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Progress in estimating the absolute abundance of anglerfish on the European northern shelf from a trawl survey

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The anglerfish stock which occupies the northern European shelf is part of a valuable mixed and targeted demersal fishery. There is a perception amongst participants in this fishery that anglerfish abundance is high, and that the abundance has increased in recent years. However, traditional assessments of their abundance are uncertain and ICES considers their abundance as unknown**.** In 2005, Fisheries Research Services started a three year project with the objective of determining the abundance of this stock. The project is unique in aiming to determine an absolute estimate of abundance and involves the explicit participation of the fishing industry. The desire for an absolute abundance estimate required several types of gear measurements to be made in order to determine an accurate swept area and contact with the seabed. Studies of the catchability of the survey trawl were also essential, although these were carried out in a separate sister project. In 2006, the Irish Marine Institute joined in the survey, extending the area coverage into Irish waters. This paper presents results of the surveys in 2005 and 2006, incorporating error propagation in the variance estimates. The survey indicates that a preliminary minimum estimate of the northern shelf anglerfish lies between 30,000 and 40,000 tonnes. This estimate is thought to be represent a preliminary minimum because the area surveyed is still smaller than that of the total population and studies of the catchability of the net are still ongoing. Methods to account for the latter factors are in development.

Keywords: anglerfish; trawl surveys; absolute abundance; industry participation.

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Introduction

Anglerfish, so named because their mode of feeding is analogous to angling, are a group of fish of the order Lophiiformes which include several families, amongst which the Lophiidae comprise some of the important commercially fished species of the genus Lophius. The most common species of the genus in the north Atlantic are the anglerfish (*Lophius piscatorius*)

which occurs in northern European waters, the black-bellied anglerfish (*Lophius budegassa*) in southern Europe and the Meditterranean, and the American goosefish (*Lophius americanus*). The former two species are more commonly known as monkfish and are considered as one of the seven fish of most importance to the Scottish fishing fleet (Anon 2005). In 2005, 9,628 tonnes of monkfish were landed into Scotland by UK vessels, with a value of £23,946,000 (Anon 2006), making it the 4th most valuable species landed after mackerel (*Scomber scombrus*), langoustine (*Nephrops norvegicus*), and haddock (*Melanogrammus aeglefinus*).

Until the 1980's monkfish were taken mainly as a by-catch in Scottish bottom trawl fisheries. The Scottish fishery for the species expanded in the late 1980's and early 1990's, peaking in 1996 with landings of just over 35,000 tonnes (ICES 2007a). Reported landings declined thereafter, although this may have been due to restrictive Total Allowable Catches (TACs) and were not necessarily representative of actual catches. In recent years there has been a perception amongst fishermen that monkfish abundance has increased in Scottish waters (Laurensen 2006). However, knowledge of the abundance of anglerfish is rather poor.

In northern Europe, there are three stocks of anglerfish: one in the Northern Shelf (Division IIIa - Skagerrak & Kattegat; Sub-area IV - North Sea; and Sub-area VI - West of Scotland and Rockall); one in Division IIa (Norwegian Sea); and one in Divisions VIIb-k and VIIIa,b,d,e (south west of the British Isles and west of France). The latter stock is assessed by the Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (ICES 2007b), whilst the former stocks are considered by the Working Group on the Assessment of Northern Shelf Demersal Stocks (ICES 2007a). The stock considered in the current paper is the Northern Shelf anglerfish.

Estimates of the abundance of anglerfish on the Northern Shelf have not been available since 2003, when the total stock biomass in 2002 was thought to be of the order of 36,590 t (ICES 2003). Since then landings data are thought to be unreliable due, in part, to restrictive TACs operating in different divisions, and traditional groundfish surveys are ineffective at catching anglerfish and do not provide a reliable indication of stock size. Several dedicated research surveys and charters of commercial vessels were carried out in 1999 and 2000 as part of a project funded by the European Commission to study the distribution and biology of anglerfish in waters to the west of Scotland (Anon 2001). Although young fish were found on the continental shelf, the adults were found close to the shelf edge and extended into deeper water. No estimates were made of the abundance of anglerfish from any of these surveys.

In 2005, Fisheries Research Services (FRS) initiated a new project to estimate the abundance and distribution of anglerfish on the Northern Shelf. The project is unique in two aspects: the aim is to produce an absolute abundance estimate (i.e. a total number and biomass of anglerfish), as opposed to an index of relative abundance which is normally produced from surveys; and, crucially, the project aims to involve the fishing industry throughout, from planning through to the execution of the surveys.

Two surveys have been carried out to date, in November 2005 and 2006: these covered the area of the known distribution of northern shelf anglerfish (ICES divisions IVa, VIa and VIb at Rockall), with the exception of the Skagerrak and Kattegat (division IIIa). As the area is so large, these are multi-vessel surveys, incorporating the research vessel Scotia, and three commercial fishing vessels. In 2006, the survey was extended south into Irish waters with the participation of the Irish Marine Institute (MI) in association with Bord Iascaigh Mhara (BIM). The fishermen have followed specific scientific instructions overseen by participating scientific staff. However, the instructions have been drawn up by an industry-science survey planning group which was set up at the start of the project. Appropriate industry representatives have, therefore, helped determine how best to incorporate fishing vessel effort and fishermen's expertise into various aspects of the survey (survey design, appropriate trawl gear etc.). A Monkfish Industry Science Planning (MISP) group was therefore instituted, comprising of representatives from FRS, the Scottish Fishermen's Federation (SFF) and the Fishermen's Association Limited (FAL).

The aim of this paper is to report the preliminary results from the surveys in 2005 and 2006. Although the absolute estimates are reported, it must be stressed that these are provisional estimates subject to further correction when studies of trawl catchability have been finalized and some account has been taken of the

incomplete area coverage. An additional project has been running concurrently to determine the catchability of the trawl used in order to correct the density estimates. Furthermore, the methodology for determining survey precision is still under development and estimates of these must also be considered provisional. Nonetheless, these estimates constitute what are thought to be estimates of possible minimum values of the total stock biomass and abundance of Northern Shelf anglerfish.

Methods and Materials

Survey design

The survey area encompassed the northern shelf of the British Isles, north of latitude 56° to a northerly limit of 62° 30' north. This area was further limited to areas where the depth was less than 1000 m. Four regions were proposed as distinct areas to be surveyed by the three commercial vessels and Scotia: Rockall; west of Scotland; north of Scotland; and east of Scotland (Figure 1). These were accepted by the fishermen in the MISP group as a reasonable division of effort amongst vessels. In 2005 it was decided that Scotia should survey the eastern region on the basis that it was perceived the least important in terms of abundance. However, the results of the 2005 survey indicated that this area, despite the low density, had the highest total abundance. Furthermore, the Rockall area is subject to a number of proposed closed areas to protect cold water corals. Prior to trawling near these areas, it is advisable to inspect them to ensure that coral is not present, both in terms of protecting the coral, but also to prevent damage to the trawl. It was thus decided that Scotia survey the Rockall area in 2006, as it has the video sampling facilities to inspect trawl sites at Rockall; a commercial vessel surveyed the eastern area in 2006. Each of the commercial charter surveys were of 10 days duration. In 2005 the Scotia survey was 10 days long and in 2006 it was 14 days.

