Stock Annex: Lemon sole (*Microstomus kitt*) in Subarea 4 and divisions 3.a and 7.d (North Sea, Skagerrak and Kattegat, eastern English Channel)

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

Stock	Lemon sole in Subarea 4 and Division 3.a and 7.d (North Sea)
Working Group	Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK)
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General

The North Sea lemon sole stock assessment was benchmarked during the winter of 2017–2018 (ICES, WKNSEA 2018), during which the available data, stock assessment methods and basis for advice were thoroughly revised and updated. This Stock Annex is therefore significantly different from the previous version, and for most sections provides a complete replacement.

Stock definition

No information on stock definition was presented at the 2018 WKNSEA meeting. It is assumed (on the basis of lack of evidence) that the management area (4, 3.a and 7.d) covers one unit stock, and that there is no migration into or out of this area. Smaller populations do exist to the south-west of the British Isles (Rae, 1965), but these are sufficiently spatially distinct to be considered to be separate stocks.

Fishery

In area 4, the UK has historically been by far the most significant participant in the lemon sole fishery. In recent years this has changed, with landings now divided more evenly between the UK, Denmark, Belgium and the Netherlands. In area 3.a, the principal fishery is conducted by Denmark, while in area 7.d lemon sole landings are split between the UK, France and Belgium. The bulk of lemon sole landings come from demersal trawlers, with a smaller proportion landed by beam trawlers.

Ecosystem aspects

Lemon sole is a commercially important flatfish that is found in the shelf waters of the North Atlantic from the White Sea and Iceland southwards to the Bay of Biscay. In Scottish waters, lemon sole start to spawn in the northwest of the North Sea in April and spawning spreads south and east as the season progresses (Rae, 1965). In the western English Channel, lemon sole spawn in April and May (Jennings *et al.*, 1993). In the English Channel, investigations of habitat association for plaice, sole and lemon sole indicated that distribution is restricted to a few sites and that lemon soles appear to prefer sandy and gravely strata, living deeper and at a higher salinity and lower temperature than plaice or sole (Hinz *et al.*, 2006). Lemon sole feeds on small invertebrates, mainly polychaete worms, bivalves and crustaceans.

Data

Commercial catch data

Catch data for the years 2002–2016 were provided by several participating nations following the 2017 WKNSEA data call, and were collated using the InterCatch system. Commercial age samples for landings and discards proved to be sparse. They were only provided by two countries (Denmark and Belgium), and although these provided 27% and 17% respectively of international landings by weight in area 4 (average 2014–2016), and the reported effort of the Danish fleet does cover most of the survey-implied distribution of lemon sole, the available age data (for discards in particular) were not deemed by WKNSEA to be of sufficient quantity or coverage to warrant further consideration of an age-based assessment using commercial data. For this reason, collation in InterCatch uses length-based sampling only.

WKNSEA investigated whether areas should be considered separately for raising discards and length compositions, but the prevailing view was that there was no evidence of distinct stocks between areas (say, between areas 4 and 3.a), and that therefore all areas should be treated together for raising. Initial exploration demonstrated that final discard raising was significantly influenced by a small number of métiers with discard ratios greater than 1.5 (in other words, those métiers for which discards/landings >1.5). Subsequently, these métiers were discounted in calculating raising factors as they were thought to be non-representative for a high-value stock such as lemon sole. Otherwise, discards for all unsampled fleets were inferred by a discard rate generated using all sampled fleets (weighted by the landings CATON), as it was not thought likely that discard rates for an (essentially) bycatch stock would vary a great deal between different métiers (apart from the extreme and unrepresentative examples discussed above).

Length-distribution allocations, weighted by mean numbers-at-length, do not differentiate between area, fleet or season, with the only distinction being made between landings and discards. WKNSEA found that length samples are reasonably well spread across the main countries catching lemon sole, albeit with a large spike in the final year (2017) for some countries following the relevant data call, and length-based allocations are likely to be sufficiently representative. The official landings for 2012 did not include estimates for the UK, which is why they are considerably lower than the new InterCatch estimates. In addition, the 2013 discard estimate is very high; the estimation was repeated three times during the WKNSEA meeting and does not appear to be in error. The problem appears to originate in the discard estimates provided by the Netherlands which will need to be corrected in due course.

In summary, for update assessments:

- Catch raising in InterCatch is undertaken using length data (rather than age data).
- No distinction is made between countries, métiers, areas or seasons for raising discards and catch compositions.
- For raising discards, only those métiers with a discard ratio of less than 1.5 are included when calculating the raising factor.
- For catch compositions, length distributions are estimated separately for landings and discards.

Abundance indices

Commercial cpue

There are no commercial cpue indices available for tuning the North Sea lemon sole assessment.

