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Abstract

In recent years stock structure recommendations for megrim on the Northern Shelf have varied, primarily due to a lack of biological and fishery data. In this study, we compared a number of life history characteristics of the common megrim *Lepidorhombus whiffiagonis* (Walbaum) between the northern North Sea and Rockall, the latitudinal extremes of the species' distribution on the Northern Shelf. Reproductive timing, sex ratio, maturity and growth were different between the two study areas. Reproductive timing in the northern North Sea was more protracted than at Rockall and other areas. There were differences in sex ratio between the study areas and female megrim in the northern North Sea exhibited different growth rates and larger size at maturity than at Rockall. The results of this study support the recent changes to the definition of the Northern Shelf stocks which recommend that the northern North Sea be treated separately to Rockall.

Keywords: Flatfish, *Lepidorhombus whiffiagonis*, Northern Shelf, Reproduction, Growth, Sex ratio

1 Introduction

The genus *Lepidorhombus* consists of two commercially important flatfish species, the common megrim *Lepidorhombus whiffiagonis* (Walbaum) and the four spotted megrim *Lepoidorhombus boscii*. The genus' distribution is confined to the north-east Atlantic from Iceland to the Mediterranean Sea (Nielsen, 1989). The two species replace each other along their distribution range with *L. boscii* more prevalent in southern waters and *L. whiffiagonis* in northern waters. Megrim are deep water fish, occurring in depths of 100-700 metres (Nielsen, 1990). They are asynchronous batch spawners, spawning from March to April (Gordon, 2001). On the Northern Shelf (Rockall, West of Scotland & North Sea) *L. whiffiagonis* is predominantly caught by twin trawl and Scottish seine vessels, 18-24 metres in length, in a multispecies demersal fishery (A Johnson 2012, Personal communication). Megrim is an 'advice poor' species, a species that lacks the basic biological and fishery data required to provide informed management. This is especially true on the Northern Shelf where a lack of data has led to uncertainty regarding stock structure. In 2011 megrim was classified as a Category 3 stock which is defined as a 'stock for which no harvest control rules have been agreed and data are insufficient to carry out an analytical assessment' (Anon, 2011b). This is due to a lack of reference points such as F_{msy} (the fishing mortality that produces the maximum sustainable yield). The Total Allowable Catch (TAC) is currently set using historical landings and quota uptake data.

Although catches on the Northern Shelf are predominantly *L. whiffiagonis,* both *L. whiffiagonis* and *L. boscii* are considered together in annual stock advice published by ICES for the Northern Shelf (e.g. ICES, 2011b). Historically megrim in ICES Division VIa (west of Scotland) and VIb (Rockall) were considered as separate stocks (see Figure 1) and, prior to 2009, the annual stock assessment produced by ICES did not consider megrim in Sub-Area IV (North Sea). In 2009 and 2010 megrim in Sub-Area IV was included with Sub-Area VI under a single assessment for the species on the Northern Shelf. In 2011 ICES concluded that megrim in IVa and VIa should be assessed as a unit stock as there was no evidence that they comprised separate stocks (ICES, 2011b). ICES also recommended that megrim in VIb be assessed as a separate stock. The recent changes in the definition of megrim stock structure on the Northern Shelf have been primarily driven by additional data provided by the annual survey of anglerfish and megrim on the Northern Shelf, undertaken from 2005-2010. The current stock assessment for the species on the Northern Shelf is based on relative trends in survey biomass in recent years (Anon, 2011a).

The variation in advice produced in recent years is indicative of the paucity of information on megrim stock structure on the Northern Shelf. A number of methods exist to assist in the determination of fish stock structure. These include the use of techniques such as morphometric studies, genetic markers, parasites as biological tags and physical tagging

(Abaunza et al., 2007; Cadrin et al., 2005). Comparisons of life history parameters such as growth, reproduction and maturity across a species' range are also thought to be useful for distinguishing between fish stocks as they are representative phenotypic expressions of genotypic and environmental interactions (Begg, 2005). Numerous studies have utilized comparisons of life history characteristics as an initial basis to differentiate between populations and recognise discrete stock units (Abaunza et al., 2008; Ballagh et al., 2012; Moore et al., 2012). Such studies are currently lacking for megrim on the Northern Shelf and there is a need to utilize some of these methodologies in order to improve the definition of stock structure on the Northern Shelf.

The aim of this study was to determine whether differences in life history parameters exist between populations of *L. whiffiagonis* along the longitudinal extremes of its distribution on the Northern Shelf. Life history characteristics including reproductive timing, sex ratio, growth and maturation were compared between megrim survey catches from Rockall (VIb) and commercial catches from the northern North Sea (IVa).

2 Materials & Methods

2.1 Sampling

The study area (Figure 1) covered ICES Subdivisions VIb (Rockall) and IVa (northern North Sea). Data collection in the northern North Sea was primarily undertaken on commercial vessels executing the mixed demersal fishery. One observer trip per month, lasting up to 7 days, was undertaken for a one year period from May 2010 to April 2011. In order to maximise coverage, data was collected from the two types of fishing vessel that predominantly target megrim, twin trawl and Scottish seine. Vessels fished nets with 120mm mesh in the wings and 120mm mesh in the cod-end. Twin trawl tows normally lasted for six hours with up to four tows in any 24-hour period. Scottish seine tows lasted for two hours during daylight with 4-8 hauls/day depending on the season. The towing speed was approximately 3 knots for both types of vessel. All fishing was undertaken in depths between 88 and 200 m. Data for Rockall was collected during the annual Anglerfish survey (co-ordinated by Marine Scotland Science (MSS)) during April/May 2009 and 2010. The survey design was stratified i.e. a greater number of tows were undertaken in areas where anglerfish abundance was perceived to be higher. Trawling took place during daylight hours on the RV *Scotia* using MSS's Jackson 575 Monk Survey single trawl with 120mm mesh in the wings and 100mm mesh in the cod-end. The survey trawl was designed to be typical of that used by the Scottish fleet targeting the west coast anglerfish fishery (Fernandes, 2008). Tows were undertaken in depths ranging from 130 to 680 m and lasted for 1 hour each (from the time the gear was on the seabed to when it was hauled). The distribution of sampling at Rockall and the northern North Sea is shown in Figure 1.

