HINKLEY POINT C PERMIT VARIATION

EPR/HP3228XT/V004

Technical Brief: TB010

Converting impingement and entrainment numbers to Equivalent Adult Values and Spawning Production Foregone.

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NOTES (to be removed on final signoff:

1) *This document has been updated since an earlier draft was shared with NNB Genco (HPC) Ltd. An error in applying mortality rates has been corrected (Step 8 of Appendix C).*

2) *A detailed clarification of the Spawner Production Foregone extended method is provided (Appendix E) in response to questions received from NNB Genco (HPC) Ltd regarding the earlier draft version of TB010.*

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EXECUTIVE SUMMARY

Mortality of fish caused by power station cooling water intakes mainly (but not wholly) involves the juvenile part of a population. Juvenile fish are particularly vulnerable to being drawn into the cooling water intakes due to their presence in inshore nursery areas and their small size, meaning they have relatively poor swimming capabilities.

Because many fish species produce large numbers of offspring, mortality of larval and juvenile fish will not have the same effect on a population as removing the same number of adults would, due to the fact that many of the larvae and juveniles would never have survived to contribute to the spawning population.

Equivalent Adult Values (EAVs) are an ‘accounting procedure’ by which large numbers of larval and juvenile fish subject to entrapment (both entrainment and impingement) at power station cooling water intakes can be converted to an equivalent number of adults. This allows mortality of fish caused by power station cooling water intakes to be compared with population measures of adults, such as Spawning Stock Biomass, fisheries landings data, or run size estimates, to give proportional losses to populations. Conclusions can then be drawn about the potential impact of the cooling water intake on the populations.

The basic procedure for calculating an EAV factor first involves estimating how many of the fish of each age class would have survived to become adults (or how many adults would be required to reproduce the fish). The EAV factor value is then the number of equivalent adults divided by the total number of fish entrapped. Different EAV methods are variations on this basic theme, aiming to bring biological data into the calculation to provide more meaningful estimates. In particular, defining the value of an adult fish can vary between methods.

An individual fish in its first year of life (termed 0-group) will have a lower EAV than an individual fish in its second year of life (1-group) by virtue of natural mortality (and other sources of mortality, such as fishing and other anthropogenic mortality) meaning that proportionally fewer 0-group fish would survive to maturity than 1-group fish.

Some methods count all maturing adults as equal, whereas others recognise that the reproductive potential of fish maturing as 1-group fish will be greater than that of fish maturing as 3-group fish; the 1-group fish potentially having the opportunity to also spawn as 2-group and 3-group fish. Methods could also consider the greater relative fecundity of older fish than younger fish in the valuation of lost fish. Finally, the conventional EAV method also considers the greater number of adults required to replace the loss of older fish, by allowing an EAV of greater than 1.

Different methods will produce different EAV values. The EAV value used matters because different estimates of the equivalent number of adults lost could lead to different interpretations of the impact of the abstraction on fish populations.

For some species or fish assemblages, or where a Habitat Regulations Assessment (HRA) may be required, it is appropriate to utilise a multi-year context, for the assessment to place losses into the context of the whole operational life of the power station in question. An EAV based on annual entrapment alone does not allow this to be considered.

Rather than calculating an equivalent adult loss for a single year of operation using an EAV method, a Spawning Production Foregone model estimates the number of equivalent adults lost to the population in any given year of operation, considering the cumulative EAV losses in previous years of operation and their future spawning potential lost to subsequent years.

The original Development Consent Order (DCO) submission calculated EAVs using a conventional EAV method (as reported in Turnpenny, 1988). A new method for calculating EAVs was used in the permit variation application and is reported in BEEMS Technical Report TR426 (Cefas, 2017) and TR456 Ed2 v10 (Cefas, 2018), the reasoning being that for many species, parameter estimates required for the conventional method could not be determined with any reliability. This new EAV method is referred to as the TR426 method, below.

The Environment Agency reviewed the TR426 method, with support from specialist consultants, checking parameters used and substituting more appropriate values, where available. This resulted in EAV values for the TR426 method being revised.

Extensions to the TR426 method were then developed to account for the underestimation of the valuation of mature fish, associated with the TR426 method; these being to standardise the lost fish to the number of age-at-50%-maturity fish required to replace them (a simplified conventional EAV method), and to include variable valuation at maturity to account for the different fecundity potential of fish maturing at different ages (termed Lifetime Fecundity). An extension was also developed to assess the lost spawning potential of the entrapped fish (termed Spawning Production Foregone) which valued lost fish based on both their probability of survival to maturity but also their future contribution to the spawning stock for their remaining life, post-maturity.

Of these extensions, the Spawning Production Foregone method was considered to be the most appropriate, as it takes into account the value of repeat spawning fish, accounts for lost spawning potential from entrapment and produces numbers of equivalent adults which are directly comparable to Spawning Stock Biomass estimates for each species.

Data to parameterise the TR426 method or Spawning Production Foregone extension are unlikely to be comprehensive for any project, and so uncertainty and variability will need to be accounted for within the models to enable robust and risk-based decisions to be made. Uncertainty ranges for the Spawning Production Foregone method are provided for each species considered.

INTRODUCTION

This report discusses the options for contextualising the losses of fish from entrapment at Hinkley Point C (HPC), and investigating the effects of the losses of fish from entrapment upon the spawning populations. The approaches applied to HPC to date are reviewed, and a recommendation made of the method which will be used by the Environment Agency in its determination of the permit variation application made for the project.

Mortality of fish caused by power station cooling water intakes mainly (but not wholly) involves the juvenile part of a population. Juvenile fish are particularly vulnerable to being drawn into the cooling water intakes due to their presence in inshore nursery areas and their small size, meaning they have relatively poor swimming capabilities (Turnpenny *et al*., 1988).

In order to successfully reproduce, individual animals generally either invest in producing and caring for a few, relatively large, offspring (e.g. mammals), or produce a large number of small offspring, with no parental care (e.g. many fish species). In the first strategy, there is a good chance of two of the offspring surviving to replace the parents. In the second strategy there is a good chance of two of the thousands, or millions, of eggs and larvae surviving to replace the parents.

Because many fish species produce large numbers of offspring, mortality of larval and juvenile fish will not have the same effect on a population as removing the same number of adults would, due to the fact that many of the larvae would never have survived to contribute to the spawning population.

Equivalent Adult Values

Equivalent Adult Values (EAVs) are an ‘accounting procedure’ by which large numbers of immature fish can converted to an equivalent number of adults (Environment Agency, 2010). This allows for comparisons of mortality of fish caused by power station cooling water intakes to be made with population measures of adults, such as Spawning Stock Biomass or fisheries landings data. Conclusions can then be drawn about the potential impact of the cooling water intake on fish populations.

Several different methods can be used to calculate an EAV. The conventional EAV value, as reported in Turnpenny (1988) represents the fraction of the average lifetime fecundity of an adult which would be required to replace the Age Y fish (e.g. an EAV of 0.1 would mean that only ten percent of the eggs produced by a female over the course of its life would survive to become an Age Y fish).

The TR426 method for calculating an EAV factor first involves estimating how many of the fish of each age class would have survived to maturity. The EAV factor value is then the number of fish surviving to maturity divided by the total number of fish entrapped.

Fish of any particular species impinged or entrained in cooling water systems will usually be made up of several age classes. An individual fish in its first year of life (termed 0-group) will have a lower EAV than an individual fish in its second year of life (1-group) by virtue of natural mortality (and other sources of mortality, such as fishing and other anthropogenic mortality) meaning that proportionally fewer 0-group fish would survive to maturity than 1-group fish, and that it would take fewer eggs to reproduce a 0-group fish. In other words, the fraction of a fish's lifetime fecundity required to replace a 0-group fish is lower than that for a 1-group fish.

The number of equivalent adults can be converted to a weight using length:weight relationships for the species and the resulting weight of fish compared to a population statistic, such as Spawning Stock Biomass[1], or fishery catch data. Alternatively, if the data are available, the number of equivalent adults can be compared with the number of adults within the population.

Different EAV methods are variations on this basic theme, aiming to bring biological data into the calculation to provide more meaningful estimates. Defining the value of an adult fish can vary between methods, however.

Individual fish within a species can reach maturity at different ages. For example a few fish may become mature as 1-group fish, a larger proportion maturing as 2-group fish and all fish being mature as 3-group fish. Some methods count all maturing adults as equal, whereas others recognise that the reproductive potential of fish maturing as 1-group fish will be greater than that of fish maturing as 3-group fish; the 1-group fish potentially having the opportunity to also spawn as 2-group and 3-group fish. Some methods could also consider the greater relative fecundity of older fish than younger fish in the valuation of lost fish.

Different methods will produce different EAV values. Dixon (2004) cites a study on the entrainment of various fish species at the Diablo Canyon power plant, California, which employed two types of EAV modelling. In the first model, numbers of entrained larvae, were extrapolated to numbers of reproductive adults using estimates of expected survival from the larval stage to maturity. In the second model, losses of entrained eggs and larvae were "hindcast" to the numbers of adult females required to produce them, using estimates of the average total lifetime fecundity of a female fish and the expected survival rate from the egg to the larval stage. In some cases the models produced similar estimates of equivalent adult losses for the same species, but in other cases the results differed substantially. Neither method produced consistently lower or higher values.

The EAV value used matters because different estimates of the equivalent number of adults lost could lead to different interpretations of the impact of the abstraction on fish populations.

[1] Spawning Stock Biomass is the combined weight of all mature fish in the population.

Whilst EAVs provide a useful tool for estimating the impact of juvenile fish mortalities on the adult population, it must be remembered that the ecological impact of juvenile losses do not solely relate losses to the spawning population. There may be ecosystem impacts too, due to the loss of juveniles that would otherwise have been available to predators. Furthermore, EAV methods can only convert the losses of fish from entrapment (impingement/entrainment) over a defined period (such as a year) to the number of adults lost to the spawning population at a single fixed point in time (be it when entering maturity or at the age where 50% of fish are mature). These EAV methods do not account for any subsequent effects of the losses of the adult fish in terms of their contribution to the population once mature. They also do not consider the cumulative effect of multiple years of losses of adult fish to the population.

Production Foregone Models

For some species or fish assemblages, or where Habitat Regulations Assessments may be required, it may be appropriate to utilise a multi-year context, or the context of the whole operational life of the power station in question (Environment Agency, 2019).

For HPC, the impact will take place over the operational life of the power station (60 years) and cumulative effects need to be taken into account. Statutory Nature Conservation Bodies have advised the Environment Agency that that our Appropriate Assessment should employ an EAV method which reflects the importance of multiple spawning events (i.e. allows for an EAV factor of greater than 1)[2].

Rather than calculating an equivalent adult loss for a single year of operation using an EAV method, a Spawning Production Foregone model (e.g. Goodyear, 1990; Goodyear, 1993) estimates the number of equivalent adults lost to the population in any given year of operation, considering the cumulative losses in previous years. The Spawning Production Foregone approach calculates the total loss to the population as the sum of equivalent adults lost from the spawning population in that year, and the future spawning potential of lost fish that would have matured in previous years.

The lost future spawning potential is a measure of the number of fish that would have been present in the population in any given year, had they not been entrapped and killed in previous years. The resulting number of equivalent adults lost in any given year will be directly comparable to Spawning Stock Biomass.

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[2] For example, see notes from ‘HPC Variation - Diadromous Fish Meeting II - 17 July 2019’. While discussing Twaite shad ‘The group agreed that AEVs should reflect multiple spawning events for older mature fish i.e. should go over the value of 1, in line with similar approaches for the other repeat-spawners in the assessment, and potential ways of calculating that were discussed.’

The approach of assessing the total loss to the population from entrapping fish each year, considering their future spawning potential, is analogous to that recently used in the fisheries assessments adopted for the Tidal Lagoon Swansea Bay project through Natural Resources Wales' Marine Licensing process.

The Spawning Production Foregone method operates in a population equilibrium scenario, where annual losses to the population are assumed to be consistent each year resulting in a new, lower baseline population level. This assumes that the losses do not result in a year-on-year decline in the population.

The Spawning Production Foregone method does not include a feedback loop to account for the subsequent change in recruitment from the total losses and thus cannot investigate the potential for a year-on-year decline. The potential for a year-on-year decline, and an effect on the sustainability of the population of each species, will be considered once the proportional losses are defined.

The potential for a year-on-year decline which may occur has been investigated for some species previously (such as Atlantic salmon, twaite shad etc.) through life-cycle models.

Uncertainty

Data to parameterise the tools are unlikely to be comprehensive for any project, and so uncertainty and variability will need to be accounted for within the models to enable robust and risk-based decisions to be made (Environment Agency, 2019).

Hinkley Point C: EAV Methods

Original approach for the Development Consent Order (DCO) process

The original assessment for the DCO process, documented within the Environmental Statement, calculated EAVs using the conventional EAV method as set out by Horst (1975), Goodyear (1978) and Turnpenny (1988)(Appendix A). This peer-reviewed method has been the standard method employed in the UK.

This method converts multi-age class impingement/entrainment data to an equivalent number of age-at-50%-maturity adults that would be needed to reproduce the lost fish (where age-at-50%-maturity is the age class in which 50% of fish are mature). Using weight-at-age data, the number of equivalent age-at-50%-maturity adults can be converted to a weight which can then be compared directly with estimates of population size.

In this method, any impinged fish that are older than the age-at-50%-maturity will have an EAV of greater than 1 as it would take more than 1 age-at-50%-maturity fish to reproduce it.

Strengths of this method are:

- It is a peer-reviewed and has previously been employed in cooling water entrapment studies.
- The number (or total weight) of equivalent adults (of age-at-50%-maturity) estimated from entrapment data is directly comparable to estimates of Spawning Stock Biomass.

Weaknesses are:

- Equivalent adult losses are estimated for a single year of entrapment but the lost future spawning potential of fish is not considered i.e. there is no accounting for the absence of spawners that would have been present in any particular year, had they not been lost in preceding years.
- A wide range of biological parameters are used (relating to sex ratios at age, proportional maturity at age, fecundity at age, and mortality rates at age) which may be difficult to obtain for some species.

New EAV for the permit variation (TR426 method)

A new method for estimating EAVs was introduced in TR383 and TR426 (BEEMS, 2016 and 2017) and is the method used to calculate the EAVs presented in TR456 Ed2 (BEEMS, 2018) (Appendix A). The reasoning for the introduction of the new method, as presented in TR426, is that for many species, parameter estimates required for the conventional EAV method could not be determined with any reliability (even to orders of magnitude, in some cases)(BEEMS, 2017).

The TR426 method (BEEMS, 2017) represents multi-age class impingement data in terms of the number of mature adults that would have been produced. Any impinged fish surviving to maturity is assigned an EAV of 1, regardless of their age or whether they will survive to spawn again in subsequent years.