International Bottom Trawl and Beam Trawl Survey Indices

WKNSEA determined that the use of age samples from the available surveys was probably appropriate (ICES, WKNSEA 2018). Age samples from IBTS are lacking from the northernmost sampling areas in Q1, but they are available in Q3; and as the Q1 length distributions are very similar between north and south, the lack of northern age samples in that quarter is unlikely to lead to biased estimates overall. WKNSEA also demonstrated that the survey length distributions (when collated over years) were broadly similar in shape and location to the equivalent from catch data, suggesting that the surveys are covering the same stock as appears in commercial catches.

At the 2017 WKNSEA data meeting, age-structured IBTS indices for Q1 and combined IBTS-BTS indices for Q3 were produced using the same GAM estimation code that is employed to derive indices for North Sea cod (amongst other stocks) and which therefore has been extensively tested and verified (Berg *et al*., 2014). The method used was covered in a separate working paper for WKNSEA. While the resultant indices were not very good at tracking year-class strength, they did demonstrate better internal and external consistency (in a wide range of diagnostic tests) than the comparable indices derived using the standard ICES approach via DATRAS. In addition, the fact that the GAM estimation method for Q3 incorporates both IBTS and BTS survey data means that it utilises the available data more fully than the ICES estimation method. Finally, in exploratory SURBAR runs (see below) the ICES method resulted in extremely uncertain estimates of recruitment for recent year classes. For these reasons, WKNSEA concluded that the GAM approach should be used to generate age-structured indices for North Sea lemon sole.

In summary, for update assessments:

- Two survey indices are to be generated each year, using the GAM estimation approach (Berg *et al*., 2014): an IBTS Q1 index (currently years 2007–2018, ages 1–5), and a combined IBTS-BTS Q3 index (currently years 2005–2017, ages 1–9).

Biological data

Proportion mature-at-age

Lemon sole are reported to spawn in the west central North Sea during the period May to November with peak spawning during July–August (starting earlier in the north; Rae, 1965). Therefore most spawning occurs between the Q1 and Q3 IBTS surveys. For this reason, the maturity ogive discussed below was derived from the age at maturity data (2006–2017) from both these surveys. Information from the spawning time would improve the accuracy of these estimates.

During the WKNSEA meeting, *SMALK* data from DATRAS were used to determine the proportion mature-at-age for each available year (2006–2017; ICES, WKNSEA 2018). A procedure was used that converts the range of different maturity indicators used in the *SMALK* dataset to a common mature/not mature indicator, and then summarises the mature proportion across ages. The analysis further attempts to fit the following model

$$Mat = \frac{\gamma}{1 + e^{\alpha + \beta A}}$$

where *A* denotes age.

The analysis suggested that lemon sole appear to be fully mature by age 3, on average. While there did look to be an upwards trend in the early years for several ages, this perception seemed to be driving principally by anomalously low values in 2007, and overall an assumption of fixed maturity-at-age was thought likely to be appropriate. Furthermore, the non-zero mean at age 1 is also driven by a single early point that is unlikely to be representative; and the smoothed values for ages greater than 2 tend to overlap with the full maturity level (Mat = 1).

In summary, for update assessments:

- Mat = 0 at age 1;
- Mat = age 2 average (= 0.72) at age 2;
- Mat = 1 for age 3 and upwards.

Mean weight-at-age

As for maturity, the mean weights-at-age estimates were summarised by year and age during WKNSEA, using data from IBTS Q1 and Q3. While the Q1 estimates were noisy for certain ages, in no case is there evidence of a significant trend with time, and WKNSEA concluded that fixed weights-at-age through time would be appropriate. Lemon sole spawn for a considerable period in the North Sea, starting as early as April in the north and ending as late as November in the south (Rae, 1965), so WKNSEA concluded further that a combined estimate including both Q1 and Q3 weights would be appropriate. For each age, the available weights were plotted together, positioned so that Q1 weights were at y+0.25 and Q3 weights at y+0.75 (an additional mean point was added at the start of each time-series to enable extrapolation). A loess smoother (span = 1) was then fitted through all points for each age, so that the final estimate was (effectively) an average of consecutive weight estimates.

In summary, for update assessments:

- The WKNSEA smoothing procedure is to be used to determine stock (= catch) weights-at-age, incorporating weight data from both IBTS Q1 and Q3 surveys.

Natural mortality

Natural mortality (M) estimates for lemon sole are not available. For current advisory purposes, however, estimates of M are not required, as the assessment is survey-based and hence estimates total mortality Z.

Assessment

As discussed in Section on Commercial Catch Data, age samples from commercial catches are not sufficient to enable to generation of robust age–length keys, and hence age-based commercial catch data. Commercial length-based data are available, but there was no fully-realised length-based assessment method presented to the 2018 WKNSEA meeting. Hence, there is no valid basis to provide an assessment that includes the use of commercial catch data.