Sagittal otoliths were removed from a length-stratified sub-sample each month and stored dry in 5 ml plastic vials. Otoliths were read whole immersed in water under reflected light at 20 x magnification to determine the age of individual fish. Age determination followed best practise protocols recommended by Egan et al. (2004).

2.2 Spawning pattern

In both areas all megrim were measured to the nearest cm and maturity stage was determined macroscopically using the standardized maturity scale proposed by Brown-Peterson et al. (2011). The maturity scale is outlined in Table 1. The spawning period in the northern North Sea was determined by calculating the frequency of male and female fish at each stage of maturity for each month. Visual assessment of gonads allowed for the distinction between immature and maturing/regenerating individuals. Differences in spawning period between the North Sea and Rockall were determined by comparing the frequency of female fish at each stage of maturity during April and May. Only adult fish were included in the analysis for both areas.

2.3 Sex ratio

The sex of individual fish was recorded for all megrim sampled at the northern North Sea and Rockall. The overall proportion of female fish at each cm length increment was plotted and compared between both areas. Fish at lengths <20 cm were omitted from the analysis due to very small sample numbers.

2.4 Maturity

Length at sexual maturity was determined at the northern North Sea using data collected during the months of December to May inclusive. Data analysis was limited to this, the main spawning period, due to the inherent difficulty in distinguishing between developing virgin and spawning recovered (stage II) fish out with the spawning season. At Rockall all data collected (April-May) was used as, at the end of the spawning season, recovering fish were easily distinguishable from virgin fish. Length at sexual maturity was calculated for male and female megrim at the northern North Sea and Rockall by fitting a logistic curve to each data set using a non-linear least squares procedure in R.

2.5 Growth

Age-length keys (ALKs) were generated from the length stratified age data for northern North Sea and Rockall females and northern North Sea males. There was insufficient data to estimate male growth parameters at Rockall. In order to accurately represent the true length distribution-at-age, ALKs were raised by the total catch. Growth parameters were estimated by fitting the von Bertalanffy growth equation to the length distribution-at-age in the raised ALKs:

$$L_t = L_\infty \left(1 - e^{-K[t - t_0]}\right)$$

where L_t is the length at age t, L_∞ the maximum length of the species, K the instantaneous growth coefficient, t the age and t_0 is the hypothetical age at which the species has zero length. The equation was fitted to the data in R using a non-linear least squares method to estimate the parameters. As samples were collected in the same year, growth curves were fitted over different cohorts. For northern North Sea females and males, all estimated parameters (L_∞, K, and t_0) had p-values <0.05. For Rockall females, the parameters L_∞ and t_0 had p-values <0.05 while K had a p-value = 1. This suggested that growth of Rockall females follows a linear trend. A linear model was subsequently fitted to the Rockall female data.

3 Results

3.1 Spawning pattern

Spawning capable fish were evident in the northern North Sea from February to August. Monthly frequencies of female and male maturity stages are shown in Figure 2 and monthly sample sizes are shown in Table 2. Gonads began to develop during the winter months, from November onwards. The first evidence of females becoming ‘spawning capable’ (Table 1) was during January. The percentage of females spawning increased during February and March, peaking in March. The prevalence of spawning females then decreased in subsequent months although there was evidence of females still developing and spawning through July. There were few developing or spawning capable fish evident in August, indicating the end of the spawning season. During September and October there was a two month inactive period where all mature fish were regenerating. The reproductive timing of males and the proportions in each maturity stage followed a similar pattern to females except during January and February. During these months males were mostly spawning capable and therefore more advanced than females, the majority of whom were still in a developing stage (Figure 2).

Although sampling at Rockall was restricted to April and May in both 2009 and 2010, the data suggests that the reproductive pattern at Rockall is different to that in the northern North Sea. At Rockall it appears that the last of the female fish were spawning capable during April (Figure 3). In May the spawning season at Rockall is almost over with no evidence of additional females developing for spawning in subsequent months.

3.2 Sex ratio

A total of 82.3% of the 16531 fish sampled in the northern North Sea were female (4.5:1 females:males). The sex ratio at length of megrim in the northern North Sea was characterised by a high frequency of males at the smallest lengths which decreased with increasing length (Figure 4). There were consistently more males than females in the size range 16-28 cm. The proportion of females steadily increased in each cm length increment greater than 28 cm and almost all fish sampled in each length increment greater than 40 cm were female.

At Rockall, females at depths <=200 m comprised 92.1% of the 2554 fish sampled (10:1 females:males) while at depths >200 m the sex ratio was 13:1 (females:males).There was a difference in the overall 1:1 sex ratio crossover between male and female megrim at Rockall (21-22cm) and the northern North Sea (28-29cm). The length at which 95% of fish sampled in each size class were female was 26 cm at Rockall and 40cm at the northern North Sea.