All fish that survive to maturity are assigned the weight of an average spawner in the population, allowing direct comparisons to be made to population data. In the TR426 method, the EAV represents the proportion of lost Age Y fish that would have survived to become mature adults (unlike the conventional EAV method, where the EAV is the fraction of the average lifetime fecundity of an adult which would be required to replace the Age Y fish),

Neither the proportion of females in each age class, nor the fecundity of mature females of each age class are needed for the TR426 method, but a number of the parameters needed (proportional maturity and natural mortality) are in common with the conventional EAV method. Furthermore, fishing mortality (F) is also a relevant parameter for some species in the development of the number of fish surviving to maturity, given the variable ages and sizes at which fish will mature. However, this parameter has not been used in this method (although would have been used in the original DCO estimates using the conventional EAV method).

The TR426 method has not been peer-reviewed but is not a wholly novel approach, and appears similar to examples of EAV methods given in EPRI (2004), although these, as with the conventional EAV method, allow for an EAV greater than 1 for fish that survive past the age-at-50%-maturity.

Strengths of the TR426 method are:

- The model is built using fewer parameters, and includes more locally-relevant data collected from impingement monitoring

- Numbers of equivalent adults are directly comparable to the Spawning Stock Biomass.

Weaknesses are:

- Although not wholly novel, the method is not peer-reviewed.

- Mortality rates at age are required, as in the conventional EAV method. Natural mortality rates may not be readily available and may have to be estimated from wider studies.

- By valuing all mature fish as 1 adult, without taking multiple spawning or differential fecundity into account, the method systematically undervalues the importance of multiple spawning opportunities and the greater fecundity of older fish.

- Equivalent adult losses are estimated for a single year of entrapment but the lost future spawning potential of fish is not considered i.e. there is no accounting for the absence of spawners that would have been present in any particular year, had they not been lost in preceding years.

The TR426 method has been used for European sprat, whiting, Dover sole, Atlantic cod, Atlantic herring, European seabass, European plaice, thornback ray and blue whiting.

The process for calculating the EAV for twaite and allis shad differs slightly to the TR426 method, as it calculates the number of individuals impinged which would survive to the age-at-50% maturity (set as age 4 for twaite shad, age 5 for allis shad). A different size-mortality relationship has also been used, which used weight-at-age rather than length-at-age to calculate natural mortality from a different sampled dataset.

The TR426 method was not used to calculate EAVs for European eel, sea lamprey, river lamprey, Atlantic salmon, sea trout or brown shrimp in the variation application, these species instead being assigned an EAV of 1 (BEEMS, 2018).

Review of the TR426 Method

The Environment Agency reviewed the TR426 method, and the method used for shads, with support from specialist consultants, checking parameters used, and substituting more appropriate values, if these were available. This resulted in EAV values for the TR426 method being revised (Table 1, Appendix A).

The TR426 method did not take into account change from 10mm to 5mm screens between Hinkley Point B and HPC, which has been subsequently addressed separately in the Environment Agency’s screen size and entrainment technical report.

Our review increased confidence in the TR426 method’s EAV estimates, but did not in itself address systematic underestimates associated with assigning all mature fish a value of ‘1’, nor did it move the TR426 method towards including an assessment of spawning production foregone.

The Environment Agency's commentary on the applicant's use of an EAV of 1 for European eel, sea lamprey, river lamprey, Atlantic salmon, sea trout is available in Feature Impact Assessment Templates (internal Environment Agency documents). In summary:

- For European eel the Environment Agency will use an EAV factor of 1 for impinged eels, based on examination of the length distribution of impinged eels. Entrained glass eels will be converted to an equivalent number of adult (silver) eels. One kilogram of glass eels (about 3,000 individuals) is taken to produce 59.4 kg of silver eels, this being derived using the standard mortality rate for eels after the glass eel stage, an elevated mortality rate during the fifty-day glass eel phase, and a 50:50 sex ratio with males maturing at 12 years (90 g) and females at 18 years (570 g) (ICES, 2018).

- For sea lamprey, an EAV factor of 1 will be used – mortality at age is not well enough known to determine an EAV factor. The four sea lamprey caught during the Comprehensive Impingement Monitoring Programme (CIMP) measured 80 cm, 73 cm, 33 cm and 22cm, and were described by the applicant as comprising two adults and two parasitic juveniles. An EAV factor of one will provide a conservative estimate of impingement numbers, as natural mortality amongst immature marine-phase lampreys will mean that not all of the parasitic juveniles will survive to maturity.

- For river lamprey, an EAV of 1 will be used. Two river lamprey individuals were recorded during the CIMP (recorded as 235-239mm and 245-249mm standard length) measuring 235-250mm standard length. These were likely to be sub-adults in their marine resident/foraging phase. Two river lamprey weights were recorded during the RIMP, both individuals weighing 20 g (one caught in 2005 and one in 2010). The weight of a lamprey after four years living in a river is around 1.5 g, with migration to sea generally occurring between three and five years of age (Maitland, 2003). As such it is likely that these two RIMP lampreys were also parasitic sub-adults. As with sea lamprey, mortality at age is not well enough known to determine an EAV factor. An EAV factor of one will provide a conservative estimate of impingement numbers, as natural mortality amongst immature marine-phase lampreys will mean that not all of these will survive to maturity.

- For Atlantic salmon, an EAV of 0.222 will be used. Due to the salmon's complex life-cycle, the Environment Agency undertook a simplified EAV procedure for this species. Each individual salmon impinged between 1997 and 2017 was assigned its own EAV factor, based on the mean of all survival estimates for smolts in English and Welsh salmon index rivers (1997 – 2017), and the probability of kelts returning to spawn again. The mean of these EAV factors was then calculated and this value (0.222) was used to convert the estimated number of impinged fish to our calculated estimate, expressed as a number of equivalent adult salmon. The standard deviation around this mean value has been used within the uncertainty analysis. The period 1997-2017 was selected as during these years both RIMP data and EA/NRW estimates of the number of adult spawners for the Severn, Wye and Usk were available. We recognise that this is a simplified EAV, which does not take into account the river-specific nature of parameters such as the ratio of single-sea-winter (grilse) to multi-sea-winter adults or the different fecundity of grilse, multi-sea-winter adults and repeat spawning fish. Also, given the poor sampling resolution of the RIMP for Atlantic salmon, the age-structure of the impinged fish from the RIMP is highly uncertain to be representative of the actual conditions at HPB (or future HPC). This will influence the value of the fish lost. However, despite the limitations of the EAV procedure used, this method is felt to give a more realistic representation of potential losses than using an EAV of 1.

- For sea trout, an EAV of one will be used, Sea trout impingement estimates are based upon one individual caught during the Routine Impingement Monitoring Programme (RIMP). This fish weighed 1,721 g and so was probably a small mature adult. As an adult fish was caught, an EAV of 1 is appropriate.

For brown shrimp *Crangon crangon*, there is no stock estimate with which comparisons of entrapment losses can be made. As such, the Environment Agency will undertake a more qualitative assessment of impacts for which the use of EAVs is not needed. Should conversion to EAVs be required however, the Environment Agency will follow the applicant's approach and assign an EAV of 1 to brown shrimp.

No EAV was used for sand goby, lesser sandeel, European flounder or sand smelt (BEEMS, 2018). These species were not investigated as part of this review and are not commented on further in this report, as a quantitative assessment will not be made for these species as part of the permit determination.

Table 1. Issues, impacts and solutions identified during the Environment Agency review of the TR426 method.

European sprat		
Issue	**Impact**	**Solution**
The evidence supplied for the conversion of standard length (SL) to total length (TL) was unclear.	Incorrect lengths could be being used in EAV calculation, which may influence natural mortality rates and subsequent survival of individuals to maturity.	Applicant's data checked using a SL:TL relationship of SL = 0.854 × TL (from www.fishbase.in). This gave very similar results to Applicant's calculations and so no change was made to the Applicant's data.
The proportional maturity is derived from PELTIC survey data, but age-4 proportional maturity is lower than age-3 proportional maturity, which is likely to be a factor of sampling limitations rather than an accurate reflection of the maturity ogive.	If uncorrected, the maturity curve used in the EAV model will not be representative	The proportional maturity data at age-4 has been amended to 0.83, the mean maturity between age 3 and age 5.

Whiting		
Issue	**Impact**	**Solution**
Whilst the proportional maturity matches that from the ICES stock assessment, survey data has shown that some whiting mature at age-1, and that sometimes not all are mature by age 2 (Gerritsen, 2003).	EAV values may be too low if published maturity at age data are not used.	Proportional maturity amended to 20% maturity at age-1, 95% maturity at age-2 and 100% maturity at age-3.

Table 1. cont.

Dover sole		
Issue	**Impact**	**Solution**
Natural mortality was assumed to be 0.1 for all ages and years (ages 1 - 10) in ICES (2017a). The correction factor used by Applicant results in a natural mortality rate of 0.14 at age 6, and higher natural mortalities at younger ages.	Incorrect mortality rates will affect the EAV values generated.	Whilst it is not considered to be valid to reduce all natural mortality values at all ages to 0.1, given the length-mortality relationship that is apparent for the majority of species, a correction to reduce the natural mortality to 0.1 from the point at which the majority of growth has occurred would be a reasonable estimate (i.e. at age 6.). Therefore a correction factor to reduce natural mortality to 0.1 at age 6 will be used (a correction factor of 2.84).
The VB curve used is one that has been fitted to the 2009 survey data on fish lengths and ages. We have assumed that the VB curve has been fitted to the DCDRC and IBTS survey data from 2009, though this is not explicitly stated. Fitting a VB curve to the local data is valid, but no detail has been provided on the model fitting process, model diagnostics or goodness of fit.	We cannot comment on the validity of the VB curve being used without data on the model fitting process, model diagnostics or goodness of fit.	No change has been made to the VB equation as it is site-specific, but further clarity on its derivation is needed.

Table 1. cont.

Atlantic cod		
Issue	**Impact**	**Solution**
The mortality rates used for age-0 and age-1 fish are substantially higher than those used by ICES for the Celtic Sea management unit that HPC is within (ICES, 2017a). ICES use M=1.12 for age-0, and M=0.51 for age-1.	Reducing the mortality rates within the EAV model would increase the EAV factor value.	Mortality rates for juveniles adjusted to match M=1.12 for age-1 and M=0.51 for age-1.
The VB equation used by the Applicant is from Fishbase and for the Irish Sea which is a separate and genetically distinct stock to the Celtic Sea stock. It is not clear why the Irish Sea estimate has been chosen over the English Channel/North Sea estimates. Both are uncertain given the limited data for the Celtic Sea stock.	The VB equation indicates a small maximum size and quick growth to this size, compared to other estimates for the species. The North Sea/English Channel stock has a slower growth rate and larger maximum size (L_{inf}=116, K=0.208; L_{inf}=132, K=0.2) which increases the EAV value by a factor of 2.5.	A VB curve has been derived from length-at-age data (as has been done by the Applicant for other species). This gives L_{inf} = 1039 mm, K (years 0-5) = 0.318.

Table 1. cont.

Atlantic herring		
Issue	**Impact**	**Solution**
The evidence for the conversion of SL to TL was unclear	Incorrect lengths could be being used in EAV calculation, which may influence natural mortality rates and subsequent survival of individuals to maturity.	The SL to TL conversion for Atlantic herring from www.fishbase.in, where SL is a mean of 86.07% of TL (mean of 3 individuals measures of 84%, 86.6%, 87.6%), results in a marginally lower converted TL estimate to that presented by the Applicant. Applying this reduces the EAV and therefore the current SL to TL conversion is retained as it is considered to be the more precautionary estimate.
The natural mortality correction factor is derived using the Gislason et al. (2010) Atlantic herring data and North Sea ICES data.	Mortality rates using the correction factor exceed those for the Celtic Sea (ICES, 2017, p148)	Mortality rates corrected to match Age 2+ mortality to 0.385
The Von Bertalanffy curve used is from Thorpe et al. (2014), which documents an ecosystem model of the North Sea. The source of the VB curve used in this paper is not provided.	The growth curve being used may not be appropriate for this population	VB curve parameters changed to values for the Celtic Sea, L_{inf}=30.2, K =0.39

Table 1. cont.

European seabass		
Issue	**Impact**	**Solution**
ICES use a single natural mortality rate for European seabass of 0.24. This is because ICES could not define age/length-specific mortality rates based on the available evidence.	0.24 may not be an appropriate mortality rate for all age classes.	Use of a single mortality rate of 0.24 for adults increases the EAV value by ~25%, though it is acknowledged that application of a length-specific mortality will be more appropriate for this species, the average mortality from age 2-15+ is 0.25. No amendment to the adult mortality rates is therefore proposed.
For juveniles, natural mortality rates are predicted to be very high using the Gislason et al. (2010) equation. Turnpenny and Henderson (1992) used much lower rates for juvenile European seabass (age-0 M=0.5, age-1 M=0.2, age-2 M=0.15)	Use of these lower rates would result in a higher EAV factor value.	Use of lower natural mortality rates for juveniles increases the EAV value by ~11% , though the use of an M=0.2 for age-1 fish and M=0.15 for age-2 fish is considered to be too low given the use of M=0.24 for adults. These mortality rates are therefore not used.
The EAV model presents a Von Bertalanffy curve for a relevant and local ICES area (7a, f and g) but this is not used within the model.	The most appropriate VB curve is not being used.	The VB curve for ICES area 7a, f and g is used as this is the most geographically relevant value.

Table 1. cont.

European plaice		
Issue	**Impact**	**Solution**
The conversion of SL to TL uses a single fish, it is not clear whether this is representative of the population within the Bristol Channel	Incorrect lengths could be being used in EAV calculation, which may influence natural mortality rates and subsequent survival of individuals to maturity.	Ciotti *et al*. (2013) states an SL to TL conversion equation of $L_t = (1.223 \times L_s) - 1.13$ for juvenile European plaice. This results in a marginally lower converted TL estimate to that presented by the Applicant. Applying this reduces the EAV and therefore the SL to TL conversion proposed by the Applicant is retained as it is considered to be the more precautionary estimate.
The natural mortality used by ICES in 7f and 7g is 0.12 (ICES, 2017a). The current correction factor leads to mortality rates for adult fish (ages 3-5) which are higher than this.	This would underestimate the EAV factor value if the natural mortality rate is actually 0.12.	The Applicant acknowledges in TR456 Ed2 that a correction factor of between 2 and 3 would more accurately reflect match the ICES mortality rates and should be used. We apply a mortality correction factor of 2.9 to bring mean mortality of ages 3-5 to a level of 0.12.

