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Stock Annex: Anglerfish (*Lophius budegassa, Lophius piscatorius*) in Subareas 4 and 6, and in Division 3.a (North Sea, Rockall and West of Scotland, Skagerrak and Kattegat)

Stock specific documentation of standard assessment procedures used by ICES.

Stock	Anglerfish
Working Group	Working Group on the Celtic Seas Ecoregion (WGCSE)
Created	
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A. General

A.1. Stock definition

Particle tracking models have shown that there is potential for considerable larval dispersal of anglerfish during the pelagic stage (Hislop, 2001). Whereas returns from tagging studies to date have been low, there is evidence that individuals are capable of migrating considerable distances, even navigating significant geographical features such as the Faroe-Shetland channel (Laurenson *et al*., 2005). There is limited recent literature addressing genetic variation within this stock area. Previous studies using a variety of methods have found no evidence of genetic differences between any of the Northeast Atlantic stocks out with the Mediterranean (Blanco *et al*., 2008; Canas *et al*., 2012; Farina *et al*., 2004). Evidence from Anon (2001) and Hislop (2001) indicate that anglerfish in Division 4.a, divisions 6.a and 6.b (Rockall) should be treated as a single stock. The stock might in fact extend into 7, 5 or 2.a, although there is currently insufficient evidence to support an extension of the stock area.

The current stock definition includes ICES subareas 4 and 6, and Division 3a. The majority of fleets fishing this 'stock' land *Lophius piscator*ius (*L. piscatorius*) and *Lophius budegassa* (*L. budegassa*) together, sold as "monkfish". Although the distributions of *L. piscatorius* and *L. budegassa* overlap, survey catches of *L. budegassa* in the Scottish Irish Anglerfish and Megrim Industry Science Survey (SCO-IV-VI-AMISS-Q2) comprise only a relatively small proportion of the estimated stock abundance (~7% 2007–2016). Proportions of *L. budegassa* in Subarea 4 and Division 6.b are negligible (~5% and ~0.5%). They are most abundant in the southerly region of Division 6.a (~15%) where their distribution appears to extend from the southern Celtic Seas stock (7.b–k,8.a–b and 8.d).

A.2. Fishery

UK vessels account for more than 60% of the total reported anglerfish landings from the total stock area. The Danish and Norwegian fleets are the next most important exploiters of this stock in the North Sea. The fishery for anglerfish in Subarea 6 occurs largely in Division 6.a (West of Scotland) with the UK and France being the most important exploiters, followed by Ireland. Reported landings from Rockall (Division 6.b) are generally less than 2000 t with the UK taking on average around 50% of the total. In the North Sea, the majority of landings are reported in Division 4.a which reflects the northerly distribution of the species within the North Sea (Knijn *et al*., 1993).

A general description of the anglerfish fisheries of the most important nations taking part in this fishery is given below:

Scottish (UK) fishery

The Scottish fisheries taking anglerfish comprise three main fleets, the demersal trawl fleet targeting mixed round fish (mesh size >120 mm), one targeting *Nephrops* (mesh size 70–99 mm); in which anglerfish are a bycatch (159 vessels in Subarea 6 and 134 in Subarea 4) and a deep-water gillnet fleet (mesh size >220 mm) targeting monkfish and ling.

The Scottish directed fishery for anglerfish developed during the 1980s and led to considerable changes in the behaviour of the fleet. Part of this was a change in the distribution of fishing effort; the development of a directed fishery having led to effort shifting away from traditional roundfish fisheries in inshore areas to more offshore areas and deeper waters. The expansion in area and depth range fished was accompanied by the development of specific trawls and vessels to exploit the stock. There was an almost linear increase in landings since the start of the directed fishery until 1996 which was then followed by a very severe decline, indicating the previous increase was almost certainly due only to the expansion and increase in efficiency of the fishery. Further declines in reported landings during the period 2003–2005 may have been due to restrictive TACs and the decline is not necessarily representative of the actual landings.

In Division 6.a the Scottish demersal trawl fleet takes around 30% of landings. Approximately 5% of landings are bycatch from the *Nephrops* trawlers.

The Scottish fleets operating in 6.b are the demersal trawl fleet (~30%) and the gillnet fleet (~18%). The majority of the trawl vessels are targeting haddock at Rockall in which anglerfish are a wanted bycatch species with the exception of a handful of quota-rich vessels exclusively targeting monkfish.

The Scottish fishery for anglerfish in the North Sea is located in two main areas: on the Shelf Edge to the north and west of Shetland and at the Fladen Ground. The fishery to the north and west of Shetland operates as an extension to that in Division 6.a, and consists mainly of trawlers targeting mixed roundfish. The highest reported landings in recent years come from the statistical rectangles around Shetland. The landings from the fishery along the western edge of the Fladen ground are lower but still significant where anglerfish are caught as a bycatch in the *Nephrops* fishery which consists of approximately 62 vessels fishing this ground.

In the mid-1990s, a deep-water gillnet fishery targeting anglerfish developed on the continental slopes to the west of the British Isles, north of Shetland, at Rockall and the Hatton Bank. In recent years (2006–2016) ~17% of total landings are from this fishery. A large proportion of the landings in the gillnet fishery are taken by Spanish owned, UK registered vessels. The fishery is not well documented or understood and there is little information on catch composition or discards.

Irish fishery

The Irish fleet, which takes around 10% of the total Division 6.a landings is a demersal bottom-trawl fleet using ≥100 mm mesh targeting anglerfish, hake, megrim and other gadoids on the Stanton Bank and on the slope northwest of Ireland. There is also an Irish demersal bottom-trawl fleet fishing in Division 6.b taking anglerfish as a bycatch in the haddock fishery on the Rockall Bank. The fleet targeting haddock uses ≥100 mm mesh; effort depends on haddock abundance and availability of quota.

Danish fishery

According to logbook records, the majority of Danish anglerfish landings are taken in the northeastern North Sea, in the part constituting the Norwegian Deeps, situated in the Norwegian EEZ of the North Sea. Other important fishing areas for anglerfish are the Fladen Ground (also in 4.a) and in the Skagerrak (3.a). More than 80% of the Danish landings come from ICES divisions 4.a and 3.a. The remaining part is from the most northern part of Division 4.b.

