Response to the comments made by O'Hagan and Fop on the methods used to estimate compliance with the management objective for salmon stocks in England and Wales.

9 May 2018

1 Overview

The current methods for setting conservation limits and management targets in England & Wales, and for assessing compliance with these, have been in place for many years. They were developed in line with agreed international guidelines by a respected statistician. They were subject to consultation and peer review during their development and subsequently.

We recognise that there are some uncertainties in the data used in assessments, that the assessments rely on certain assumptions and that procedural improvements are always possible. Scientists from various Government agencies met at the end of last year to start considering ways in which the current procedures might be improved and to plan ways for taking this forward.

However, we remain of the view that the current assessment procedures, alongside other independent measures of stock status, such as adult counts and juvenile surveys, provide a reliable basis for evaluating the status of salmon stocks in England and Wales. We do not share the view that the assessments which underpin the current need for proposed management action are: '*formed on invalid statistical principles and use modelling that has major flaws and weaknesses*'.

We believe that many of the points raised in the review by O'Hagan and Fop are unfounded and appear to be based, in part at least, on a misunderstanding of the procedures applied. In particular, we emphasise that the model in use is based on a Bayesian statistical approach rather than the frequentist interpretation that has been assumed. In this context, we note that the consultant's assessment was based on an overview of the methodology published in the annual salmon stock status reports for England and Wales and not the full technical details. We recognise that this may account for some of the apparent differences in interpretation.

The current model estimates future egg deposition trajectories in a Bayesian framework that includes an autoregressive term and 20-percentile regression to estimate compliance with the management objective – i.e. meeting conservation limit (CL) in four years out of five. In this instance, we consider fitting a linear trend to the data is appropriate to evaluate temporal trends in egg deposition and the inclusion of "year" as a proxy variable is prudent because it captures the potential influence of multiple explanatory variables at once.

2 Specific comments

The following section addresses various specific issues raised in the review by O'Hagan and Fop.

2.1 Fitting a regression where the egg counts are expressed as a linear function of the year

We recognise that various factors may affect egg counts (e.g. as noted in the review: *'rod effort/catch performance/success and weather factors')* and take account of some of these in generating annual estimates of egg deposition in different rivers, although not in the process used to test compliance. We remain of the view that year ('time') is a valid and reasonable numerical variable to use in a regression model. This might capture the potential influence of multiple explanatory variables at once - in a sense, it is a proxy for variables that might influence egg counts that have not previously been used to generate the egg counts. We further note that the inclusion of other factors in a multiple regression model would require additional predictions to be made on the future trajectories of those factors (e.g. rod effort and weather), potentially increasing uncertainty in the predictive performance of the model.

2.2 Taking account of time dependence in egg counts from one year to the other

The current model does include a 1-LAG autoregressive term to model correlation of the residuals in the Bayesian regression of log(eggs) with year. Hence, an autoregressive term has already been included in the calculation of predicted egg deposition.

2.3 Use of a linear trend

We acknowledge that the exact process to model egg counts might be seen as subjective and open to the preferences of the modeller. A regression-type approach was favoured on the assumption that there could be some underlying driver that is behind any decrease (or increase) in egg numbers and that this is represented (albeit, possibly in a proxy way) by time in a regression model. We have also recognised the need for a precautionary approach to avoid the possibility of salmon stocks reaching unfavourable levels. We thus consider it reasonable to base decisions on the precautionary question: "what if levels fell in the same linear fashion in the next X years". In this instance, a period of 5 years has been chosen since this approximates to one generation in the salmon life-cycle. The use of a 20-percentile regression to fit a linear trend to the data has been considered appropriate given the management objective of meeting or exceeding the CL in four years out of five.

We recognise that patterns of egg deposition are likely to vary between rivers and over time. However, we consider that it is important to apply a consistent methodology and that linear trends continue to provide a reasonable fit to the data in many cases (and represent a suitable approach overall). Time series methods were considered during preliminary discussions to establish the current system. However, it was felt that moving average and autoregressive approaches might result in predictions that relied too much on the most recent changes in the data. In the event, it was therefore decided to assume some underlying trend.

We recognise that it could be informative to explore possible alternative scenarios by means of General Additive Models and will aim to investigate this further as part of the planned review of methods. We note, however, that whichever model is used, predictions into the future are problematic and can only assume that what has gone on before will continue.

2.4 Applying a 20-percentile regression

The justification for fitting a 20-percentile regression to the data relates to the management objective of meeting or exceeding the conservation limit (CL) in 4 years out of 5. In line with international guidelines, and the precautionary approach, managers should aim to ensure that CLs are achieved with a high degree of probability. In England and Wales, managers have specified that this level should be set at 80% (other jurisdictions apply similar levels). The current method fits a 20-percentile regression line to the data and calculates the probability that this regression line is above the CL, and thus that the CL will be exceeded in four years out of five (the management objective). We consider that this approach is reasonable and appropriate when done in a Bayesian context.