Table 1. cont.

Thornback ray		
Issue	**Impact**	**Solution**
The source of the length at age data is not provided. Longer mean lengths at age have been published by Whittamore and McCarthy (2005) for Caernarfon Bay and Ryland and Ajayi (1984) for Carmarthen Bay.	The accuracy of the length at age data cannot be determined. If the mean length at age used is lower than is actually the case, EAV factor values will be too low.	The length at age data for thornback ray has been updated to match Ryland and Ajayo (1984)
The source of the proportional maturity data is not provided. Published work refers to earlier maturity - There is evidence of maturing female thornback rays from 50cm total length, which corresponds to an age-3 individual using the age-length relationship in the same paper (Whittamore and McCarthy, 2005). In the same paper, proportional maturity was 100% by ~65cm total length.	The accuracy of the proportional maturity data cannot be determined. Including earlier maturing thornback rays will increase the EAV factor value.	Proportional maturity assigned as 5% at age-3, 50% at age-4 and 100% at age-5.
Ryland and Ajayi (1984) provide a mean natural mortality rate (M) for age 1-10 thornback ray of 0.16. The current correction factor provides a mean natural mortality rate (M) for age 1-9 thornback ray of 0.17.	The assessment is not conservative.	Mortality rate correction factor adjusted to make mean M for ages 1-9 = 0.16.
The source of the Von Bertalanffy curve data is not provided. There is evidence from Whittamore and McCarthy (2005) and Ryland and Ajayi (1984) of alternative VB curves from surveys in Welsh waters.	Growth parameters may not be appropriate for this population.	We will use a VB curve of L_{inf} = 1391.77 mm, K = 0.090 (Ryland and Ajayi, 1984)

Table 1. cont.

Blue whiting		
Issue	**Impact**	**Solution**
Whilst the proportional maturity matches that from the ICES stock assessment, survey data has shown that some whiting mature at age-1, and that sometimes not all are mature by age 2 (Gerritsen, 2003).	EAV values may be too low if published maturity at age data are not used.	Proportional maturity amended to 20% maturity at age-1, 95% maturity at age-2 and 100% maturity at age-3.

Not an independent estimate. The Applicant used whiting as a proxy, therefore identical figures to whiting used

Table 1. cont.

Twaite shad		
Issue	**Impact**	**Solution**
Lengths and weights of impinged fish were taken directly from the CIMP dataset	These are considered appropriate	No changes needed
The applicant assumes all age-0 twaite shad impinged are 5 months of age. Twaite shad spawn in the Wye, Usk and Severn in mid-May to mid-July (Maitland and Hatton-Ellis, 2003). Age-0 fish were impinged at HPB between Sept. and March (with individuals also impinged in May). Impinged fish could have been between min. 2 months old (i.e. hatched in July, impinged in Sept.) or max. 10 months old (i.e. hatched in May, impinged in March) with some age-0 fish potentially being impinged at age 12 months.	Underestimating mean age will increase the estimate of mortality amongst Age-0 fish.	We have assumed Age-0 twaite shad to be 6 months of age, this being a more appropriate mean.
For twaite shad, the number of individuals impinged which would survive to the age-at-50% maturity (age 4 for twaite shad) is calculated.	This approach differs to that used for other species, where the value of fish based on maturation throughout their whole maturity ogive was calculated (i.e. proportions of fish maturing from when 0% to 100% of the population is mature over a number of years).	Maturation of twaite shad across their whole maturity ogive has been used to estimate survival to maturity (as done for other fishes using the TR426 method).
A weight-at-age (Peterson and Wroblewski, 1984) relationship is used to calculate natural mortality (M)	This is inconsistent with the method used for other fish species, for which length-at-age relationship was used (Gislason et al., 2010)	We derived EAV values using both relationships. Weight-mortality gave lower estimates of natural mortality and higher EAVs (0.153) than did length-mortality (0.104). We have adopted an EAV factor using the more precautionary weight-mortality relationship

Table 1. cont.

Twaite shad cont.		
Issue	**Impact**	**Solution**
The dry weight of individuals is used within the weight-at-age relationship to calculate natural mortality. An assumption of the dry weight being 20% of the wet weight is used. The evidence for this conversion is not presented, but it appears to be drawn from conversions used for the pollutant concentrations in tissue between wet weight and dry weight (where concentrations in wet weight are 20% of concentrations in dry weight), such as WHO (1990) (as referenced in Lochet et al., 2008). This relationship is not specific to twaite shad however.	Pereira *et al*. (2013) report the moisture content of a small number of allis shad to be mean=66.4% (SD=0.1%) of the total wet weight based on drying the sample overnight at 105^{o}C. Therefore, dry weight of these individuals would be a mean of 33.6% of wet weight. This indicates that the use of 20% conversion may underestimate the dry weight of the individuals and thus overestimate the mortality rate.	We have used a dry weight of 33.6% of wet weight (recognising that this ratio is for allis shad but assuming it to be similar for the closely-related twaite).
The applicant's model reaches a mortality rate of 0.61 for twaite shad of age-5 (when over 90% of individuals are mature).However, Aprahamian (1988) calculated a natural mortality rate for mature twaite shad of mean=0.53, SD=0.18.	The mortality rate of twaite shad individuals may be overestimated within the applicant's model.	Mortality rates have been scaled for twaite shad to be 0.53 at age-5

Table 1. cont.

Allis shad

Issue	Impact	Solution
Lengths and weights of impinged fish were taken directly from the CIMP dataset	These are considered appropriate	No changes needed
There is confusion over the ages that have been assigned to impinged allis shad. SPP071/S identified them as being between 2 and 3 years of age, and noted they were assumed to be 3 years of age within the EAV calculations on a precautionary basis. The EAV spreadsheet provided however, assigned an age of 1+ to one individual and 2+ to the other	EAVs will be incorrect if fish have been incorrectly aged.	Following a review of the data presented in Maitland and Lyle (2005) for the Solway Estuary, the lengths and weights of individuals impinged at HPB reflect an age 1+ and age 2+ individual. No change to the aging of the allis shad has been made.
The number of individuals impinged which would survive to age 5 is calculated, this being the assumed age-at-50%-maturity.	This approach differs to that used for other species, where the value of fish based on maturation throughout their whole maturity ogive was calculated (i.e. proportions of fish maturing from when 0% to 100% of the population mature over a number of years).	Maturation of twaite shad across their whole maturity ogive has been used to estimate survival to maturity (as done for other fishes using the TR426 method).
A weight-at-age (Peterson and Wroblewski, 1984) relationship is used to calculate natural mortality (M)	This is inconsistent with the method used for other fish species, for which length-at-age relationship was used (Gislason et al., 2010)	We derived EAV values using both relationships. Weight-mortality gave lower estimates of natural mortality and higher EAVs (0.410) than did length-mortality (0.319). We have adopted an EAV factor using the more precautionary weight-mortality relationship

Table 1. cont.

Allis shad cont.		
Issue	**Impact**	**Solution**
The dry weight of individuals is used within the weight-at-age relationship to calculate natural mortality. An assumption of the dry weight being 20% of the wet weight is used. The evidence for this conversion is not presented, but it appears to be drawn from conversions used for the pollutant concentrations in tissue between wet weight and dry weight (where concentrations in wet weight are 20% of concentrations in dry weight), such as WHO (1990) (as referenced in Lochet et al., 2008). This relationship is not specific to allis shad however.	Pereira et al. (2013) report the moisture content of a small number of allis shad to be mean=66.4% (SD=0.1%) of the total wet weight based on drying the sample overnight at 105°C. Therefore, dry weight of these individuals would be a mean of 33.6% of wet weight. This indicates that the use of 20% conversion may underestimate the dry weight of the individuals and thus overestimate the mortality rate	We have used a dry weight of 33.6% of wet weight.

Options For Extending The TR426 Method

As described above, our review increased confidence in the TR426 method's EAV estimates, but did not in itself address systematic underestimates associated with assigning all mature fish a value of '1', nor did it move the TR426 method towards including an assessment of spawning production foregone. This section discusses the options for addressing these two aspects of the assessment.

Standardising to an equivalent number of age-at-50%-maturity fish

The conventional EAV method standardises the equivalent adult number to the number of age-at-50%-maturity fish required to reproduce the lost fish (where age-at-50%-maturity is the Age Class in which 50% of fish are mature). The TR426 method does not do this (although the applicant's method for twaite and allis shad does), instead producing a total number of impinged fish which would otherwise have survived to reach maturity – fish maturing at different ages are ascribed the same value regardless of the age at which they would have become mature.

For all species that an EAV was calculated for using the TR426 method, the number of fish impinged at each age class can be converted to an equivalent number of age-at-50%-maturity fish required to replace that loss. A worked example is provided in Appendix B, using simulated impingement data for a hypothetical fish species.

This method was intended only as an illustration of the effect of standardising fish to the age-at-50%-maturity, rather than as a proposed EAV to use in further analysis. Standardising fish to the age-at-50%-maturity, rather than counting all fish reaching maturity as EAV=1, has the effect of raising the EAV value for every species (Appendix A).

Spawning Production Foregone method

This method attempts to account for the lost future production of entrapped fish that is included in the TR426 method by its ascribing of an EAV value of 1 to all mature fish, regardless of age or future spawning potential.

The TR426 method is followed to estimate the number of impinged fish that would have been expected to survive through subsequent years and the number of these that would have become mature in each year (the TR426 method does not go beyond this point).

In an addition to the TR426 method, the Spawning Production Foregone model then calculates the proportion of maturing fish of each age class which survive through subsequent year classes to spawn, up to the maximum age of the fish. This gives the total number of spawners that would have been alive in each subsequent year, had they not been impinged (see Appendix C for a worked example using simulated impingement data for a hypothetical fish species).

Assuming no other pressures change, the Spawner Production Foregone model applied from the commencement of operation soon reaches an equilibrium point, where the number of equivalent adults lost each year does not change.

All EAVs calculated by the Spawner Production Foregone method are higher than those resulting from the TR426 method (Appendix A).

When compared to EAVs standardised to equivalent number of age-at-50%-maturity fish, some EAVs calculated by the Spawner Production Foregone method are higher (sprat, sole, herring, seabass, plaice, thornback ray) and some lower (whiting, cod, blue whiting) (Appendix A).

Strengths of the Spawner Production Foregone approach are that:

- The value of repeat spawning fish are taken into account in the method
- Numbers of equivalent adults are produced which are directly comparable to Spawning Stock Biomass
- Future spawning potential is incorporated into the model.

Weaknesses are:

- The method is not peer reviewed. However it is similar to published models e.g. Goodyear (1990) and Goodyear (1993), and analogous approaches have previously been used for assessments of the impact of the Tidal Lagoon Swansea Bay.
- Differential fecundity of different age groups is not currently taken into account but could potentially be added in.

Lifetime Fecundity Method

This approach takes into account the fact that not only do mature individuals of many species spawn on multiple successive years, but that the fecundity (number of eggs produced) of female individuals also varies with age.

From the impinged fish, the total number that would have entered maturity at each age is multiplied by the value of the contribution of that age group fish to the population, taking into account repeat spawning and differential fecundity with age (see Appendix D for a worked example using simulated data for a hypothetical fish species)

EAVs calculated by the Lifetime Fecundity approach are higher than the TR426 values, for sprat, Dover sole, Atlantic cod, Atlantic herring, European seabass, European plaice and thornback ray, but marginally lower for whiting and blue whiting (Appendix A).

When compared to EAVs standardised to equivalent number of age-at-50%-maturity fish, some EAVs calculated by the Lifetime Fecundity method are higher (sole, herring, thornback ray) and some lower (sprat, whiting, cod, seabass, plaice, blue whiting) (Appendix A).

For all species, EAVs calculated by the Lifetime Fecundity method are lower than those calculated using the Spawner Production Foregone method, with the exception of thornback ray (Appendix A)

Strengths of the Lifetime Fecundity approach are that:

- The underestimation of the value repeat spawning fish make to the population in the TR426 method is corrected for by accounting for repeat spawning and the relative fecundity of different age classes of fish.

Weaknesses are:

- The EAV value needs to be compared to the Spawning Stock Biomass in order to comment on potential effects on the population. The SSB data are not corrected to account for the relative contribution each age group could make to the population, and so we would not be comparing like-for-like.
- The method is not peer-reviewed.

Selecting The Most Appropriate Equivalence Estimate

Standardising fish to the age-at-50%-maturity, Spawning Production Foregone and Lifetime Fecundity methods all return EAV factor values that are higher than those using the TR426 method and there is considerable variation in EAV factor values between the different methods (Appendix A).

The increase in the factor value between the conventional EAV method (as used in the DCO submission) and the Spawning Production Foregone will be greatest for fish such as Atlantic cod and European seabass which are long-lived and spawn multiple times. The difference will be less pronounced for shorter-lived species with fewer spawning year classes. The absolute factor values are not necessarily highest for long-lived, repeat spawning species (such as Atlantic cod and European seabass) as the values are also influenced by the lengths of the fish impinged and how close to maturity they are at impingement.

For example, European sprat mature early and are impinged at ages near to maturity so have a relatively high base TR426 EAV factor value (0.556). However, they are not long-lived so the relative increase in the Spawning Production Foregone EAV factor value from the TR426 EAV factor value is lower than for other species (≈ three times larger). Atlantic cod however, mature late and are impinged at small sizes - far from maturity. Their base TR426 EAV value is therefore relatively low (0.012). Being long-lived and potentially spawning multiple times, Atlantic cod have a larger relative increase between the TR426 EAV factor value and the Spawning Production Foregone method than sprat, with the production foregone value being approximately fourteen times larger than that of the TR426 value.

All methods for calculating EAVs are approximations but the most appropriate method will use locally-sourced data and be biologically meaningful. The most appropriate method will also need to produce an estimate of number of equivalent adults for impingement/entrainment losses which can be directly compared to measures of population size.

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.

Consideration of Uncertainty

Uncertainty within the mortality rates and Von Bertalanffy (VB) growth curves has been reduced as far as possible through validation against published mortality rates and local VB curves. It is not therefore, proposed to incorporate any uncertainty into these parameters.

Uncertainty within the length-frequency distribution of impinged fish is also limited due to the use of measurements from HPB.

Uncertainty within the aging of fish may exist but at present there are no data to estimate this.

Uncertainty within the Standard Length (SL) to Total Length (TL) conversion, and proportional maturity rates still also exists.

Variability within the SL to TL conversion and proportional maturity parameters have been programmed in to the models where appropriate based on our review to generate a probability distribution around the Spawner Production Foregone estimate by re-sampling the outputs over 5,000 iterations. Beyond this number of iterations it was found that the difference in subsequent runs was limited (within 0.01 of the mean).