3.3 Maturity

There was a difference in the length at first maturity between Rockall and the northern North Sea. At the northern North Sea the $L_{50\%}$ for females was 31 cm while at Rockall it was 25 cm. The $L_{50\%}$ for males was similar between both areas at 21-22 cm. The length frequency distribution of both male and female megrim is shown in Figure 5. The proportion of mature females at each cm length increment from the 13709 fish sampled from the northern North Sea and 2393 fish sampled from Rockall is shown in Figure 6.

3.4 Growth

There was evidence that growth of females in the northern North Sea exhibits a different pattern to that seen at Rockall. Age was determined for 984 females and 263 males from the northern North Sea and 474 females and 69 males from Rockall. Fitted growth models for females and males at the northern North Sea and females at Rockall are shown in Figure 7. Von Bertalanffy growth parameters are given in Table 3. Growth for Rockall females was described by a linear equation ($L = 2.6006A + 15.102$, $R^2 = 0.785$), where L is the length and A is the age of the fish.

4 Discussion

The results show that there are clear differences in life history characteristics between the latitudinal extremes of the species' distribution on the Northern Shelf. These include differences in timing of spawning and sex ratio distribution between the areas. There is also evidence of an extended spawning period, differing growth patterns and larger length at maturation of females at the northern North Sea.

The data collected here, relating to the timing of spawning at Rockall, is consistent with the only other previously published data by Gordon (2001) which reports that in Area VI (West of Scotland and Rockall) spawning capable fish were present from January to April and were absent by May. Spawning in the Celtic Sea was also reported to take place between January and April (Aubin-Ottenheimer, 1987). In this study we found spawning capable megrim present at the northern North Sea into August. Similarly, Laurenson & Macdonald (2008) noted that the spawning season for megrim in IVa continued into August with very few fish still spawning capable in September. Differences in the spawning pattern reported here between the northern North Sea and Rockall may be indicative of differences in spawning strategy between the two areas. In the northern North Sea the presence of spawning capable fish in samples through to August and September is evidence of a different spawning strategy compared to other areas of the species' distribution. Gordon (2001) reported that the spawning season along the shelf edge on the west coast of Scotland, including the shelf edge along the western edge of IVa, was similar to that at Rockall. The study did not however, include individuals from within the North Sea basin. It would therefore be beneficial to ascertain whether any spatial differences exist in spawning pattern within IVa i.e. east of Shetland (within the North Sea basin) and west of Shetland, towards and along the shelf edge. Further work is also required to determine what underlying mechanisms contribute to the protracted spawning season in the northern North Sea.

Length distributions of megrim differed between males and females at both the northern North Sea and Rockall. The size distribution of males evident at Rockall is similar to those seen in other areas (Gerritsen et al., 2010; Poulard et al., 1993) while the size distribution of males that we report for the northern North Sea is larger than that reported for any other area. Gerristen et al. (2010) reported that males to the west of Ireland rarely grow larger than 35 cm. In this study northern North Sea males at 35 cm comprised 33% of the total catch at length, while 23% of all males were at sizes larger than 35 cm. Poulard et al. (1993) found greater numbers of females than males in depths up to 150m while the trend reversed in depths greater than 150m in the Celtic Sea and Bay of Biscay. Gerristen et al. (2010) also reported that males were more common in deeper water west of Ireland. There were variations in length distribution corresponding to the differences in sex ratio between the northern North Sea and Rockall and these together suggests that there are significant differences in population structure between these areas. While it is clear that the ratio and size of males in the northern North Sea is greater than other areas, it is unclear what biological and/or ecological factors are driving this difference.

The difference in female $L_{50\%}$ maturities between our two study areas correlates with the variation in growth patterns evident between the areas. Differences in female growth rates are known to exist throughout the distribution range of *L. whiffiagonis*. For example Landa et al. (1996) reported that growth in area VIIIc (southern Bay of Biscay) was higher than other areas in VIII (Bay of Biscay) and VII (west of Ireland and southwest United Kingdom). A number of studies indicate that in all areas there is also a prevalence of sexual dimorphism, with female megrim attaining a greater length and age than males (Gerritsen et al., 2010; Gordon, 2001; Landa et al., 1996; Moguedet and Perez, 1988). However, the degree of sexual dimorphism evident in the northern North Sea is markedly less than that seen in other areas, including Rockall. In many flatfish species females are typically larger than males, often by several orders of magnitude, as this typically increases the fecundity of the individual females (Parker, 1992). Studies on maturation of plaice (Rljnsdorp and Ibelings, 1989) and dab (Lozan, 1992) suggest that sexual dimorphism in flatfish is the result of a combination of earlier reproduction in males and reduced surplus energy acquisition above a certain size. Rijnsdorp and Witthames (2005) noted that this hypothesis predicts that the largest flatfish will exhibit the greatest degree of sexual dimorphism.

Differences in the trawls deployed at the northern North Sea and Rockall may have contributed to a small amount of the variation seen between the areas. The survey net used at Rockall, designed to be representative of the nets deployed when targeting anglerfish, had 100mm mesh in the codend which would be expected to retain smaller fish compared with the 120mm mesh deployed in commercial nets in the northern North Sea. This will have had an effect on the size selection of the smallest fish sampled in each of the areas, with an expectancy of a greater proportion of smaller fish retained at Rockall. However, the gear differences would not be expected to influence the parameters of any of the life history characteristics measured here other than not allowing for a direct comparison of sex ratio between the two areas.

