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Monkfish across the world: common problems and common solutions: **ICES CM 2007/K:06**

Biological aspects of the *Lophius piscatorius* catch in Scottish waters.

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Abstract

In this paper data from 49,258 *L. piscatorius* sampled on board commercial fishing vessels during observer trips and chartered surveys at Shetland, to the west of Scotland and at Rockall between 1998 and 2006 are analysed. Modal size increased with depth and larger fish were caught in hauls in deeper waters; significant differences *(P*<0.001) in length related to depth were detected in all areas. The sex ratio of all data combined was 0.88:1 females:males but varied according to area, depth and season. Proportions of mature monkfish also differed between areas and depth; the highest proportions of mature fish were found in deep water at Rockall and the west of Scotland. $L_{50\%}$ maturities, of all data combined, were 101.8 cm for females and 58.0 cm for males.

Keywords: monkfish, *L. piscatorius*, Scotland, Shetland, Rockall.

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Introduction

Monkfish, also known as anglerfish (*Lophius piscatorius*) are found from Iceland, Faroe and Norway (Thangstad *et al.*, 2006) in the north, to the Straits of Gibraltar and the Mediterranean in the south (Caruso, 1989) and are widely distributed in waters around Scotland. The fishery for monkfish by Scottish vessels is mainly concentrated on the shelf around Shetland (Laurenson, 2003), the shelf edge to the west and northwest of Scotland and at Rockall (Anon., 2007). Catches are predominantly of the white-bellied anglerfish, *L. piscatorius,* although the black-belled anglerfish *Lophius budegassa* also occur accounting for between 0.1 and 17% of landings (Laurenson *et al.*, 2007).

The fishery for anglerfish in ICES Sub-areas IV and VI expanded rapidly with landings increasing from around 5,000 t in the early 1980s to a peak in excess of 30,000 t in the mid-1990s, declining thereafter (Eurostat/ICES, 2007). Concerns about the level of exploitation lead to the introduction of precautionary TACs in 1984 for Sub-area VI and 1999 for the North Sea. Since then assessment of the stock on the northern shelf has proved problematic and management advice has reflected the uncertainty (see Dobby et al., 2007 this meeting). ICES consider that there is inadequate information to evaluate the state of the stock which is currently ‘unknown’ (Anon, 2006).

In Scotland considerable effort is being made to improve knowledge of the fishery and stock dynamics. This includes enhanced observer coverage in the Scottish fleet in 2005/06; joint science industry surveys to estimate monkfish biomass in the northern shelf area (Fernandes, 2007 this meeting) and a tally book scheme in which fishermen record catches and fishing effort on a haul by haul basis (Dobby *et al.*, 2007).

The importance of the fishery has also prompted studies on the biology of the species e.g. (Afonso-Dias and Hislop, 1996, Afonso-Dias, 1997, Hislop *et al.*, 2001, Laurenson, 2003, 2006, Laurenson *et al.*, 2004, Laurenson *et al.*, 2005, Laurenson and Priede, 2005). The focus of these studies has included age and growth, reproduction, egg development, *in situ* behaviour, diet, and movement and migration. Amongst the findings of these studies it has been shown that the average growth rate is around 10 cm/yr; they spawn mainly in late winter and spring, probably in deep water; they are ichthyophagous with the diet changing with the seasonal availability of species and they are capable of large-scale movements between, for example Shetland and Iceland.

In all studies where maturity has been recorded, it is noted that females in spawning condition are rarely caught. It is believed that these fish may mainly be located in deep waters (Hislop *et al.*, 2001) and that these areas may act as a refuge for a spawning stock. If such a refuge exists, then the traditionally used assessment methods which make dynamic pool assumptions are likely to be inappropriate.

In this paper we present a synthesis of information on the characteristics of catches in the northern North Sea (Division IVa), west of Scotland (VIa) and at Rockall (VIb) based on length and other biological data collected by scientific observers on commercial vessels between 1998 and 2006 and discuss the implications of this for assessment of the stock.

Materials and Methods

The data were collected by observers on demersal trawlers during chartered surveys and commercial fishing trips in waters around Shetland (Division IVa), to the west of Scotland (Division VIa) and at Rockall (Division VIb) between 1998 and 2006. The number of trips in each area, year and quarter are shown in Table 1. Catches were examined on a haul by haul basis. A total 1,004 hauls were sampled. Total lengths (TL) of the 49,258 *L. piscatorius* were measured to the nearest cm. Where possible, other measurements including, total (TW), gutted (GW), and gonad (GdW) weight were made. Sex and maturity stage were recorded for 12,191 females and 12,339 males. The maturity staging was as described by Afonso-Dias and Hislop (1996). Weights were recorded from 3,171 female and 3,108 male monkfish.

Data were grouped into areas (Rockall, west of Scotland and Shetland) based on the calculated mid-points between shooting and hauling positions. Differences between lengths of *L. piscatorius* caught within 50 m depth strata in each area were investigated using Kruskall-Wallis tests and post-hoc Nemenyi tests (Zar, 1999). Lengths at depth were compared between areas using Kruskall-Wallis tests and post-hoc Nemenyi tests and Mann-Whitney U tests, as appropriate.