Table 2 below provides uncertainty ranges for the EAV of each species using the Spawner Production Foregone method. These will be used in the Environment Agency's uncertainty analysis surrounding entrapment estimates for HPC.

Table 2: Uncertainty estimates applied to Spawner Production Foregone EAV factor estimates

Species	Summary of uncertainty applied to Spawner Production Foregone estimates	EAV distribution shape and parameters (range/standard deviation etc.)
European sprat	SL to TL conversion between TL=SL/0.854 and TL=(1.1508*SL)+2.5026. Uniform distribution. Proportional maturity – 79%-88% age 4. Uniform distribution.	Approximately normal (Mean=1.586, SD=0.002)
Whiting	Proportional maturity – 15-25% age 1, 90-100% age 2. Uniform distribution	Approximately uniform (Max=0.439, Min=0.338)
Dover sole	No uncertainty programmed into SL to TL conversion or proportional maturity	NA
Atlantic cod	No uncertainty programmed into SL to TL conversion or proportional maturity	NA
Atlantic herring	SL to TL conversion between TL=SL/0.8607 and TL=(1.161*SL)+2.5591. Uniform distribution	Approximately normal (Mean=1.711, SD=0.006)
European seabass	No uncertainty programmed into SL to TL conversion or proportional maturity	NA
European plaice	SL to TL conversion between TL=(1.223*SL)-1.13 and TL=SL*1.264. Uniform distribution	Approximately normal (Mean=0.564, SD=0.004)
Thornback ray	Proportional maturity – 5-10% age 3, 15-50% age 4, 50-100% age 5. Uniform distribution	Approximately normal (Mean=0.556, SD=0.034)
Blue whiting	Proportional maturity – 15-25% age 1, 90-100% age 2. Uniform distribution	Approximately uniform (Max=0.439, Min=0.338)
Twaite shad	Twaite shad age mean=6 months, SD=1.33 months. Normal distribution. Mortality rate of fish until the end of their first year, Mean=1.01, SD=0.23. Normal distribution	Normal (Mean=0.153, SD=0.008)

Table 2: Cont.

Species	Summary of uncertainty applied to Spawner Production Foregone estimates	Distribution shape and shape parameters (range/standard deviation etc.)
Allis shad	The assumption within the allis shad calculation is that they spawn only once. Maitland and Hatton-Ellis (2003) suggest that some populations show a degree of repeat spawning (up to 13.5%). Therefore, the EAV value has been distributed by a range of between 1 and 1.135 its original value to account for this potential repeat spawning behaviour.	Uniform (Max=0.466, min=0.410)

Table 3. Conclusion Results

Species	EAV factor		
	Used in Applicant's assessment	Used in the Environment Agency's assessment	
		Predicted	Uncertainty Range
European sprat	0.556	1.592	1.586 Mean, 0.002 SD
Whiting	0.142	0.388	0.34 – 0.44
Dover sole	0.236	1.070	N/A
Atlantic cod	0.012	0.171	N/A
Atlantic herring	0.113	1.741	1.711 Mean, 0.006 SD
European seabass	0.121	0.582	N/A
European plaice	0.192	0.582	0.564 Mean, 0.004 SD
Thornback ray	0.339	0.618	0.556 Mean, 0.034 SD
Blue whiting	0.142	0.388	0.338 – 0.439
European eel	1.000	1.000	N/A
Twaite shad	0.035	0.153	0.153 Mean, 0.008 SD
Allis shad	0.262	0.410	0.410 – 0.466
Sea lamprey	1.000	1.000	N/A
River lamprey	1.000	1.000	N/A
Atlantic salmon	N/A	0.222	0.222 Mean, 0.456 SD
Sea trout	N/A	1.000	N/A
Brown Shrimp	1.000	N/A	N/A

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Appendix A: EAV factors for fish species impinged at Hinkley Point B during CIMP monitoring, calculated using methods from the DCO submission, the variation application, and three extensions to the variation application method discussed in this report.

Species	Turnpenny (1988) (DCO)	TR426 Method (Variation)	TR426 method, incorporating revised parameters	Impingement data standardised to equivalent number of age-at-50%-maturity fish	Spawner Production Foregone extension (length-mortality relationship)	Spawner Production Foregone extension (weight-mortality relationship)	Lifetime fecundity extension
European sprat	1.000	0.556	0.557	0.709	1.592		0.690
Whiting	0.140	0.142	0.236	0.472	0.388		0.234
Dover sole	0.050	0.236	0.349	0.400	1.070		0.576
Atlantic cod	0.090	0.012	0.066	0.370	0.171		0.110
Atlantic herring	0.490	0.113	0.356	0.479	1.741		0.523
European seabass	Not assessed	0.121	0.133	0.200	0.582		0.156
European plaice	0.090	0.192	0.257	0.550	0.582		0.401
Thornback ray	Not assessed	0.339	0.311	0.535	0.618		0.674
Blue whiting *	0.140	0.142	0.236	0.472	0.388		0.234
Twaite shad	0.120	0.035		**	0.104	0.153	***
Allis shad	0.120	0.262		**	0.319	0.410	***

* Not an independent estimate. The Applicant used whiting as a proxy, therefore identical figures to whiting have been used.

** The TR426 method standardised twaite shad and allis shad to an equivalent number of age-at-50%-maturity fish

*** Information was requested from the applicant in order for the Environment Agency to calculate EAVs . This arrived after the Spawner Production Foregone model had been decided upon as the most appropriate model to take forward. Consequently, lifetime fecundity EAV factors were not calculated for these species.

APPENDIX B: Standardised Age Worked Example, using simulated impingement data for a hypothetical fish species

The TR426 method calculates an Equivalent Adult Value by comparing the number of fish lost in one year (Year A) with the number of fish lost that would otherwise have entered the adult spawning population. Calculations of survival rates stop when fish reach sexual maturity.

In a standard EAV (e.g. Turnpenny, 1988), fish losses are standardised to an equivalent number of adult fish, of the age where 50% of fish are mature (i.e. age-at-50%-maturity). It is possible to express the number of fish lost in Year A in terms of an equivalent number of age-at-50%-maturity fish, using mortality rates and proportional maturity rates for that species.

For a hypothetical fish species, impingement data for age and size classes (Total Length) are:

TL (mm)	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group
30	100	0	0	0	0	0	0
35	300	0	0	0	0	0	0
40	1700	0	0	0	0	0	0
45	16300	0	0	0	0	0	0
50	58500	0	0	0	0	0	0
55	82909	13091	0	0	0	0	0
60	85345	13655	0	0	0	0	0
65	82935	23696	2370	0	0	0	0
70	63784	44821	6896	0	0	0	0
75	53985	44730	3085	0	0	0	0
80	26153	23911	3736	0	0	0	0
85	16182	19916	5601	0	0	0	0
90	2613	20032	3919	435	0	0	0
95	678	12542	5424	1356	0	0	0
100	0	8386	11857	868	289	0	0
105	0	10780	28233	6673	513	0	0
110	0	7972	39862	9301	664	0	0
115	0	2885	38231	18034	5049	0	0
120	0	502	21101	16580	2010	1507	0
125	0	0	5381	13632	3229	359	0
130	0	0	711	2489	711	89	0
135	0	0	39	748	394	118	0
140	0	0	0	0	0	100	0
	Total number of fish lost in each Age Class						
	491483	246922	176447	70116	12860	2173	0

Mortality rate and proportion mature data for each age class are:

	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group
Natural mortality (M)	0.80	0.57	0.34	0.29	0.28	0.26	0.24
Proportion mature	0.01	0.3	0.6	0.8	0.9	0.95	1

2-Group fish are taken as age-at-50%-maturity fish (proportion mature = 0.6)

The number of age-at-50%-maturity fish required to reproduce an Age 0 fish is:

$$\frac{\text{Probability of survival to end of Age 0} \times \text{Probability of survival to end of Age 1} \times \text{Probability of survival to end of Age 2}}{\text{Probability of survival to end of Age 0}}$$

The number of age-at-50%-maturity fish required to reproduce an Age 1 fish is:

$$\frac{\text{Probability of survival to end of Age 0} \times \text{Probability of survival to end of Age 1} \times \text{Probability of survival to end of Age 2}}{\text{Probability of survival to end of Age 0} \times \text{Probability of survival to end of Age 1}}$$

The number of age-at-50%-maturity fish required to reproduce an Age 2 fish is:

$$\frac{\text{Probability of survival to end of Age 0} \times \text{Probability of survival to end of Age 1} \times \text{Probability of survival to end of Age 2}}{\text{Probability of survival to end of Age 0} \times \text{Probability of survival to end of Age 1} \times \text{Probability of survival to end of Age 2}}$$

The number of age-at-50%-maturity fish required to reproduce an Age 3 fish is:

$$\frac{\text{Prob.surv. to end Age 0} \times \text{Prob.surv. to end Age 1} \times \text{Prob.surv. to end Age 2}}{\text{Prob.surv. to end Age 0} \times \text{Prob.surv. to end Age 1} \times \text{Prob.surv. to end of Age 2} \times \text{Prob.surv. to end Age 3}}$$

And the pattern continues for Age 4, Age 5 and Age 6 fish.

The number of age-of-50%-maturity fish required to reproduce a fish of each age class is then multiplied by the number of fish impinged in that age class, to calculate how many age-of-50%-maturity fish the lost fish were equivalent to.

Dividing the equivalent number of age-of-50%-maturity fish by the number of fish originally lost gives the EAV value for this method.

Age Class	M	Survival to end of Age ($1\times e^{-M}$)	Proportion mature	No. 2-Group fish required to reproduce one fish	Total no. lost in each age class	No. 2-Group fish required to reproduce entrapment losses
0-Group	0.80	0.45	0.01	0.40	491,483	197,834
1-Group	0.57	0.57	0.3	0.71	246,922	175,752
2-Group	0.34	0.71	0.6	1	176,447	176,447
3-Group	0.29	0.75	0.8	1.34	70,116	93,705
4-Group	0.28	0.76	0.9	1.77	12,860	22,739
5-Group	0.26	0.77	0.95	2.29	2,173	4,983
6-Group	0.24	0.79	1	2.92	0	0
				Totals	1,000,000	671,460
					EAV	**0.67**

APPENDIX C: Spawner Production Foregone Worked Example, using simulated impingement data for a hypothetical fish species

Note: Steps 1 to 6 are identical to the TR426 method.

Steps 7 to 9 are extensions of the TR426 method.

Step 1

One million fish of the same species are killed by impingment annually, the length distribution (total length TL) of the lost fish being:

TL mm	Numbers
30	100
35	300
40	1700
45	16300
50	58500
55	96000
60	99000
65	109000
70	115500
75	101800
80	53800
85	41700
90	27000
95	20000
100	21400
105	46200
110	57800
115	64200
120	41700
125	22600
130	4000
135	1300
140	100

Step 2

Each length class is assigned a natural mortality rate M, where the number of fish in length class X surviving to length class X+1 is (number of fish length X)*e^{-M}

TL mm	Numbers	M
30	100	2.55
35	300	1.99
40	1700	1.60
45	16300	1.32
50	58500	1.11
55	96000	0.95
60	99000	0.83
65	109000	0.73
70	115500	0.65
75	101800	0.58
80	53800	0.52
85	41700	0.47
90	27000	0.43
95	20000	0.39
100	21400	0.36
105	46200	0.34
110	57800	0.31
115	64200	0.29
120	41700	0.27
125	22600	0.25
130	4000	0.24
135	1300	0.22
140	100	0.21

Step 3

From length-at-age data, the number of fish of each length class, in each age class is estimated as:

No. of length X fish that are Age Y = (No. of fish of length X) × (proportion of length X fish that are Age Y)

The total number of fish lost of each age class is also calculated.

TL (mm)	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group
30	100	0	0	0	0	0
35	300	0	0	0	0	0
40	1700	0	0	0	0	0
45	16300	0	0	0	0	0
50	58500	0	0	0	0	0
55	82909	13091	0	0	0	0
60	85345	13655	0	0	0	0
65	82935	23696	2370	0	0	0
70	63784	44821	6896	0	0	0
75	53985	44730	3085	0	0	0
80	26153	23911	3736	0	0	0
85	16182	19916	5601	0	0	0
90	2613	20032	3919	435	0	0
95	678	12542	5424	1356	0	0
100	0	8386	11857	868	289	0
105	0	10780	28233	6673	513	0
110	0	7972	39862	9301	664	0
115	0	2885	38231	18034	5049	0
120	0	502	21101	16580	2010	1507
125	0	0	5381	13632	3229	359
130	0	0	711	2489	711	89
135	0	0	39	748	394	118
140	0	0	0	0	0	100
	Total number of fish lost in each Age Class					
	491483	246922	176447	70116	12860	2173

Step 4

The proportion of fish that are mature in each Age Class (from published data) is used to calculate the number of lost fish in each Age Class that would have been mature when impinged.

TL (mm)	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5
30	100	0	0	0	0	0
35	300	0	0	0	0	0
40	1700	0	0	0	0	0
45	16300	0	0	0	0	0
50	58500	0	0	0	0	0
55	82909	13091	0	0	0	0
60	85345	13655	0	0	0	0
65	82935	23696	2370	0	0	0
70	63784	44821	6896	0	0	0
75	53985	44730	3085	0	0	0
80	26153	23911	3736	0	0	0
85	16182	19916	5601	0	0	0
90	2613	20032	3919	435	0	0
95	678	12542	5424	1356	0	0
100	0	8386	11857	868	289	0
105	0	10780	28233	6673	513	0
110	0	7972	39862	9301	664	0
115	0	2885	38231	18034	5049	0
120	0	502	21101	16580	2010	1507
125	0	0	5381	13632	3229	359
130	0	0	711	2489	711	89
135	0	0	39	748	394	118
140	0	0	0	0	0	100
	Total number of fish lost in each Age Class					
	491483	246922	176447	70116	12860	2173
	Proportion mature in each Age Class					
	0.01	0.3	0.6	0.8	0.9	0.95
	Number of lost fish that were mature when impinged					
	4,915	74,077	105,868	56,093	11,574	2,064

Step 5

Using natural mortality rates M for each size class (see Step 2, above), the number of immature fish lost in Year A that would have survived to the next year (Year A+1) is calculated, where:

No. of immature Y-Group fish in Year A surviving to Year A+1 = (No. in Y-Group) × (1 - proportion of Y-Group fish that are mature) * e^{-M}

So for example, 100 0-Group fish were in the 30 mm Length Class were lost in Year A, and the proportion of 0-Group fish that are mature is 0.01 (from Step 4). So, the number of immature 30 mm long Age 0 fish that would have survived to Year A+1 is (100) × (1 – 0.01) × $e^{-2.55}$ = 8 fish (rounded to whole fish)

The total number of immature lost fish of each age class that would have survived to Year A+1 is then calculated.