In 2005, strata were initially defined

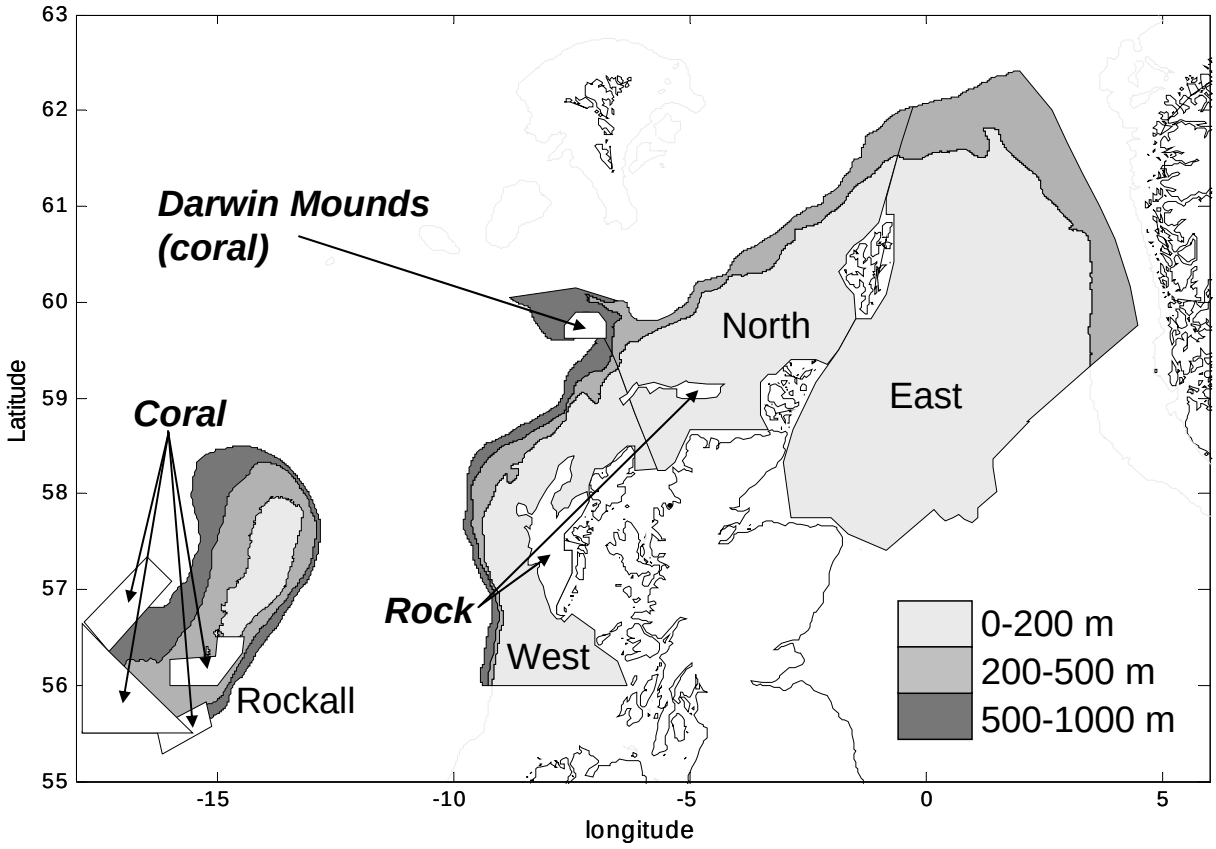

Figure 1. Map of the northern continental shelf around Scotland showing the four areas surveyed during the 2005 anglerfish survey. The areas are shaded according to the depth strata as indicated in the legend. Areas which were not surveyed are unshaded and also labelled.

according to depth, substrate, bottom water temperature, and respecting closed areas or provisional closed areas for coral. The principal basis for stratification was depth, with strata set at 500-1000 m, 200-500 m, and <200m. Four times as much effort (number of samples per unit area) was allocated to the deepest strata (500-1000 m) as the shelf strata (<200 m); with the mid depth strata (200-500 m) having twice as much effort as that on the shelf. This was to account for the increased abundance (by weight) of fish in deeper water that had been observed in previous surveys (Anon 2001). Another level of stratification within the <200 m stratum was to be based on substrate; however, the maps were not thought to be accurate enough for this to be possible. Rocky areas, such as that to the west of the southern outer Hebrides, were not sampled.

In 2006 this stratification was reviewed on the basis of further discussions with the industry science planning group and on the results from the 2005 survey. The effort applied to the different areas changed and additional strata were added on the basis of perceived and observed abundance in consultation with the MISP. The new strata are illustrated in Figure 2.

Within strata, the samples were chosen at random within strips of equal area. This ensures that (a) each possible sample point has an equal chance of being selected; and (b) that there is an even coverage of samples throughout the strata (avoiding clustering of samples and concomitant large open spaces without samples). The surveys were carried out in November on the basis of fishermen's advice that this was the best time of year to obtain high catch rates, which are indicative of reasonable availability to the sampling tool (demersal trawl).

Sample (tow) location and duration

Co-ordinates of the sample sites (trawl locations) were pre-allocated and provided to each scientist in charge (SIC). Once this location was reached it was up to the skipper, in consultation with the SIC, to decide on the best way to fish the location (e.g. tow direction; slight shift in location due to obstacles or hard ground). The SIC ensured, where possible, that the sample