Kruskall-Wallis tests were used to investigate differences between lengths of *L. piscatorius* per haul between 50 m depth groupings in each of the areas. ANOVA was used to investigate differences in mean lengths per haul between areas at specific depth bands and t-tests or Mann-Whitney U tests were used as appropriate to investigate differences in mean lengths per hauls between two areas.

Kruskal-Wallis tests were applied to length data from Shetland to investigate inter-annual differences. The analysis was restricted to 100-149 m and 150-199 m depth strata obtained from Shetland in quarters 1 to 4.

Kruskal-Wallis tests were applied to length data from Shetland to investigate intra-annual differences in lengths from 100-149 m depths.

The proportion female at length of catches at depths <450 m and > 450 m were compared using Wilcoxon signed rank tests. The proportion female at length at given depths were compared between areas using paired-samples t-tests. Seasonal and annual differences in the proportion female at length were investigated using paired-samples t-tests and Freidmans tests as appropriate.

Relationships between length and weight related to season and area were investigated using ANCOVA.

Table 1 Numbers of observer (Obs) and charter (Ch) trips in Shetland (IVa), the west of Scotland (VIa) and Rockall (VIb) between 1998 and 2006.

	Yr	1998		1999				2000				2001				2002		2005				2006		
	Qr	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	1	2	3	4	1	2	Tot
IVa	Obs	1	4	1	2	2		1	1			2	2			3				3	4	5		31
	Ch						2	3	3	3	1		3	4										19
VIa	Obs																			1	1	1		3
	Ch										1				1	1								3
VIb	Ch									1				1										2

Results

The locations and depths of hauls are shown in **Error! Reference source not found.**. The distribution of samples covers the main fishing areas.

Length

Length frequency distributions of *L. piscatorius* in each area and in all areas combined are shown in Figure 2. Overall, 57% of *L. piscatorius* caught were in the 40-60 cm size range. Lengths ranged from 11 to 137 cm and the overall modal length was 50 cm. The overall length frequency distribution is dominated by the data collected at Shetland. Modal length was 50 cm at both Shetland and at the west of Scotland and 56 cm at Rockall. The % of small fish (< 40 cm) in the west of Scotland was 9% compared to 24 and 34% at Rockall and Shetland respectively. At Rockall, there was a greater % of large (>60 cm) individuals in the catch (31%) compared to 13% at both the west of Scotland and Shetland.

Depth comparisons: Length frequency distributions of catches in 50 m depth strata in each area are shown in Figure 3. In general, modal size increased with depth and larger fish were caught in hauls in deeper waters. Significant differences (P<0.001) related to depth were detected in all areas. At Shetland, post-hoc Nemenyi tests indicated a number of significant differences between strata and all of the comparisons involving the <50 m and 50-99 m strata were significantly different to each of the other strata. To the west of Scotland, lengths in each 50 m depth strata <350 m differed significantly from those at depths >350 m. At Rockall lengths in depth strata <450 m were significantly different to those from depth strata >500 m.

Area comparisons: Length in the 100-149 m, 150-199 m and 200-249 m depth strata differed significantly among areas (100-149 m: P<0.0001; 150-199 m: P<0.0001; 200-249 m: P<0.005). Post hoc Nemenyi tests indicated significant differences between each of the area comparisons at 100-249 m; between Shetland and other areas at 150-199 m and between Rockall and the west of Scotland at 200 and 249 m.

Comparing Rockall and the west of Scotland, significant differences in length were detected both at 250-299 m (P<0.01) and 300-349 m (P<0.001) but not at 350-399 m.

Inter-annual comparisons: Significant differences were found in each set of quarterly data from both the 100-149 m strata and the 150-199 m strata at Shetland (Kruskal Wallis tests: P<0.001 in each case). These appeared to be related to variable proportions of fish <40 cm in the catches. Quarterly length frequencies generally showed a very strong cohort of small fish in 2000 (Figure 4).

Intra-annual comparisons: Quarterly length distributions in 100-149m at Shetland were found to differ in 1999 (Kruskal Wallis: χ^2 = 687, df = 3, P<0.0001) but not in 2000 (χ^2 = 2.796, df = 3, P = 0.424).

