Stock Annex: Megrim (*Lepidorhombus ssp.*) in divisions 4.a and 6.a (northern North Sea, West of Scotland)

Stock-specific documentation of standard assessment procedures used by ICES.

Stock	Megrim
Working Group	Working Group for the Celtic Seas Ecoregion (WGCSE)
Created	
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A. General

A.1. Stock definition

Since the end of the 1970s, ICES has assumed three different stocks for assessment and management purposes: megrim in ICES Subarea 6, megrim in divisions 7.b–k and 8.a,b,d and megrim in divisions 8.c and 9.a. Megrim stock structure is uncertain and historically the Working Group has considered megrim populations in 6.a and 6.b as separate stocks. The Review Group questioned the basis for this in 2004. Data collected during an EC study contract (98/096) on the 'Distribution and biology of anglerfish and megrim in the waters to the West of Scotland' demonstrated significantly different growth parameters and significant population structure difference between megrim sampled in 6.a and 6.b (Anon, 2001). Spawning fish occur in both areas but whether these populations are reproductively isolated is not clear.

As noted by WGNSDS 2008, megrim in 4.a has historically not been considered by ICES, and WGNSDS 2008 recommended that 6.a megrim should be considered by WGCSE. Landings data from 4 and 2.a are now included in this report and work is underway to collect international catch and weight-at-age data for 4 as well as 6. However, the availability of aggregated and age-disaggregated is sporadic.

Data from both the commercial fishery (using VMS and catches by statistical rectangle) and from fishery-independent surveys provide little evidence to support the view that megrim in 6.a and 4.a are indeed separate stocks. Based on the recommendations from WKFLAT (2011), megrim in 6.a and 4.a are considered a single unit stock and assessed accordingly. Megrim in 6.b is considered a separate stock unit for assessment purposes.

Stock description and management units

Megrim stock structure is uncertain, and historically the Working Group has considered megrim populations in 6.a and 6.b as separate stocks. The review group questioned the basis for this in 2004. Data collected during an EC study contract (98/096) on the 'Distribution and biology of anglerfish and megrim in the waters to the West of Scotland' showed significantly different growth parameters and significant population structure difference between megrim sampled in 6.a and 6.b (Anon, 2001). Spawning fish occur in both areas, but whether these populations are reproductively isolated is not clear. As noted by WGNSDS (2008), megrim in 4.a has historically not been considered by ICES and WGNSDS (2008). Since 2009 data from 4 and 2.a are included in this report, but international catch and weight-at-age data for 4 prior 2006 were not available to the Working Group or WKFLAT (2011). Given that there is little evidence to suggest that megrim in 6.a and 4.a are separate stocks, based on a visual inspection of the spatial distribution of commercial landings and fishery-independent survey data, WKFLAT (2011) concluded that megrim in 6.a and 4.a should be considered as a single stock. This has subsequently been supported through recent genetic studies (MacDonald and Prieto, 2012) indicating that there is one stock consisting of divisions 4.a (northern North Sea) and 6.a (West of Scotland) and another separate stock in Division 6.b (Rockall). As a consequence, the assessment area is now incompatible with the management area.

A.2. Fishery

Megrim are predominately taken in otter trawl and to a lesser extent by Scottish seine. Analysis of VMS data indicates that megrim is taken in spatially discrete shelf fisheries and also in trawl fisheries conducted along the 200 m shelf break. Historically, ICES has assumed that megrim catches are closely linked to those of monkfish. Area misreporting of monkfish from 6.a into 4.a as a result of restrictive TACs in 6.a is known to have occurred historically, and catches have been redistributed into 6.a using an algorithm developed by the Marine Science Scotland (see stock annex for monkfish). Due to the assumed linkage between megrim and monkfish, megrim caught in 6.a are also considered to have been area misreported and therefore the Working Group has historically applied the same redistribution method as used for monkfish. It remains unclear whether this pattern has continued in recent years, in 2009 the Working Group did not redistribute megrim catches in 6.a as the historic pattern, higher catches in the statistical rectangles immediately east of the 4° line, was not observed in 2009, indeed the 2009 pattern may indicate a reversal of the process due to a more restrictive TAC in 4.a. However, treating megrim in 6.a and 4.a as a single unit stock has mitigated this problem.

The introduction of the Cod Long-Term Management Plan (EC Regulation 1342/2008) and additional emergency measures applicable to 6.a in 2009 (EC Regulation 43/2009, annex III 6) has impacted on the amount of effort deployed and increased the gear selectivity pattern of the main otter trawl fleets. Figure 5.3.1 shows the effort pattern for the main fleets (TR1) catching megrim in 6.a. Additionally, EC regulation 43/2009 has effectively prohibited the use of mesh sizes <120 mm for vessels targeting fish, which had been used particularly by the Irish fleet up to that point, the resultant rapid decline in effort for this category (IRE TR2) and is now 1% of historic levels Much of the effort has been transferred into the TR1 fleet. Effort associated with the French fleet has continued to decline while the substantial declines seen in the Scottish TR1 fleets (120 mm mesh) appears to have stabilized at levels well below the earlier part of the time-series. The increase in mesh size (from 100 to 120 mm) has also impacted on the retention length of megrim, increasing L50 from 28 cm to 42 cm, an increase of almost 50%.