The majority of the Danish vessels are taking anglerfish with demersal trawls with over 90% of these vessels in the size range 20–40 m.

Fishery definitions by gear type and mesh size as currently used by Danish Fisheries Directorate for the North Sea are given in the following text table:

Fishery/gear	Mesh size, mm
Dem. Trawl	>= 100 mm
Nephrops trawl	70–99 mm
Shrimp trawl	33–69 mm
Industrial trawl	< = 32 mm
Beam trawl	>= 80 mm

Note that in the North Sea demersal trawls account for more than 90% of total Danish landings. However, it is necessary to further specify that at present the majority of the Danish catches of anglerfish are taken by fisheries in the Norwegian zone of 4.a applying demersal trawls with mesh size >= 120 mm. In the Skagerrak (3.a) the two main fisheries taking anglerfish are the (mixed) *Nephrops* fishery (~60%) and the demersal trawl fishery (~15%). In both areas minor landings are taken in gillnets and as bycatch in fisheries for shrimp (*Pandalus*).

Typically anglerfish constitutes less than 15% by weight of the landings from demersal trawlers fishing in the Norwegian Deeps.

Norwegian fisheries

A Norwegian directed gillnet fishery (360 mm mesh size), targeting large anglerfish, carried out by small vessels in coastal waters in the eastern part of the northern North Sea started in the early 1990s. Historically these vessels are responsible for around 60–70% of the total Norwegian landings from this area although in recent years (since 2014) this has decreased to around 50% and they comprise around 7% of the total landings from Division 4.a since 2006. The remaining Norwegian landings in 4.a are mostly bycatch in various trawl fisheries. A similar pattern of fishing is found in the Skagerrak (3.a). The third quarter has in recent years been the most important season for the directed fishery, while the second quarter is apparently most important for other gears.

Other fisheries

French demersal fishing vessels also take a considerable proportion of the total landings from Subarea 6 (38% from 2006–2016) with demersal and deep-water trawls (>100 mm mesh) used in 6.a and gillnets (>100 mm mesh) in 6.b. The vessels catching anglerfish may be targeting saithe and other demersal species or fishing in deep water for roundnose grenadier, blue ling or orange roughy.

There is also a traditional Basque demersal fishery targeting hake, anglerfish and megrim operating in Subarea 6. Historical landings data suggest that there has been a shift in distribution of fishing effort for this fleet in the early 2000s from 6.b to 6.a. In this last decade there have been 2–4 vessels (around 40 m in length and 1200 horse power) fishing annually, typically with landings around 200–300 t in total.

A.3. Ecosystem aspects

Sea temperature limits the distribution of anglerfish to the north of the Northern Shelf particularly at depths where cold-water currents of polar descent occur. *Lophius piscatorius* is predominant throughout the area, with *Lophius budegassa* occurring in greater density towards the southern part of the area as befits the more general distribution of these two species (Fariña *et al.*, 2008).

B. Data

B.1. Commercial catch

B.1.1. Fishery landings data

Fishery landings data for this stock are compiled from official statistics supplied by individual countries for ICES divisions 3.a, 4.a–c, 6.a and 6.b. Since 2012 countries have submitted these data via the ICES InterCatch web application.

The absence of a TAC for Subarea 4 prior to 1999 means that before 1999, landings in excess of the TAC in other areas were likely to be misreported into the North Sea. In 1999, a precautionary TAC was introduced for North Sea anglerfish, but was set in accord with recent catch levels from the North Sea which included a substantial amount misreported from Subarea 6. The area misreporting practices thus became institutionalised and the statistical rectangles immediately east of the 4°W boundary (E6 squares) accounted for a disproportionate part of the combined 6.a/North Sea catches of anglerfish. The following method has been developed to estimate and correct for area misreporting by the Scottish fleets. Whereas this stock remains ICES category 3 (Stocks for which survey-based assessments indicate trends) this area corrected data are not being utilised for assessment purposes.

1) Estimate a value for the true catch in each E6 square and then allocate the remainder of the catch into 6.a squares in proportion to the reported catches in those squares.
2) Estimate the ‘true’ catches in the E6 squares by replacing the reported values by the mean of the catches in the adjacent squares to the east and west. This mean is calculated iteratively to account for increases in catches in the 6.a squares resulting from reallocation from the E6 squares. Such a reallocation of catches may still inadvertently include some landings taken legally in Division 4.a on the shelf edge to the west of Shetland, but these are likely to comprise fish within the distribution of the Division 6.a stock component.

From WGCSE 2010, this procedure was adjusted to reallocate data to the whole of Area 6: i.e. not just 6.a but including Rockall (6.b). This was based on information received from Marine Scotland Compliance indicating that some vessels fishing for anglerfish at Rockall are reporting large catches in the E6 squares from the same voyage. The distribution of landings this new scheme produced was more in keeping with the distribution of the stock as indicated from the anglerfish surveys. This modified procedure has now been retrospectively applied back to data from 2002.

The TACs for both the West of Scotland and North Sea areas were reduced substantially in 2003 and 2004, and at previous WGs it has been highlighted that these reductions would likely imply an increased incentive to misreport landings and increase discarding unless fishing effort was reduced accordingly (Section 6.4.6, ICES WGNSDS 2003). Anecdotal information from the fishery in 2003 to 2005 appeared to suggest that the TACs were particularly restrictive in these years. The official statistics for these years are, therefore, likely to be particularly unrepresentative of actual landings. The introduction of UK and Irish legislation requiring registration of all fish buyers and sellers may mean that the total reported landings from 2006 onwards are more representative of actual total landings in the UK and Ireland.

B.1.2. Split of landings data by species (*L. piscatorius* and *L. budegassa*)

The landings data are not currently split by species.

B.1.3. Fishery discards estimates

Sampling schemes are in place through DCF to estimate discards in European fleets, and with no MLS (although there is a minimum marketable weight of 500 g) discard rates appear to be relatively low. Scottish discard rates estimated from Scottish observer scheme (see next section for details) have been low in recent years.