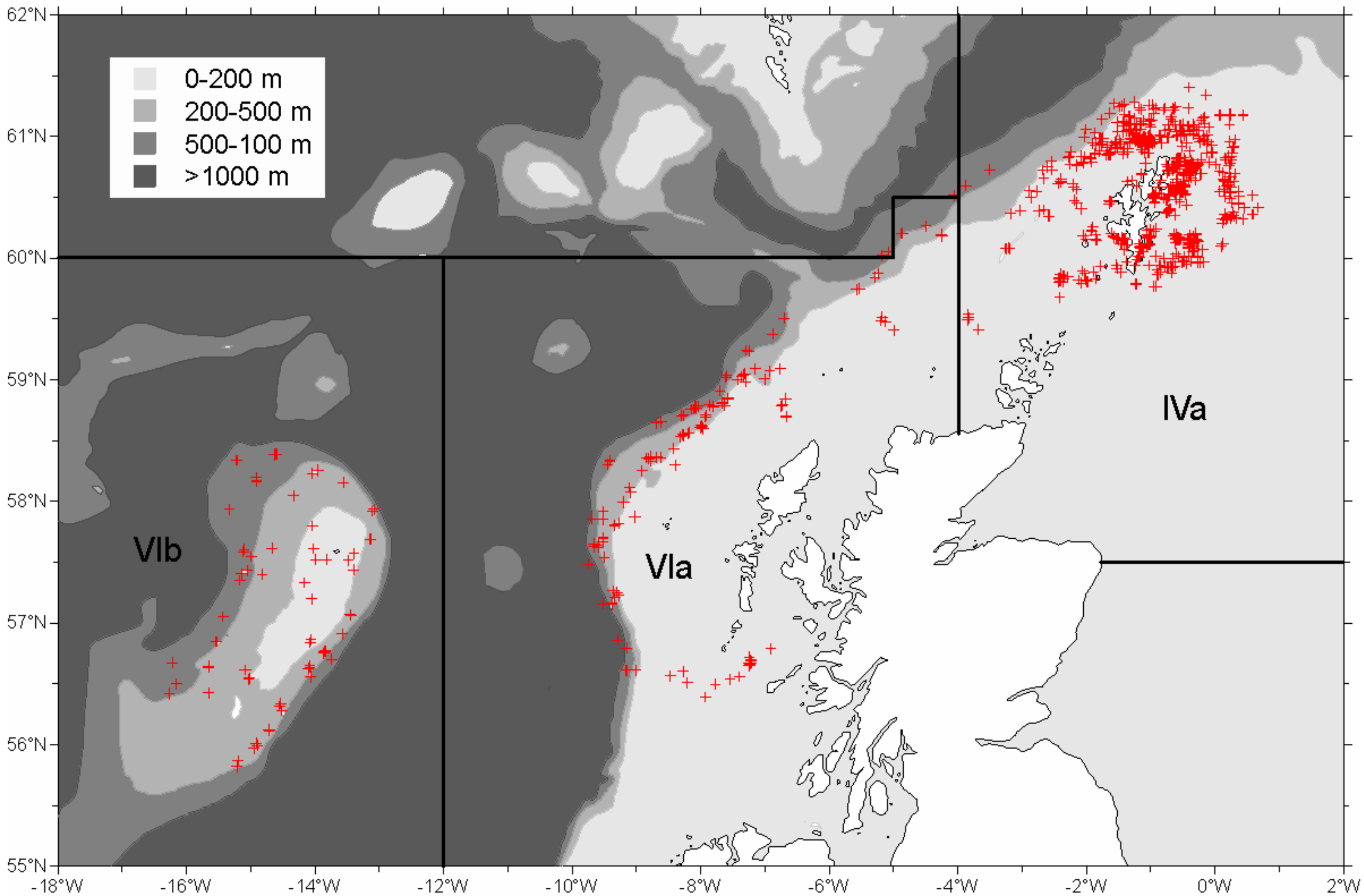

Figure 1. Locations of mid-points of hauls.