Fishing effort in 4.a (Figure 5.3.2) for the main Scottish whitefish directed otter trawl fleets (TR1) have stabilized since the large total effort reductions observed between 2000 and 2003.

Fishing effort in 4 for the main Scottish otter fleet (TR1) have stabilized since the large effort reductions observed in previous years, effort levels associated with this mesh band have fallen by 64% since 2000. Following the increases in Irish effort in Subdivision 6.b from 2004–2008, effort in 2009 has declined significantly. These reductions in effort in Scotland and Ireland are considered to have contributed to the decline of landings in Subarea 6. Landings in 6 are well below the TAC. Uptake by France, who account for 44% of the TAC, is very low (~11%). Official landings in Subarea 4 and Division 2.a in recent years are close to the TAC.

There is anecdotal information from the Scottish industry that since the introduction of the Conservation Credits Scheme in Area 4, those vessels have responded with increasing focus on anglerfish and megrim in both 4.a and 6.a. Based on landings data presented to the Working Group, only 53% of the overall TAC for 6, EC waters of 5.b and international waters of 12 and 14 was used. The TAC in 4 was fully utilized.

Commercial catches are dominated by female megrim, typically 90% of the total catch. Analysis of Irish logbook data by Anon (2002) showed that cpue trends varied throughout the year, showing a maximum in late spring/early summer following the spawning period and at their lowest in late autumn.

A.3. Ecosystem aspects

None considered.

A.4. Megrim in 4.a and 6.a (Northern North Sea and West of Scotland) and Megrim in 6.b (Rockall)

A.4.1. Megrim in Divisions 4.a and 6.a (Northern North Sea and West of Scotland)

Stock assessment

To assess the sensitivity of the model outputs to this assumption, two alternative model runs with (i) a fixed 20% discard proportion over the full landings time-series and (ii) a linear decline in proportion from 30% at the start of the time-series to 15% at the end (see discards section). It is probable that the proportion of megrim discarded in 4.a has declined since 2000 and in 6.a since 2009 the mesh size in the North Sea increased from 100 to 110 mm and was further increased to 120 mm in 2001, while in Division 6.a, the mesh size was increased from 100 to 120 mm in 2009. It is therefore likely that the discarding profiles have probably changed significantly in line with these mesh size increases.

Previous runs have shown that the inclusion of discard data has some impact on the output.

PARAMETER	LANDINGS ONLY	FIXED 15%	SLOPE 30–15%	%DIFF. 15%	% DIFF. SLOPE
r.hat	0.59	0.61	0.62	3%	5%
K.hat	32996	35760	38536	8%	14%
MSY	4539	5147	5645	12%	20%
F_{MSY}	0.29	0.30	0.31	3%	5%
B_{MSY}	16498	17880	19268	8%	14%
B_{2011}	26762	28697	30617	7%	13%
F_{2010}	0.15	0.14	0.13	-8%	-18%
B_{lim}	4949	5364	5780	8%	14%
B_{trig}	8249	8940	9634	8%	14%

Effectively, the inclusion of discard information into the catch introduces more fish into the system back in time. As a result the carrying capacity (K) is scaled upwards by 8% and 14% for the fixed 15% discard and linear decline from 30–15% respectively. This impacts on all the biomass estimates and biomass reference points. The impact on *r* less pronounced (3 and 5%) and as a consequence there is less impact on the F_{MSY} (F_{MSY} = r/2). Despite increase in catch final year estimate of fishing mortality (F_{2010}) revised downwards. IBP-MEG (2012) concluded that in the absence of a historic time-series of discard data, the assumption of a linear decline is appropriate given the technical changes in the fishery. In future discard estimates from national observer programmes will be used.

Type of assessment in 2016

Update of 2015 assessment with new landings and survey data.

ICES advice applicable to 2015

ICES advises if discard rates do not change from the average of the last three years (2012–2014), this implies landings of no more than 7539 tonnes.

ICES advice applicable to 2016 and 2017

ICES advises that when the MSY approach is applied, catches in each of the years 2016 and 2017 should be no more than 8567 tonnes. If discard rates do not change from the average of the last three years (2012–2014), this implies landings of no more than 7539 tonnes.