TL (mm)	M	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5
30	2.55	8	0	0	0	0	0
35	1.99	41	0	0	0	0	0
40	1.60	340	0	0	0	0	0
45	1.32	4307	0	0	0	0	0
50	1.11	19019	0	0	0	0	0
55	0.95	31610	3529	0	0	0	0
60	0.83	36886	4173	0	0	0	0
65	0.73	39642	8008	458	0	0	0
70	0.65	33102	16447	1446	0	0	0
75	0.58	29994	17572	692	0	0	0
80	0.52	15386	9947	888	0	0	0
85	0.47	9994	8697	1398	0	0	0
90	0.43	1682	9120	1020	57	0	0
95	0.39	453	5919	1463	183	0	0
100	0.36	0	4084	3299	121	20	0
105	0.34	0	5396	8075	954	37	0
110	0.31	0	4089	11682	1363	49	0
115	0.29	0	1512	11448	2700	378	0
120	0.27	0	268	6441	2530	153	58
125	0.25	0	0	1671	2117	251	14
130	0.24	0	0	224	393	56	4
135	0.22	0	0	13	120	32	5
140	0.21	0	0	0	0	0	4
		Total number of immature fish lost in Year A that would have survived to Year A+1					
		222,462	98,761	50,218	10,537	975	84

Step 6

The proportional maturity at age value is applied to the number of fish in each Age Class that survived to Year A+1 in order to calculate how many would have matured in Year A+1 and how many would remain immature.

Example: 222,462 0-Group fish lost in Year A would have otherwise survived to Year A+1, of which 222,462 × 0.3 = 66,739 would have matured in Year A+1.

The number of 0-Group fish lost in Year A that would have remained immature in Year A+1 is (222,462 – 66,739)

Average mortality rates are then applied to the number of immature fish in Year A+1, to calculate how many would survive to Year A+2.

Example: The number of 0-Group fish lost in Year A that would still be immature in Year A+1 and would survive to Year A+2 is: Number of survivors = (222,462 – 66,739) × EXP – 0.57 = 88,065

The proportional maturity at age value is then applied to the number of fish that survive to Year A+2, to calculate how many of these fish will mature in Year A+2.

Example: Of the 88,068 fish that survive to Year A+2, 88,068 × 0.6 = 52,839 will mature in Year A+2.

This process is then repeated, up to the maximum age of the fish (in this example, the maximum age class is 6)

	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	
Mean length (cm)	6.3	7.9	10.6	11.7	11.9	12.3	12.6	In this example mean length for each age group is: ∑(no. in each size class * length))/(no. fish in age group)]. Ordinarily, mean length at age will be derived from wider survey data.
Natural mortality	0.80	0.57	0.34	0.29	0.28	0.26	0.24	In this example M for each age group is: ∑(no. in each size class * M of that size class))/(no. fish in age group)]. Ordinarily, M for each age class will be derived from wider survey data.
Proportion mature	0.01	0.3	0.6	0.8	0.9	0.95	1	
Survivors		222462	88065	25073	3752	284	11	
			98761	28118	4208	2290	88	No. fish that were immature in Year A that would have survived to Year A+6 (mature and immature)
				50218	7515	568	324	No. fish that were immature in Year A that would have survived to Year A+5 (mature and immature)
					10537	796	31	No. fish that were immature in Year A that would have survived Year A+4 (mature and immature)
						975	38	No. fish that were immature in Year A that would have survived to Year A+3 (mature and immature)
							84	No. fish that were immature in Year A that would have survived to Year A+2 (mature and immature)
								No. fish that were immature in Year A that would have survived to Year A+1

	1-Group	2-Group	3-Group	4-Group	5-Group
of which, this number reach maturity	66739	52839	20058	3377	269
		59257	22495	1178	2175
			40174	6764	148
				9483	757
					926

- Number of fish that were immature in Year A that would have survived to Year A+5 and matured this year
- Number of fish that were immature in Year A that would have survived to Year A+4 and matured this year
- Number of fish that were immature in Year A that would have survived to Year A+3 and matured this year
- Number of fish that were immature in Year A that would have survived to Year A+2 and matured this year
- Number of fish that were immature in Year A that would have survived to Year A+1 and matured this year

The TR426 Method finishes at Step 6, creating an EAV by adding together i) the number of mature fish lost in Year A, ii) the number of lost fish that would have survived to Age 6, and iii) the number of fish becoming mature up to Age 6 (i.e. Ages 1 to 5), then dividing this total by the total number of fish lost in Year A.

From Step 4:

Number of lost fish that were mature when impinged					
4,915	74,077	105,868	56,093	11,574	2,064

Total = 254,590

From Step 6:

No. that would have survived to Age 6

11
88
324
31
38
84

Total = 575

No. that would have matured (Ages 1 to 5)

66739	52839	20058	3377	269
	59257	22495	1178	2175
		40174	6764	148
			9483	757
				926

Total = 286,639

254,490 + 575 + 286,639 = 541,704

TR426 EAV = 541,704 ÷ 1,000,000 = 0.54

Step 7

The TR426 method calculates an Equivalent Adult Value based on the number of fish lost in one year (Year A). However, Hinkley Point C will operate for ~60 years. In addition to the fish lost in any one year, there will also be a number of fish that would be alive, had they not been lost in previous years. The Spawner Production Foregone model continues the calculations, to consider the number of spawners that would have been present, had they not been lost in previous years.

In Step 7, the total number of fish that would have reached maturity in each age group (had they not been lost in Year A) is calculated, this being the number of mature fish of Y-Group impinged in Year A, added to the total number of fish that would have entered maturity as Y-Group fish in subsequent years, had they not been lost as immature fish in Year A.

Example: The total number of fish that would have reached maturity at Age 1 is:

The total number of fish that would have entered maturity at Age 1 had they not been lost as immature fish in Year A (66,739), plus the number of Age 1 fish that were mature when impinged (74,077).

66,739 + 74,077 = 140,815

	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	
Natural mortality	0.80	0.57	0.34	0.29	0.28	0.26	0.24	In this example M for each age group is: ∑(no. in each size class * M of that size class))/(no. fish in age group)]. Ordinarily, M for each age class will be derived from wider survey data.
		No. of immature fish lost in Year A that would otherwise have reached maturity in each Age Class (Figures from Step 6)						
		66739	52839	20058	3377	269	11	
			59257	22495	1178	2175	88	Number of fish that were immature in Year A that would have survived to Year A+6 and matured this year
				40174	6764	148	324	Number of fish that were immature in Year A that would have survived to Year A+5 and matured this year
					9483	757	31	Number of fish that were immature in Year A that would have survived to Year A+4 and matured this year
						926	38	Number of fish that were immature in Year A that would have survived to Year A+3 and matured this year
							84	Number of fish that were immature in Year A that would have survived to Year A+2 and matured this year
								Number of fish that were immature in Year A that would have survived to Year A+1 and matured this year
	0	66,739	112,096	82,727	20,802	4,275	575	No. fish that would have entered maturity (by age) in subsequent years but are now lost
	4,915	74,077	105,868	56,093	11,574	2,064	0	No. lost fish that were mature when impinged
	4,915	140,815	217,964	138,820	32,376	6,340	575	Total no. fish that would have entered maturity but are now lost

Step 8

A fish becoming mature in Year A while in 0-Group, could potentially also have been present and spawning in Year A+1 (1-Group), Year A+2 (2-Group), Year A+3 (3-Group), Year A+4 (4-Group), Year A+5 (5-Group) and Year A+6 (6-Group). However, not all of the fish that matured in Year A would have survived through to 6-Group. The proportion surviving to each successive year class would be a function of natural mortality rate (M). Fishing mortality rate (F) is also likely to be a factor for many species. We have not considered F, as discussed in the main body of the report. Therefore the Spawner Production Foregone method represents a 'worst case' scenario. Including F would lead to an increased mortality rate (M + F) which would result in fewer fish reaching the oldest ages, thus reducing the effect of accounting for iteroparity.

Fish impinged in Year A would have produced the following numbers of fish, entering maturity in each age group (from Step 7):

0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	
4,915	140,815	217,964	138,820	32,376	6,340	575	Total no. fish that would have entered maturity but are now lost

Natural mortality rates are then applied to these to calculate how many of these fish entering maturity for the first time would survive to spawn in successive years.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	
Natural mortality	0.80	0.57	0.34	0.29	0.28	0.26	0.24	In this example M for each age group is: ∑(no. in each size class * M of that size class))/(no. fish in age group)]. Ordinarily, M for each age class will be derived from wider survey data.
	4,915	140,815	217,964	138,820	32,376	6,340	575	Total no. fish lost in Year A that would have entered maturity, for each Age Class
	2,208	79,635	155,140	103,874	24,469	4,888		Total no. mature fish, originating from Year A and surviving to Year A+1
	1,249	56,681	116,086	78,506	18,867			Total no. mature fish, originating from Year A and surviving to Year A+2
	889	42,413	87,736	60,532				Total no. mature fish, originating from Year A and surviving to Year A+3
	665	32,055	67,649					Total no. mature fish, originating from Year A and surviving to Year A+4
	503	24,716						Total no. mature fish, originating from Year A and surviving to Year A+5
	388							Total no. mature fish, originating from Year A and surviving to Year A+6
	10,816	376,315	644,575	381,732	75,712	11,228	575	Total number of spawning events that would have occurred had fish not been lost in Year A

Step 9

i) Fish impinged in **Year A** would have produced the following numbers of fish (future spawning potential), entering maturity in each age group (from Step 7):

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A fish	4,915	140,815	217,964	138,820	32,376	6,340	575	**541,804**

ii) In **Year A+1**, assuming the same number of fish were impinged as in Year A, their future spawning potential would be:

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+1 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804

A proportion of the fish impinged in Year A would otherwise have survived to Year A+1. Their future spawning potential will have been reduced, as natural mortality would have reduced their number. Had there been no impingement, we would now expect the future spawning potential of the Year A fish to be:

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214

So the overall future spawning potential of all fish in Year A+1 is that of the remaining Year A fish, added to that of the Year A+1 fish:

370,214 + 541,804 = **912,019**

iii) In **Year A+2**, the future spawning potential of the Year A fish will have again been reduced, as natural mortality would have reduced their number. Similarly, the future spawning potential of the Year A+1 fish will have also been reduced. The future spawning potential of new fish, lost in Year A+2, would be as for Year A.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+2 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804
FSP of Year A+1 fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214
FSP of Year A fish	1,249	56,681	116,086	78,506	18,867			271,389
								1,183,408

iv) In **Year A+3**, the future spawning potential of the Year A fish will have again been reduced, as natural mortality would have reduced their number. Similarly, the future spawning potential of the Year A+1 and Year A+2 fish will have also been reduced. The future spawning potential of new fish, lost in Year A+3, would be as for Year A.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+3 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804
FSP of Year A+2 fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214
FSP of Year A+1 fish	1,249	56,681	116,086	78,506	18,867			271,389
FSP of Year A fish	889	42,413	87,736	60,532				191,570
								1,374,978

v) In **Year A+4**, the future spawning potential of the Year A fish will have again been reduced, as natural mortality would have reduced their number. Similarly, the future spawning potential of the Year A+1, Year A+2 and Year A+3 fish will have also been reduced. The future spawning potential of new fish, lost in Year A+4, would be as for Year A.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+4 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804
FSP of Year A+3 fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214
FSP of Year A+2 fish	1,249	56,681	116,086	78,506	18,867			271,389
FSP of Year A+1 fish	889	42,413	87,736	60,532				191,570
FSP of Year A fish	665	32,055	67,649					100,369
								1,475,347

vi) In **Year A+5**, the future spawning potential of the Year A fish will have again been reduced, as natural mortality would have reduced their number. Similarly, the future spawning potential of the Year A+1, Year A+2, Year A+3 and Year A+4 fish will have also been reduced. The future spawning potential of new fish, lost in Year A+5, would be as for Year A.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+5 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804
FSP of Year A+4 fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214
FSP of Year A+3 fish	1,249	56,681	116,086	78,506	18,867			271,389
FSP of Year A+2 fish	889	42,413	87,736	60,532				191,570
FSP of Year A+1 fish	665	32,055	67,649					100,369
FSP of Year A fish	503	24,716						25,219
								1,500,566

vii) In **Year A+6**, the future spawning potential of the Year A fish will have again been reduced, as natural mortality would have reduced their number. Similarly, the future spawning potential of the Year A+1, Year A+2, Year A+3, Year A+4 and Year A+5 fish will have also been reduced. The future spawning potential of new fish, lost in Year A+6, would be as for Year A.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+6 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804
FSP of Year A+5 fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214
FSP of Year A+4 fish	1,249	56,681	116,086	78,506	18,867			271,389
FSP of Year A+3 fish	889	42,413	87,736	60,532				191,570
FSP of Year A+2 fish	665	32,055	67,649					100,369
FSP of Year A+1 fish	503	24,716						25,219
FSP of Year A fish	388							388
								1,500,954

viii) In **Year A+7**, none of the fish originally impinged in Year A would have otherwise been expected to still be alive. The future spawning potential of the Year A+1, Year A+2, Year A+3, Year A+4, Year A+5 and Year A+6 fish will have reduced. The future spawning potential of new fish, lost in Year A+7, would be as for Year A.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+7 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804
FSP of Year A+6 fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214
FSP of Year A+5 fish	1,249	56,681	116,086	78,506	18,867			271,389
FSP of Year A+4 fish	889	42,413	87,736	60,532				191,570
FSP of Year A+3 fish	665	32,055	67,649					100,369
FSP of Year A+2 fish	503	24,716						25,219
FSP of Year A+1 fish	388							388
FSP of Year A fish								0
								1,500,954

ix) In **Year A+8**, none of the fish originally impinged in Year A or Year A+1 would have otherwise been expected to still be alive. The future spawning potential of the Year A+2, Year A+3, Year A+4, Year A+5, Year A+6 and Year A+7 fish will have reduced. The future spawning potential of new fish, lost in Year A+8, would be as for Year A.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	Total future spawning potential
FSP of Year A+8 fish	4,915	140,815	217,964	138,820	32,376	6,340	575	541,804
FSP of Year A+7 fish	2,208	79,635	155,140	103,874	24,469	4,888		370,214
FSP of Year A+6 fish	1,249	56,681	116,086	78,506	18,867			271,389
FSP of Year A+5 fish	889	42,413	87,736	60,532				191,570
FSP of Year A+4 fish	665	32,055	67,649					100,369
FSP of Year A+3 fish	503	24,716						25,219
FSP of Year A+2 fish	388							388
FSP of Year A+1 fish								0
FSP of Year A fish								0
								1,500,954

The overall future spawning potential of all the lost fish has now reached an equilibrium value of 1,406,181 lost spawners. In other words, from this year onwards, year on year entrapment mortality will result in 1,406,181 spawning fish not being present in the population which would otherwise have been there.