Over time the métier codes that have been used by countries to aggregate landings and assign discards have varied although there has been greater consistency since the development of InterCatch and the data call process, For some smaller fleets which have variable effort levels over the years such as the Irish gillnet and squid fisheries in 6.b discarding practices are less well estimated or unknown and the methods by which these are incorporated into countries catch estimation procedure is often unclear.

Following the data call for WKAnglerfish, additional information on discard estimates from Denmark, France, Ireland, UK (England) and UK (Scotland) are now available. There is very limited information on discard rates for the gillnet fisheries operating in this stock area with observer sampling occurring on an irregular basis. For light demersal trawling gears fishing with mesh sizes 100–119 mm there are discard sampling data for 2003 onwards from both Ireland and France. For both demersal crustacean otter trawls (mesh size <99 mm) and for large mesh demersal otter trawls (mesh size ≥120 mm) there are discard data available for all years since 2002 for Denmark, UK (England) and from 2007 for UK (Scotland). The discard rates estimated for the Danish demersal trawl fleet (≥120 mm) in the years prior to 2005 are higher than in recent years (20% in 2002 and 15% in 2005). In the absence of discard data for the Scottish fleets prior to 2007 raised discard estimates, based on the available information from smaller fleets of other nations, are significantly higher than for 2007 onwards. For this reason raised discard estimates are only considered accurate after 2007.

B.1.4. Fishery length compositions

Scotland

Scottish anglerfish catch compositions are estimated from data collected under the Scottish demersal market and observer sampling programmes. Data are currently recorded for both anglerfish species but reported for both species combined. Anglerfish discards for the demersal trawl fleet (mesh size ≥120 mm) have been very low in recent years 1% by weight (2007-2016) whereas discards for *Nephrops* trawl gears has increased significantly in the last three years to from 7% (2007–2013) to 39% (2014–2016).

The current demersal market sampling scheme is stratified by market, aiming to visit each of the four major Scottish markets, which account for around 80% of demersal species landings by weight, at least 36 weeks per year. Trips are selected at random with typically 200 fishing trips from Area 4, and around 40 fishing trips from Area 6 sampled each year. In the years prior to 2010, the sampling scheme was more target based (i.e. target number of samples/fish measured for each area and stock), but still aimed to cover the main landings markets on a regular basis in order to get representative coverage of the fisheries.

The demersal observer programme samples fishing trips allocated in very rough proportion to landings across Areas 4 and 6, and covering the three main vessel groups that land the majority of Scottish demersal species: demersal trawlers, small *Nephrops* trawlers which mainly work inshore and large *Nephrops* trawlers which mainly work offshore. Each trip in each area and vessel group combination is selected by contacting consecutive vessels on a randomly ordered vessel list until a vessel is found that intends to fish in the correct area, will accept the observer on board, and the observer considers meets their logistical and safety criteria. Annual sample sizes are approximately 50 fishing trips for Area 4 and 20 for Area 6. Like the market sampling programme, the observer programme was redesigned in 2010 with the aim of ensuring a more statistically sound sampling strategy.

Estimates for landed numbers-at-length are obtained by "raising" market samples to the six vessel group and area combinations by quarter (TR1 in Subarea 4, Divisions 6.a and 6.b, TR2 in Subarea 4 and Division 6.a and TROther in Division 6.b) by means of post-stratification, including appropriate sampling probabilities, and using species landed weight as an auxiliary variable. Estimates for discarded numbers-at-length are obtained by "raising" discard samples to the six vessel group and area combinations by year, including appropriate sampling probabilities and using gadoid landed weight as an auxiliary variable. Mean weights-at-length are obtained using survey-based weight–length relationships. Scottish discard data prior to 2007 are insufficient to provide estimates of fleet level discard rates and length compositions.

Landings length compositions are available for both the Scottish *Nephrops* trawl and demersal fish trawl fleets from 2002 onwards. There are also landings length compositions available from 2010–2016 for vessels in the demersal trawl fleet that were participating in the fully documented fishery (FDF), operating with remote electronic monitoring systems under a total discard ban for cod. Discard length compositions are available for the same three fleets from 2007 onwards (2010 for FDF) with the exception of 2011 when no length samples were available for the *Nephrops* trawl fleet.

Denmark

Denmark has provided numbers-at-age samples for several of its fleets. In general the coverage of Subarea 4 is greater than for Division 3.a. Length–frequency data for landings taken in Subarea 4 are available from 2002 for the gillnet, *Nephrops* trawl and demersal (>100 mm) trawl fleets. Numbers-at-length data for landings taken in Division 3.a are available only for recent years (2014 onwards) for the *Nephrops* trawl fleet and the demersal trawl fleet with no samples for the gillnet fleet.

For numbers-at-length in the discards data are only available from 2013 onwards for the gillnet fleet in Subarea 4 and not at all for Division 3.a. For the *Nephrops* trawl fleet there are only a handful of sampled years for each area. For the demersal trawl fleets there is a complete time-series of discard length samples available from 2002 for Subarea 4 and 2003 for Division 3.a.

France

Length compositions have been supplied by France for landings only, primarily for the demersal light trawl fleet (100–119 mm) for the years 2002–2016 excluding 2009–2010. In more recent years there are also length frequencies for a large demersal trawl fleet (2011–2016). For the gillnet fleet there is only one length sample for landings from 2008.

Ireland

Length composition data are available for both landings and discard for the Irish light trawl fleet (100–119 mm) from 2003 onwards.

UK (England)

England has provided length compositions of landings for both the *Nephrops* and demersal trawl fleet (>120 mm) from 2002. For these fleets there are also discard length compositions for most years from 2002 with the exception of 2013 for *Nephrops* trawls and 2008, 2012 and 2016 for demersal trawls. There are also landings length compositions for beam trawl fleets of varying mesh sizes and demersal seine-nets for a handful of early years.