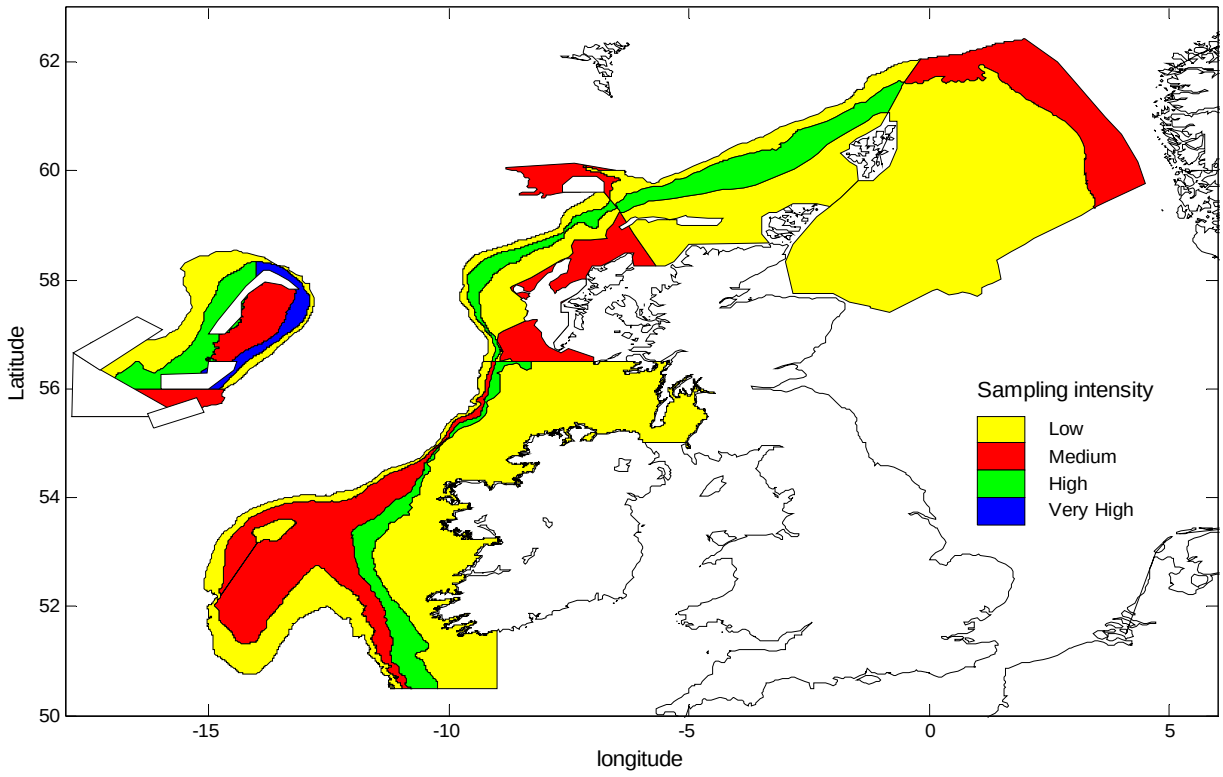

Figure 2. Map of the northern continental shelf around the British Isles showing the areas surveyed during the 2006 anglerfish survey. The areas are shaded according to the survey strata as indicated in the legend. Areas which were not surveyed are unshaded.

location did not deviate by more than 5 nautical miles from the intended location.

The sample size was dictated by the tow (trawl) duration. Scientifically, it is desirable to obtain as many samples as possible over the area and so a short tow duration was preferable (Pennington and Volstad 1991). Trawl surveys usually employ half hour tows, although 15 minute tows have in some cases been shown to provide a more precise estimate (Wieland *et al.* 2004). The MISP group recognized the need to obtain representative samples of fish density, i.e. numbers of fish per unit area as oppose to absolute total quantities of fish. However, at least one fisherman remarked that catches of longer tows can sometimes be proportionally larger than shorter tows. This may indicate some form of avoidance behaviour of the fish to the mouth of the trawl and will be investigated during studies of whole gear selectivity. In 2005, the tow duration was, therefore, set to two hours. However, there was no evidence from the 2005 survey that shorter tows caught proportionally less anglerfish. In 2006, therefore, it was agreed that tow duration should be reduced to one hour in order to take more samples in the allotted time.

The tow duration is actual "bottom time". Initially (on-site), this was estimated by the skipper according to his perception of when the gear arrived at and left the seabed. The exact bottom time was determined later from analysis of gear measurements (see below); this avoided problems associated with estimating "end effects" (Battagliaa *et al.* 2006).

Survey gear (trawl specification)

There have been a number of high profile cases in recent years where survey results have been brought into question as a result of inconsistent gear specification (Van Zile 2003). It was essential, therefore, that: (a) all vessels, including the Scotia, used the same trawl gear for the anglerfish surveys; (b) the gear was rigged in a consistent manner; and (c) no modifications to the trawl were employed. FRS therefore, purchased four new trawls to equip each vessel on the anglerfish survey with the same sampling tool.

More importantly, the type of trawl used was that accepted by the industry as being the most effective to catch anglerfish. The specification for the trawl was, therefore, drawn up by a sub-group of the MISP group and included the following specification:

- Each trawl to be towed in a single trawl configuration by chartered commercial fishing vessels and FRV Scotia.
- The trawl design should be typical of that used by the Scottish fleet targeting the west coast anglerfish fishery down to water depths of 1000 m and be suitable for vessels with main engine power in excess of 1200 hp.
- Ground gear length to be 150 ft.
- Rockhopper discs in the centre to be 16" diameter and rigged on 19 mm chain.
- To ensure no anglerfish pass over the headline the design must incorporate a 'ballooned' top sheet (approximately 20% more) similar to that already supplied to the fleet.
- To ensure small anglerfish and megrims are retained, the mesh size in the lower wings must be 120 mm.
- High tenacity twine should be used throughout the trawl's construction.
- Both headline and footrope to be wrapped with rope and include selvedge ropes.
- Design must incorporate measures to give added strengthening to weak points around the mouth and belly of the trawl. This strengthening to be similar to that which would normally be built into commercial scraper trawls (i.e. top and bottom guard meshes and tearing strips etc).
- Must include a tickler chain of 19 mm chain as per standard length to suit this gear.
- The wire rig should include 6 x 20 fm lengths of 26 mm wire single spreaders, 2 x 10 fms of 22 mm chain and 20 fm double spreaders, 18 mm wire for the top and 19 mm chain on the bottom.
- Trawl doors to be provided by the vessels. This was thought to be feasible by the MISP group. FRS purchased a set of doors which were specified as part of the charter tender: Ovalfoil OF12, 1700 kg, 3.3 m x 2.1 m, 5.82 m2. In the case of FRS these have been supplied by Morgere.

Charter (commercial vessel) specification

In 2006, the MISP group discussed the content of FRS' Invitation to Charter document and made appropriate alterations according to experiences from the 2005 survey. The main points regarding vessel requirements for 2006 included: Vessel to be full shelter decked and have a length to be equal to or greater than 27 m (88 ft); fishing wire greater than or equal to 2000 m; doors for the trawl (only the latter supplied)

are Morgere Ovalfoil OF12, 1700 kg, 3.3 m x 2.1 m, 5.82 m^2; wire rig should include 4 x 20 fm lengths of 26 mm wire single spreaders, 2 x 10 fms of 22 mm chain and 20 fm double spreaders, 18 mm wire for the top and 19 mm chain on the bottom; accommodation and victuals for up to three scientific staff; and a working hull mounted Scanmar hydrophone.