General

Stock description and management units

Megrim stock structure is uncertain and historically the Working Group has considered megrim populations in 6.a and 6.b as separate stocks. The review group questioned the basis for this in 2004. Data collected during an EC study contract (98/096) on the 'Distribution and biology of anglerfish and megrim in the waters to the West of Scotland' showed significantly different growth parameters and significant population structure difference between megrim sampled in 6.a and 6.b (Anon, 2001). Spawning fish occur in both areas but whether these populations are reproductively isolated is not clear. As noted by WGNSDS (2008), megrim in 4.a has historically not been considered by ICES and WGNSDS (2008). Since 2009 data from 4 and 2.a are included in this report, but international catch and weight-at-age data for 4 prior 2006 was not available to the Working Group or WKFLAT (2011). Given that there is little evidence to suggest that megrim in 6.a and 4.a are separate stocks, based on a visual inspection of the spatial distribution of commercial landings and fishery-independent survey data, WKFLAT (2011) concluded that megrim in 6.a and 4.a should be considered as a single stock. This has subsequently been supported through recent genetic studies (MacDonald and Prieto, 2012) indicating that there is one stock consisting of divisions 4.a (northern North Sea) and 6.a (West of Scotland) and another separate stock in Division 6.b (Rockall). As a consequence, the assessment area is now incompatible with the management area.

B. Data

B.1. Commercial catch

Commercial landings by country are available since 1990. The UK accounts for ~80% of the total landings. Over 50% of the landings are taken in the North Sea (4.a) with the remainder taken in 6.a (~40%) and 6.b, there are also landing reported from other areas (4.b and 4.c), but these are negligible.

International landings-at-age data based on quarterly market sampling are available from 1990 for 6. Note that up until 2000, catch-at-age data from 6.a and 6.b were aggregated, only partial landings-at-age are available for 6.b (post-2000). Landings numbers-at-age are available for 4.a (post-2005), depending on year and country.

Ireland provides landings numbers-at-age by quarter, age-disaggregated discard numbers-at-age by annum for both 6.a and 6.b. Scotland provides annual catch numbers-at-age by divisions 6.a and 6.b and discards estimates by weight and number with associated length distribution. Since 2011, France has provided landings and effort (hours fished) by statistical rectangle with quarterly length distributions of landings and discards with associated sampling effort (hours fished).

The general paucity of both landings and discard data covering the assessment area has prevented the construction of a fulltime and spatial series for megrim separately in 6.a, 6.b and 4.a. The available data are not separated by sex. Females make up approximately 90% of the landings, but survey data show that the relative proportion of males increases with depth.

The quality of the available landings data (unknown area misreporting), discard information, lack of effort data and cpue data for the main fleet in the fishery, and disaggregated landings-at-age data at an appropriate area level severely hamper the ability of ICES to carry out an assessment for this stock.

Prior to 2000, discard data for 6.a were combined together with data from 6.b and no data fom 4.a are available prior to 2005. The available data show that discarding is variable and given the increases in mesh sizes introduced in 2000 (North Sea) and 2009 (West of Scotland) it is expected that discard rates have declined. Laurenson and MacDonlad (2008) note that while discarding of megrim below minimum landing size is low (<1%), discarding of legal sized fish was much higher at 22%. This is attributed to low market price for small grades and bruised fish, resulting in highgrading of catches on length/quality reasons to maximise the value of a restrictive quota.

Official landings data for each country together with Working Group best estimates of landings from 6.a are shown in Table 5.3.1 and for 4.a in Table 5.3.2. The WG best estimates of landings are those supplied by stock coordinators of the various countries and differ from the official statistics in some years. Landings have increased in recent years and are more in line with historical trends.

Catches of megrim comprise two species, *Lepidorhombus whiffiagonis* and *L. boscii*. Information available to the Working Group indicates that *L. boscii*, are a negligible proportion of the Scottish and Irish megrim catch (Kunzlik *et al*., 1995; Anon, 2001). It is not clear to the WG whether landings of other countries are accurately partitioned by megrim species. Megrim are caught in association with anglerfish by some fleets and are area-misreported along with anglerfish. Previously, the reported Division 6.a landings have been adjusted to the Working Groups estimate of catch by including landings declared from Subarea 4.a in the ICES statistical rectangles immediately east of the 4°W line (see anglerfish Annex 5.2 for a detailed methodology). Area-misreporting peaked in 1996 and 1997 when around 50% of the estimated Working Group landings for Division 6.a were area-misreported. The correction process has not been conducted for the past two years. There are indications that more recently the process has reversed. Laurenson and MacDonald (2008) note that in more recent years that megrim TAC in the North Sea has become more restrictive and anecdotal evidence suggest that megrim catches from 4.a are misreported as coming from Division 6.a. Therefore, because of conflicting information on the potential direction of area-misreporting, megrim landings at a statistical rectangle level has not been adjusted. However, the decision to consider megrim in 6.a and 4.a as single unit stock negates this problem. However, it is unknown whether misreporting from Division 6.b is an issue.

B.2. Biological

Megrim exhibit a strong negative growth relationship with increasing depth. Fish found in deep water (>200 m) are commonly the same size as fish one year younger found in shallower areas (Gerritsen *et al*., 2010). Analysis of age-at-length data shows a wide length distribution within ages and that age precision deteriorates when sampling levels fall below ~500 per annum. Poor age precision in recent years prevents the development of an age-based assessment.