Total length–frequency distributions

Since 2002, all national data have been uploaded into InterCatch. A large number of fleets were used, for ease of analysis the fleets were grouped into broad categories which reflect the gears with the largest proportion of catches (OTB <99 mm, OTB 100–119 mm, OTB >120 mm and GNS) with the remainder combined into miscellaneous. For any countries which submit catch data by quarter, the data are split evenly across the 4 quarters so quarterly outputs can be produced.

Missing discards were estimated in three steps;

1) If discard data were available for the same country, gear group and year, the weighted average of the discard proportions for the same country-fleet-year combination were applied to the landings of the strata with missing discards.
2) If discard data were only available for the same gear group and year, the weighted average of these discard proportions were applied.
3) If discard data were only available for the year, a mean discard proportion weighted by landings were applied.

Length distributions were assigned to unsampled catches in the following sequence:

1) From samples from the same area, quarter, year and catch category (landings/discards)

    Area was chosen as opposed to country due to the different length–frequency distributions between ICES divisions within the stock area (in particular at Rockall).

2) From the same quarter, year and catch category if there were samples for a country.

Prior to 2002, total international landings-at-length distributions were calculated slightly differently. For Division 6.a, data were obtained by summing national raised landings-at-length distributions and then raising this distribution to the ICES estimates of total international catch from this area. Landings officially reported to ICES were used for countries not supplying estimates directly to the WG. Sampled data were supplied by Scotland, Ireland, France (not all years) and Spain (not all years).

For the North Sea, only Scottish length compositions have been made available for the period 1993–2001. These have been raised to ICES estimates of total landings to provide an international landings-at-length composition (Scottish landings represent over 60% of the total during this period). Insufficient sampling data are available from Rockall prior to 2002 to provide fleet level estimates.

Previous assessments (ICES, 2003) made use of international landings-at-length compositions for the whole stock (Division 3.a, Subareas 4 and 6) derived by summing the length distributions from the individual areas and assuming that this distribution is representative of the whole Northern Shelf. This was then raised to Working Group estimates of total landings for the Northern Shelf.

Length composition data (landings and discards) for the whole stock area (as required for an analytical assessment) are currently not provided. In order to obtain such data, area specific data will need to be raised to landings by area which have been adjusted to account for area misreporting before being combined to provide an overall length–frequency distribution.

B.2. Biological

B.2.1. Growth and ageing

An international ageing exchange in 2011 (ICES, 2012b) found little agreement between age estimation from both otoliths and *illicia* and concluded that anglerfish ages could not be determined accurately enough for the purposes of producing an international catch-at-age dataset for stock assessment purposes.

WKFLAT (ICES, 2012c) concluded that for *Lophius piscatorius* the studies of growth of Landa *et al*. (2012) should be used as the basis for length-based assessments, and this growth rate is supported by data in Laurenson *et al*. (2005). However, the available growth curves assume asymptotic growth whereas anglerfish length-at-age data from the SCO-IV-VI-AMISS-Q2 survey appear to show linear growth (over the range of caught ages), based on otolith age readings.

Further growth and (ageing) age validation studies taking sex into account are required.

B.2.2. Maturity

There are a number of maturity ogives available for this stock area within the literature. Afonso-Dias and Hislop, 1996 give a length–maturity ogive for West of Scotland, with 50% maturity at approximately 74 cm in females, and 50 cm in males.

More recently Laurenson *et al*., 2008 indicated L_{50} female maturity at 101 cm and males at 53 cm for the same region with similar estimates for females in Rockall (104 cm) and Shetland (96 cm) but higher estimates for males in these respective regions (57 cm and 61 cm). The corresponding age-based ogives indicate L_{50} maturity-at-approximately age ten in females and age five in males.

B.2.3. Natural mortality

Several methods of estimating natural mortality are available and were investigated with input parameters associated with *Lophius piscatorius* at WKAnglerfish (Gerritsen, 2018; Cope, 2017). Given existing knowledge of anglerfish spp. life history and biological traits including their fast initial growth, late maturation, high female gonadosomatic index (GSI) and relatively low predation based on body morphology and sedentary foraging behaviour, the methods likely to produce realistic estimates of M could be fine-tuned. WKAnglerfish recommended that the t_{max} method of Then *et al*., (2015) is preferable which would give a range of potential values of M (0.25–0.4).

B.3. Surveys

A number of surveys are available for this stock and are described in the next sections.

B.3.1. Sco-IV-VI-AMISS-Q2 survey

B.3.1.1 Design of survey

Marine Scotland Science began a new joint science–industry survey in 2005 (current survey name is SCO-IV-VI-AMISS-Q2).This is a targeted anglerfish survey with a scientific design using commercial gear, currently covering part of 4.a and the whole of 6.a and 6.b. In 2005, 2008 and 2010, the survey covered 6.a down to 56°. In 2006, 2007 and 2009, Ireland also participated, extending the anglerfish survey to cover the remaining part of 6.a (from 54°30′ to 56°39′). Since 2011, the Scottish survey covered the whole of 6.a. The survey area is stratified into four main areas, East–East of Orkney and Shetland, North–North of Scotland, West–West of Scotland and Rockall, as shown in Figure 1, which are stratified by depth (0–200, 200–500, 500–1000), and with the 0–200 stratum being further stratified in all except the East Stratum, based on industry perceptions and the results of the 2005 survey. Within a stratum, the expected densities in substrata are defined as “very high”, “high”, “medium” or “low”. The sampling effort within each substratum is allocated according to its expected density, and the sample locations are chosen at random from grids of points within strips of equal area. This is to ensure equal probability of selection and even coverage within a stratum. Approximately 100–150 tows are taken each year. Tow duration is one hour. Each stratum is surveyed by one vessel, with at least one stratum being surveyed by MSS RV Scotia and with the other 2–4 strata being surveyed by industry charters. Each vessel on the survey employs exactly the same gear, the specification of which was drawn up in partnership with industry. Every anglerfish caught is measured for length, sex, maturity, total weight and gutted weights, and otoliths and *illicia* taken. In 2005–2007, surveys took place towards the end of October and beginning of November. However bad weather affected survey coverage to the extent that the survey was moved to April from 2008 onwards (with the exception of 2013 which occurred in October). The stratification and station locations used in 2012 are presented in Figure 1.