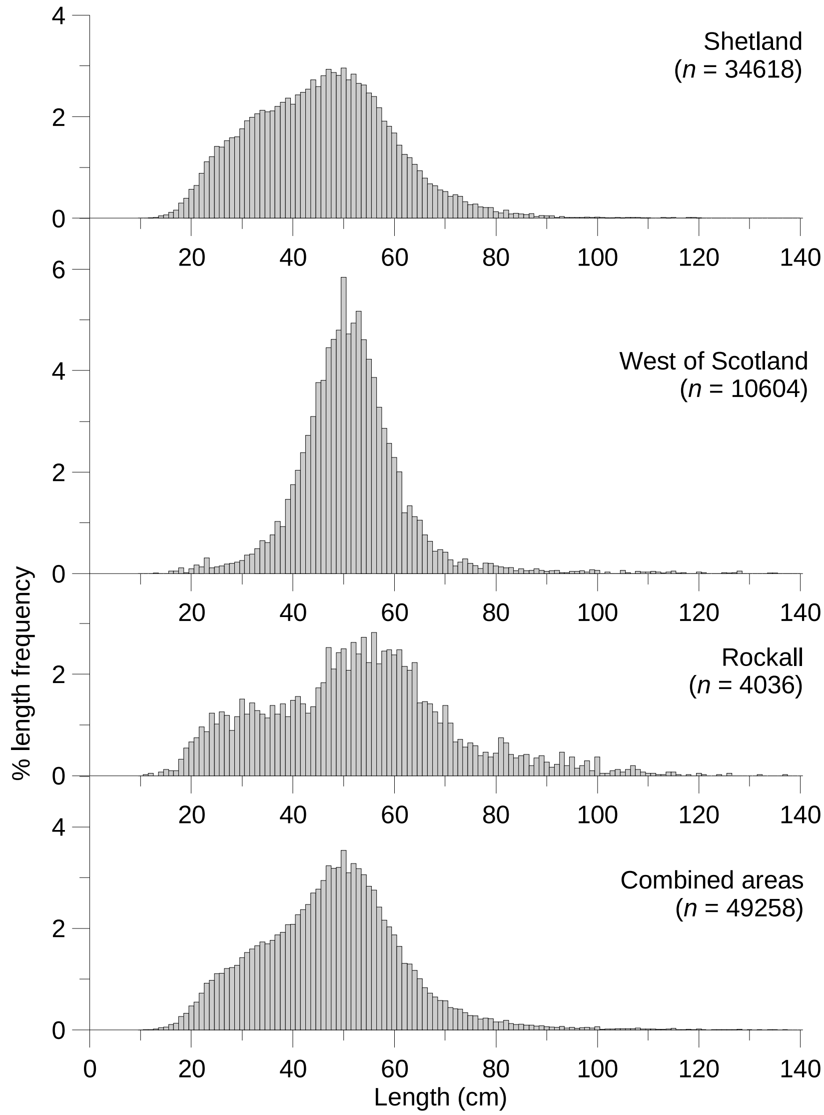

Figure 2. Percent length frequency distributions of *L. piscatorius* sampled at Shetland, the west of Scotland, Rockall and all areas combined.

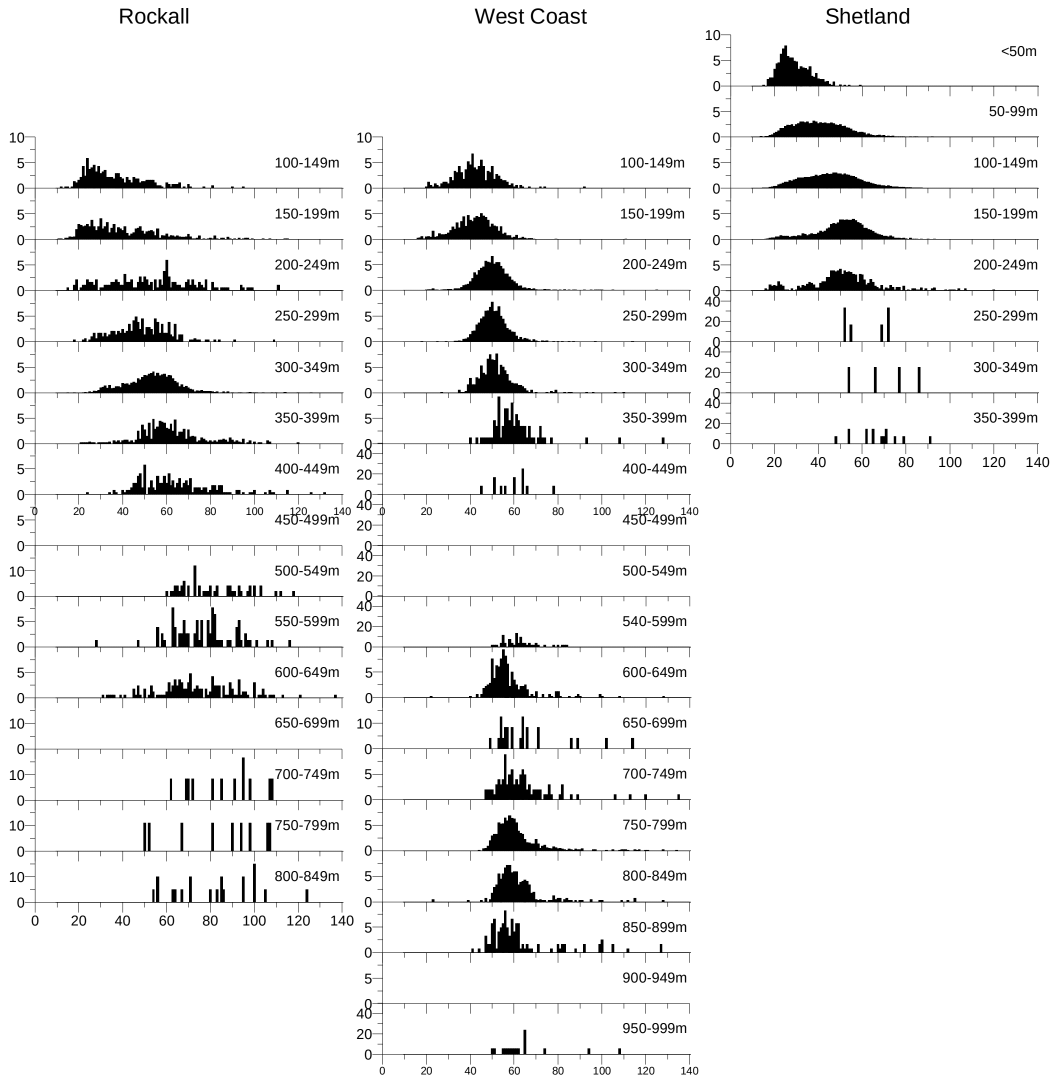

Figure 3. Length frequency distributions of *L. piscatorius* in each 50 m depth strata and in each geographical area.

