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Cefas

Use of Spawning Production Foregone EAVs for impingement assessment

Use of Spawning Production Foregone EAVs for impingement assessment

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Version and Quality Control

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1 Background

For nuclear new build sites (NNB) where there is an existing operational power station, predictions of the impingement of fish and invertebrates at the NNB are based on the observed numbers of individuals impinged by the existing station scaled up to represent the new station. To evaluate the impacts of a new build on fish stocks, the predicted losses due to the new station (by number or weight) are compared with a known population estimate, such as the annual Stock Spawning Biomass (SSB) or, in the absence of this, annual international fishery landings as a highly conservative measure of stock abundance.

*The SSB is the combined weight of all individuals in a fish stock that are capable of reproducing. To calculate the spawning stock biomass, you need to have estimates of the number of fish by age group, estimates of the average weight of the fish in each age group and an estimate of the amount of fish in each age group that are mature. For example, if there are 1,000 fish of age three that weigh on average 0.5 kg and 50% of these fish are mature, the spawning biomass of this age group is 250 kg (1000 X 0.5 X 0.5).*Source: International Council for the Exploration of the Sea (ICES).

ICES advises public authorities with competence for marine management including the European Commission (EC) and provides peer reviewed estimates of SSBs and compilations of international fisheries landings data**.**

Mortalities of fish and crustaceans caused by power station cooling water intakes often involve the juvenile part of a population because it is that part that is particularly vulnerable because of their presence in inshore nursery areas and their poorer swimming capability compared with adults (Turnpenny *et al*., 1988). The natural mortality of juveniles is much higher than that of the adults of a species, as juveniles are often prey for other species, or simply have a larger proportion of their natural lives to survive. Consequently, the loss of a single juvenile does not equate to the loss of a breeding adult of the same species. The concept of the Equivalent Adult Value (EAV) metric provides a means to relate the numbers of impinged juveniles to the corresponding number of adults. This allows for a realistic evaluation of the impact of the station.

A previous method of estimating EAVs is described in Turnpenny (1989) where the EAV of a juvenile fish is defined as the average lifetime fecundity of an adult that has just reached maturity which is required to replace that juvenile. However, the approach requires the input of several parameters related to female maturity and fecundity, many of which are difficult to estimate with any level of certainty. Consequently, Turnpenny (1989) only estimated EAV's for six fish species. Although the Turnpenny (1989) EAVs may be applied to other species within similar functional groups, in the absence of an appropriate EAV a precautionary value of 1 must be applied, giving rise to an overestimate, often substantial, of the potential impingement losses and therefore impacts on populations.

To overcome the limitations with the Turnpenny EAV approach, a method has been developed based upon well-established fisheries science principles. The approach assumes that it is the level of natural mortality experienced by an individual in the wild between the age at impingement/entrainment and the age at which it would have reached maturity that determines the EAV. This is determined by two biological characteristics, natural mortality and growth. The benefit of this approach is that these two parameters are more readily obtained for a given species, or if they are not available in the literature, could be collected with a moderate amount of effort. Further, the approach allows for EAVs to be calculated for specific geographic areas, reflecting the stock structures of specific populations. A description of the approach and the underlying concepts along with any assumptions of growth or natural mortality used are given in BEEMS Technical Reports TR383 and TR426 for Sizewell and Hinkley Point respectively.

The Environment Agency in their draft note TB010 (Environment Agency 2019) have proposed an alternative method of calculating EAVs based upon the spawning production foregone (SPF) approach. The SPF approach calculates the total loss to the population as the sum of the equivalent adults lost from the spawning population in a year plus the future spawning potential of lost fish that would otherwise have matured.

Spawner Production Foregone is a branch of fisheries science that was developed to determine how much spawning capacity could be taken per year by fishing without affecting population sustainability. The science was adapted for use in USA to formulate a compensation equation for entrainment and to the knowledge of the authors of this SPP, SPF EAVs have not been used in those studies to produce quantitative impingement effects calculations using SSBs or landings data.