Catch sampling procedures

Each chartered vessel carried three scientific staff from FRS who were responsible for processing the catch. Samples were processed in accordance with FRS standard operating procedures for trawl surveys. Every single anglerfish was measured for: species (*Lophius piscatorius* or *Lophius Budagassa*); length; sex; maturity (Alfonso Dias and Hislop 1996); total weight; and gutted weight. The otoliths and illicia were taken for analysis back in the laboratory.

The rest of the catch was processed by the crew and landed to offset the cost of the charter. There were no quota restrictions: each vessel was provided with an appropriate derogation to ensure that no days at sea were lost due to participation in the survey, to allow the use of small mesh netting, and to fish in any area currently closed to fishing for the duration of the survey (with the exception of closed areas to protect deep water corals).

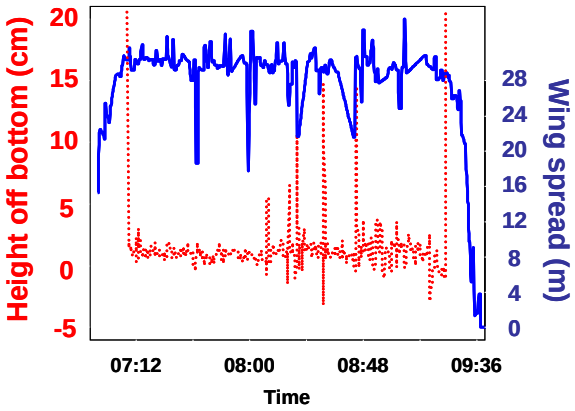

Figure 3. An example of the gear measurements made during a single trawl sample from 07:00 to 09:36 hrs during the 2005 anglerfish survey. The solid blue line is the wing spread (right axis in metres) as measured by Scanmar distance sensors. The dotted red line is the height of the trawl off the bottom (left axis in centimetres) as measured by the bottom contact sensor.

Gear measurements

Three types of acoustic gear sensors were installed on each vessel: Scanmar door spread, and wingspread sensors and a NOAA bottom contact sensor. Data from door, wing spread & bottom contact were collated from each haul. An example of the data collected from a single trawl haul is given in Figure 3. Measurements of wing spread and door spread were filtered (for spurious values) and where necessary interpolated to provide values at all times. These data were matched to bottom contact data (where available) and truncated to measurements made only when the trawl was on the bottom on the basis of bottom contact information (e.g. see Figure 3). This avoids any bias due to end effects where the swept are is underestimated if haul duration is used (Battaglia et al., 2006). In 2006, bottom contact sensors used on two of the surveys (Rockall and North of Scotland) were damaged, and so measurements of trawl depth and trawl height were used to identify points where the trawl had arrived and departed from the seabed. The data were matched to positional information (GPS) at the same time resolution. The swept areas of the wings and doors were then calculated as the sum of the individual wing/door spread measurements multiplied by the distance traveled between successive measurements. Where wing spreads and/or door spreads were not available (due for example to instrument failure) these were estimated from the trawl depth using a wing or door spread to depth relationship derived from the 2005 data.

Data analysis

All anglerfish counts and weights were taken for each haul.

The average fish density at age a in stratum s, ρ_{as}, was estimated by correcting the haul counts for catchability and swept area as follows:

$$\hat{\rho}_{as} = \frac{1}{m_s} \sum_i \frac{n_{ais}}{v_{1i} \hat{Q}_i} \qquad (1)$$

where:

n_{ais}=number of fish of age a caught in trawl i in stratum s

m_s=number of trawl hauls in stratum s

v_{1i}=area swept by net in trawl i (the area swept by the wings)

$\hat{Q}_i$ =catchability estimate for trawl i

Catchability was estimated as follows (Sommerton 1996):

$$\hat{Q}_i = e + e\hat{h}\frac{v_{2i}}{v_{1i}} \qquad (2)$$

where:
e =proportion in v_1 caught (assumed to be 1)
v_{2i}= sweep area in trawl i i.e. the area swept by the door minus that swept by the wing
h=herding coefficient i.e. the proportion in v_2 herded into v_1.

Estimates of the herding coefficient $\hat{h}$ = 0.017 (S.E.=0.002) were made from an individual based model using results from video observations of anglerfish in the area of the sweeps (Reid *et al.* 2007).

The variance estimate for $\hat{\rho}_{as}$ must take the variance of $\hat{Q}_i$ and hence $\hat{h}$ into account. Here we used the delta method for approximating variance (e.g. Seber 1982 pages 7-9), resulting in the following:

$$\hat{\text{var}}(\hat{\rho}_{as}) = \frac{1}{m_s^2}\left\{\hat{\sigma}^2_{nas}\sum_i \frac{1}{\left(v_{1i}\hat{Q}_i\right)^2} + \hat{\sigma}^2_h\left(\sum_i \frac{ev_{2i}\, n_{ais}}{\left(v_{1i}\hat{Q}_i\right)^2}\right)^2\right\} \qquad \textbf{(3)}$$

where**:**

σ^2_{as} = the sample variance of counts at age a in stratum s

σ^2_h = the variance of $\hat{h}$.

The number of fish at age in stratum s was then:

$$\hat{N}_{as} = A_s\hat{\rho}_{as} \qquad (4)$$

and the corresponding variance:

$$\hat{\text{var}}(N_{as}) = A_s^2\,\hat{\text{var}}(\hat{\rho}_{as}) \qquad \textbf{(5)}$$

where:

A_s=area of stratum s.

The total number of fish at age was then:

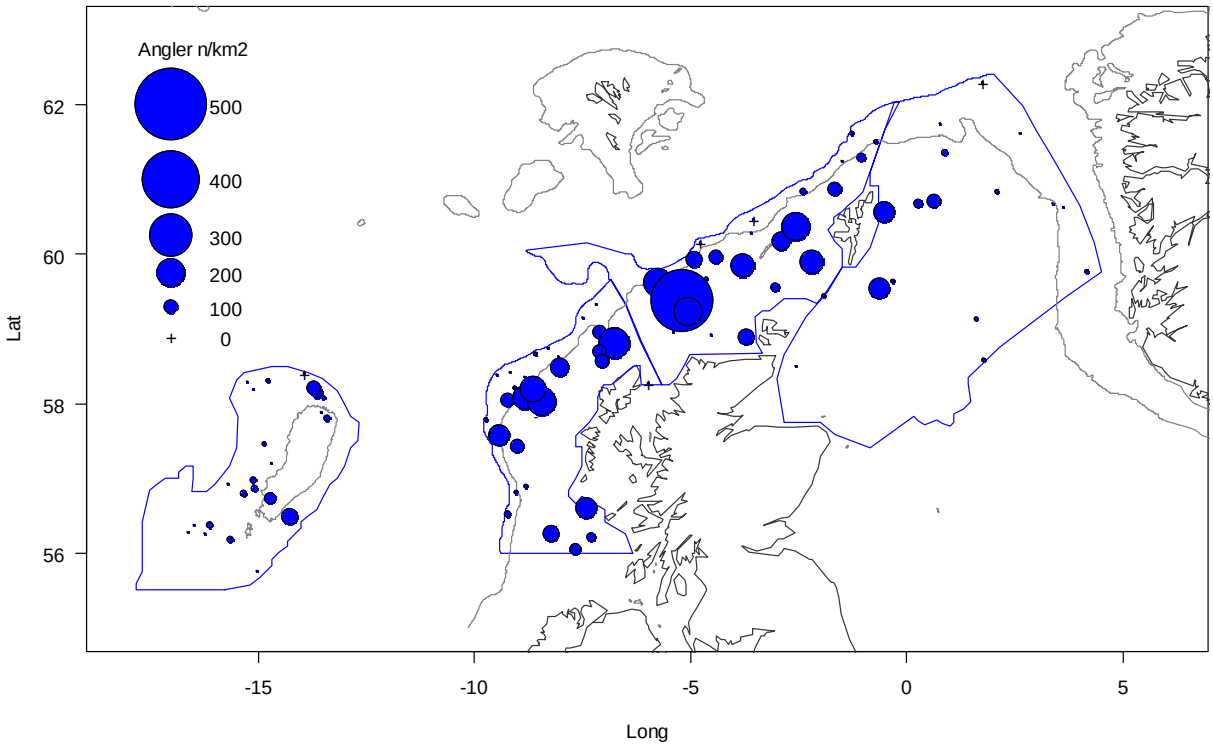

Figure 4. Map of the northern continental shelf around Scotland showing the number density of anglerfish caught during the 2005 anglerfish survey. Each circle is centred on the sample location and the size of the circle is proportional to the number density in n/km^2 according to the legend (top left).

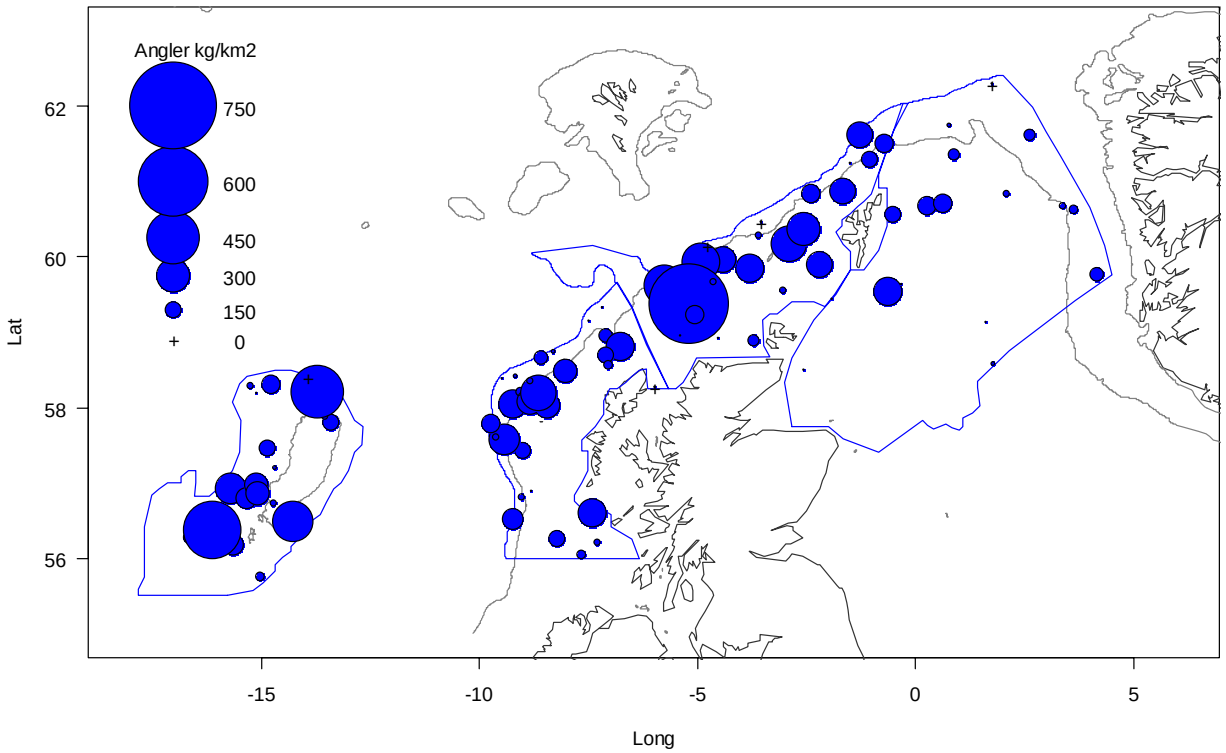

Figure 5. Map of the northern continental shelf around Scotland showing the weight density of anglerfish caught during the 2005 anglerfish survey. Each circle is centred on the sample location and the size of the circle is proportional to the weight density in kg/km^2 according to the legend (top left).

$$\hat{N}_a = \sum_s \hat{N}_{as} \qquad \textbf{(6)}$$

and the total variance at age was:

$$\hat{v}ar(\hat{N}_a) = \sum_s \hat{v}ar(\hat{N}_{as}) \qquad \textbf{(7)}$$

Survey precision was expressed as the relative standard error (RSE) according to (ICES 2004) as: 100% × standard error / estimate (Jessen 1978), as well as 95% confidence intervals, assuming a normal distribution of estimates. A similar scheme was carried out for the weight density to estimate biomass.

To obtain regional estimates relevant to ICES sub-areas, the survey strata were divided further into sub-strata to reflect ICES boundaries: i.e. east and west of longitude 4° west; and north and south of latitude 56°30' North. If any one of the resultant strata contained fewer than 3 observations, the density for the original stratum was applied to each of its sub-strata before being multiplied by the appropriate sub-stratum area. If a stratum contained a single observation, data from this stratum were pooled with the nearest stratum of similar density to obtain a variance estimate for both strata.

Irish participation

In 2006 the Irish Marine Institute also participated in the survey extending the area south, from the coast of Ireland west to the Porcupine from 56.5ºN to 50.5ºN (see Fig. 2). The Irish survey added another dimension to the study by externally tagging and releasing 724 anglerfish with spaghetti dart tags. To date two of these fish have been recaptured displaying limited movement patterns for the fish in question. The vessels followed the same methods as described above, employing the same demersal trawls, with the exception that the anglerfish sampled on the Irish survey were not aged. The Irish data also had several missing gear measurements and so the wing spread and door spreads were estimated from the depth using wing/door spread to depth relationships derived from existing measurements in the Irish data.