C. Assessment: data and methodThe assessment method: Schaefar Surplus production process model (Bayesian State-Space) in r and Winbugs

C.1. Input data

C.1.1. Catch

International landings data collated by the ICES Working Group on the Celtic Seas Ecoregion (WGCSE) are used as an estimate of catch. However, it is recognised that discarding is a feature of the fishery but note that discard data are not available for the entire time-series and the availability or raised discard data are highly variable across fleets and areas therefore if catch data are to be used, then some assumptions regarding the historic discard pattern must be made.

To assess the sensitivity of the model outputs to this assumption, two alternative model runs with (i) a fixed 20% discard proportion over the full landings time-series and (ii) a linear decline in proportion from 30% at the start of the time-series to 10% at the end. It is probable that the proportion of megrim discarded in 4.a has declined since 2000 and in 6.a since 2009 the mesh size in the North Sea increased from 100 to 110 mm and was further increased to 120 mm in 2001, while in Division 6.a, the mesh size was increased from 100 to 120 mm in 2009. It is therefore likely that the discarding profiles have probably changed significantly in line with these mesh size increases, and this option is used for the final run. For catch data from 2011 onwards, discard estimates provided to the Working Group are used.

C.1.2. Survey indices

Indices from six fishery-independent surveys are used in the assessment. These comprise of the Scottish North Sea IBTS survey (IBTSWG, 2011), Scottish quarter 1 (ScoGFS-WIBTS-Q1) and quarter 4 (ScoGFS-WIBTS-Q4) West of Scotland survey and the Scottish and Irish (SIAMISS-Q2) dedicated anglerfish survey which provides estimates of absolute biomass and abundance (see Reid *et al*., 2007 for further details), however the survey also catches significant quantities of megrim, but as there are no estimates of catchability, for the purposes of this work, the indices are treated in a relative sense.

For the 2016 assessment, survey indices were revised. For the IBTS and WIBTS this was associated with a switch from using IBTS exchange data to using data directly obtained from DATRAS. For the Sco-IBTS-Q1; ScoGFS-WIBTS-Q1 and ScoGFS-WIBTS-Q4, the revision has resulted in some minor changes in estimates but these revisions were largely consistent across the full time-series (Figure 5.3.3). The revisions to the Sco-IBTS-Q3 have resulted in a more moderate change the individual delta-gamma estimates. In addition, an error in the raising procedure used for deriving the SIAMISS-Q2 a was found during the 2015 analysis of this time-series. Incorrectly, the areas of each strata were calculated in terms of Km^2 while this should have been estimated in terms of Nm^2, This had the result of over inflating the estimates across all areas, but due to year-on-year variability in catches between strata, the level of inflation differs between years. Additionally, an area to the west of the Hebridies was incorrectly included in the revision of strata undertaken in 2011. This has resulted in a moderate %) downward revision in the indices.

To assess whether the revised indices have resulted in a change in perception of the stock, the 2014 assessment was re-run with the updated survey estimates. While there are some changes across the time-series, the differences do not significantly alter the perception of the stock or the exploitation rates. WGCSE 2015 concluded that there was no basis to reopen the advice. Figure 5.3.4 contrasts the outcome of the 2016 assessment with those from 2014 and 2015. This shows the clear difference between the 2014 and 2015 assessments due to the revision in the DATRAS indices. However, there is little difference when comparing the 2015 and 2016 assessments.

Surveys Sco VIa IVa Index shows the abundance for the Sco GFS data. Sco IVa Q1/Q4 WIBTS surveys show an increase in biomass.

Table 1.2.1. Survey indices used for surplus production model.

NUMBER	SURVEY	NATIONALITY	AREA	TIME-SERIES	DEPTH RANGE(M)
1	Sco-IBTS-Q3	Scotland	4.a	1987–present	<400 m
2	Sco-IBTS-Q1	Scotland	4.a	1987–present	<400 m
3	ScoGFS-WIBTS-Q1	Scotland	6.a	1986–2010	40–400
4	ScoGFS-WIBTS-Q4	Scotland	6.a	1986–2010	50–300
5	SIAMISS-Q2	Scotland	6.a*/4.a	2005–present	50–1050
6	SIAMISS-Q2	Ireland	6.a*	2006,7,9, 2017–present	50–850

***6.a data from IAMISS-Q2 and SAMISS-Q2 combined into a single cpue estimate with variance.**

Table 1.2.2. Input parameters, individual survey cpue indices, landings and modelled discards for the final assessment run.