TB010 concludes:

> *"From our review of the available methods, the **Spawning Production Foregone** method is considered by the Environment Agency to be the most appropriate to use to assess the entrapment losses at HPC over the operational lifetime of the station. It addresses many of the factors of relevance in the valuation of lost fish by incorporating natural mortality rates, proportional maturity rates, and repeat spawning potential. The Spawning Production Foregone method takes into account the value of repeat spawning fish, and produces numbers of equivalent adults which are directly comparable to Spawning Stock Biomass.*
>
> *The Spawning Production Foregone method does not consider the effect of fishing mortality. Survival both before and after maturity may be less than indicated by the method if commercial fishing is removing fish from the population with fishing mortality generally beginning at sizes less than 100% maturity. This means that the Spawning Production Foregone method may overvalue older fish to some extent by not considering fishing mortality. However, for key species of concern such as Atlantic cod, and many of the diadromous species, fishing mortality is limited given the current status of the stocks."*

All EAV calculation methods are accounting procedures and the SPF EAV is an extension of the 6 step Cefas methodology to account for future spawning potential by adding three additional steps 7-9 (TB010) to the original 6 steps. The difference in the results between the two methods is that by accounting for the future spawning potential, SPF EAVs can potentially have a value greater than 1 (i.e. a juvenile fish can be assigned a value of greater than 1 adult if the species can spawn repeatedly over multiple years and some of those spawners could survive numerous spawning seasons after attaining maturity). The Cefas methodology calculates the number of juvenile fish that could reach maturity and therefore has a maximum value of 1 (i.e. the impinged fish could have an EAV of 1 if the whole catch was mature at point of capture but for most species the EAV is much less than 1 due to the large number of juveniles in the catch which would not survive to maturity due to natural mortality).

2 Purpose of this Report

For stocks where suitable data exist, quantitative assessment of the annual effects of anthropogenic mortality on fish populations (of which fishing is the largest component) is done by comparison with the annual spawning stock biomass. For impingement assessment the number of juveniles impinged must be transformed into the equivalent number of mature adults to permit a valid comparison with the annual SSB by use of EAV factors. The calculated impingement effect of an NNB is therefore directly proportional to the EAV i.e. the larger the EAV, the larger the indicated impingement effect. It therefore matters that the EAV calculation is founded on the most appropriate science and that EAVs are then used correctly in an assessment process.

The algorithm used in TB010 makes several biological assumptions that may or may not be valid to derive its calculations and to arrive at the 'population equilibrium' described in the note; however, in this SPP we have neglected these biological assumptions and focussed the study on four straightforward issues:

1. Neglecting the assumptions used to derive population equilibrium, is the algorithm for calculating SPF EAVs correct?
2. TB010 recognises that the method has not included fishing mortality (F). For commercial species F is additional to natural mortality (M) and often impacts before fish are mature and therefore the

number of repeat spawning opportunities in future years will be more limited than implied by the calculations in TB010. Is not including F in the calculation of SPF EAVs significant?

3. How can SPF EAVs be used to calculate impingement effects?

4. Finally, given the conclusions from issue 2 above, is the omission of F from the Cefas EAV methodology significant?

To illustrate the differences in EAV approaches we have applied the results by using impingement data for bass (Stock area: ICES divisions IVbc, VIIa, VIId-h). Bass is a long lived, slow maturing demersal species that would be expected to have very different calculated EAVs using the SPF and Cefas methodologies.

Some broad conclusions are reached in Section 7 that are site and species independent.

3 Data used for the assessment and calculated EAVs

The data used in the assessment are described below. For all calculated EAVs the same values for growth, maturity and natural mortality are used in order to ensure comparability of the results. The impingement dataset is common for both the Cefas and SPF EAV methodologies and uses the Sizewell B CIMP impingement data for bass for the period 2009 – 2017 as described in BEEMS Technical Report TR406. The calculated EAV from these data using the Cefas methodology is 0.224 and reflects the predominantly juvenile composition of the impinged bass.

98% of the impinged bass were immature (not yet capable of spawning) and 2 % were mature at the point of impingement. The peak numbers of impinged bass were aged 2 whereas bass do not begin to mature before age 4, 50% maturity is not reached until ages 5 to 6 and 89% maturity is at age 8 followed by a slow asymptotic rise to 100% maturity at age 14. Large numbers of the impinged bass would therefore be expected to suffer natural mortality before reaching maturity, thereby leading to a small EAV value of much less than 1 with the Cefas methodology (0.224).

