, an area acknowledged to be part of the northern stock for management purposes. This information, independent of fisheries, should be taken into consideration when assessing and managing this commercially important European species.

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