A more detailed description of the survey including information on design, sampling, gear and vessel can be found in Fernandes *et al*. (2007). However, estimation has been further developed since then and is described below.

B 3.1.2 Estimation of abundance and catchability components

a) The estimation of abundance and biomass from these surveys is described below. The estimates represent the take into account the following factors: herding of anglerfish by the trawl doors and sweeps;

b) escapes of fish under the trawl footrope (details given below);

c) anglerfish abundance and biomass in the southern part of Area 6 not covered in 2005, 2008 and 2010;

d) visual counts of anglerfish in areas closed to trawling at Rockall;

e) variability due to:

  i) sampling;

  ii) missing ages;

  iii) herding (based on experimental data);

  iv) footrope escapes (based on experimental data).

The estimates currently do not take account of the following:

- areas in the central and southern North Sea (eastern part of ICES Division 4.a and all of 4.b and 4.c);
- areas inaccessible to the trawl in Division 6.a.

To estimate the total number of anglerfish, *N*, from the survey, *S*, carried out in year *y*, $\hat{N}_y$, a Horvitz-Thompson estimator is used. This requires the inclusion probability, π_f, of each fish, *f*, captured in the survey (i.e. the probability of that fish being captured on the survey), which we also need to estimate:

$$\hat{N}_y = \sum_{f \in S} \frac{1}{\hat{\pi}_f}$$

It is assumed that the inclusion probability of a fish depends on its length *l*, the haul *i*, and the stratum *s*, of the survey the haul is in, as we shall see below, so that $\pi_f = \pi_{ils}$. Since the inclusion probability is the same for fish of the same length on the same haul, the estimation equation can be written as:

$$\hat{N}_y = \sum_{s \in S} \sum_{i \in s} \sum_{l} \frac{n_{ils}}{\hat{\pi}_{ils}}$$

where n_{ils} is the number of fish of length *l* captured in haul *i* of stratum *s*.

Millar and Fryer (1999) partition the probability of capture for a fish in the population into three parts, potentially all being a function of length *l*: the probability of being retained in the net given the fish has encountered the net, r_l, the probability that the fish encounters the gear given that it is available to the gear, and the probability of the fish being available to the gear.

It is assumed that all fish in a stratum are randomly distributed in that stratum so that they have equal probability of encountering the gear, so that the probability that a fish is in the path of haul *i* towed in the stratum *s* is given by v_i/A_s, where v_i gives the area swept by the doors (and the net) on tow *i* and A_s gives the area of stratum *s*.

Somerton *et al*. (1999) show that the probability that a fish contacts the fishing net given that it was in the area swept by the haul *i* is given by $\frac{v_{1i}+hv_{2i}}{v_{1i}+v_{2i}}$, where v_{1i} is the area swept by the net in haul i (the area swept by the wings), v_{2i} is the sweep area in trawl *i* i.e. the area swept by the doors minus that swept by the wings, and *h* is the herding coefficient, which gives the proportion in v_{2i} herded into v_{1i}.

Thus the inclusion probability of a fish of length *l* is given by the following equation:

$$\pi_{il} = \hat{r}_l\left(\frac{v_{1i}+hv_{2i}}{v_{1i}+v_{2i}}\right)\frac{v_i}{A_s}$$

where

$\hat{r}_l$ is the estimated probability that a fish which encounters the net is retained in the codend of the fishing net, i.e. does not escape under the footropes,

$v_i = v_{1i} + v_{2i}$,

and N_y can be estimated by:

$$\hat{N}_y = \sum_{s\in S}\sum_{i\in s}\sum_{l}\frac{n_{ils}}{\pi_{ils}} = \sum_{s\in S}\sum_{i\in s}\sum_{l}\left[\frac{n_{ils}}{\hat{r}_l\left(\frac{v_{1i}+hv_{2i}}{v_{1i}+v_{2i}}\right)\frac{v_{1i}+v_{2i}}{A_s}}\right] = \sum_{s\in S}\left\{A_s\sum_{i\in s}\left[\frac{1}{(v_{1i}+hv_{2i})}\sum_{l}\left(\frac{n_{ils}}{\hat{r}_l}\right)\right]\right\}$$

Similarly, the biomass B_y in year *y* is estimated by:

$$B_y = \sum_{s\in S}\left\{A_s\sum_{i\in s}\left[\frac{1}{v_{1i}+hv_{2i}}\sum_{l}\left(\frac{1}{\hat{r}_l}\sum_{j=1}^{n_{ils}}w_{ilsj}\right)\right]\right\}$$

where w_{ilsj} is the weight of fish *j* of length *l* on haul *i* of stratum *s* of survey *S*.

a) Estimation of herding of anglerfish by the trawl doors and sweeps

The estimation of the herding coefficient ($\hat{h} = 0.017$) is described in Reid *et al*. (2007a). An individually based particle-tracking model to simulate the capture process was constructed using behavioural observations of 54 anglerfish captured from TV footage from the wingends and along the sweeps. Detailed analysis of the recordings showed that the fish did not appear to herd and many of the encounters with the wires were passive. All fish in the path of the net were captured, whereas more than half of the fish between the wings and the doors were not.

b) Estimation of escapes of fish under the trawl footrope

The proportion of fish at-length that escaped below the gear was estimated from a series of experimental trawls using bags below the fishing line. These trials are described in Reid *et al*. (2007b). Selectivity functions were fitted to these data in a GLM framework assuming a Binomial distribution. A comparison of three selectivity functions were made: simple logistic, asymmetric logistic (estimating an asymptote parameter) however the simple logistic curve was found to be adequate for these data:

$$r(l) = \frac{\exp(\beta_0 + \beta_1 l)}{1 + \exp(\beta_0 + \beta_1 l)}$$

with β_0= -3.21946 and β_1=0.11386.