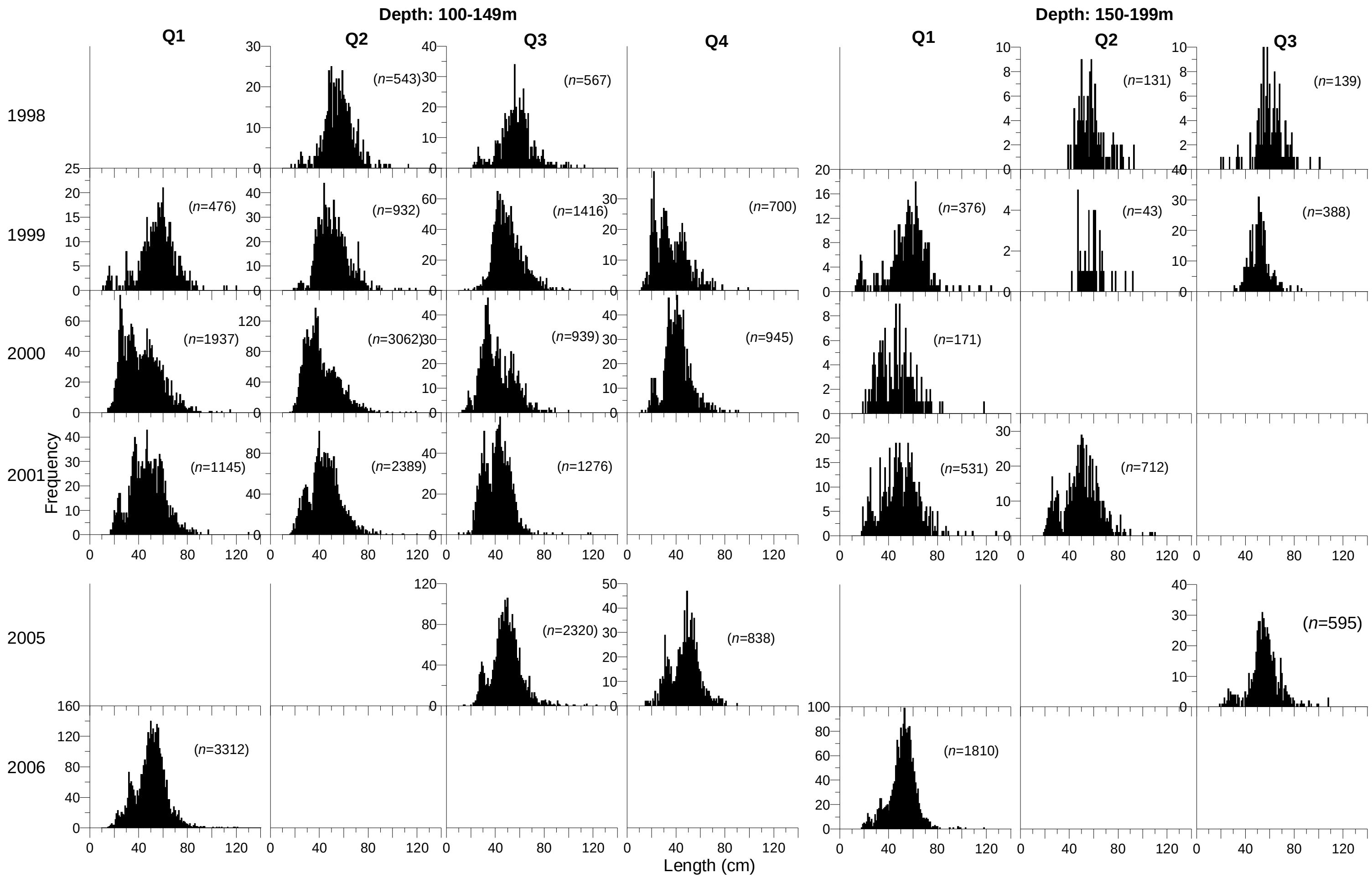

Figure 4. Length frequency distributions at Shetland in depths 100-149 m and 150-199 m by quarter between 1998 and 2006.

Sex Ratio: The sex ratio in catches (all data combined) was 0.88:1 females : males. At lengths up to 65 cm the ratio was 0.82: females:male. At lengths >60 cm the proportion of females increased and no males were recorded at lengths greater than 101 cm (Figure 5).

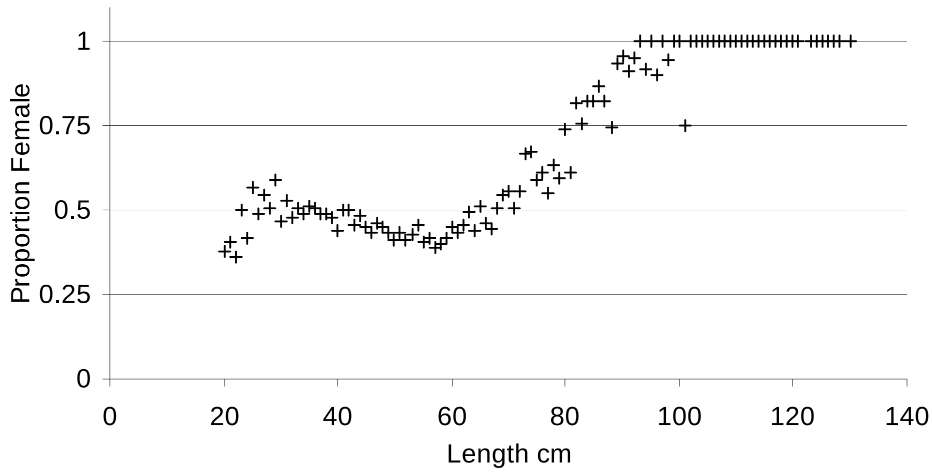

Figure 5. Sex ratio of *L. piscatorius* in the study area between 1998 and 2006.