Results

The 2005 survey

The 2005 anglerfish survey took place from 4-14 November and involved FRV *Scotia*

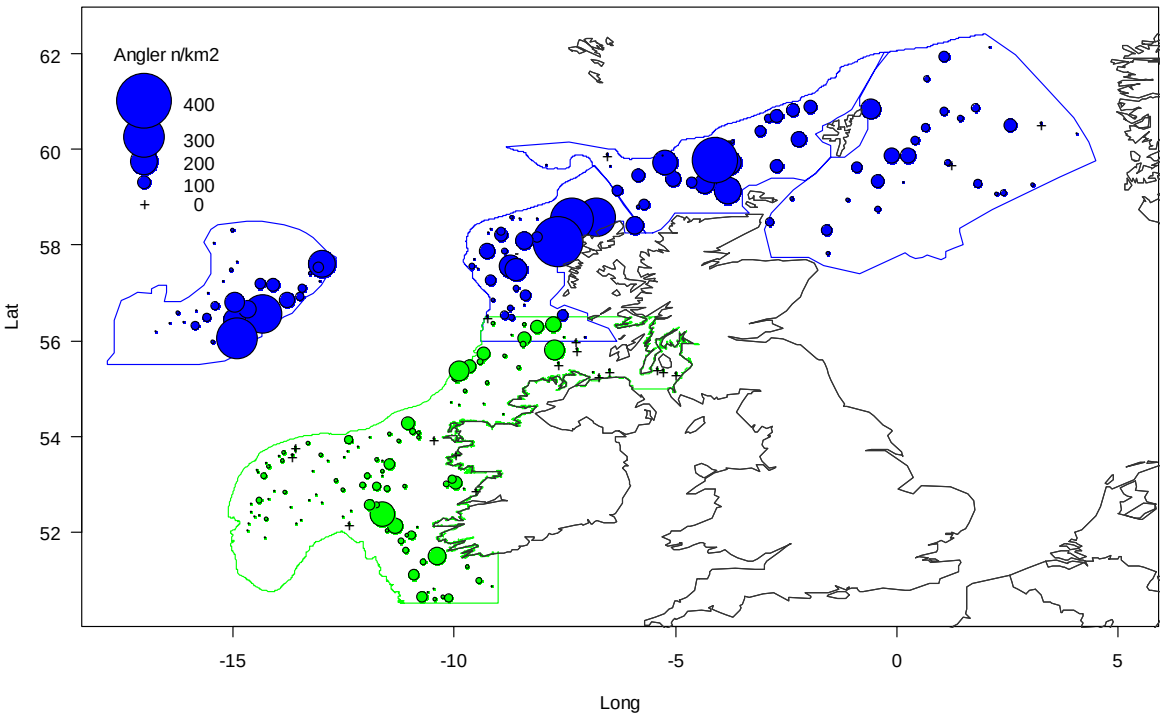

Figure 6. Map of the northern continental shelf around the British Isles showing the number density of anglerfish caught during the 2006 anglerfish survey. Each circle is centred on the sample location and the size of the circle is proportional to the number density in n/km^2 according to the legend (top left): green circles: Irish surveys; blue circles Scottish surveys.

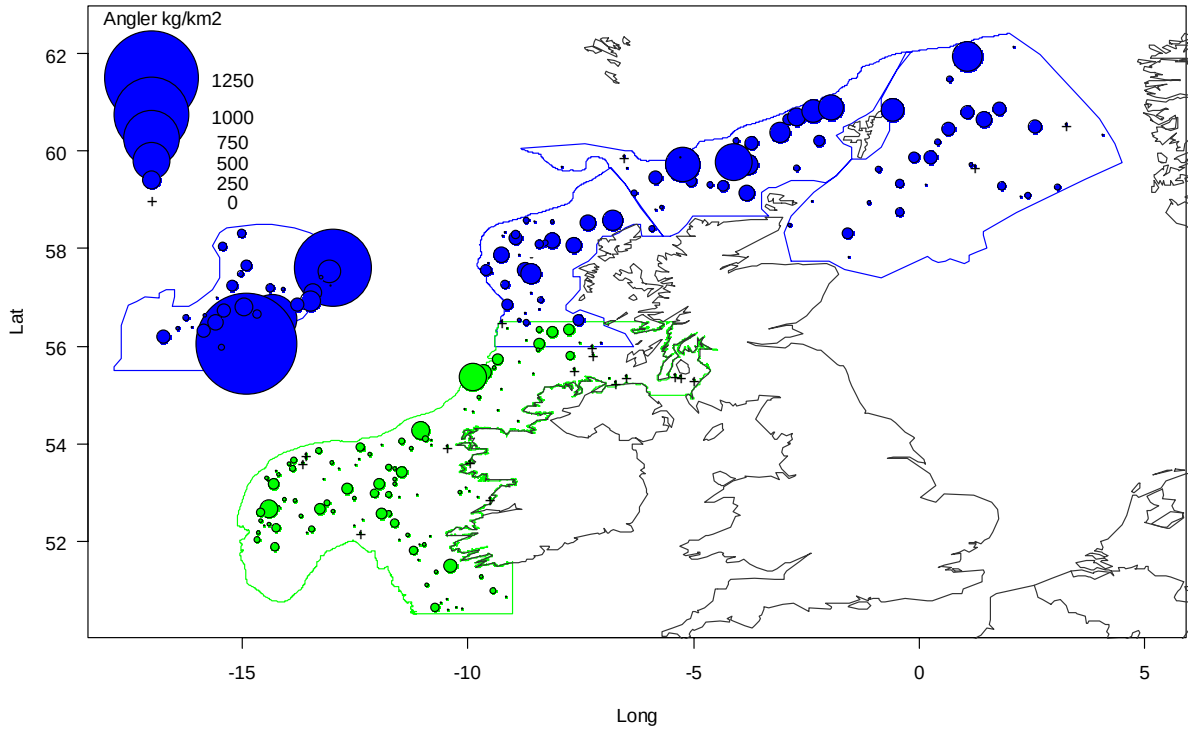

Figure 7. Map of the northern continental shelf around Scotland showing the weight density of anglerfish caught during the 2006 anglerfish survey. Each circle is centred on the sample location and the size of the circle is proportional to the weight density in kg/km^2 according to the legend (top left): green circles = Irish surveys; blue circles = Scottish surveys.