The hydrography of the northern North Sea and Rockall are known to be very different (Howell et al., 2009; Maravelias, 1997; Turrell, 1992; Turrell et al., 1996) and the resulting variation in water inflows, current patterns and nutrient availabilities could result in very different productivities between the two areas. These environmental differences may be one of the factors driving the variation in growth patterns seen between northern North Sea and Rockall females. Northern North Sea females exhibit rapid growth rates prior to maturity with growth slowing after maturity. This trend is similar to that seen in other species in the North

Sea such as haddock (Baudron et al., 2011). Haddock are also known to exhibit slower growth rates and a smaller maximum size at Rockall than their neighbouring Atlantic populations (ICES, 2011a). In contrast, the linear growth rates exhibited by female megrim at Rockall are indicative of a different growth pattern, with a steady growth rate before and after maturity. It is also important to note that although the von Bertalanffy growth model fitted well to North Sea males, the unrealistically high L_{inf} is more indicative of linear growth. This suggests that male growth in the northern North Sea may exhibit a similar growth pattern to that of females at Rockall. The variation in male and female growth patterns within the North Sea suggest that factors other than environmental variables may be contributing to these differences.

While there is evidence of differences in life history characteristics of megrim between the two longitudinal extremes on the Northern Shelf, it is also important to recognise that the study undertaken here did not include the ICES Area that separates them along the west of Scotland (IVa). The results presented here may therefore be two extremes of a graduated change in life history characteristics across the longitudinal distribution of the species, rather than evidence of discrete stock units. It would therefore be beneficial to undertake further analysis at the west of Scotland to ascertain whether the variation in life history characteristics is due to a natural gradual change in these parameters across the Shelf or whether there is evidence of discrete stock units.

5 Conclusion

The results of this study indicate that there are significant differences in the life history characteristics of the megrim populations at the northern North Sea and Rockall. These differences include length distributions, growth rates, length at maturity of females, sex ratios and the timing and duration of the spawning season. The most recent Northern Shelf stock structure for megrim that has been recommended by ICES is that IVa (northern North Sea) and VIa (West of Scotland) comprises one stock and VIb (Rockall) is a separate stock. Our results support the northern North Sea being treated separately to Rockall. However, given the variation found between the results from the North Sea presented here and previous studies covering the West of Scotland, further work is needed in order to investigate possible spatial differences between megrim in IVa and VIa.

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Table 1 Macroscopic maturity scale used in the visual assessment of *L. whiffiagonis* maturity.

Stage	Female	Male
1	Immature: Ovaries very small (<4 cm down the side of the body). Ovary wall thin and easily broken. Yellowish-orange in colour.	Immature: Testis tight against the back of the gut cavity and very small (<10x2mm).
2	Regenerating: Ovary increasing in size (>4cm down the side of the body) in immature fish. Ovary wall thin, no eggs visible, little or no slime inside the ovaries.	Regenerating: Testis increasing in size (>10x2mm) in immature fish. Testis yellow/brown in colour.
3	Developing: Ovaries filling with eggs, body distended. Varying amounts of hyaline eggs in more advanced individuals. Ovaries will not run even under heavy pressure.	Developing: Testis filling but not running with moderate pressure. Creamy white in colour.
4	Spawning capable: Hyaline eggs can be extruded copiously under light pressure.	Spawning capable: Sperm can be extruded under light pressure.
5	Regressing: Few eggs in a state of re-absorption (mainly opaque eggs) and much slime in ovaries.	Regressing: Testis flabby often red in places, little sperm left.

Table 2 Monthly sample sizes of male and female megrim from the northern North Sea and Rockall

Northern North Sea			Rockall		
Month	Female	Male	Month	Female	Male
Jan	558	72	April	1426	109
Feb	169	9	May	967	95
Mar	1433	188			
Apr	1132	293			
May	816	252			
Jun	2439	427			
Jul	3108	254			
Aug	1092	635			
Sep	310	55			
Oct	949	88			
Nov	1108	37			
Dec	595	640			

Table 3 Von Bertalanffy model parameters and associated *p*-values *()* for female and male megrim from the northern North Sea and female megrim from Rockall.

Area/Sex	L_∞	K	t_0
North Sea female	60.8 *(<0.05)*	0.1415 *(<0.05)*	-1.1218 *(<0.05)*
Rockall female	447.0 *(<0.05)*	0.0062 *(=1)*	-5.3726 *(<0.05)*
North Sea male	125.5 *(<0.05)*	0.0249 *(<0.05)*	-5.0333 *(<0.05)*