The sex ratio of the catch varied in relation to depth. At depths <450 m at the west of Scotland and at Rockall the sex ratio was 0.82:1 females:males whereas and at depths >450 m there were 0.35:1 females: males. The proportion female at length in these areas differed significantly between depths <450 m and >450 m (Z = -5.18, P<0.0001, Wilcoxon signed ranks test). At depths <450 m the transition from approximately equal numbers of males and females to females being more prevalent occurred at around 65 cm at Shetland and the west of Scotland and around 70 cm at Rockall. In contrast in waters >450 m there was no *ca* 50/50 sex ratio at lengths below 65-70 cm. Instead males predominated at shorter lengths but the proportion of females gradually increased with length and at around 80 cm there was a transition to females predominating and this continued with increasing length. No males were recorded above 91 cm in length.

At depths <450 m there were significant differences in the proportion female at length between Shetland and the west of Scotland (t = 4.04, df = 82, P = 0.0001) and between Shetland and Rockall (t = 1.66, df = 90, P = 0.026) but not between the west of Scotland and Rockall (t = -1.48, df = 85, P = 0.141). At depths >450 m there was a significant difference in the proportion female at length between the west of Scotland and Rockall (t = -4.91, df = 60, P <0.001).

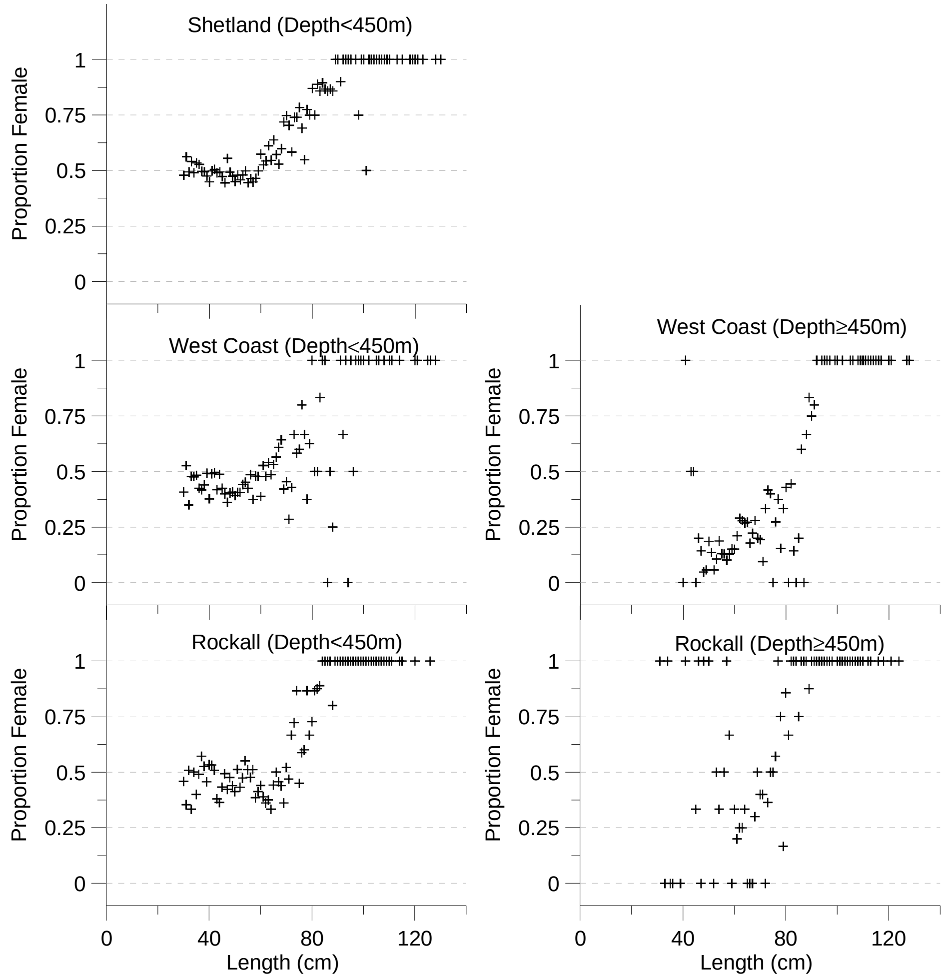

Figure 6. Proportion female at length in each area at depths <450 m and depths ≥450 m.