(overall length 68.6 m) and three commercial vessels: the MFV *Atlantic Challenge* (33.9 m), MFV *Endeavour III* (27.4 m), and the MFV *Minerva* (24.8 m). Each of the four vessels surveyed four different areas (illustrated in Figure 1). A few areas were excluded from sampling due to the nature of the substrate making them inaccessible to the trawl. These were either areas of deep water coral or hard ground (see Figure 1). The sample locations (n=93) are illustrated in Figure 4 as the number density (number per square kilometre); and in Figure 5 as weight density (kilograms of anglerfish per square kilometre). The highest densities of anglerfish were observed close to the 200 m contour in the North and West areas, and also in the 200-500 stratum in the Rockall area. There were very few samples (4) where no anglerfish were caught.

The catch rates expressed in terms of kilograms of anglerfish per hour trawled were similar to those observed in the fishery. In eight years of observed fishery data (1998-2005), the average catch rate was 22.4 kg/hr (ICES 2007a). In the survey, the catch rate, when expressed in these units, was 21.8 kg/hr. In recent years, the commercial catch rate has increased and so the former figure would be greater in the recent directed fishery. Nonetheless, it was reassuring to see that the catch rates from the survey (which is taken from throughout the area) were similar to those from the fishery.

The 2006 survey

The 2006 anglerfish survey took place from 31 October - 13 November and involved FRV Scotia (overall length 68.6 m) and three commercial vessels: the MFV *Seagull* (27.4 m), MFV *Caspian* (27.4 m), and the MFV M*arigold* (28.3 m). Each of the four Scottish vessels surveyed the same four areas as in 2005, albeit with new strata (illustrated in Figure 2). An additional area at Rockall was excluded from sampling due to the establishment of an area to protect deep sea coral. The Irish survey was carried out on a thirty-day charter on three commercial fishing vessels; MFV *Avro Warrior*, MFV *Catherine R* and the MFV *Marliona*. The sample locations (Scottish surveys n=115; Irish surveys n=121) are illustrated in Figure 6 as the number density (number per square kilometre) and in Figure 7 as weight density (kilograms of anglerfish per square kilometre). The highest densities of anglerfish were once again observed close to the 200 m contour in the North and West areas, and also in on the steep slopes on the east side of Rockall. There were again only a few samples (n=4) where no anglerfish were caught in the Scottish survey; in the Irish survey there were 14 samples without any anglerfish.

Survey estimates

The provisional results of the two surveys are presented by stratum in Tables 1 and 2 (2005 and 2006 respectively) and by age, where available, in Tables 3 and 4.

In 2005, the estimate for Area IV was 15,578 t and for Area VI 16,506 t; the total survey estimate was 32,084 t. The area with the biggest biomass was the largest – the east stratum (northern North Sea) with 11,130 t, although this was also the area with the greatest uncertainty (relative standard error of 45%).

In 2006, the estimate for Area IV was 18,953 t and for Area VI 16,021t; the total survey estimate was 34,974 t. The northern North Sea

Table 1. Abundance of anglerfish from the 2005 survey by region. RSE = relative standard error; 95% CI= 95% confidence interval. *Note that these estimates represent only a partial area of the stock and therefore represent a minimum estimate only.

2005 Region	Abundance Millions	RSE	-95% CI Millions	+95% CI Millions	Biomass Tonnes	RSE	-95% CI Tonnes	+95% CI Tonnes
East	6.584	51.2	0.000	13.331	11130	44.9	1139	21122
North (West of 4°)	2.719	35.8	0.771	4.667	4612	34.5	1432	7792
North (East of 4°)	2.357	22.0	1.320	3.394	4448	19.8	2684	6212
Rockall	1.574	18.9	0.978	2.170	6128	29.8	2476	9779
West	4.040	20.5	2.380	5.699	5767	20.8	3367	8166
Area IV*	8.942	38.2	2.115	15.768	15578	32.6	5432	25725
Area VI*	8.333	15.8	5.705	10.961	16506	16.4	11103	21910
Northern shelf*	**17.275**	**21.2**	**9.960**	**24.589**	**32085**	**17.9**	**20589**	**43580**

Table 2. Abundance of anglerfish from the 2006 survey by region. RSE = relative standard error; 95% CI= 95% confidence interval. *Note that these estimates represent only a partial area of the stock and therefore represent a minimum estimate only.

2006 Region	Abundance Millions	RSE	-95% CI Millions	+95% CI Millions	Biomass Tonnes	RSE	-95% CI Tonnes	+95% CI Tonnes
East	6.728	10.9	5.261	8.194	13940	15.1	9726	18155
North (East of 4°)	3.077	38.0	0.738	5.416	5112	26.3	2424	7799
North (West of 4°)	2.158	18.0	1.380	2.935	3210	21.5	1832	4588
West (North of 56°30'N)	3.341	16.9	2.215	4.467	4144	12.3	3125	5162
Rockall	2.433	14.5	1.728	3.138	6320	13.2	4650	7990
Irish (North of 54°30'N)	1.668	25.2	0.828	2.508	2248	23.3	1202	3294
Irish (South of 54°30'N)	3.664	11.4	2.830	4.499	6333	10.6	4987	7680
Area IV*	9.771	14.1	7.014	12.529	18953	13.2	13964	23941
Area VI	9.633	9.1	7.874	11.393	16021	8.2	13391	18651
Area VII*	3.664	11.4	2.830	4.499	6333	10.6	4987	7680
Northern shelf*	**19.405**	**8.4**	**16.134**	**22.675**	**34974**	**8.1**	**29334**	**40613**

was once again the largest contributor to the biomass with 13,940 t and on this occasion the precision was much better at 15%.

The estimates at age indicate some selection at younger ages (Tables 3 and 4), as is typical for fisheries trawl based surveys. This is partly due to the size selection of the trawl gear, which is being investigated, but also due to the availability of juveniles which may be distributed further inshore. The estimates at younger ages are also rather imprecise. At the older ages, the estimates are also imprecise due to the small numbers encountered.

Discussion

The estimates of abundance of anglerfish from the two surveys are in line with previous attempts to quantify their abundance (ICES 2003, total stock biomass of 36,500 t), particularly when one considers that the area covered by the surveys is less than the total area of the Northern Shelf (the survey omitted the central and southern North Sea, the Skaggerak and Kattegat). The areas surveyed in 2005 and 2006 are also not directly comparable due to the participation of the Irish Marine Institute in 2006 which allowed for a complete estimation in Area VI. Interpolation schemes to deal with this are under development, such as, for example, geostatistical simulations (Gimona and Fernandes 2003) using the more complete survey coverage of the International Bottom Trawl Survey as external drift.

A common problem in fisheries surveys is that of survey precision. In this case, the precision has improved significantly from an RSE of 21% in 2005, to 8% in 2006. This justifies the decision to reduce the tow length from two hours in 2005 to one hour in 2006; and to re-allocate samples to the different strata in 2006 based on fishermen's knowledge. The precision of the survey in the northern North Sea was particularly improved on in 2006.