Step 10

The Spawner Production Foregone EAV is the number of spawners that would have been present in that year (once equilibrium has been achieved) had they not been lost in previous years, divided by the number of fish impinged annually.

Number of fish impinged annually = 1,000,000

Number of spawners that would have been present had they not been lost in previous years (equilibrium value) = 1,500,954

Spawner Production Foregone EAV = 1.50

APPENDIX D: Lifetime Fecundity Worked Example, using simulated impingement data for a hypothetical fish species

Steps 1 to 8 are identical to those shown in the Spawner Production Foregone worked example.

Step 9

Step 8 concludes with the production of a table showing the numbers of fish that would have entered maturity in each age group (had they not been lost) and then applies natural mortality rates to calculate how many of these fish would have survived to spawn in successive years.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group	
Natural mortality	0.80	0.57	0.34	0.29	0.28	0.26	0.24	
	4,915	140,815	217,964	138,820	32,376	6,340	575	Total no. fish lost in Year A that would have entered maturity, for each Age Class
	2,208	79,635	155,140	103,874	24,469	4,888		Total no. mature fish, originating from Year A and surviving to Year A+1
	992	45,035	110,424	77,725	18,493			Total no. mature fish, originating from Year A and surviving to Year A+2
	446	25,469	78,597	58,159				Total no. mature fish, originating from Year A and surviving to Year A+3
	200	14,403	55,943					Total no. mature fish, originating from Year A and surviving to Year A+4
	90	8,145						Total no. mature fish, originating from Year A and surviving to Year A+5
	40							Total no. mature fish, originating from Year A and surviving to Year A+6
	8,892	313,502	618,069	378,577	75,338	11,228	575	Total number of spawning events that would have occurred had fish not been lost in Year A

The number of eggs resulting from maturing fish is then calculated by multiplying the age-specific fecundity (number of eggs per gram of fish weight) by the total number of fish lost in Year A that would have entered maturity (Row One, above), then by the total number of mature fish, originating from Year A and surviving to Year A+1 (Row Two, above), and so on down the table.

The total reproductive output (number of eggs) of spawners entering the population at each age is then calculated.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group
Fecundity (eggs/gram)	850	1,500	2,700	3,500	4,000	4,500	4,750
No. eggs resulting from maturing fish	4,177,604	211,222,643	588,503,302	485,868,790	129,502,671	28,528,506	2,731,250
	1,877,119	119,451,778	418,879,185	363,557,914	97,876,013	21,996,949	
	1,061,558	85,022,230	313,432,034	274,771,161	75,467,455		
	755,586	63,619,037	236,886,835	211,862,739			
	565,377	48,082,234	182,651,970				
	427,303	37,073,883					
	329,473						
Total reproductive output	9,194,020	564,471,805	1,740,353,326	1,336,060,605	302,846,140	50,525,455	2,731,250

Step 10

The average number of eggs deposited per fish maturing at age (lifetime fecundity), accounting for multiple spawning and variable fecundity at age, is calculated by dividing the total reproductive output by the total number fish lost in Year A that would have entered maturity, for each age group.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group
Total no. fish lost in Year A that would have entered maturity, for each Age Class	4,915	140,815	217,964	138,820	32,376	6,340	575
Average no. eggs deposited per fish maturing at age	1,871	4,009	7,985	9,624	9,354	7,970	4,750

The **overall average lifetime fecundity** is the average of the lifetime fecundity across all ages of first maturity

- (1,871 + 4,009 +7,985 + 9,624 + 9,354 + 7,970 + 4,750) / 7 **= 6,509 eggs**

Step 11

The ratio of average lifetime fecundity for fish maturing at each age, to overall average lifetime fecundity is then calculated. This gives an assessment of the relative contribution of each group of age of first maturity fish to the population.

Age of first maturity	0-Group	1-Group	2-Group	3-Group	4-Group	5-Group	6-Group
Total no. fish lost in Year A that would have entered maturity, for each Age Class	4,915	140,815	217,964	138,820	32,376	6,340	575
Average no. eggs deposited per fish maturing at age	1,871	4,009	7,985	9,624	9,354	7,970	4,750
(Average no. eggs deposited per fish maturing at age) / (overall average lifetime fecundity)	0.29	0.62	1.23	1.48	1.44	1.22	0.73

Step 12

The value of each age class is then calculated by multiplying this ratio by the total number of fish lost in Year A that would have entered maturity at each Age Class.

Age of first maturity	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	
Total no. fish lost in Year A that would have entered maturity, for each Age Class	4,915	140,815	217,964	138,820	32,376	6,340	575	
Average no. eggs deposited per fish maturing at age	1,871	4,009	7,985	9,624	9,354	7,970	4,750	
(Average no. eggs deposited per fish maturing at age) / (overall average lifetime fecundity)	0.29	0.62	1.23	1.48	1.44	1.22	0.73	**Total**
Value of each Age Class	1,413	86,723	267,381	205,267	46,528	7,763	420	615,495

Step 13

The sum of the values of each Age Class (615,495), divided by the number of fish impinged (1,000,000) gives:

Lifetime Fecundity Value Factor = 0.62

APPENDIX E: Clarification of the Spawning Production Foregone method, in response to questions received from NNB Genco (HPC) Ltd.

E.1 INTRODUCTION

E1.1 Regulatory history of Equivalent Adult Value techniques

Many species of fish produce very high numbers of offspring, few of which survive to become adults. Entrapment losses of large numbers of juvenile fish will therefore not have the same effect on the species' population as would the loss of the same number of adult fish. Conversion to Equivalent Adult Values (EAVs) is a method by which losses of all ages of fish can be contextualised through expression of the lost fish in terms of the equivalent number of adult fish that they represent.

In 2010, the Environment Agency published an Evidence Report entitled 'Cooling Water Options for the New Generation of Nuclear Power Stations in the UK' (Environment Agency, 2010). This report drew together information to assist regulatory authorities in evaluating the environmental impacts of cooling water options on biota and included discussion of methods of assessing the ecological significance of impingement and entrainment. The report was not prescriptive about which method should be used for any particular type of application. A method of calculating EAVs was described, as published by Turnpenny (1988), this having been widely used in power station assessments at the time (Section 6.1.5 in Environment Agency, 2010). Calculation of 'Habitat Production Foregone' was also discussed as a means of evaluating the impacts of fish losses. In this method, fish losses (which can be expressed as EAVs) are compared to estimates of estuarine production in order to allow quantities of fish removed to be equated to an equivalent area of marine habitat being taken out of production, The Habitat Production Foregone approach is described as being useful when considering ecological compensation once mitigation measures have been applied (Environment Agency, 2010).

The 2018 document, 'Protection of biota from cooling water intakes at nuclear power stations: scoping study' (Environment Agency, 2018) recognised there had been a number of developments since the 2010 report was published, and presented key developments and experience to highlight where further clarification was needed. The complexity of the Turnpenny (1988) EAV method was highlighted and the method presented in BEEMS Technical Report TR383 was introduced as a possible alternative (Metcalfe *et al*., 2016) – this being the method that NNB Genco (HPC) Ltd has used in their application to vary their Water Discharge Activity permit. As a scoping study, Environment Agency (2018) was published with the intention to produce a full review in due course. However, the scoping study recognised that through the use of readily available data on the general relationships between fish growth rate, maximum size and natural mortality rates, the BEEMS method avoided the need for reproductive data which are required by the method used in Turnpenny (1988) and are difficult to collect. Furthermore, the BEEMS method could make use of locally collected fish length-at-age data. As with the original Evidence Report (Environment Agency, 2010), the scoping study was not prescriptive about which method should be used.

The review that followed the scoping study was published as ‘Nuclear power station cooling waters: evidence on 3 aspects’ (Environment Agency, 2019a). This notes that the BEEMS method needed to be ‘treated with caution and critically reviewed’ with regard to its application of general relationships to different species. Such a review has taken place in the context of the Environment Agency’s determination of NNB Genco (HPC) Ltd’s application to vary the Water Discharge Activity permit at Hinkley Point C and is included in Technical Brief: TB010 (Environment Agency, 2019b).

International expert opinion was sought and a literature review conducted as part of the 2019 cooling water report (Environment Agency, 2019a). Feedback indicated that a number of models and assessment methods were available for contextualising entrapment losses, but that these could potentially be adapted and improved in the future in all cases. Papers presenting Production Foregone techniques are reviewed, for example EPRI (2004), where this is defined as the fish biomass that would have resulted from the survival and growth of entrapped fish. These techniques can include calculation of the amount of energy that would have been transferred to predatory fishes, which may be of commercial value.

EAV and Production Foregone techniques are described as being useful indicators of the scale of annual losses from entrapment, but it is noted that contextualising using these methods does not consider the wider population implications of entrainment and impingement over a number of years, or changes across the ecosystem and trophic levels (Environment Agency, 2019a). Other methods are introduced which can be employed to understand the implication of entrapment pressure on fish species and the wider ecosystem, such as life cycle or ecosystem modelling (Environment Agency, 2019a). Life cycle models allow long-term pressures on populations to be understood through evaluation of recovery rates, age structures, long-term population stability, reductions in population abundance, and extinction probability. Ecosystems models evaluate the effect of entrapment loses through the wider food web. Environment Agency (2019a) considers that these further techniques should be evaluated on a project-specific basis depending upon the sensitivity of species or the wider ecosystem and that for some species or fish assemblages it may be appropriate to utilise these models in relation to Habitats Regulations Assessments (HRAs) where an additional level of detail is required within the appropriate assessment.

E.1.2 EAV methods and NNB GenCo (HPC) Ltd's application to vary their Water Discharge Activity permit.

NNB Genco (HPC) Ltd have used EAV values calculated using the BEEMS method (see above) in their application to vary their Water Discharge Activity permit following their decision not to include Acoustic Fish Deterrents as mitigation. At the time of writing this current document (May 2020), the application to vary the permit for HPC has not yet been determined

The Environment Agency conducted a detailed review into the BEEMS method during the determination stage of the variation application, documenting the review in Technical Brief: TB010 (Environment Agency, 2019b). The review broadly accepted the BEEMS method for use at HPC, although the Environment Agency's view was that the method by which NNB Genco (HPC) Ltd had converted impingement losses to numbers of equivalent adults systematically undervalued the impact of impingement losses by considering only fish entering maturity and not taking repeat spawning into account. Repeat spawning refers to the ability of many species of fish to spawn in multiple years, beyond the age at which they first mature.

While it may be appropriate to use life cycle models to examine the long-term pressures on populations (Section 1.1 above and Environment Agency, 2019a) NNB Genco (HPC) Ltd did not take this approach at Hinkley. The Environment Agency considered their use, but felt that given the increased level of uncertainty that would be introduced by further modelling, a qualitative assessment of long-term pressures would add a sufficient level of detail to the Habitat Regulations Assessment.

In order to consider the potential of many fish species to repeat spawn, the Environment Agency developed an extension to the BEEMS method. This extension is described in Technical Brief TB010, in which it is referred to as the Spawning Production Foregone (SPF) extension (Environment Agency, 2019b). The SPF extension uses the same processes and assumptions as NNB Genco (HPC) Ltd's method, to calculate the total number of spawning fish (first time and repeat spawners) that would have been present in the population, had they not been impinged.

Although similar in name to the Habitat Production Foregone and Production Foregone techniques referred to in the Environment Agency's Evidence Reports (see Section 1.1 above and Environment Agency, 2010 & 2019a), the Spawning Production Foregone extension should not be confused with these methods. The Spawning Production Foregone extension simply develops the applicant's method further, using the same processes and assumptions to calculate, from impingement predictions, the total number of spawning fish that would have been present in the population without the operation of the new nuclear power station.

The Environment Agency and NNB GenCo (HPC) Ltd met on 1 April 2020 to discuss the Habitat Regulations Assessment provided by the company in support of their Water Discharge Activity permit variation application.

The objectives of the meeting included to ensure that:

- The Environment Agency has full understanding of NNB Genco (HPC) Ltd's Habitat Regulations Assessment (HRA) provided in support of its application,
- NNB Genco (HPC) Ltd has full understanding of the Environment Agency's assessment of their HRA, and
- NNB Genco (HPC) Ltd understands the reasoning behind the Environment Agency's interim HRA conclusions

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NNB Genco (HPC) Ltd stated that they did not understand how they could use SPF EAVs in annual effects assessments where entrapment losses have to be compared against SSB or landings. The company then explained their belief that if they used SPF EAVS for assessment purposes they could not reasonably quantify entrapment effects unless the SPF EAV were compared to the future spawning potential of the SSB or future spawning potential of the landings data. This being because:

- SSBs are annual assessments of fish populations at one moment in time not of theoretical potential future populations assuming no exploitation, and;
- Landings data are records of how many fish are caught in a year (together with their size and weight) not of theoretical catches in future years.

In other words, both sides of the equation would need to be inflated by the use of SPF EAVs and this would result in the same answer as before the use of SPF EAVs.

A further concern expressed by NNB Genco (HPC) Ltd was that by not including fishing mortality, the SPF EAVs were exaggerated.

Following the meeting, NNB Genco (HPC) Ltd submitted Scientific Position Paper SPP102 to the Environment Agency detailing their concerns and illustrating these using worked examples based upon impingement data for bass from Sizewell B (Cefas, 2020). Sizewell data are used in the example as NNB Genco (SZC) Ltd are proposing to use the same EAV method that has been used in the variation application for HPC and the Environment Agency has raised concerns about this during the pre-application process. NNB Genco (SZC) Ltd have submitted SPP102 to the Environment Agency team that will be determining permit applications for Sizewell C.

The following document addresses NNB Genco (HPC) Ltd's concerns and provides further explanation of the Environment Agency's SPF extension to the method used by the company. For brevity, NNB Genco (HPC) Ltd's method will be referred to below as the 'core method' and the Environment Agency's SPF extension as 'the extended method' or 'the extension'. The core method calculates the number of first time spawners that would have resulted from the impinged fish, whereas the extension continues the calculations to also include the number of repeat spawners.

SPP102 (Cefas, 2020) described an error found in the example calculations illustrating the extended method presented in TB010 (Environment Agency, 2019b), whereby incorrect values of natural mortality were applied to calculate numbers of survivors in Step 8 of the process. We have corrected this error in a revised version of TB010 and have confirmed that the error occurred in the example only. Extended method EAVs calculated as part of the Environment Agency's determination of NNB Genco (HPC) Ltd's application to vary their Water Discharge Activity permit do not contain the error which appeared in the version of TB010 which was shared with the company.