Year	ScoGFS WIBTS-Q1	ScoGFS WIBTS-Q4	Sco-IBTS-Q1	Sco-IBTS-Q3	SAMISS-Q2 / IAMISS-Q2	SAMISS-Q2	6.a & 4.a Catch
1985	2.903559	NA	NA	NA	NA	NA	6427
1986	1.929094	NA	1.265329	NA	NA	NA	4051
1987	1.358222	NA	1.32665	NA	NA	NA	6488
1988	2.08337	NA	1.669439	NA	NA	NA	7273
1989	1.236084	NA	1.350466	NA	NA	NA	4778
1990	1.158327	1.693348	0.702685	NA	NA	NA	4187
1991	0.822158	1.299643	0.495672	0.346043	NA	NA	4514
1992	0.942249	1.941365	0.670378	0.337655	NA	NA	4837
1993	0.971044	2.263661	1.121323	0.3208	NA	NA	5107
1994	1.723013	3.579677	0.250753	0.40137	NA	NA	5200
1995	1.649429	1.865522	0	0.411065	NA	NA	6181
1996	2.008043	2.099782	0.512056	0.646006	NA	NA	6902
1997	1.1908	1.117966	0.426121	0.455827	NA	NA	6334
1998	1.137063	1.935873	0.785832	0.359194	NA	NA	5507
1999	1.442447	2.20036	0.996572	0.315471	NA	NA	4833
2000	1.640153	2.097323	1.040049	0.340623	NA	NA	4460
2001	1.560615	1.593783	0.35874	0.117063	NA	NA	4527
2002	1.209742	1.906003	1.455423	0.570154	NA	NA	3528
2003	1.311394	1.243176	0.498267	0.370054	NA	NA	2961
2004	1.332722	1.100146	0.266803	0.493347	NA	NA	2566
2005	0.723567	1.055193	0.599171	0.890539	1660.379	4753.223	1883
2006	1.041877	1.21523	0.807708	1.045221	2688.942	3344.997	2515
2007	0.974628	1.277615	0.8882	1.449534	3380.351	6347.544	2856
2008	1.312686	0.975444	1.571201	1.268062	2467.076	7754.143	3496
2009	1.758078	1.467909	1.915956	1.114903	3830.668	5946.946	3445
2010	1.288946	NA	1.733848	1.733026	3312.129	5394.946	3811
2011	2.601637	2.413067	1.872994	1.657346	2501.99	4683.594	3857
2012	2.204759	2.903679	2.526282	1.577915	3450.807	4839.468	3186
2013	3.646905	3.459725	2.66054	1.449047	6174.864	6460.015	3064
2014	2.347423	2.625564	2.170752	1.299442	3033.072	11970.3	2809
2015							

C.1.2.1. IBTS survey indices

IBTS survey data from Scottish groundfish survey data (surveys 1–4 shown above) are available for quarters 1 and 4 in ICES Area 6.a and quarters 1 and 3 in ICES Area 4.a north. The survey design is based on ICES statistical rectangles. One tow is selected per rectangle based on a library of clean tows. The tow location is largely the same every year and as such the design may be considered fixed station although minor changes to tow locations can occur.

Catch weights are not routinely collected on all IBTS surveys so the length data were converted to weight using the length–weight relationship.

$$W = 0.0047L^{3.13} \quad [1]$$

where W is the weight in grams and L is the length in centimeters. This relationship was estimated using all available megrim length–weight measurements from the dedicated monkfish survey. The weights were then raised by the numbers-at-length per tow and summed to provide a catch in kilograms per tow. This was divided by the duration of the tow in decimal hours to provide a cpue measured in units of kg.hr-1.

The data from all four surveys exhibit a relatively large proportion of zeroes, therefore the delta method of Stefánsson (1996) was used to extract indices. This method (delta-gamma model) comprises fitting two generalized linear models. The first model (binomial GLM) is used to obtain the proportion of non-zero tows and is fit to the data coded as 1 or 0 if the tow contained a positive or zero cpue, respectively. The second model is fit to the positive only cpue data using a gamma or lognormal GLM.

The data are modelled at the level of the station (largely synonymous with tow for a quarterly fixed-station survey design). The binomial data were modelled as follows

$$\ln\left(\frac{p_{st}}{1-p_{st}}\right) = \alpha_1 + \delta_{1,s} + \gamma_{1,t} \quad (2)$$

where p_{st} is the probability of non-empty tow at station s in year t ; note the logit link function; $\delta_{1,s}$ is the station (ICES rectangle) effect (number subscript used to differentiate from parameters of the second GLM below); stratum effects (strata defined as sampling areas 40–48 for 6.a surveys and roundfish areas in 4.a) were included as alternatives to the more spatially resolved station effects or potentially modelled in a nested hierarchy (not considered further here); and $\gamma_{1,t}$ is the year effect. Additional covariates such as depth could also be included here. The predominantly best fitting model by survey (lowest AIC) of those considered (from a single overall mean; yearly effects only; stratum effects only; station effects only and various combinations) was that given in Equation 2, i.e. including year and station effects. Quarter 4 in 6.a differed in that year was not significant (proportion of non-zero tows constant across time).

Positive cpue observations were modelled using a gamma-distributed GLM with a log link. The linear predictor given by

$$\ln(\mu_{st}) = \alpha_2 + \delta_{2,s} + \gamma_{2,t} \quad (3)$$

where μ_{st} is the mean positive cpue at station s in year t - note the log link function; $\delta_{2,s}$ is the station effect; again, stratum effects were included as alternatives to the more spatially resolved station effects; and $\gamma_{2,t}$ is the year effect. The best fitting model was that given in Equation 3. Model diagnostics including Q-Q plots of the residuals indicated the suitability of the gamma distribution; although the percentage of the deviance explained was only 42% (VIa Q1), indicating substantial unexplained variability in the data.