2.5 Number of observations used in the assessment

We do not share the view that using ten observations to compute the regression line makes the current assessments invalid. The number of observations affects only the variability of the assessment. However, the uncertainty of any assessment will be a function of the variability of the data around the model and the number of observations. Ten annual observations were chosen to balance having enough information to estimate the model and be a biologically relevant period for a temporal trend that covers two generations of the salmon life-cycle. Time-series or moving average based approaches are unlikely to improve the model predictions, because an autocorrelation term has already been included in the calculation of log(egg deposition) estimates prior to inclusion in the regression model. We further note that there is no biological justification for changing the egg deposition calculations to apply over shorter periods of time than annually because Atlantic salmon only spawn once per year.

2.6 Incorporating additional variables

As noted previously, some additional variables are already considered in deriving the annual estimates of egg deposition. Including other factors in a regression model might, or might not, improve the predictive performance of the model. However, we currently consider ‘year’ to be a reasonable proxy variable to capture the potential influence of multiple explanatory variables at once, as noted above. Exploring the possibility of incorporating additional explanatory variables could be considered as part of the planned review. However, there would be limits to the possible inclusion of extra variables as this would reduce the degrees of freedom to estimate the uncertainty in the estimates. We further note the problem of incorporating factors such as weather in a predictive capacity.

2.7 Model validation

We accept the suggestion that some form of model validation might be a good addition to the assessment. This could be achieved by examining retrospective patterns in the predictions of egg deposition over time. There are, however, certain caveats that would need to be taken into account in exploring retrospective patterns. Firstly, the forecasts of future egg deposition trajectories are precautionary (based on the 20-percentile regression). Secondly, changes in management practices might influence realised egg deposition over time. Indeed, the projected stock status is specifically used to trigger management action. Thus, if stock status is predicted to be poor, then management actions are applied to try to avoid this occurring. In addition, we also need to recognise that any prediction-based approach needs to be precautionary. The current process considers what the egg deposition levels might be in 5 years’ time if the linear projection is maintained. Where a fall is projected, this might not actually happen, but in terms of stock management it would be prudent to assume that it might. So, forecasting underestimates of egg deposition are less likely to adversely affect the conservation status of Atlantic salmon stocks than forecasting overestimates of egg deposition. In effect, it is better to be safe than sorry.

2.8 Inferring probabilities from confidence bounds and implications for stock classification

The reviewers seem to have misinterpreted the fact that the assessment procedure is a Bayesian analysis. We recognise that the description of the methodology included in the annual assessment report of salmon stocks and fisheries for England and Wales refers to confidence intervals when these should strictly have been reported as 'Bayesian credible intervals' (BCI), and that this may have contributed to the misunderstanding. The current assessment procedure estimates the (posterior) distribution of the 20th percentile conditional on the year; the use of probabilities in this context is appropriate. We do not, therefore, consider that the current procedures for the classification of rivers into the 'At Risk', 'Probably at Risk', 'Probably Not at Risk' and 'Not at Risk' categories are invalid, as suggested by the reviewers.

Using the current Bayesian approach, we are aware that, for a small number of rivers, egg deposition estimates may be consistently above the CL, but the stock still be assessed as having a relatively low probability of meeting the management objective. In part, this reflects the marked year-to-year variation in egg deposition estimates on these rivers, which produces a broad BCI around the regression lines, but also arises because of the slope of the trend line and the increasing uncertainty associated with all regressions once extrapolated beyond the data set. It might also be noted that the direction of the trend in the 10-year time-series of egg deposition estimates, and its statistical significance, are also taken into account in considering the need for management action and the degree of intervention required. Thus, a clear negative trend would give additional cause for concern.

3 Conclusion and next steps

We remain of the view that the current Bayesian assessment and forecast methods for evaluating compliance with the management objective have been carefully considered, are fit for purpose and are consistent with the precautionary approach. As such, we are satisfied that the current procedures provide an adequate basis for taking management action to safeguard stocks.

We recognise, however, that alternative assessment approaches are possible and, as noted previously, we will be considering these as part of the ongoing review of procedures. Amendments that might be considered include: investigating whether linear, quadratic, or other, potentially more subjective, models most frequently have the best fit to the data across rivers, and undertaking some form of retrospective analysis for model validation. The precise details of the methodology would also be documented carefully and publicised more widely to improve transparency in the procedures used.

In closing, we would note that salmon stock assessment procedures applied in neighbouring jurisdictions may differ in their detail, but are built around the same international guidance and precautionary principles as our own. In both Scotland and the Republic of Ireland, recent assessments have also indicated substantial declines in salmon stock status and have resulted in extensive further controls on exploitation in order to protect declining stocks.

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