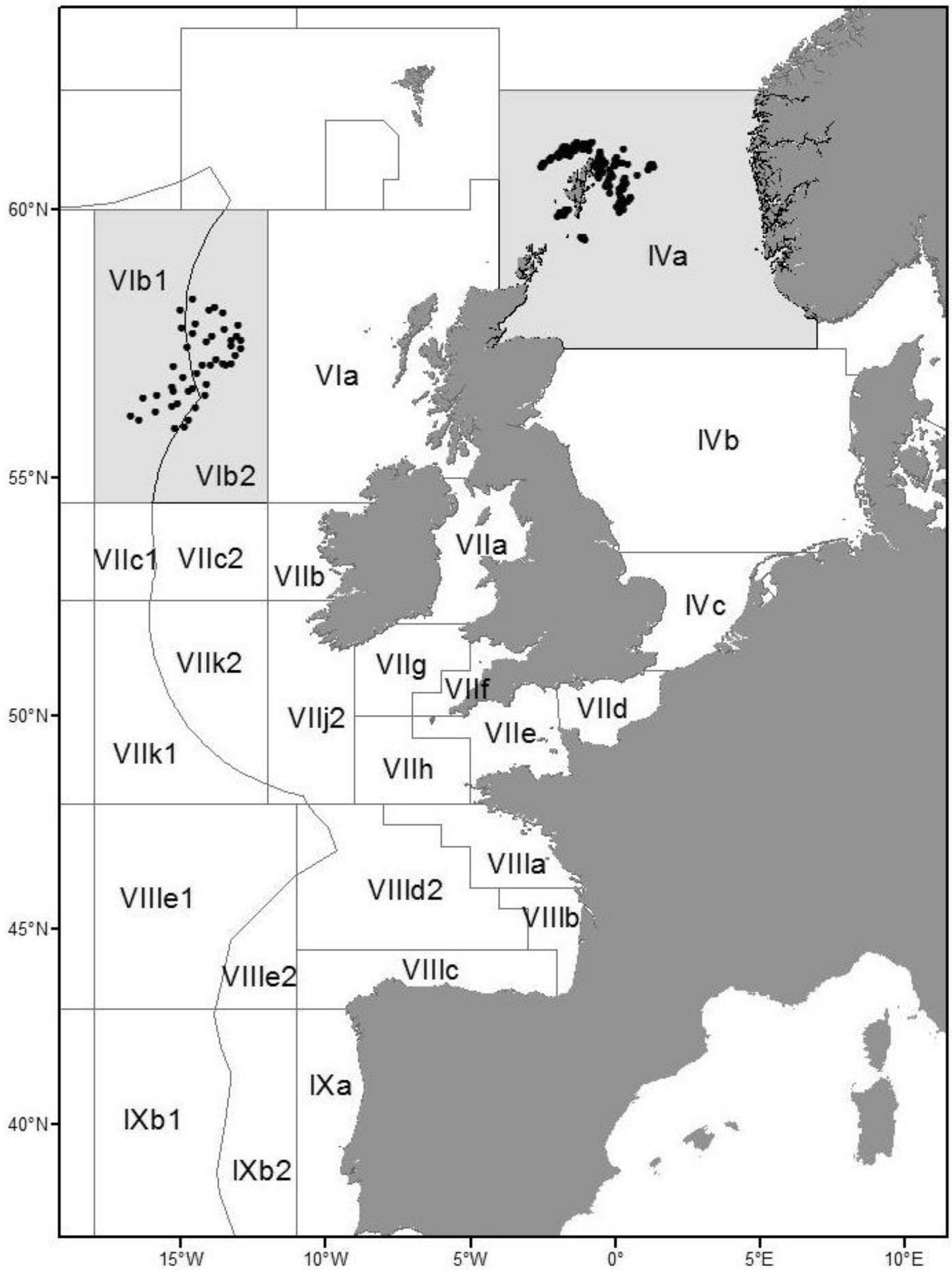

Figure 1 Map of study area with individual trawl tows (●) at Rockall (VIb1 & VIb2) and the northern North Sea (IVa) highlighted.