The estimated probability of a non-zero tow and the mean of the positive tows were combined to produce the mean estimated cpue per station by year:

$$\widehat{CPUE}_{st} = \hat{p}_{st}\hat{\mu}_{st} \quad (4)$$

These values are combined across stations within strata by the taking the average of the station-level estimates by stratum. Similarly, the overall mean is then taken as the average of the stratum-level means (Stefánsson, 1996).

IBTS survey data from Scottish groundfish survey data (Surveys 1–4, Table 2.2.1) are available for quarters 1 and 4 in ICES Area 6.a and quarters 1 and 3 in ICES Area 4.a north. The survey design is based on ICES statistical rectangles. One tow is selected per rectangle based on a library of clean tows. The tow location is largely the same every year and as such the design may be considered fixed station although minor changes to tow locations can occur. In 2010 both the groundgear and the survey design associated with the ScoGFS-WIBTS Q1 and Q4 surveys were changed. Rather than relying on fixed trawling locations moved to a new random-stratified survey design with trawl locations randomly distributed within ten *a priori* sampling strata. While there were rationale reasons for these changes, it has resulted in a breach in the time-series and it will not be possible to use these indices until a reasonable time-series, ca. five years, has been built up.

Catch weights are not routinely collected on all IBTS surveys so the length data were converted to weight using the length–weight relationship.

$$W = 0.0047L^{3.13} \qquad [1]$$

where W is the weight in grams and L is the length in centimeters. This relationship was estimated using all available megrim length–weight measurements from the dedicated monkfish survey. The weights were then raised by the numbers-at-length per tow and summed to provide a catch in kilograms per tow. This was divided by the duration of the tow in decimal hours to provide a cpue measured in units of $kg.hr^{-1}$.

The data from all four surveys exhibit a relatively large proportion of zeroes; therefore the delta method of Stefánsson (1996) was used to extract indices. The uncertainty surrounding each survey index (observation error) can be estimated within the assessment model or estimated externally and entered into the assessment model as a fixed quantity. For the present analysis, we used the mean delta-gamma cpue estimates (for the IBTS surveys only) and allowed the model to estimate the measurement error of each survey.

C.1.2.2. Anglerfish survey indices

Scottish (SAMISS) and Irish (IAMISS) dedicated anglerfish surveys (surveys 5–6 shown above) have been undertaken in 6.a and 4.a (SAMISS only) since 2005. The survey design is stratified based on expected densities of anglerfish (not megrim), within each strata, the location of individual tows are randomly selected. The modelling approach of Stefánsson, (1996) is mainly applicable to a fixed station design and therefore for the anglerfish indices we used the weighted cpue estimates and allow the observation error to be estimated within the model. The anglerfish survey provides absolute estimates of abundance and biomass. The average fish density-at-age a in stratum s, ρ_{as}, is estimated from the weighted mean of fish densities corrected for the catchability of each trawl, as follows:

$$\hat{\rho}_{as} = \sum_{i \in s} w_i \left\{ \sum_{l \in a} \frac{n_{lai}}{v_{1i} \hat{Q}_{li}} \right\} = \sum_{i \in s} w_i \left\{ \sum_{l \in a} \frac{n_{lai}}{\hat{e}_l (v_{1i} + v_{2i} \hat{h})} \right\}$$

where:

n_{lai} is the number of fish of age a and length l caught in trawl i,

$$w_i = \frac{v_{1i} + v_{2i}}{\sum_i (v_{1i} + v_{2i})},$$

v_{1i} is the area swept by gear in trawl i (the area swept by the wing),

v_{2i} is the sweep area of gear in trawl i i.e. the area swept by the door minus that swept by the wing,

$\hat{Q}_{li} = \hat{e}_l + \hat{e}_l \hat{h} \frac{v_{2i}}{v_{1i}}$ is the catchability estimate for a fish of length l in trawl i, following the definition by Somerton *et al*. (2007),

$\hat{e}_l$ is the estimated footrope selectivity-at-length l, is the proportion of fish of length l originally in the area swept by the wing which are caught by the net and do not escape under the footrope,

$\hat{h}$ is the estimated herding coefficient. ($\hat{h}$=0.017).

It should be noted that the methods outlined above were specifically designed for anglerfish. The most significant issue for megrim is that as there is no estimates of footrope selectivity, $\hat{e}_l$ is assumed to be 1. While this is not an issue when the survey indices are treated in a relative sense as presented here for megrim, Fernandes (2010) does use this approach to provide a raised absolute biomass based but notes that due to the full retention assumption for ground gear selectivity, the estimates are considered as a minimum estimate.