Seasonal differences in the proportion female at length were not found at depths <450 m at the west of Scotland in a comparison between Qr4 2005 and Qr1 2006 (t = 1.68, df = 49, P = 0.49) but were detected in a similar comparison for depths >450 m (t = 3.14, df = 37, P = 0.003). The overall sex ratio was 0.31 females : 1 male in Q4 and 0.19 females : 1 male in Q1 in depths >450 m at the west of Scotland. At Shetland no significant differences in the proportion female were detected in available data (September/October vs January-March in 2000-2001, t = 1.18, df = 35, p = 0.246; and in comparisons between October/November, December/January and February/March in 2005 – 2006: Freidman test: X^2 = 5.056, df = 2, P = 0.08). Data were not available for seasonal comparisons at Rockall.

Annual differences in the proportion female at length were investigated for Rockall and no significant differences were found for depths <450 m (t = 0.28, df = 83, P = 0.78). There were insufficient data to compare the proportion female at length at depths >450 m. The proportion female at length did not differ at Shetland between 1999-2001 and 2006 in Q1 (t = -0.94, df = 65, P =

0.35), Q3 in 2001 and 2006 (t = 1.23, df = 60, P = 0.22) but did differ in Q4 between 2000 and 2005 (t = -2.80, df = 51, P = 0.007).

<u>Maturity</u>: Maturing females (stage 3) were mainly recorded between August and December. Ripe females (stage 4) were recorded from November to March, and recently spent females mainly from February onwards. Mature males mainly occurred from October to March and the proportion of recently spent males increased during late February. While mature males had a wide distribution and were relatively numerous the numbers of mature females were relatively low (less than 6%), with the highest numbers being recorded in deep water at the west of Scotland and Rockall (11%). Overall, the $L_{50\%}$ maturity was 101.8 cm for females and 58.0cm for males (Figure 7).

$L_{50\%}$ values determined for each area were similar: 96.7 cm, 93.8 cm and 104.4 cm for females and 60.6 cm, 57.1 cm and 57.3 cm for males at Shetland, west of Scotland and Rockall respectively. At Shetland $L_{50\%}$ values were 98.2 cm and 57.8 cm for females and males for the period 1998-2001 and 92.6 cm and 61.5 cm for females and males in 2005-2006.

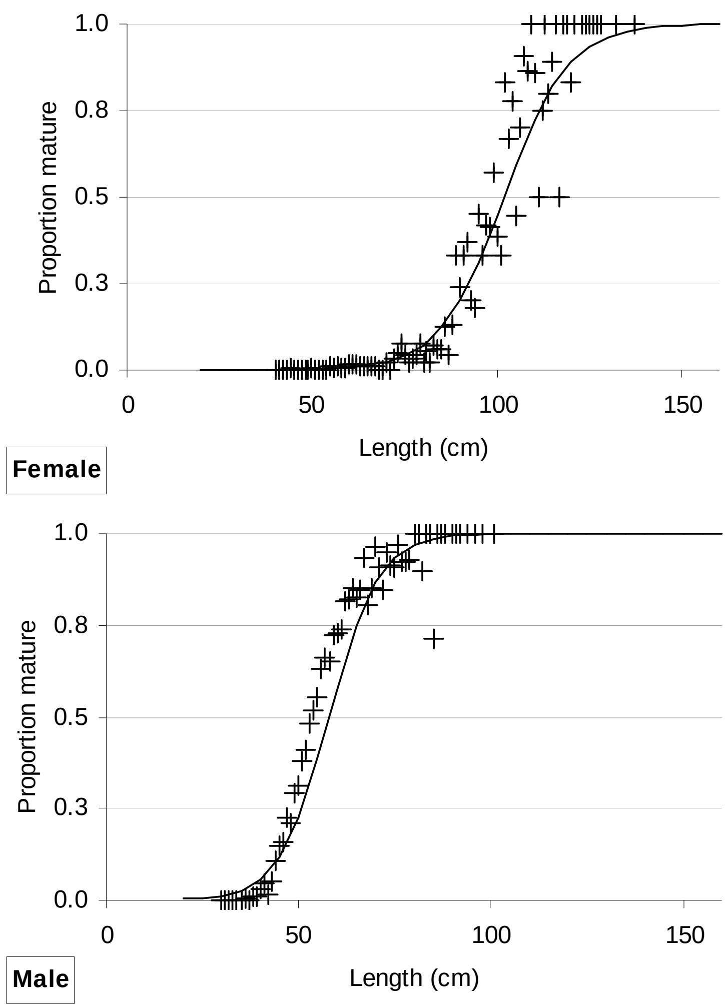

Figure 7. Proportions mature at length and fitted maturity ogives for female (top) and male (bottom) *L. piscatorius* in IVa and VI combined.

Relationships between length and total and gutted weight (fitted to log transformed data), were determined for males and females and for sexes combined, data from all areas, as follows:

Female GW = $0.027TL^{2.8027}$, R^2 =0.9771, n = 3175

Male GW = $0.0315TL^{2.7548}$, R^2 = 0.969, n = 3112

Female TW = $0.0333TL^{2.803}$, R^2 = 0.9819, n = 3181

Male TW = $0.0415TL^{2.7374}$, R^2 = 0.9772, n = 3112

Sexes combined GW = $0.028TL^{2.7896}$, R^2 = 0.9743, n = 6287

Sexes combined TW = $0.0354TL^{2.7837}$, R^2 = 0.9801, n = 6293.