There are more age samples available from research-vessel surveys, and WKNSEA considered these to cover the length and spatial distribution of the stock sufficiently (see Section on International Bottom Trawl and Beam Trawl Survey Indices). Following exploratory runs with the SURBAR (Survey-Based Assessment in R) model (Needle, 2015a), WKNSEA concluded that stock status for North Sea lemon sole would be evaluated using estimates of mean total mortality Z, and relative estimates of SSB and recruitment, from a SURBAR runs based on GAM-estimated age-base survey indices for Q1 (IBTS) and Q3 (IBTS & BTS) (Section on International Bottom Trawl and Beam Trawl Survey Indices). This replaces the simple SSB estimates used in the lemon sole 3:2 advice rule in previous years. Note that the stochastic production model SPiCT (Pedersen and Berg, 2017) proved to be unsuitable for use as an assessment model for lemon sole (see Section on Biological Reference Points).

The exploratory runs evaluated the likely impact of a number of SURBAR run-time parameter settings. On the basis of these runs, the following setup was proposed for future SURBAR runs for this stock:

- The age- and year-effect smoother λ was set to 3.
- Mean mortality Z was calculated over ages 3–5.
- The reference age a_r for age-effect estimates was set to 3.
- GAM-estimated survey indices from both Q1 (IBTS) and Q3 (IBTS & BTS) are to be used.
- Catchability for ages was set as $q_1 = 0.1, q_2 = 0.5$ and $q = 1.0$ for all older ages.
- No downweighting of ages in the SURBAR SSQ estimation is to be used.

The surveys indices used, and the subsequent SURBAR output, should be summarised by a standard set of figures:

- Four-panel plot showing estimated mean total mortality Z, recruitment R, spawning–stock biomass S and total stock biomass. In each, the best (median) estimate is given along with approximate 90% pointwise confidence intervals.
- Six-panel plot summarising SURBAR parameter estimates.
- Residuals for each survey index (line plots, and point plots with loess smoothers).
- Retrospective analysis (with at least five peels).
- Bivariate survey scatterplots.
- Survey catch curves.
- Mean-standardised survey data by year-class, with lines for each age.

Short-term forecast

As North Sea lemon sole is a category 3 stock in the ICES definition scheme, advice is given on the basis of estimated trends in historical SSB (using the standard 3:2 rule). This does not require a short-term forecast, and therefore no forecast approach was defined by WKNSEA.

However, WKNSEA discussed the possibility of basing the 3:2 advice rule not on historical data alone, but on a combination of historical and forecast data. The idea would be to run a deterministic short-term (two-year) forecast within the SURBAR model, and then apply the 3:2 rule using the last three historical years and the two forecast years. This would require assumptions about mortality, growth and recruitment, but it would (importantly) allow consideration of low (or high) incoming year classes which currently is not possible. Application of the standard 3:2 rule to the 2018 lemon sole assessment, without consideration of the low incoming year class, is likely to allow for more fishing than would be sustainable. This modification should be considered at the earliest available opportunity by WGNSSK, with a potential recommendation for further action to ACOM.

Medium- and long-term projections

No medium or long-term projections are carried out for North Sea lemon sole.

Biological reference points

As there is no age- and catch-based assessment for lemon sole, the application of the standard EqSIM approach to estimating $F_{(MSY)}$-based biological reference points is not possible. One alternative would be to use the stochastic production model SPiCT (Pedersen and Berg, 2017) to estimate $F_{(MSY)}$. Unfortunately, a stable SPiCT run for lemon sole could only be achieved by extending the IBTS Q1 survey series back to the 1960s. WKNSEA concluded that the use IBTS data before 1983 would be questionable without further analysis (specifically, whether the apparent lower abundance indicated by IBTS data in the 1960s was seen in other stocks which could indicate lower survey catchability at the time): and therefore that SPiCT could not be used for this stock for the time being.

Stock status is therefore evaluated using $F_{(MSY)}$ proxies estimated using a suite of length-based indicators (LBIs), following the standard approach outlined by WKLIFE (ICES, 2017b) and WKMSYCat34 (ICES, 2017c). LBI analysis works best when there is a smooth increase from the start of the observed length distribution, and bimodal peaks can cause false estimates of L(c) (length at first catch). For this reason, the length distributions are modified before the analysis is carried out: lengths less than 100 mm are removed (these would not be representative of the commercial catch), and the bin widths are increased from 10 mm to 20 mm to improve smoothness. LBIs are necessarily qualitative to a certain extent, but they are valuable here in determining the likely status of the stock in relation to $F_{(MSY)}$ and hence whether precautionary buffers need to be applied to the standard 3:2 rule.

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