The estimates are however, only provisional. There are a number of aspects still under consideration, most notably an estimate of trawl selectivity (e in Equation 2). In the longer term, a more accurate estimate of anglerfish catchability, incorporating an estimate of the proportion caught by the gear (e) will be available from the results of another research project being conducted at FRS. This project aims to determine how many anglerfish escape under the footrope (which will increase the estimate – because the true density would be higher). This will hopefully contribute to a correction of some of the bias associated with the estimation of the smaller (younger) fish (as evidenced from the relatively low numbers caught).

There is also the question of the availability to the trawl of anglerfish swimming in midwater. Studies of the vertical distribution of anglerfish using data storage tags (DSTs) have been carried out in Iceland and the north east coast of the United States of America (Rountree et al., 2006). These indicated that angler spend a very small proportion of their time in midwater. The extent of this behavoiur on the northern shelf will be determined by studies of anglerfish vertical

Table 3. Abundance of anglerfish from the 2005 survey by age. RSE = relative standard error; 95% CI= 95% confidence interval

2005 Age	Abundance Thousands	RSE	-95% CI Thousands	+95% CI Thousands	Biomass Tonnes	RSE	-95% CI Tonnes	+95% CI Tonnes
0	926	43.8	115	1737	130	42.4	20	240
1	692	44.7	73	1311	192	50.2	0	385
2	2311	48.8	55	4567	1144	48.8	28	2261
3	2029	21.7	1147	2911	1712	27.4	776	2649
4	3927	32.3	1390	6463	5387	35.9	1519	9256
5	4023	25.2	1996	6051	8192	27.3	3724	12660
6	1818	16.7	1212	2424	5614	17.1	3690	7538
7	946	29.2	393	1499	4500	33.2	1511	7488
8	298	48.4	9	586	2040	52.8	0	4196
9	153	50.9	0	308	1336	51	0	2699
10	24	101.9	0	74	341	107.8	0	1077
11	25	82.9	0	67	406	88	0	1120
12	34	53.7	0	70	715	54.7	0	1497
13	5	348.3	0	41	159	348.3	0	1268
14	0				0			
15	4	129.1	0	14	113	129.1	0	405

Table 4. Abundance of anglerfish from the 2006 survey by age. RSE = relative standard error; 95% CI= 95% confidence interval

2006 Age	Abundance Thousands	RSE	-95% CI Thousands	+95% CI Thousands	Biomass Tonnes	RSE	-95% CI Tonnes	+95% CI Tonnes
0	323	32.7	112	533	31	28.6	13	48
1	1251	16.3	843	1660	351	17.7	227	476
2	3224	14.6	2281	4168	1400	15.5	965	1836
3	2753	14.3	1964	3541	1994	13.7	1446	2542
4	3645	14.2	2610	4681	4956	14.2	3545	6368
5	2971	11.2	2303	3639	6381	11	4982	7779
6	2567	11.2	1991	3143	8104	11.9	6171	10037
7	1219	16.6	813	1625	5444	18.5	3424	7463
8	180	32.7	62	298	1163	36.5	313	2014
9	184	34.3	58	309	1722	35.3	505	2938
10	40	68.3	0	94	615	71.8	0	1497
11	30	83.6	0	81	482	81.5	0	1268
12	13	61.3	0	29	345	60	0	758
13	0				0			
14	4	83.8	0	10	177	83.8	0	473
15	0				0			

movements based on the deployment of DSTs. A total of 24 DSTs were surgically implanted into 24 anglerfish in the northern North Sea in 2005 and 12 were deployed at Rockall in 2006. These tags record time, depth and temperature. There is a £50 reward for any tag that is returned. To date none have been retrieved. The DST should also provide information which may allow for the anglerfish horizontal movements to be determined (from knowledge of depth and sea temperature).

In 2006, a visual survey of anglerfish was also conducted using FRS' video survey equipment which is normally used to count Nephrops burrows. The video camera is mounted on a towed sled and has a field of view

of the seabed which is approximately 80 cm wide. The sled was towed at a speed of 1 knot for half an hour: this gave a sampled area of approximately 800 m^2. The equipment was rather delicate and in the poor weather encountered could only be deployed on 5 occasions. In total, these five samples covered an area of 4167 m^2 which is $1/70^{th}$, or less than 2%, of the area swept by a single 2 hour trawl. Only one anglerfish was seen in the area sampled which gave an anglerfish density of 240 individuals per square kilometre (cf. an average of 84 individuals per square kilometre for the trawls) – but this is extremely imprecise as it is based on just one observation.

Clearly, the equipment used for the 2005 visual survey was not fit for purpose and at least one industry representative expressed reservations about conducting further such work in 2006. Two main drawbacks were apparent: i) The area that the equipment is capable of sampling [viewing] was too small for the comparatively low density of anglerfish and; ii) the equipment was too vulnerable to poor weather in its deployment. This equipment, as it was configured in 2005, will not be used again. A new system has been designed in 2006 and is currently being built for the 2007 surveys. This will encompass a robust small vehicle, capable of being deployed and recovered in all but the worst of weather, which will fly at both a higher altitude above the seabed and a much faster speed so that the area sampled can be increased substantially.

As yet, no attempts have been made to consider how these estimates might be used in the formal assessment of the stock or how to manage the stock. Using the recommended precautionary fishing mortality of 0.3 (equivalent to an annual harvest rate of 26 %) would imply a TAC of just over 9,000 t for the northern shelf anglerfish based on the current estimate. However, until a better estimate, taking into account the net's full catchability, can be obtained, such measures can not be recommended.

Conclusions

The 2005 and 2006 FRS & MI industry science anglerfish surveys have provided estimates which reflect the minimum abundance of the anglerfish population on the northern shelf. However, these estimates must be considered provisional until estimates of the bias associated with the catchability of the gear can be finalised. The latter is the subject of a research project at FRS which has already yielded useful results regarding the herding of the trawl sweeps. Investigations into escapes under the footrope will be carried out next.

Various attempts were made to improve the precision of the survey from 2005 to 2006, notably the restratification, and the reduction in tow duration, which allowed for more samples to be collected. Indications are that these resulted in an improvement in the precision of estimates of biomass from 18% to 8% (relative standard error).

Further collaboration with industry and with other nations can only improve the quality and coverage of the surveys. Another joint FRS MI survey is planned for 2007, with the MI extending it's tagging programme to include DST tag deployment. Finally, the area of the northern shelf is considerable and, as such, the survey can only be expected to produce a minimum estimate, until either an appropriate extrapolation method has been developed, or additional vessels can cover those areas that remain unsampled. In the latter regard, the survey would benefit greatly from participation of other nations with an interest in this fishery, such as Norway, Denmark and France. In the meantime, work will continue in an attempt to determine the best possible minimum estimates of the absolute abundance of this stock.

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