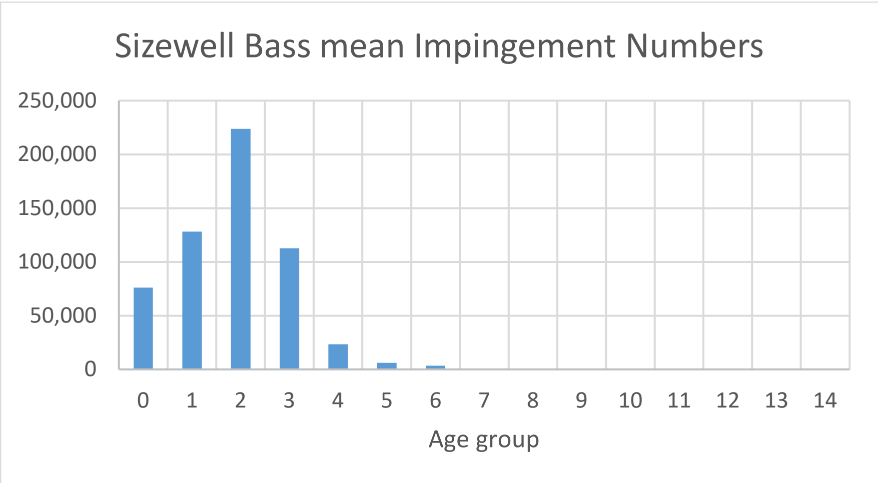

Figure 1 Distribution of mean impingement numbers by age group in the period 2009-2017 (maturity starts to occur at age 4)

The calculated SPF EAV from the original TB010 method is 0.99. Compared with the EAV calculated with the Cefas methodology, the larger SPF EAV reflects the possible contribution of future spawning and indicates that 1 impinged juvenile is nearly equivalent to 1 mature adult. As stated in TB010, the SPF EAV methodology does not include fishing mortality (F) which is additional to natural mortality.

To derive F we have used fishing mortality at age, based on the mean F for bass calculated from the years 2009-2017 (to be consistent with the SZC impingement outputs) from ICES WGCSE 2019 (French fleet which represented a mean of 57% of total bass landings in the period 2009-2017 – ICES WGCSE 2018).

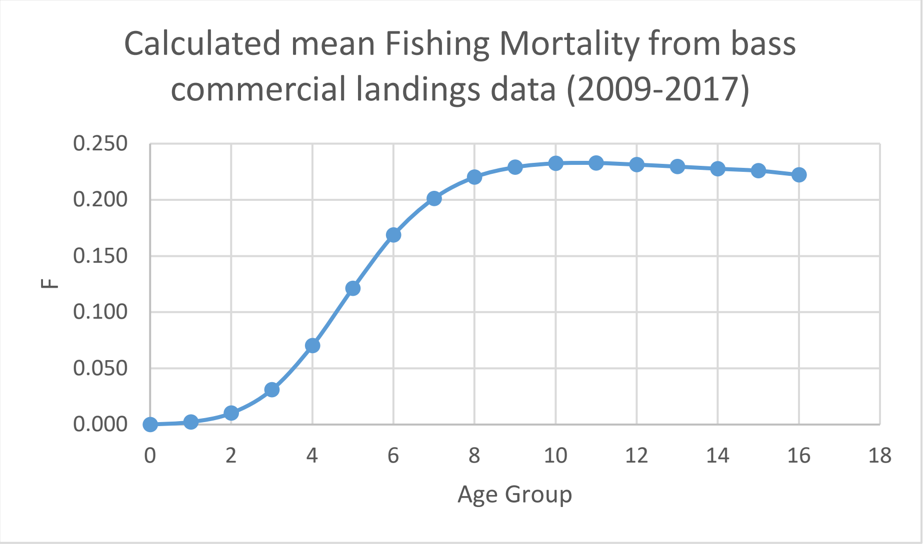

Figure 2 Fishing mortality for bass from ICES WGCSE working group report 2019

The associated landings data are shown in Figure 3.