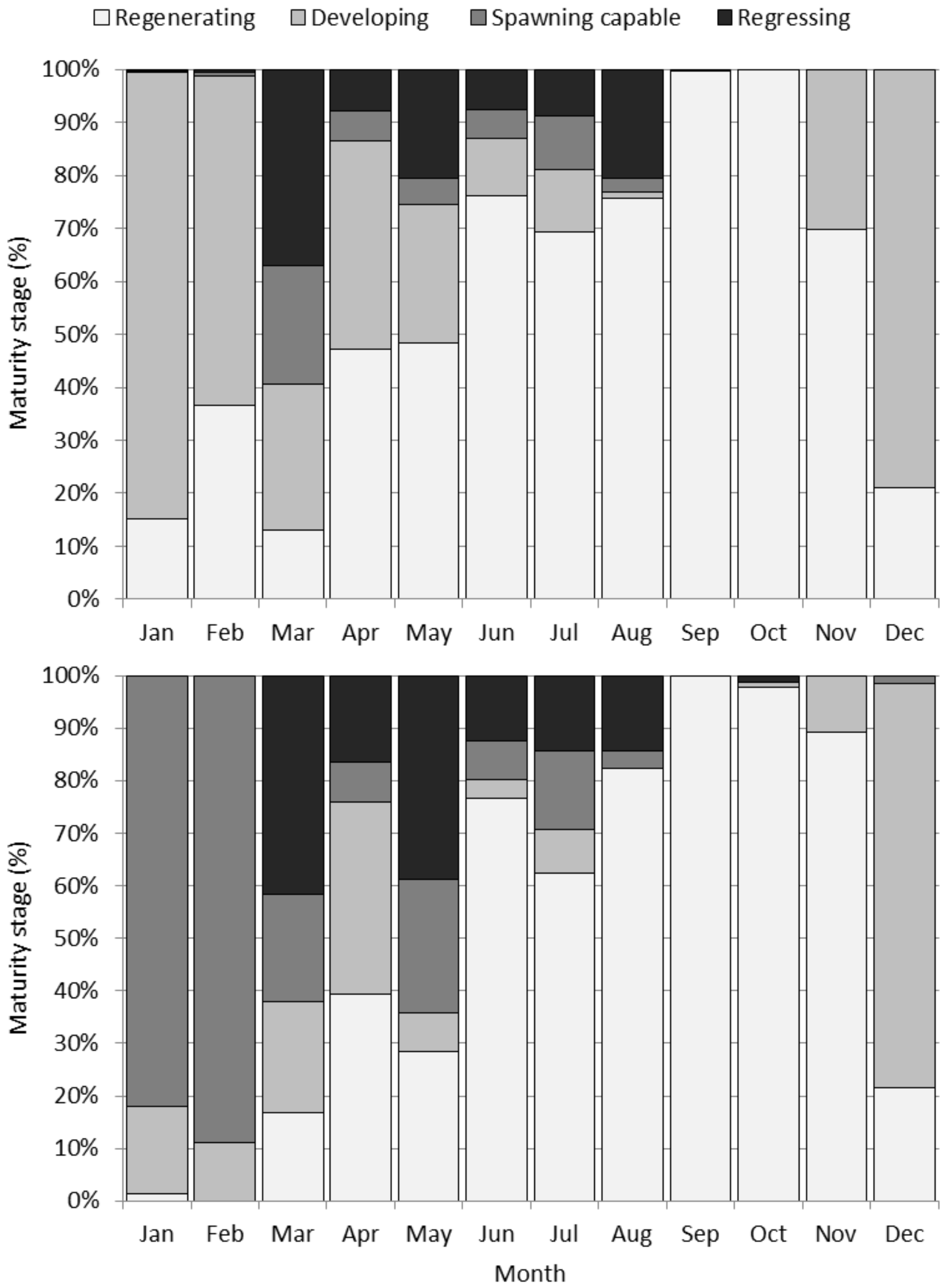

Figure 2 Monthly frequencies of female (top) and male (bottom) maturity stages in the northern North Sea for mature megrim (stages 2 – 5) (n = 13773 and 2949 respectively).

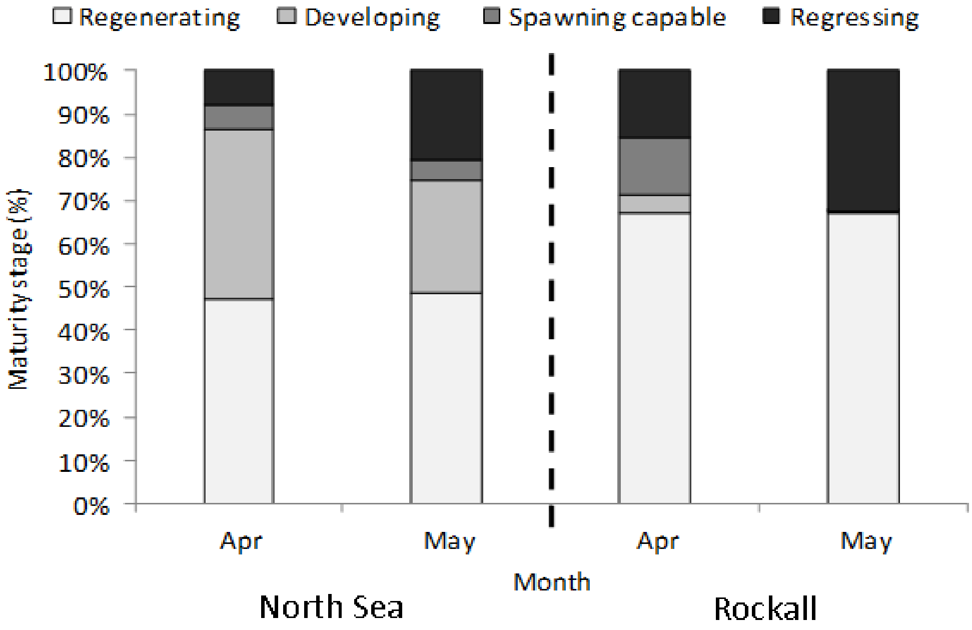

Figure 3 Comparison of monthly maturity frequencies of female megrim in the northern North Sea and Rockall for mature megrim (stages 2 – 5) (n = 1948 & 2395 respectively).