E.2 COMPATIBILITY OF THE CORE METHOD AND ITS EXTENSION WITH FISHERIES STOCK ASSESSMENTS.

In order to estimate the scale of potential impacts, fish losses (expressed as numbers or weights of equivalent adults) are compared to estimates of population size. For marine fishes, NNB GenCo (HPC) Ltd have used Spawning Stock Biomass (SSB) as their preferred population measure, with fisheries landings data being used where an SSB is not available. The SSB is the combined weight of all individuals in a fish stock that are capable of reproducing (ICES, 2015).

Specific concerns of NNB Genco (HPC) Ltd are that EAVs calculated using the extended method are not comparable to population estimates because:

1. SSBs are annual assessments of fish populations at one moment in time not of theoretical potential future populations assuming no exploitation.
2. Landings data are records of how many fish are caught in a year (together with their size and weight) not of theoretical catches in future years

NNB Genco (HPC) Ltd also consider that in order to make a valid comparison between an SPF-extension EAV and a measure of population size (SSB or landings data), the population size needs to be increased by multiplying by the same number (the 'EAV factor') as was used to convert impingement data into a number of equivalent adults (Cefas, 2020). This is based on the belief that because the SPF EAV considers the future spawning potential of the impinged fish, the population estimate must also consider the future spawning potential of the fish in the population.

The extended method is derived from the core method, and relies upon the same assumptions. Both the core method and its extension function by calculating how many of the fish lost through impingement in any year would have otherwise survived in subsequent years, up to the age when 100% of the fish are mature.

In both core and extension methods, for the year of impingement and each subsequent year, data on proportional maturity at age are used to calculate the number of fish that would have matured in that year, and how many would have remained immature. The difference between the core method and the extension is that in the core method, calculation of survival in subsequent years finishes once fish have reached maturity (Appendix One, below). In the extension, calculations continue in order to consider survival rates of mature fish as they spawn repeatedly (Example E.II).

The core method is a calculation of the potential loss of maturing fish to the spawning population in each year. The fish impinged in any one year will be made up of a number of ages and sizes. Some of these individuals may have otherwise matured in the year they were impinged, some may have otherwise matured the following year, or the year after that, with the number of years when fish may have become mature being determined by the life-history of the fish.

Therefore, in the core method, for a single year's impingement, the impact upon the number of fish maturing occurs over a number of future years. This means that after the first year of operation, the impact of impingement upon the number of fish maturing and entering the spawning population in any given year, will consist of impacts accumulated from across several preceding years. Under assumptions of consistent impingement number and consistent SSB, then over multiple years of operation, the number of impinged individuals that would otherwise have survived to reach maturity in each year settles at a constant level (Table 1 and Example E.I). Assumptions of constant recruitment and mortality also underlie one of the original 'classic' methods of EAV calculation, that of Turnpenny (1988) who explained that 'To have any long-term validity, it is assumed that the population is in equilibrium, i.e. births balance deaths'.

It is worth noting that both the core method and the extension consider the numbers of fish maturing up to the age where 100% of the fish of that Age Group are mature. However, this does not necessarily correspond to the maximum age of the fish. In the example NNB Genco (HPC) Ltd present for sea bass (Cefas, 2020), 100% maturity occurs at Age 14, although a small proportion of fish will survive beyond this age, with ICES reporting fishing mortality for sea bass up to Age 16+ (Table 27 of ICES (2019)). The extended method has followed the procedure of the core method and so similarly does not consider survival past the age where all fish in that Age Group are mature. Were older fish to be included this would lead to both core and extended method EAVs increasing slightly.

Table 1. The number of impinged fish that would have matured in each year following the commencement of operation of a power station in Year A (using simulated data, see Example E.I). Consistent colouration indicates fish lost in the same year of impingement, which would otherwise have matured in successive years (see Key).

	Year of operation								
	A	A+1	A+2	A+3	A+4	A+5	A+6	A+7	A+8
No. fish impinged	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
No. of fish that would have **matured** had they not been impinged:									
This year	254 590	254 590	254 590	254 590	254 590	254 590	254 590	254 590	254 590
Last year		176 663	176 663	176 663	176 663	176 663	176 663	176 663	176 663
Two years ago			82 892	82 892	82 892	82 892	82 892	82 892	82 892
Three years ago				21 415	21 415	21 415	21 415	21 415	21 415
Four years ago					5 876	5 876	5 876	5 876	5 876
Five years ago						358	358	358	358
Six years ago							11	11	11
Total no. fish which would have reached age-of-first-maturity had they not been impinged in previous years	254 590	431 253	514 144	535 559	541 436	541 793	541 804	541 804	541 804

KEY	
Fish impinged in Year A	
Fish impinged in Year A+1	
Fish impinged in Year A+2	
Fish impinged in Year A+3	
Fish impinged in Year A+4	
Fish impinged in Year A+5	
Fish impinged in Year A+6	
Fish impinged in Year A+7	
Fish impinged in Year A+8	

Using the hypothetical data first presented in Technical Brief TB010 (Environment Agency, 2019), this constant level of 541,804 maturing fish, is the same value as the total number of impinged fish that would otherwise have reached age of first maturity from a single years' impingement, as calculated by the core method (Table 1). For example, the total number of fish that would have matured in Year A+6 (541,804) is the sum of the number of fish that would have reached maturity in that year had they not been impinged (in Years A, A+1, A+2, A+3, A+4, A+5 or A+6);

A+6
1,000,000
254 590
176 663
82 892
21 415
5 876
358
11
541 804

the number of maturing fish that would have resulted from the fish impinged in any one year is also 541,804 (barring rounding errors), with the impact spread across the year of impingement and the subsequent six years.

A	A+1	A+2	A+3	A+4	A+5	A+6
254 590						
	176 663					
		82 892				
			21 415			
				5 876		
					358	
						11

The core method is a shorthand way of calculating this effect, but the true effect described by the core method is of an impact that builds to a steady level across multiple years (Table 1 and Example E.I).

Using the core method, the one million impinged fish can be contextualised as being equivalent to 541,804 fish that would have otherwise matured.

The extension functions in the same way as the core method and relies upon the same assumptions of consistent impingement and consistent SSB. As with the core method, impingement in a single year of operation impacts across multiple subsequent years. The difference between the core and the extension is that instead of stopping calculation of survival when fish first mature, the extension goes on to consider how many of those mature fish would have survived to spawn again in future years.

By applying the extended method to simulated data for a hypothetical fish species (Environment Agency, 2019b), the effect of impingement in any single year can be seen to be spread across six subsequent years (Table 2, Example E.II), just as was the case for the core method (Table 1, Example E.I).

Calculation of the total number of spawning fish that would have been present in each year (the extended method) settles at a higher equilibrium number (1,500,953) than does the calculation of the number of fish maturing in each year (541,804; the core method). This is because the extension accounts for lost fish that would have otherwise been present in the population, spawning for a second, third, fourth, fifth, sixth or seventh time in our example.

Table 2. The numbers of impinged fish that would have spawned in each year following the commencement of operation of a power station in Year A (using simulated data, see Example E.II), including maturing fish and repeat spawners. Consistent colouration indicates fish lost in the same year of impingement, which would otherwise have spawned in successive years (see Key).

	Year of operation								
	A	A+1	A+2	A+3	A+4	A+5	A+6	A+7	A+8
No. fish impinged	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000	1 000 000
No. of spawners that would have been present had they not been impinged:									
This year	254 590	254 590	254 590	254 590	254 590	254 590	254 590	254 590	254 590
Last year		348 428	348 428	348 428	348 428	348 428	348 428	348 428	348 428
Two years ago			326 671	326 671	326 671	326 671	326 671	326 671	326 671
Three years ago				258 495	258 495	258 495	258 495	258 495	258 495
Four years ago					178 551	178 551	178 551	178 551	178 551
Five years ago						94 784	94 784	94 784	94 784
Six years ago							39 434	39 434	39 434
Total number of spawners impinged	254 590	603 018	929 689	1 188 184	1 366 735	1 461 519	1 500 953	1 500 953	1 500 953

KEY	
Fish impinged in Year A	
Fish impinged in Year A+1	
Fish impinged in Year A+2	
Fish impinged in Year A+3	
Fish impinged in Year A+4	
Fish impinged in Year A+5	
Fish impinged in Year A+6	
Fish impinged in Year A+7	
Fish impinged in Year A+8	

In our example (Table 2, Example E.II), this equilibrium level of 1,500,953 spawners missing in any one year as a result of impingement, is the same value as is reached by considering the total number of spawning events that would have resulted over their lifetimes from all the fish impinged in a single year. In other words, the number of spawning fish that would otherwise be present in any single year once equilibrium is reached is the same as the spawning production foregone of the fish impinged in any one year.

For example, the total number spawners that would have been present in Year A+6 (Table 2) is the sum of the number of spawners that would have been present had they not been impinged (in Year A, A+1, A+2, A+3, A+4, A+5 and A+6):

A+6
1 000 000
254 590
348 428
326 671
258 495
178 551
94 784
39 434
1 500 953

This number (1,500,953) is the same as the total number of times all the fish impinged in Year A would have spawned, over their whole lives – in other words the ‘spawning production foregone’ from those impinged fish:

A	A+1	A+2	A+3	A+4	A+5	A+6
254 590						
	348 428					
		326 671				
			258 495			
				178 551		
					94 784	
						39 434

As with the core method, the extension (SPF) method is a shorthand way of describing what is happening, but the true effect described by the extension is of an impact that builds to a steady level across multiple years.

Using this SPF extension method, the one million impinged fish can be contextualised as being equivalent to 1,500,953 mature fish that would have otherwise have formed part of the spawning population, had they not previously been impinged. For any fish species, the number of times repeat spawning may occur will depend upon the life-history of that fish and varies from species to species

– some species have the potential to spawn more times than shown in our example, while some will have shorter lifespans and will have fewer opportunities for repeat spawning.

In SPP102 (Cefas, 2020), NNB Genco (HPC) Ltd present worked examples of the core method and the extended method as applied to Sizewell B Comprehensive Impingement Monitoring Programme (CIMP) data for seabass for the period 2009 – 2017. The core method generates an EAV of 0.224, meaning that, once equilibrium has been reached, 128,882 maturing seabass would be missing from the population each year as a result of impingement (575,367 × 0.224). Taking repeat spawning into account, the extended method generates an EAV of 1.050, meaning that 604,135 spawning seabass would be missing from the population in each year, as a result of impingement (575,367 × 1.050), these being a combination of maturing fish and repeat spawners, For seabass, the extended method EAV is 4.7 times larger than the core method EAV. This compares to an extended method which is 2.8 times larger than the core method for our hypothetical fish species (Example E.I and E.II) – the effect of taking repeat spawning into account will generally be greater for fish which are capable of many years of repeat spawning (e.g. seabass) than it is for fish with fewer opportunities for repeat spawning (e.g. the hypothetical fish species illustrated in Example E.I and E.II).

The core method and its extension are both:

- Based upon the same assumptions (including consistent impingement number and consistent SSB)
- Considering the survival of fish in years subsequent to the year of impingement.
- Forecasting future numbers of fish and comparing these to the population measure.
- Comparable with SSB when considered over multiple years of operation.
- Considering <u>actual numbers of fish which would have been part of the SSB</u> had they not been impinged.

As both the core method and the extension are considering actual numbers of fish which would have been part of the SSB had they not been impinged, neither the core nor the extension method require the stock comparator (SSB or landings data) to be modified to account for its future spawning potential.

The SSB is a measurement of the total spawning stock, which is comprised not only of fish which would be entering the spawning stock for the first time, but also fish which matured in previous years and are now spawning for a second, third, fourth time, or more. Consequently, by calculating the number of maturing fish <u>and</u> the number of repeat spawners that would have been present in the population had they not been impinged, the extension provides an EAV figure which is <u>more</u> comparable to the SSB than that which is calculated using the core method. To compare the core method with the SSB, the SSB needs to be scaled down so as to count only the number of fish maturing and entering the spawning stock for the first time.

E.3. CONSIDERATION OF FISHERIES MORTALITY

NNB Genco (HPC) Ltd have expressed their concern that the EAV calculated by the Spawning Production Foregone extension was exaggerated, due to fishing mortality not being included in the method.

As with the core method, the extension does not include fishing mortality in the calculations. The extension references natural mortality rates to calculate the number of mature fish that will survive to spawn again in subsequent years, considering the same age range of fish as the core method. NNB Genco (HPC) Ltd's argument is that fewer fish will survive in subsequent years than we are calculating as many of the mature repeat spawners will be taken by fisheries.

We acknowledge that fishing mortality (F) from either direct, targeted catch or indirect by-catch, is a key source of additional mortality for some species of fish. We have said:

> '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.' (Environment Agency, 2019b)

NNB Genco (HPC) Ltd have acknowledged that as fishing pressure can and does occur before the age of maturity, the core method can also overestimate the EAV for populations with large numbers of fish at or near maturity but that the potential error in ignoring fishing mortality is much less than with the extended method (Cefas, 2020). This is demonstrated in SPP102 where values for F are applied to the core method, resulting in an EAV which is reduced from F=0, but by a smaller proportion than when the same values for F are applied to the extended method (Cefas, 2020). Although the effect is smaller, if fishing mortality is to be considered (and if it is technically feasible for appropriate values to be included) then it is a relevant factor for both the core method and its extension. Fishing mortality for seabass in the Irish Sea, Celtic Sea and North Sea is considered to be occurring from Age 4 (ICES, 2019), with both the core and extension methods considering fish entering maturity at different ages, up to Age 14.

Fishing mortality can be included within the calculations for the core method and its extension, as demonstrated in SPP102 (Cefas, 2020), although there are substantial difficulties associated with doing this. The principle difficulty is that fishing mortality is not constant but varies from year to year. Fishing quotas are set with the aim of managing stocks sustainably. If fishing mortality is considered to be too high then quotas and fishing effort can be reduced to mitigate for population reductions. For some species fishing mortality may be limited at present due to the current status of the stocks.

The reason for using an EAV is to contextualise impingement losses over the whole operational life of the power station, which is expected to be around 60 years.

Applying a fixed level of fishing mortality to the EAV calculation may result in impacts being overestimated in some years and underestimated in others. In terms of Habitats Regulations Assessment (HRA), a method which underestimates impacts in some years would not be consistent with the precautionary principle.

In SPP102, mean values of F for each Age Group over the time period that impingement monitoring was taking place (2009-2017) are applied to seabass that would have survived beyond the year of impingement (Cefas, 2020). Mean values for F are calculated from ICES data for seabass (ICES, 2019), but there was considerable variation in F over this time period, with some of the highest values of F seen since 1985 followed by a decline following the peak in 2013, to the lowest value on record in 2018 (Figure 1).