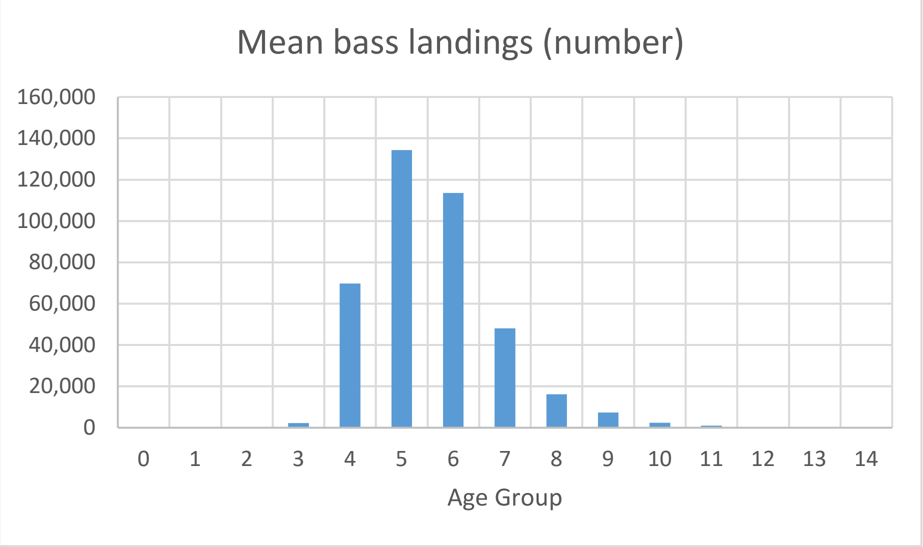

Figure 3 Bass landings number at age (mean 2009 to 2017)

From the landings data it can be seen that the peak landings are at age 5 when only 42% of bass are mature. A total of 52% of the entire commercial landings were estimated to be mature but the remaining 48% would have had no opportunity to reproduce before death. The young age at capture means that proportionately few bass live to spawn in multiple years. These landings data do not include discards (unwanted fish) which predominantly takes place with fish of age groups 3 and 4, which are below landing size limits. From 2009 to 2014 the estimated discard rate was approximately 5% of the catch, but after 2015 the discard rate is less certain and has been estimated to be in the range 10% to 27% of the catch. The change was due to the change in minimum landing size from 36cm until 2015 and 42 cm thereafter. This had the effect of increasing the discards of fish caught as bycatch in other fisheries (ICES WGCSE 2019). Accordingly, juvenile mortality is understated by the landings data and therefore the majority of fish caught in the commercial bass fishery are in fact immature.

The discard rates are considered subject to considerable uncertainty which reduces the accuracy of F at age calculations (See section 6).

4 Are the SPF EAVs calculated correctly in TB010?

This brief discussion ignores the assumptions used to model population equilibrium in TB010 and focuses on the algorithm as described.

We have examined the methodology described in TB010 and have recreated the analysis spreadsheets. The first 6 steps of the 9 step SPF EAV methodology are identical to those described for the Cefas methodology in BEEMS Technical Reports TR383 and TR426. Steps 7-9 are new.

Step 7 contains an error whereby the same natural mortality was applied annually to each age class - Age 0 fish were subject to the same value of M each year. However, with every year, the fish surviving should have been subject to the next year's natural mortality. This has been corrected in the spreadsheets we have used (Excel spreadsheets with “sw modified” in the filename).

Using the SZB impingement data, the SPF EAV is 0.99 using the original TB010 algorithm and 1.05 in the corrected algorithm. All subsequent calculations have used the corrected SPF EAV algorithm.

5 What is the effect of omitting F from the SPF EAV calculations?

Including published values of F into the SPF EAV calculation is simply a matter of replacing all occurrences of natural mortality at length in the algorithm with total mortality at length (Total mortality is equal to fishing mortality plus natural mortality). This reduces the calculated bass SPF EAV to 0.598 from 1.050 (57% of the original SPF EAV) and reflects the fact that far fewer fish would survive to spawn on multiple occasions than estimated in the original TB010 algorithm. However, even after correcting for F, the resultant SPF EAV is still 2.67 times larger than the EAV calculated via the Cefas EAV methodology.

6 How can SPF EAV be used for impingement effect predictions?

ICES’ fisheries assessment models do not account for production foregone as they simply reflect the Spawning Stock Biomass (SSB) of fish alive in a particular year. Landings data only describe the number of fish landed in a year. Neither of these two indicators include future spawning potential. As such, comparison of impingement numbers derived with SPF EAVs against SSBs or landings data is an invalid calculation as the measures are fundamentally incompatible.