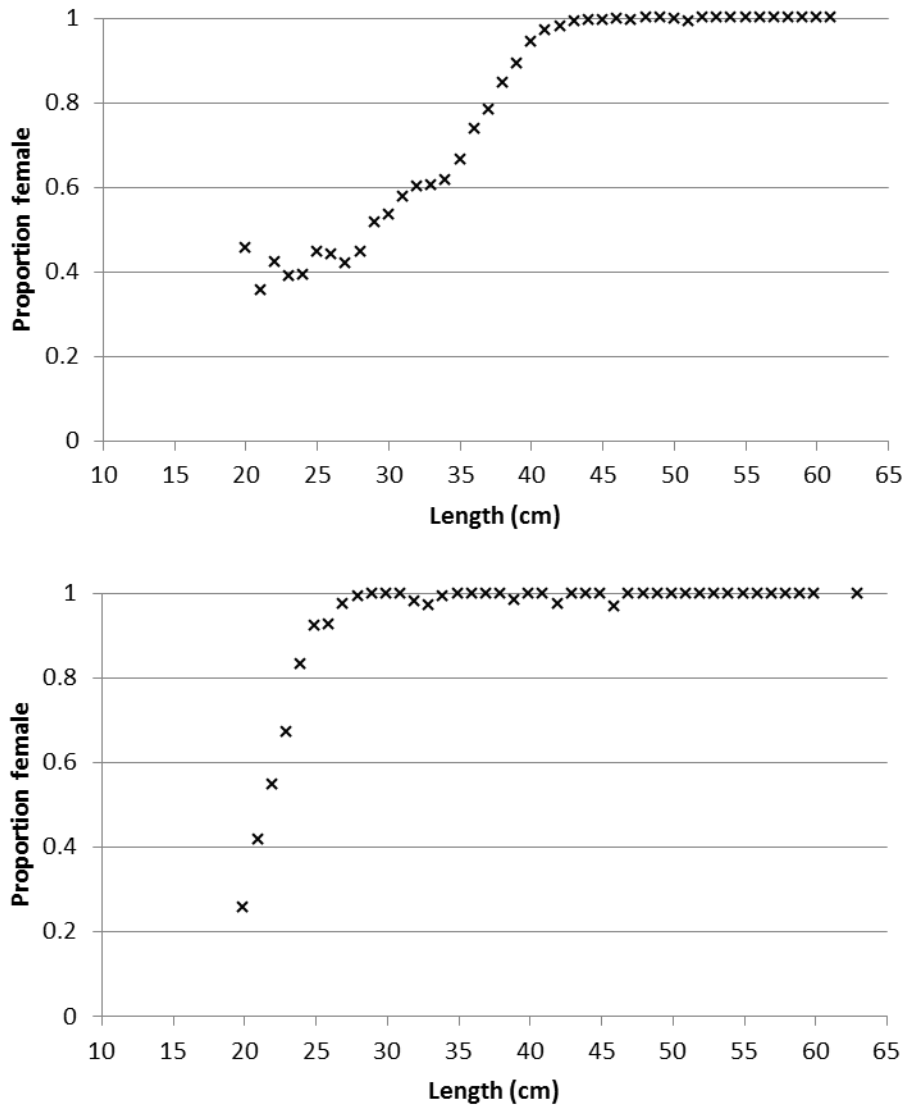

Figure 4 Sex ratio per cm length of megrim from the northern North Sea (top) and Rockall (bottom).

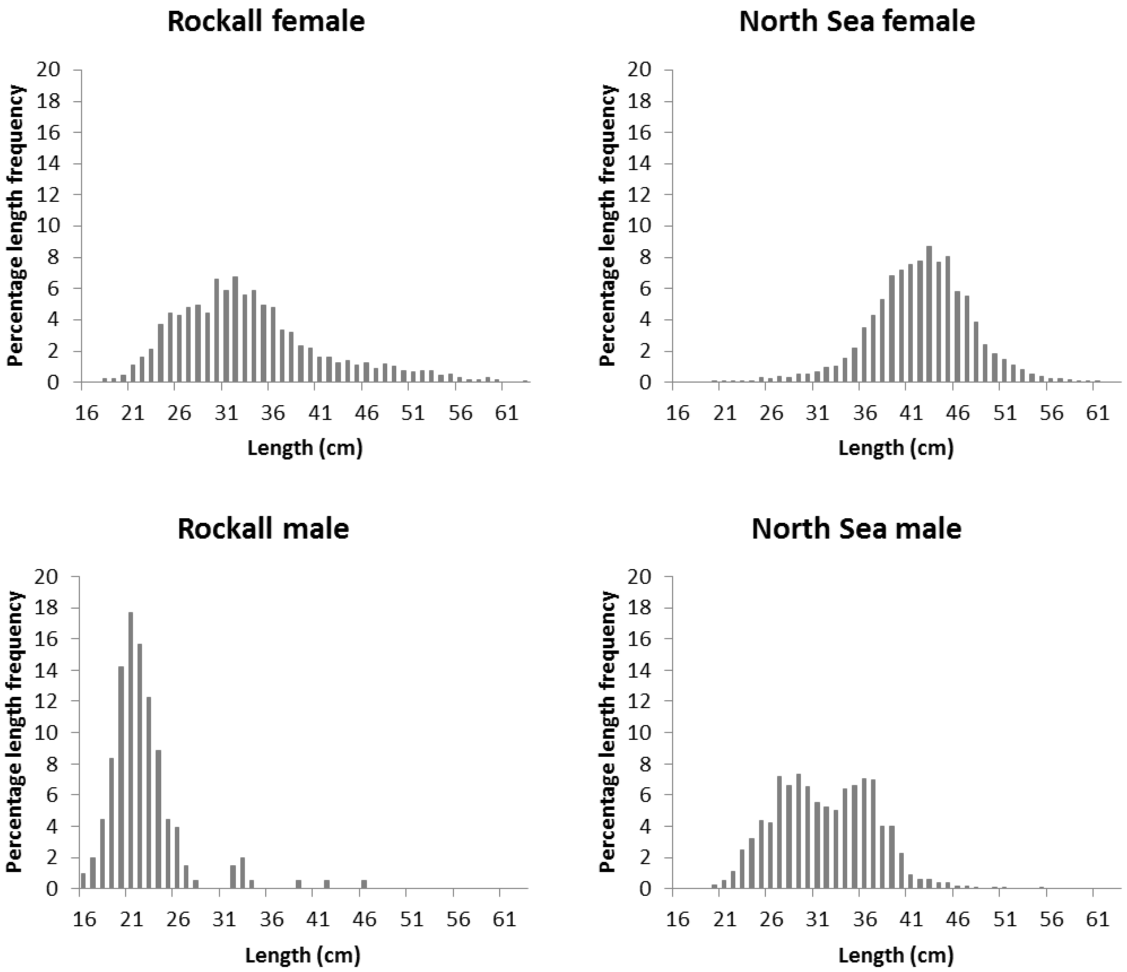

Figure 5 Length frequency distribution of male and female megrim at Rockall and the northern North Sea.