Surveys

Indices from six fishery-independent surveys are used in the assessment. These comprise of the Scottish North Sea IBTS survey (IBTSWG, 2011), Scottish quarter 1 (ScoGFS-WIBTS-Q1) and quarter 4 (ScoGFS-WIBTS-Q4) West of Scotland survey and the Scottish (SAMISS-Q2) and Irish (IAMISS-Q2) dedicated anglerfish survey which provides estimates of absolute biomass and abundance (see Reid *et al*., 2007 for further details), however the survey also catches significant quantities of megrim, but as there are no estimates of catchability, for the purposes of this work, the indices are treated in a relative sense.

For the 2016 assessment, survey indices were revised. For the IBTS and WIBTS this was associated with a switch from using IBTS exchange data to using data directly obtained from DATRAS. For the Sco-IBTS-Q1; ScoGFS-WIBTS-Q1 and ScoGFS-WIBTS-Q4, the revision has resulted in some minor changes in estimates but these revisions were largely consistent across the full time-series (Figure 5.3.3). The revisions to the Sco-IBTS-

Q3 has resulted in a more moderate change the individual delta-gamma estimates. In addition, an error in the raising procedure used for deriving the IAMISS-Q2 and SAMISS-Q2 was found during the 2015 analysis of this time-series. Incorrectly, the areas of each strata was calculated in terms of Km^2 while this should have been estimated in terms of Nm^2, This had the result of over inflating the estimates across all areas, but due to year-on-year variability in catches between strata, the level of inflation differs between years. Aditionally, an area to the west of the Hebridies was incorrectly included in the revisiom of strata undertaken in 2011. This has resulted in a moderate % downward revision in the indices.

To assess whether the revised indices have resulted in a change in perception of the stock, the 2014 assessment was re-run with the updated survey estimates. While there are some changes across the time-series, the differences do not significantly alter the perception of the stock or the exploitation rates. WGCSE 2015 concluded that there was no basis to reopen the advice. Figure 5.3.4 contrasts the outcome of the 2016 assessment with those from 2014 and 2015. This shows the clear difference between the 2014 and 2015 assessments due to the revision in the DATRAS indices. However, there is little difference when comparing the 2015 and 2016 assessments.

NUMBER	SURVEY	NATIONALITY	AREA	TIME-SERIES	DEPTH RANGE(M)
1	Sco-IBTS-Q3	Scotland	4.a	1987–2015	<400 m
2	Sco-IBTS-Q1	Scotland	4.a	1987–2015	<400 m
3	ScoGFS-WIBTS-Q1	Scotland	6.a	1986–2010	40–400
4	ScoGFS-WIBTS-Q4	Scotland	6.a	1986–2010	50–300
5	SAMISS-Q2	Scotland	6.a*/4.a	2005–2015	50–1050
6	IAMISS-Q2	Ireland	6.a*	2005–2015	50–850

The anglerfish surveys cover a depth range of up to 1050 m (SAMISS-Q2/IAMISS-Q2) while the Sco-WIBTS surveys are distributed to depths of 400 m. In 2011, both the groundgear and the survey design associated with the ScoGFS-WIBTS Q1 and Q4 surveys were changed. Rather than relying on fixed trawling locations moved to a new random-stratified survey design with trawl locations randomly distributed within ten *a priori* sampling strata. While there were rationale reasons for these changes, it has resulted in a breach in the time-series and it will not be possible to use these indices until a reasonable time-series, ca. five years, has been built up. The indices from the six surveys, together with commercial landings are given in Table 5.3.3.

C.2. Method

Surplus production methods (Schaefer, 1954; Pella Tomlisson, 1969) offers a potential modelling approach in the absence of reliable catch-at-age data. Surplus production pools the overall positive contributory effects (growth and recruitment) with removals due to mortality into a single production function, thus the stock is considered solely in terms of biomass without regard for differences in age, size of sex structure. Surplus production models are commonly used when only relative biomass indices, either from survey or from commercial fisheries, and landings data are available. For computational simplicity, earlier methods assumed that the yield from the fishery is in equilibrium, where each year's catch and effort data represent an equilibrium (steady-state) situation where the catch is assumed to equal the surplus production. This can result in overly optimistic estimates of MSY, particularly problematic when a stock is in decline. Process error methods also use catch and effort data, but do not make the assumption that the population is in equilibrium. Process error methods make the assumption that the measurement of catch and effort are measured without error. Conversely, observation error methods assume that the biomass response is correct and that all error is associated with measurement error. Polacheck *et al*. (1993) compared the performance of all three approaches and found that observation methods performed best, with the process method proving very imprecise. However, it would be preferable to consider both process error associated with the inherent population dynamics and observation error which describes the inherent variance in catch and effort observations. The development of state–space models has the ability to separately model and incorporate both process and observation error (Meyer and Millar, 1999).