This model was then applied to the length data from each survey to correct for those fish that were likely to escape under the net as described above.

c) anglerfish abundance and biomass in the southern part of Division 6.a not covered in 2005, 2008 and 2010;

Estimates of the proportion of anglerfish in the southern part of ICES Division 6.a were derived from 2006, 2007 and 2009 when Ireland contributed to the survey and covered this area completely. The proportions of abundance in this area relative to the whole Northern shelf were 8.6% in 2006, 13.6% in 2007 and 4% in 2009; the proportions of biomass were 5.5% in 2006, 7.4% in 2007 and 2.5% in 2009. The averages of these proportions (i.e. 8.7% for abundance and 5.1% for biomass) were used to raise the estimates of the surveys in 2005, 2008 and 2010 when Scotland did not survey this area and the Irish did not participate.

d) Estimation of anglerfish abundance in areas closed to trawling at Rockall;

Visual counts of anglerfish in areas closed to trawling at Rockall have been carried out in all years since 2007, as described in McIntyre *et al*. (in press). A deep-towed vehicle was developed, equipped with video, lights and other sensors, to enable visual surveying at depths of over 300 m, at speeds of up to 3 knots and altitudes of up to 10 m (from the seabed). This vehicle was used to survey large areas of the seabed around Rockall, in areas which are closed to trawling due to the presence of the deep-water coral *Lophelia pertusa*. Counts were made from visual inspection of the TV footage. The total area surveyed by video was calculated by summing the area surveyed every second over the entire transect, the latter being calculated from the trapezoid between the midpoints of one image frame and the next image frame a second later.

The number of anglerfish $N_{c,y}$ in closed area *c* in year *y* was estimated by:

$$\hat{N}_{c,y} = A_c \hat{\rho}_{c,y} ,$$

where A_c is the surface area of the closed area *c* (km²)

and $\hat{\rho}_{c,y}$ is the mean density of closed area *c* in year *y*, estimated from the survey in year *y* as follows:

$$\hat{\rho}_{c,y} = \frac{1}{t_{c,y}} \sum_{i \in c} \frac{n_{i,c,y}}{A_{i,y}} \qquad (11)$$

where:

$t_{c,y}$ is the number of tows in closed area c in year y

$n_{i,c,y}$ is number of anglerfish recorded in tow i in closed area c in year y

A_i is the area of the seabed (km²) surveyed by the visual tow i in year y.

Biomass in these areas was calculated by multiplying the abundance by the average weight of anglerfish in the adjacent trawl strata of each survey. The abundance and biomass of anglerfish in the northwest Rockall closure was added to the estimates as additional strata. The proportions of abundance and biomass in the northwest Rockall closed areas relative to that in the adjacent two strata were then used to estimate the abundance and biomass in the Empress of Britain bank closure.

Abundances in the closed areas surveyed between 2007 and 2011 have been estimated by this method as 150–220 thousand fish, approximately 1% of anglerfish in numbers on the Northern Shelf.

B.3.1.3 Estimation of length compositions

Each fish caught on the survey is measured and aged and so the number-at-length, N_{ly} are estimated from the survey data in a similar way to the total numbers and biomass:

$$\hat{N}_{ly} = \sum_{s \in S} \left\{ A_s \sum_{i \in s} \left[\frac{n_{ils}}{\hat{r}_l \left(v_{1i} + h v_{2i} \right)} \right] \right\}$$

The survey biomass indices and length compositions are currently for both *L. piscatorius* and *L. budegassa* combined.

B.3.2 North Sea IBTS (NS-IBTS-Q1 and NS-IBTS-Q3.

A full description of the North Sea IBTS survey can be found on the ICES DATRAS website: http://datras.ices.dk/Home/Descriptions.aspx.

Survey data were extracted for both anglerfish species, *L. piscatorious* and *L. budegassa*. Scottish data were extracted from the database of the Marine Laboratory in Aberdeen (Fisheries Survey System, FSS) while data for the other countries in the North Sea were extracted from DATRAS. The Scottish data included those collected during the North Sea survey in Q1 (1987–2017) and the North Sea survey in Q3 (1987–2017). The international data for the North Sea were available for Q1 (1987–2017) and for Q3 (1991–2016). Survey coverage is shown in Figures 2–3.

For all surveys, a common approach was used in the derivation of the survey size compositions and abundance/biomass indices. In common with the approach used to derive North Sea IBTS indices for use in other demersal fish stock assessments, the survey indices for anglerfish are based on a subset of the statistical rectangles covered by each survey (ICES, 2012d). An 'anglerfish area' was delineated comprising statistical rectangles for which the mean catch rate of anglerfish over all hauls in the whole time-series was ≥0.1 individual per hour (Figure 4).

The abundance index calculation follows the IBTS approach whereby the catch rate in number per hour for each haul is averaged over all hauls within an ICES rectangle and then averaged over all rectangles within the 'anglerfish area'.

In addition to the catch rate in number, the same procedure was used to calculate a survey index in terms of catch weights using fish numbers and individual weights. The latter were estimated from the L–W relationship obtained from the monkfish surveys (conducted in 2013–2017):

$$W = 0.0372\, L^{2.77}$$

where W is the individual weight (in g) and L is length (in cm).

B.4. Commercial cpue

B.4.1. Official logbook data

Previous length-based assessments attempted to use effort data to constrain the temporal trend in fishing mortality. Scottish Light Trawl data, disaggregated into an inshore and offshore component, the latter of which is associated with the anglerfish fishery, for both West of Scotland and Shetland (North Sea) were provided to previous assessment Working Groups. However, these data are no longer considered to be reliable due to non-mandatory recording of hours fished in the logbook data. Further details of the Scottish fleet effort recording problem can be found in the report of the 2000 WGNSSK (ICES, 2001). Since these data are considered unreliable, they are not presented here.

Spanish lpue series standardised using a generalised linear model are available for both *L. piscatorius* and *L. budegassa* from the Basque fleet fishing in Subarea 6 from 2004 to 2016 and were presented at WKAngler (WKAngler 2018). Fishing effort is calculated as fishing days = trips*(days/trip) with the inclusion of only trips where anglerfish were landed. The lpue index is based on 2–4 demersal otter trawls fishing a mesh size between 100–120 mm. The lpue series show consistent trends with the results of Sco-IV-VI-AMISS-Q2 however the landings of the Basque fleet account for only 4% of the Subarea 6 total landings (2004–2016) and currently do not address spatial changes in effort.