However, with appropriate manipulation modified SSB and landing numbers can be created that do include future spawning potential. For example, bass landings are simply a much larger form of anthropogenic mortality than impingement losses from an NNB. As such the spawning production foregone can be calculated using exactly the same SPF EAV algorithm by just replacing the impingement numbers at age with the landing numbers at age. Similarly, from the estimated annual SSB in a year a modified SSB can be calculated that includes potential future spawning production (i.e. the modified SSB would include the spawning stock in the year of interest plus the predicted future spawning production from that annual SSB). (Noting that to do so exposes the questionable biological basis behind the SPF methodology e.g. recruitment in any year is poorly correlated with stock size).

As an example, we have computed the SPF EAV for bass landings to be 2.52 (Including the effects of F). As would be expected the landings SPF EAV is much larger than the impingement SPF EAV at 0.598 because there are far fewer juvenile fish in the landings data (with peak age 5) compared with the impingement data (with a peak age 2) and therefore much lower losses from natural mortality. It is worth reflecting on what the use of the SPF EAV implies. If the actual landings in a year are 1000 fish, the use of the SPF EAV means that the landings represent 1000 fish caught in that year plus the potential production of 1520 fish spread over several future years. This form of assessment is not compatible with ICES' assessments of the sustainability of fish stocks nor with any management regime under the Common Fisheries Policy.

6.1 Summarised effect calculation – incorrect use of SPF EAVs

Using the Cefas EAV methodology, the calculated impingement effect = Impingement number*impingement EAV/landings = impingement numbers*0.224/landings

If the SPF EAVs are applied only to the impingement numbers the calculated impingement effect = impingement number *SPF EAV/landings = impingement number *0.598/landings (Corrected TB010 EAV methodology including the effects of F).

i.e. The corrected TB010 calculated effect is 2.67 times the Cefas effect value (0.598/0.224) or 4.42 times the Cefas value based on the original TB010 algorithm.

However, the effect calculation using the SPF EAV is incorrect as it has adjusted only one side of the equation for future production whereas the landings have to be multiplied by the appropriate SPF EAV as well. On first principles we would expect the additional SPF EAV factors to approximately cancel out.

6.2 Summarised effect calculation after correcting the landings for SPF.

SPF EAV for landings data = 2.52 (including the impact of F)

I.e. correct effect calculation using SPF EAVS is:

Calculated impingement effect = (impingement SPF EAV * impingement number)/ (landings SPF EAV * landing number) i.e.

Calculated impingement effect = 0.598* impingement number/2.52*landings = 0.237*landings

Compared with the calculated effect using the Cefas EAV of 0.224*landings

As expected the two results are approximately the same with the calculated SPF EAV impingement effect being 1.058 times the calculated effect using the Cefas EAV methodology (or a difference of less than 6%).

6.3 Limitations on the reliability of SPF EAVs

By adjusting both sides of the impingement effect equation (i.e. impingement and landings) by the appropriate SPF EAVs we would have expected the calculated effects from using the Cefas and SPF EAV methodologies to be approximately the same and indeed the calculated difference in impingement effects is apparently less than 6%.

That prompts the question of why the numbers are different. In short, the disparity is considered most likely to be due to the additional uncertainties introduced by requiring estimates of F in the SPF EAV.

The SPF EAV calculations are sensitive to assumptions of F at age (Section 5). F is an estimated quantity that varies annually and depends on:

- the accuracy of landings data; and
- the adequacy of biological sampling at the landing ports.

Most commercial species experience discarding and until recently bass was at the lower end of the discard spectrum with an apparent estimated rate of 5% (ICES WGCSE 2019). More recently this has increased into the range of approximately 10% to nearly 27%. As it is the smaller fish that are rejected so F at younger ages (3 and 4) is biased by discarding. The Impingement SPF EAV is particularly sensitive to this bias which will lead to overestimated EAVs.

Effective biological sampling is required to derive Age-length keys but this has been an area where a lack of funding in member states has resulted in under sampling in the ports leading to poorly estimated length at age values and further uncertainty in the F at age calculations.

The resulting uncertainties in the values of F at age and also in the conversion of recorded landing weights into landing numbers are considered to result in low precision in estimated SPF EAVs. We have not attempted to quantify potential errors in the SPV EAVs due to uncertainties in F but we do expect that uncertainty will easily exceed the indicated 6% difference between the different effect predictions in Section 6.2.

6.4 Should the EAVs calculated with the Cefas methodology be adjusted for fishing mortality?

In the Cefas EAV methodology the impact of fishing mortality is not included in the algorithm on the assumption that fishing mortality will not substantially increase total mortality until fish become mature. Based upon the work in this report that assumption is questionable for bass.