Due to ageing issues with megrim in 6.a and 4.a associated with low sampling size and depth-dependent growth issues, a surplus production process model is used (Schaefer, 1954) to describe the current exploitation of megrim relative to F_{MSY} and stock biomass relative to B_{MSY}. The biomass dynamics are given by a difference form of a Schaefer biomass dynamic model:

$$B_t = B_{t-1} + rB_{t-1}\left(1 - \frac{B_{t-1}}{K}\right) - C_{t-1}$$

where B_t is the biomass at time t, r is the intrinsic rate of population growth, K is the carrying capacity, and C_t is the catch, assumed known exactly. To assist the estimation the biomass is scaled by the carrying capacity, denoting the scaled biomass $P_t = B_t/K$. Log-normal error structure is assumed giving the scaled biomass dynamics (process) model:

$$P_t = \left(P_{t-1} + rP_{t-1}(1 - P_{t-1}) - \frac{C_{t-1}}{K}\right)e^{u_t}$$

where the logarithm of process deviations are assumed normal $u_t \sim N(0, \sigma_u^2)$; σ_u^2 is the process error variance.

The starting year biomass is given by $B_{1985} = aK$, where a is the proportion of the carrying capacity in 1980.The biomass dynamics process is related to the observations on the indices through the measurement error equation:

$$I_{j,t} = q_j P_t K e^{\varepsilon_{j,t}}$$

where $I_{j,t}$ is the value of abundance index j in year t, q_j is index-specific catchability, $B_t = P_t K$, and the measurement errors are assumed log-normally distributed with $\varepsilon_t \sim N(0,\sigma_{\varepsilon,j}^2)$; $\sigma_{\varepsilon,j}^2$ is the index-specific measurement error variance.

C.2.1. Estimation-prior distributions

Estimation is undertaken in a Bayesian framework with Markov Chain Monte Carlo (MCMC) sampling using WinBUGS (Spiegelhalter *et al*., 1999). Prior distributions are given in Table 2.1.1. Note that prior distribution assumptions are important. In these preliminary runs we have assumed largely uninformative priors to see what information is present in the data to update these priors.

Sensitivities to K, assuming uniform normal or log-normal, distributions have been tested and although the fitted and posterior parameters are quite similar. The major difference being in the parameter *K*, which has an extremely long tail when a uniform prior is assumed. Most of the density of *K* is similarly distributed (good overlap when the distributions are overlayed). As the uniform prior distribution on the logarithm of *K* avoided long tails (which may have a very large effect on the mean), this was chosen in subsequent runs (e.g. retrospective and final).

Catchability sensitivity

Assigning a prior distribution that is uniform on the logarithmic scale is recommended for catchability in biomass dynamics models (Punt and Hilborn, 1997). A corresponding fit allowing for catchability to range over $[0, \infty]$ resulted in a poorly converged model with unrealistic estimated absolute abundances (order of 500 thousand tonnes). The range of the catchability parameter was thus scaled to have a lower limit of -11 on the logarithmic scale, this corresponds to a lower limit on *q* of exp(-11)= 1.67e-05, which allowed for biomass to range over 100 thousand tonnes from each series.

Table 2.1.1. *Lepidorhombus whiffiagonis* in ICES Areas 6.a and 4.a. Prior distributions on parameters.

Parameter	Symbol	Prior distribution	Notes
Intrinsic rate of population growth	r	$\text{Uniform}(0.001, 2.0)$	
Carrying capacity	K	$\text{Uniform}(\ln(\max(C)), \ln(10 \times \sum_{t=1985}^{2010} C_t)$	From the maximum catch to ten times the cumulative catch across all years assuming uniform distribution on the logarithmic scale
Catchabilities	$\log(q_j)$	$\text{Uniform}(-11.0, 0.0)$	Uniformly distributed on log-scale. See catchability sensitivity in Section 2.2.3.1
Process error variance	$1/\sigma_u^2$	$\text{Gamma}(\text{shape} = 0.001, \text{rate} = 0.001)$	Gamma distributed on inverse variance (precision) scale
Measurement error variances	$1/\sigma_{\varepsilon,j}^2$	$\text{Gamma}(\text{shape} = 0.001, \text{rate} = 0.001)$	Gamma distributed on inverse variance (precision) scale
Proportion of K in 1985	a	$\text{Uniform}(0.01, 2.0)$	

D. Short-term projection

Model used: Risk-based forecast.

Software used: R and Winbugs and Perl.

The lack of recruitment data and age data precludes the provision of a short-term forecast based on spawning–stock and recruitment relationships. Instead, using the historic dynamics of the stock, the likelihood of the stock exceeding F_{MSY} under a range of catch options is presented. Advice is based on maintaining the risk of F_{MSY} exceeding 5%.

A forward projection on the risk of the stock falling below $B_{MSY\ trigger}$, B_{lim} was carried out last year this has not be updated as the advice was given for 2016 and 2017.

E. Medium-term projection

F. Long-term projection

G. Biological reference points

	Type	Value	Technical basis
MSY	$B_{trigger}$	9633	50% of B_{MSY}
Approach	F_{MSY}	0.31	Estimated from model
Precautionary Approach	B_{lim}	5780	30% of B_{MSY}
	B_{pa}	Not defined	
	F_{lim}	1.7 F_{MSY}.	Fishing mortality that drives the stock to B_{lim}
	F_{pa}	Not defined	

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