A standardized lpue index for a Norwegian reference fleet of gillnetters targeting mainly 70–120 cm anglerfish is available. The lpue was estimated for each vessels seasonal fisheries (three subareas, with at least two vessels in each) and was then averaged annually for the two ICES areas. The fishing effort is measured as number of gillnet soaking days per year giving a catch (landing) rate in kg per gillnet soaking day, inclusive precision measure.

B.5. Other relevant data

C. Assessment: data and method

C.1. Stock development index

Further work is required to develop an appropriate assessment which can account for all the uncertainties and potential biases in the commercial fishery data. In the absence of an analytical assessment, the Sco-IV-VI-AMISS-Q2 survey is considered to provide the most appropriate biomass indicator for use in the ICES approach for the provision of advice for category 3 data-limited stocks (ICES, 2012a).

Given the results of limited analysis conducted by WKLIFE (ICES, 2017), the 2-over-3 rule (average of the two most recent index values compared to the previous three) with application of the Uncertainty Cap and consideration of the Precautionary Buffer is used as the basis for advice for this stock.

The index of total biomass (corrected for footrope escapes and herding) is used in the advice rule.

C.2 Additional indicators

A harvest rate is calculated as total catch (weight) divided by Sco-IV-VI-AMISS-Q2 total biomass index. This is mean standardized and used as an indicator; to provide a qualitative evaluation of fishing pressure.

D. Short-term projection

E. Medium-term projections

F. Long-term projections

G. Biological reference points

H. Other issues

In previous ('catch-at-length') assessments of this stock, the SSB was always estimated to be at a very low level. The length data have largely been based on the UK landings (in subdivisions 4.a and 6.a), where very few individuals over 80 cm appear in the catch and therefore the model predicts very few in the population. Since females do not mature until they are over 90 cm in length the SSB was estimated to be very low. The length data from the eastern part of the North Sea (Danish and Norwegian fisheries) for the recent years indicate a higher amount of larger individuals in the catches. Although the Danish and Norwegian landings are small in comparison to the UK landings, the inclusion of the Danish and Norwegian length frequencies in the data used for any future assessment may change the magnitude of the SSB.

The fact that mature female anglerfish are rarely observed either on scientific surveys or by observers on board commercial vessels supports a very low estimate of spawning–stock biomass, yet there is little evidence of reduction in spatial distribution as fish are still recruiting to relatively inshore areas. Little is known about the location of the main spawning areas or if there is any systematic migration of younger fish back into deep waters to spawn. It has been hypothesized that females may become pelagic when spawning as they produce a buoyant, gelatinous ribbon of eggs, and would therefore not appear in the catch of trawlers. (Anglerfish have been caught near the surface, Hislop *et al.*, 2000). This would imply different exploitation patterns for males and females: a dome-shaped pattern (decreased exploitation at larger sizes) for females and a logistic pattern for males. It is also not known whether anglerfish are an iteroparous or semelparous species. The latter would also account for the almost complete absence of spawning females in commercial catches or research vessel surveys. If spawning is occurring in deep water off the edge of the continental shelf may offer the stock some degree of refuge. However, this assumes that the spawning component of the stock is resident in the deep water, and is thus not subject to exploitation. It is not known to what extent this is true, but if such a reservoir exists then the currently used assessment methods which make dynamic pool assumptions about the population are likely to be inappropriate.

H.1. Historical overview of previous assessment methods

A length-based model was used up to 2003 (Dobby, 2002) but was subsequently abandoned due to lack of confidence in the landings data. Since then WGs have presented trends from the Sco-IV-VI-AMISS-Q2 survey.

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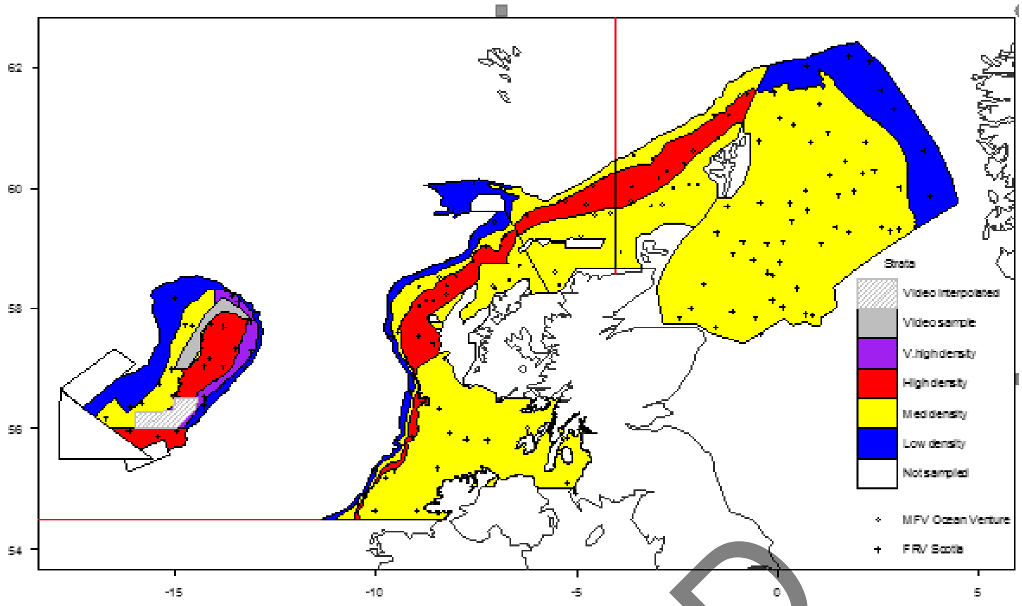

Figure 1. Map of the northern continental shelf around the British Isles showing the areas surveyed during SCO-IV-VI-AMISS-Q2 in 2011, shaded according to the survey strata as indicated in the legend. Sample positions (n=153) are indicated by the black crosses (FRV Scotia, n=104) and black circles (MFV Ocean Venture, n=49).