F was therefore inserted into the Cefas EAV methodology by replacing natural mortality with total mortality (equal to natural mortality plus fishing mortality). The calculated EAV changed from 0.224 without F to 0.197 with F, or a 12% reduction. In comparison and, as expected, the SPV EAV is much more sensitive to F, with the SPF EAV changing from 1.05 without F to 0.598 with F, or a 43% reduction.

In theory it would be more accurate to include F in the Cefas methodology. However, given the uncertainties in the derivation of F at age it is not considered that the additional step is justified.

7 Conclusions

Considering the aims of this study in turn:

1. **Is the algorithm for calculating SPF EAVs correct?**

TB010 contains a small error in the methodology, which underestimates the SPF EAV. This has been corrected.

2. **Is not including F in the calculation of SPF EAVs significant?**
Neglecting F produces a significantly overestimated EAV for bass; TB010 understates the likely errors in so doing. We conclude that F cannot be neglected in SPF EAV calculations for species subject to commercial fishing. Most species including diadromous species are subject to fishing mortality.

3. **How can SPF EAVs be used to calculate impingement effects?**
Impingement calculated with SPF EAVs cannot be compared with annual SSBs or landings as the comparators are not compatible with each other. If SPF EAVs are used for impingement assessment, landings or SSBs also need to adjusted by specific SPF EAVs. The net effect is that the introduction of SPF EAVs makes no material difference to the calculated impingement effect and is a redundant additional calculation step. SPF EAVs rely on estimates of F at age and this additional parameterisation introduces a new set of uncertainties into the assessment.

4. **Is the omission of F from the Cefas EAV methodology significant?**
There is a small reduction in calculated EAVs by including F at age into the Cefas EAV methodology but the additional step is not considered beneficial due to the uncertainties in the derivation of F at age. The Cefas EAV methodology is much less sensitive to F than the SPF EAV methodology.

It is concluded that there is no benefit from the use of SPF EAVs in impingement assessment and that their use is considered likely to increase, rather than decrease, uncertainty in assessments.

8 Accompanying spreadsheet calculations

This report is accompanied by a set of spreadsheets containing the calculations described in this report as follows:

Table 1 EAV calculation spreadsheets

Filename	Contents
EAV-SZ-bass v5a – EA method	Original TB010 SPF EAV for bass impingement.
EAV-SZ-bass v5a – EA method sw modified	Modified TB010 impingement SPF EAV as described in section 4.
EAV-SZ-bass v5a – EA method sw modified plus F SZC no mitigation2	Modified TB010 impingement SPF EAV including impact of fishing mortality (F). The same spreadsheet calculates the EAV using the Cefas methodology including the impact of F.
EAV-SZ-bass v5a – EA method sw modified plus F commercial land2	Modified TB010 SPF EAV including impact of fishing mortality (F) for commercial bass landings.

9 References

BEEMS Technical Report TR383. Sizewell Equivalent Adult Value (EAV) metrics. Cefas, Lowestoft.

BEEMS Technical Report TR406. Sizewell C – Impingement predictions based upon specific cooling water system design. Cefas, Lowestoft

Environment Agency. 2019. Technical Brief: TB010 Draft. Converting impingement and entrainment numbers to Equivalent Adult Values and Spawning Production Foregone

ICES WGCSE 2018 Report Section 31 -Seabass (*Dicentrarchus labrax*) in divisions 4.b–c, 7.a, and 7.d–h (central and southern North Sea, Irish Sea, English Channel, Bristol Channel, and Celtic Sea)

ICES WGCSE 2019. Report Section 29 -Seabass (*Dicentrarchus labrax*) in divisions 4.b–c, 7.a, and 7.d–h (central and southern North Sea, Irish Sea, English Channel, Bristol Channel, and Celtic Sea)

Turnpenny, A.W.H., Utting, N.J., Millner, R.S., Riley, J.., 1988. The effect of fish impingement at Sizewell "A" Power Station, Suffolk on North Sea Fish stocks, CERL Report No. TPRD/L/3279/R88.

Turnpenny, A.W.H., 1989. The equivalent adult approach for assessing the value of juvenile fish kills, with reference to commercial species in British Water. CERL Report No. RD/L/3454/R89.