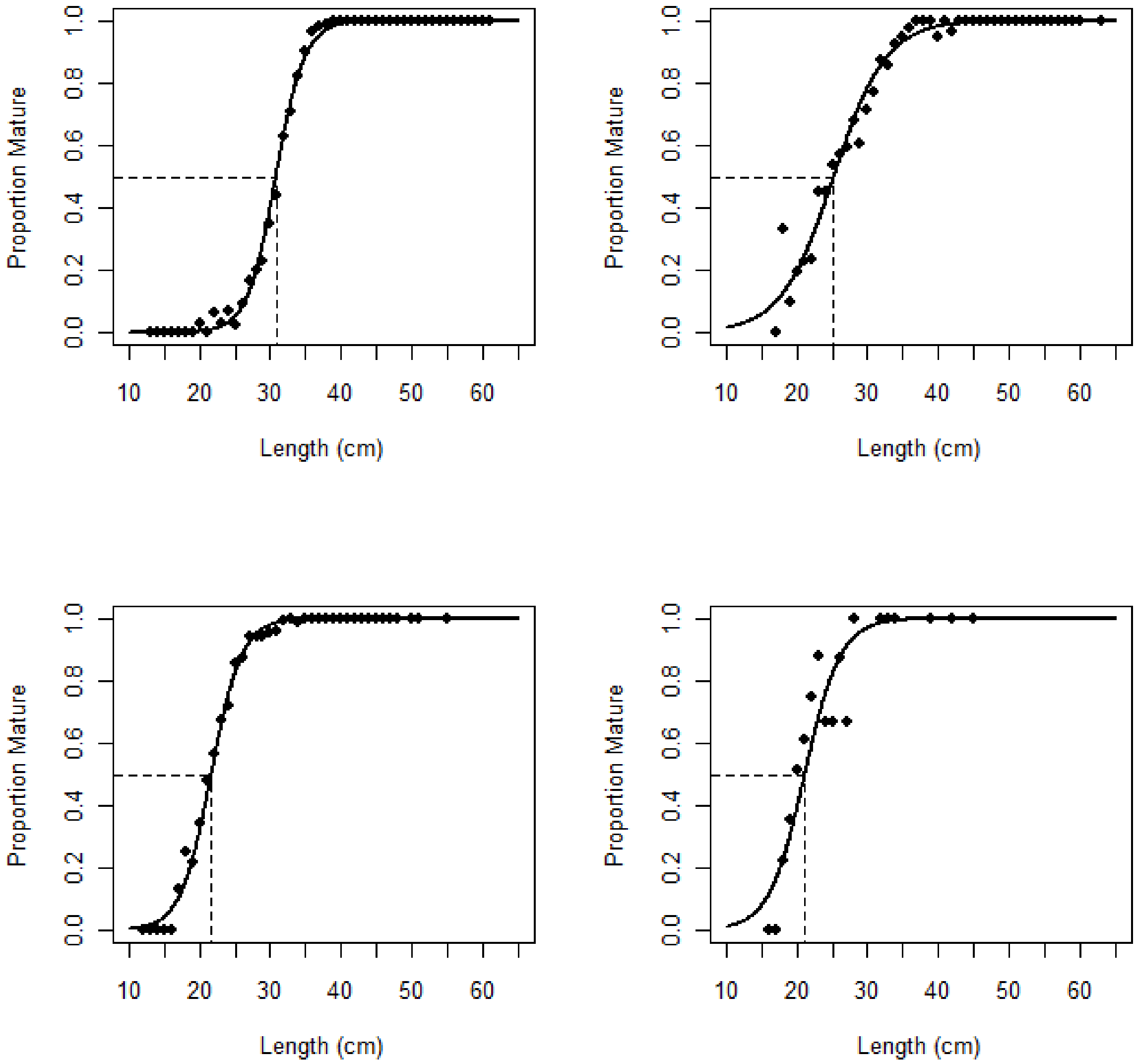

Figure 6 Proportion of mature female (top left) and male (top right) megrim from the northern North Sea and female (lower left) and male (lower right) megrim from Rockall per cm length increment with fitted logistic ogives.

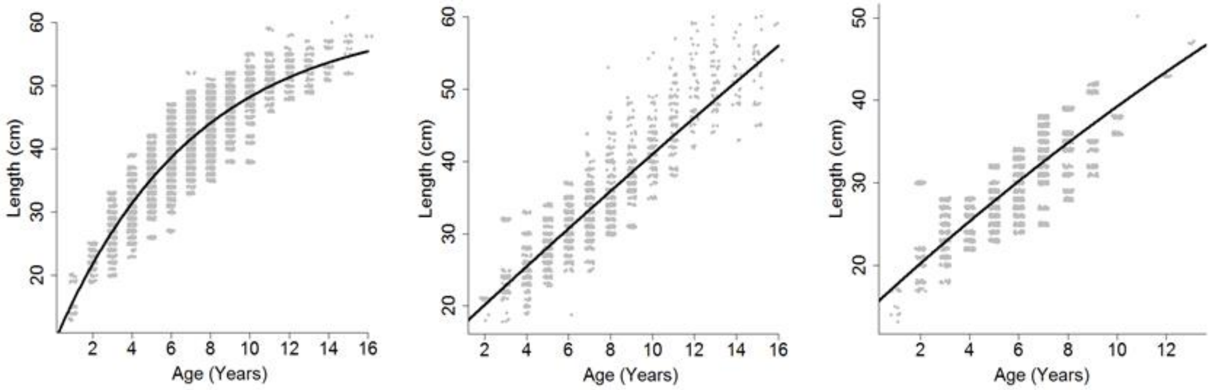

Figure 7 Age length scatter plots with fitted models for North Sea female (left, n=13709), Rockall female (middle, n=2393) and North Sea male (right, n=2949).