Figure 2. Map of the proposed survey grid for all participants of the NS-IBTS-Q2.

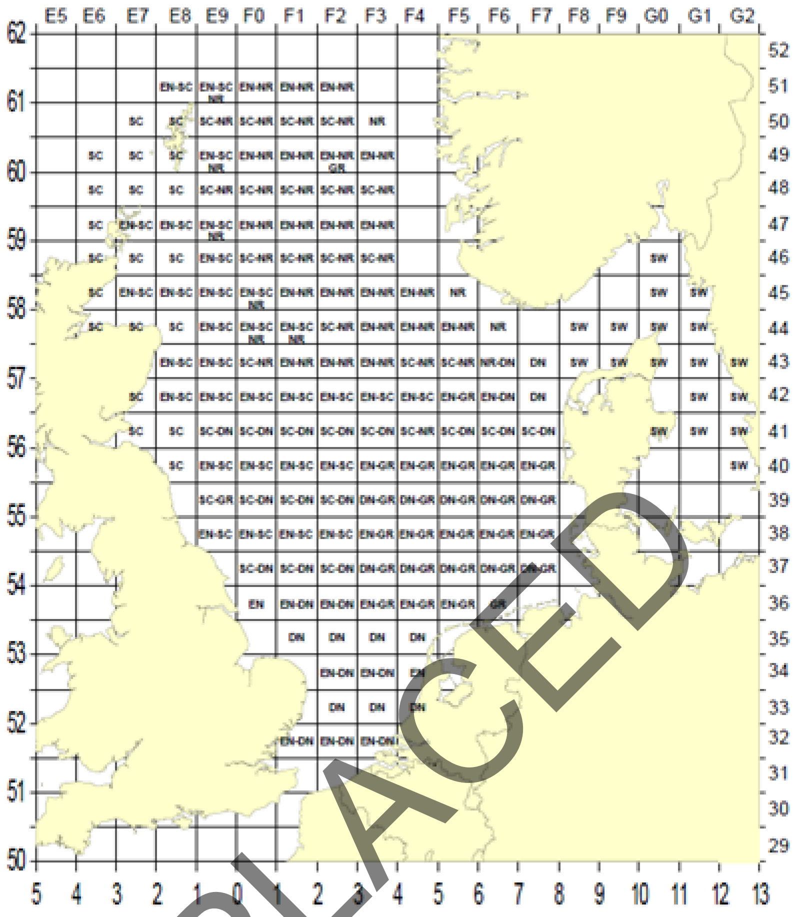

Figure 2.2.1. IBTS Quarter 3 Proposed Survey Grid all participants.

Figure 3. Map of proposed survey grid for all participants NS-IBTS-Q3.

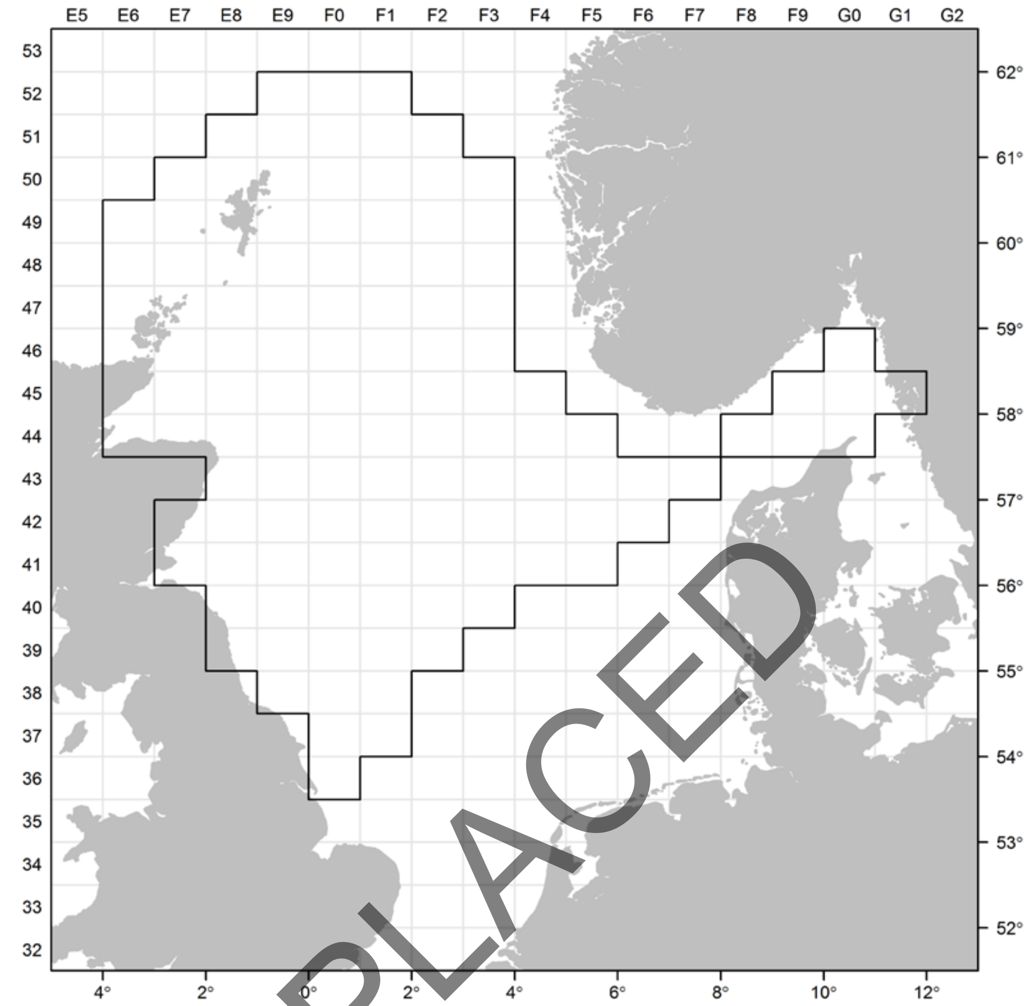

Figure 4. North Sea anglerfish area for calculation of cpue indices.