Length weight relationships fitted to subsets of the data were compared using ANCOVA. In some cases significant differences related to area and season were detected (P<0.05).

Discussion

The data presented above have revealed variation in anglerfish catch composition in terms of both length distribution and sex ratio related to depth and geographical area. In general, catches on the shelf (<200 m) consist of anglerfish which are mainly less than 60 cm in length. At these lengths the sex ratio is approximately equal and fish are mainly immature. Catches from the upper slope (200 – 450 m) are mainly of fish between 40 cm and 80 cm in length and at these depths the proportion of females increases in catches from around 65-70 cm. In deeper water at the west of Scotland catches are mainly between 50 and 70 cm in length, while at Rockall lengths are mainly between 60 and 100 cm at this depth. In both areas the sex ratio with length differs significantly from that in shallower waters with males being more prevalent at lengths below ca. 80 cm before females dominate at greater lengths.

When investigated by 50 m depth strata, the most striking feature of the anglerfish catch composition is the general increase in fish length with depth, which was evident to depths of around 450 m, in all areas from which samples were obtained. Although this is consistent with fishermen's knowledge and our (scientific) experience of the fishery there is little published information apart from Ungaro *et al.* (2002) who reported that *L. piscatorius* caught on the continental shelf in the Mediterranean Sea (<200 m) were smaller than those caught in deeper water.

Hauls at Shetland at depths <50 m were dominated by anglerfish less than 30 cm and the length distributions suggest that certain areas could be nursery grounds The appearance of a strong cohort in late 1999, which could be followed through 2000 confirms anecdotal reports from fishermen at that time. Laurenson (2003) suggested that high abundances of small anglerfish on some inshore grounds at Shetland is related to seasonal abundances of sandeels *Ammodytidae*, which are their main prey at certain times of year. Further analyses would be required to locate such areas and determine whether they persisted from year to year. It is also noted that there was a preponderance of fish under 30 cm at Rockall at depth 100-149 m suggesting that any nursery grounds may not exclusively be in the shallowest waters of its bathymetric distribution.

Overall, it was found that the sex ratio was approximately equal at lengths below 65 cm. Above 65 cms the proportion of females increased and at lengths greater than around 100 cm all monkfish were female. This is similar to that previously reported by (Afonso-Dias, 1997) and (Duarte *et al.*, 2001). The difference in sex ratio with length between depths <450 m and >450 m has not previously been reported for this species although an increase in the proportion of males increasing with depth was described for *L. budegassa* in the Spanish Mediterranean (García-Rodríguez *et al.*, 2005).

The preponderance of males less than 80 cm in length in deeper waters may be related to spawning. The proportion female at length from waters >450 m at the west of Scotland and Rockall were obtained in the months of September, November and March. The spawning period at the west of Scotland is between November and May (Afonso-Dias and Hislop, 1996). The observed pattern of proportion female at length at these depths could be interpreted as a congregation of males in deep waters at a time when spawning activity is at its highest. Fishermen from Shetland report that they target areas along the shelf edge to the west and northwest of Shetland between around January and March as catch rates of anglerfish are significantly higher in those locations at that times (*Pers. Comm..* Various). This suggests that there could be a spawning migration to deeper waters from, at least, the shelf around Shetland.

(Fulton, 1903) and (Bowman, 1920) were the first to suggest that anglerfish spawn in deep water. However confirmation of spawning locations has been hindered in all studies to date by the apparent scarcity of mature females (e.g. (Quincoces *et al.*, 1998, Duarte *et al.*, 2001, Anon., 2001). This study has compiled data from a number of studies and, over the areas and times represented, mature females were found to be most prevalent in deep water at Rockall. While this does not rule out spawning in other areas, it suggests that of the areas sampled, the deep water around Rockall is the most significant for reproduction. However despite the level of sampling, and the times of year at which samples were obtained, the number of ripe females was low.

The lengths at first maturity ($L_{50\%}$ mature) found in this study exceed those reported by other authors for females and are within the range previously reported for males (Table 2). The sample size used in this study is much larger than in other studies; however the number of mature females, in particular, was still relatively small. What is consistent is that females mature at a much larger size than males and this, combined with the variation in distribution with depth and, in some cases with area, and the variation in sex ratio with length with depth have consequences when estimating the proportion of mature male and female anglerfish in catches.

Table 2. Lengths at first maturity of *L. piscatorius* in studies in the northeastern Atlantic

	$L_{50\%}$ maturity (cm)		
Area	Female	Male	Author(s)
Rockall	101.1	60.0	Anon, 2001
West of Scotland	92.3	56.4	Anon, 2001
West of Scotland	73.5	48.9	Afonso-Dias and Hislop, 1996
Spanish & Portuguese waters	93.9	50.3	(Duarte *et al.*, 2001)
Bay of Biscay	83.6	54.6	(Quincoces *et al.*, 1998)

In conclusion, the data presented in this paper, suggest there is considerable heterogeneity in the biological characteristics of the anglerfish stock on the Northern shelf related to area, season and depth. Whilst this may to some extent reflect migratory patterns of the species, it highlights the need to obtain representative samples of the landings for stock assessment purposes.

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