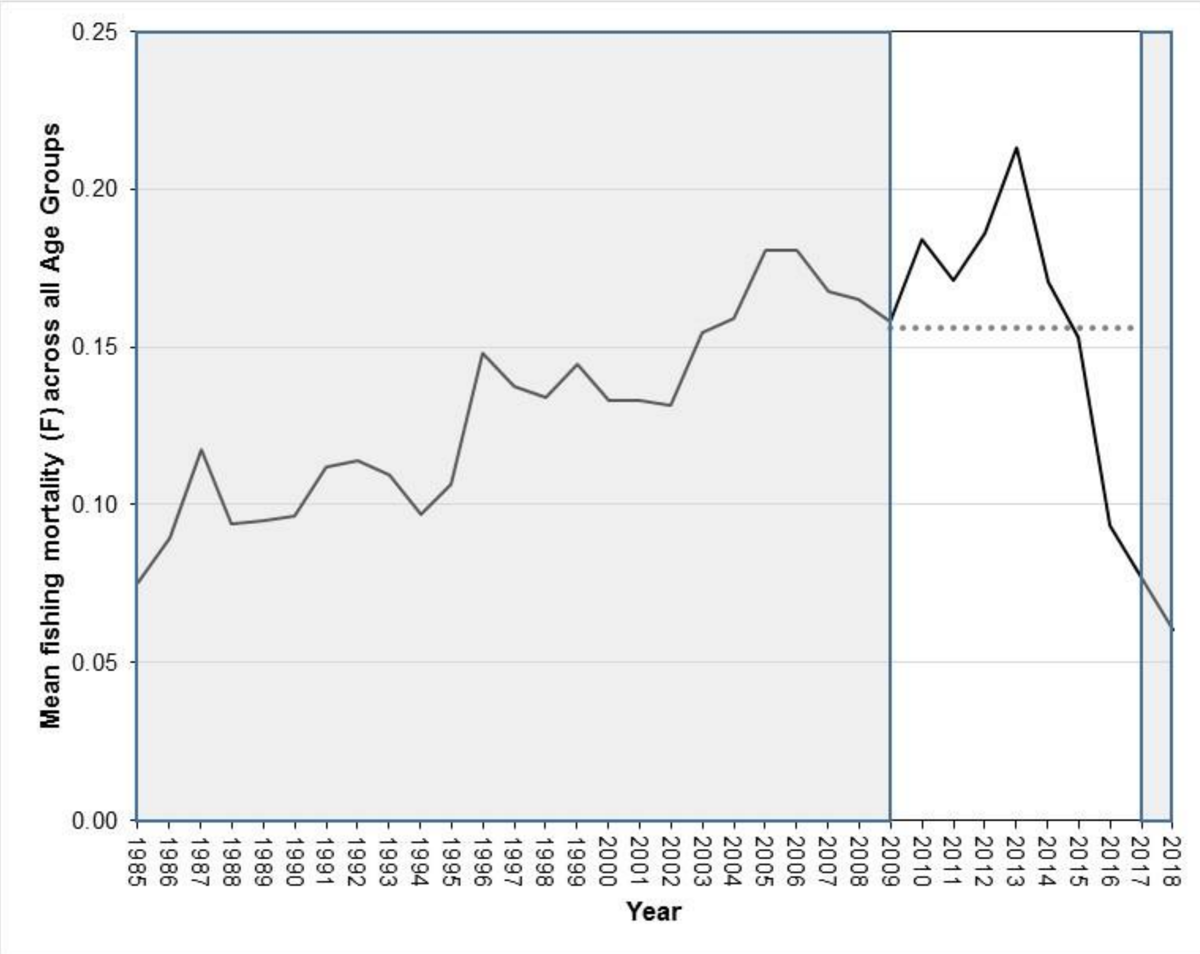

Figure 1. Mean fishing mortality (F) across all Age Groups of seabass for the years 1985 to 2018 (—) together with the mean value of F across all Age Groups for the years 2009 – 2017 (…..) coinciding with the period of the Comprehensive Impingement Monitoring Programme at SZB. Data from ICES (2019).

We can see the effect that different values of F have on core and extended method EAVs by substituting different values for F into the seabass worked examples of SPP102 (Cefas, 2020) (Table 3). When using F values for each Age Group from 2013 (when mean F across all Age Groups was at its peak) the core method calculates an EAV that is 85% of the value calculated when considering natural mortality only. As F decreases, the core method EAV calculated incorporating F, forms a higher proportion of the unadjusted EAV which considers natural mortality alone (Table 3). Using the minimum F values of 2018, the EAV incorporating F is 95% of the unadjusted value (Table 3). A similar pattern is seen when considering the extended method. When F is included, the extended method EAV is reduced by a greater proportion than the core method EAV, but again the effect is less when fishing pressure is at its lowest, with the extended EAV being 77% of the unadjusted value using 2018 values for F, compared to 55% using 2013 values of F (Table 3).

Table 3. EAV Factors and numbers of equivalent adults for seabass from the worked example in SPP102 (Cefas, 2020) using a range of values for F in each Age Group, from years with high F (2013) and low F (2017, 2018) as well as the mean from 2009 2017 (this being the value used in SPP102).

	Core method			**Extended method**		
F values	EAV Factor	Number of equivalent adults	% of unadjusted EAV	EAV Factor	Number of equivalent adults	% of unadjusted EAV
2013	0.190	109 320	85	0.525	302 068	50
Mean (2009 – 17)	0.197	113 347	88	0.598	344 069	57
2017	0.208	119 676	93	0.751	432 101	72
2018	0.212	121 978	95	0.806	463 746	77
None (unadjusted EAV)	0.224	128 882	-	1.050	604 135	-

If EAVs are calculated using average fishing mortality over the 2009-2017 time period, the impact of the power station, over the course of its sixty year operational period, will be underestimated for years when fishing mortality is lower than this average value. F over the 2009-2017 time period is not typical of F over the whole period for which there are data (1985-2017) and may therefore not be typical of fishing mortality that would be experienced by seabass over the sixty-year operational period of a new build power station. It should also be noted that even when values of F at age from 2013 are used, when fishing mortality was exerting its greatest effect, the extended method still produces an EAV that is over twice that calculated using the unadjusted core method (Table 3).

Fishing mortality is controlled by fishery managers, such that when stocks are declining, targeted fishing pressure can be reduced or even removed. For example, ICES have recommended zero catch of cod in 2020 in the western English Channel and southern Celtic Seas to allow the species to recover (ICES, 2019b). When these conditions occur, HPC impacts will continue unchanged and so we need to understand the effect that the station has under conditions of zero catch for commercial species. As such, the extended method EAV calculated using natural mortality (M) alone, is a relevant figure to refer to in assessing the potential impact of entrapment, particularly so within the context of Habitat Regulations Assessment, as low or zero fishing mortality will occur as a result of management action taken when stocks are below levels where sustainable commercial fishery exploitation could be achieved.

In addition to difficulties in choosing an appropriate temporal range from which to draw an estimate of fishing mortality, there are also difficulties with regard to determining F for an appropriate geographic area. Many marine fish stocks exhibit a complex, meta-population structure with species showing little population structure being the exception rather than the rule (Kerr *et al.*, 2017) - a topic we have explored further in Technical Brief TB010: Scale of assessment areas for marine fishes and assessment method comparing sprat losses with Spawning Stock Biomass (Environment Agency, 2020). Fishing mortality rates used by ICES are calculated for the entire stock area and fishing effort (and thus fishing mortality) might not be uniform across the whole of this area. If fishing effort is concentrated in an area distant from the power station under consideration, then the published value of F may not be representative of fishing mortality on the local sub-population that is being impacted by entrapment.

Fishing mortality across the Bristol Channel and Celtic Sea is not uniform with fishing pressure being lower in Subdivision 7f compared to other areas of the Celtic Sea, Irish Sea and North East Atlantic, with the exception of the beam trawling occurring off the North Cornwall coast (Figure 2, ICES, 2018). Fishing mortality rates used for ICES stock assessments are drawn from across the whole of the stock unit, so for example from across the Irish Sea, Celtic Sea and North Sea for European seabass. Therefore, fishing mortality rates cannot be used directly from ICES stock assessments.

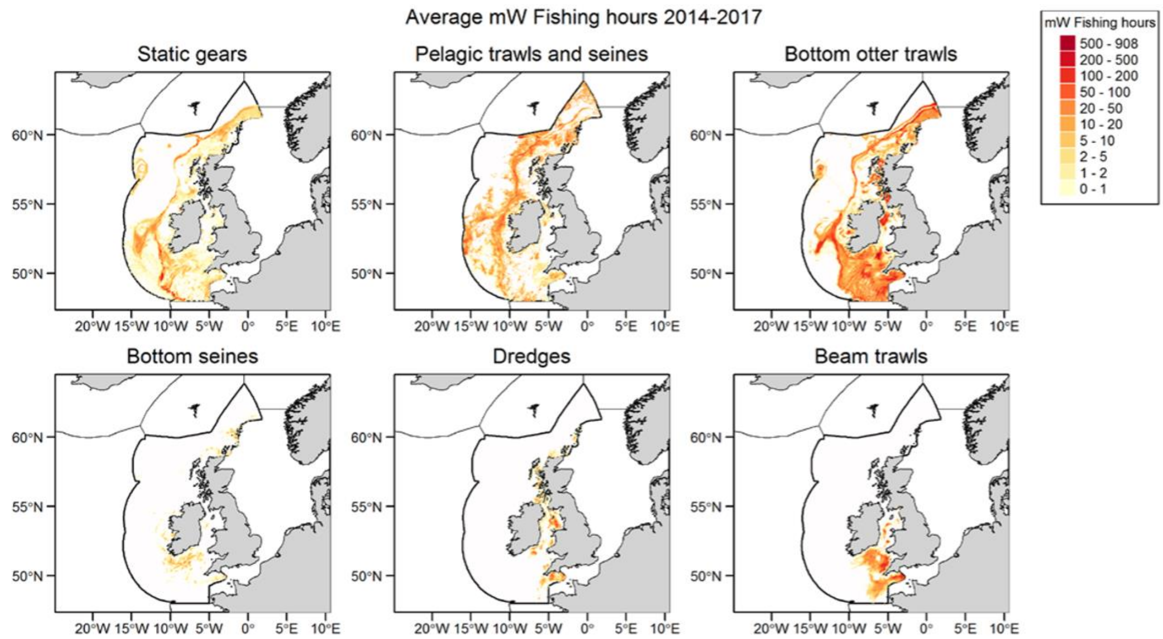

Figure 1. Spatial distribution of average annual fishing effort (mW fishing hours i.e. number of days of sea x vessel engine power) in the Celtic Seas ecoregion during 2014– 2017, by gear type. Fishing effort data are only shown for vessels > 12 m having vessel monitoring systems (VMS), this will bias the distributions, particularly in coastal areas. Reproduced from Figure 9 (p9) in ICES (2018).

SPP102 highlights further concerns about the accuracy of values for F at age which include uncertainty over discard rates, particularly affecting the accuracy of estimates of fishing mortality for smaller size classes, and also under-sampling, leading to poorly estimated length at age values (Cefas, 2020).

Applying fishing mortality to the calculation of either the core or extension EAV would also complicate some of the comparisons that are drawn in TR456 (Cefas, 2019) between the scale of impingement losses and the scale of losses due to commercial fishing. For example, Section 5.1.3.2 (p56) of TR456 (Cefas, 2019) describes sustainable harvest rates for data rich stocks as being ‘much greater than 20%’ in many cases and says that set against such numbers an impingement mortality of less than 1% from HPC is negligible (Cefas, 2019).

If fishing mortality were incorporated into the core method or its extension then such a comparison would be more complex to interpret as the EAV would be describing the effect of impingement in addition to that of commercial fishing, rather than the effect of impingement alone.

In summary, we still acknowledge that fishing mortality is a relevant factor for predicting the entrapment effects of nuclear new build power stations. However, the complexities of predicting F over the operational life of the power station, the selection of a geographically relevant value for F, and potential issues of accuracy over any F values that may be obtained, mean that practically incorporating meaningful values of F into the derivation of EAVs is extremely challenging. Incorporating inappropriate values of F into the calculation of EAVs would add increased uncertainty to estimates and, as with life cycle modelling (see Section 1.2, above) is felt to be an unnecessary quantification in the assessment of potential impacts. Fishing mortality varies from year to year and can be controlled by fishery management, with low, or zero, F being required when fish stocks are recognised as being fished at unsustainable rates. Consequently, EAVs calculated without including fishing mortality need to be considered when taking a precautionary approach to assessing the potential impact of a new power station over the course of its operational life, with the extended method being preferred over the core method for the reasons outlined in TB010 (Environment Agency, 2019b) and in Section 2 (above).

E.4. REFERENCES

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EXAMPLE E.I

Demonstration of how the core method for EAV calculation exerts an influence across multiple years.

This demonstration is based on the simulated data for a hypothetical fish species that was presented in Environment Agency (2019). For further detail see Steps 1–6 in Appendix C of Environment Agency (2019).

We will assume one million individuals of our species are impinged in the first year of operation of a power station (Year A). Length-at-age data would be used to assign the number of fish impinged from each Age Class (Table 1).

Age Class	Number of individuals
Age 0	491 483
Age 1	246 921
Age 2	176 447
Age 3	70 116
Age 4	12 860
Age 5	2 173
Age 6	0
Total	1 000 000

Table 1. The number of fish impinged in each Age Class in Year A.

Although the maximum age for this species is six, no six-year old individuals were impinged during sampling. Calculations of survival will however consider the number of impinged fish that would have survived through to Age 6.

Of the one million fish impinged in Year A, the number in each Age Class that would have been mature is calculated using proportional maturity-at-age data (Table 2).

Age Class	Number of individuals	Proportion mature	Number of mature individuals
Age 0	491 483	0.01	4 915
Age 1	246 921	0.3	74 077
Age 2	176 447	0.6	105 868
Age 3	70 116	0.8	56 093
Age 4	12 860	0.9	11 574
Age 5	2 173	0.95	2 064
Age 6	0	1	0
Total	1 000 000	-	~~264~~ 254 590

Table 2. The number of fish impinged in each Age Class, proportional maturity for that Age Class, and the number of mature individuals in that Age Class (number of individuals x proportion mature).

In Year A, of the one million individuals impinged, a total of ~~264~~ 254 590 would have been mature. The number of individuals lost in Year A that would otherwise have contributed to the spawning population in Year A is therefore 254 590 and there would have been 745 410 immature fish impinged across all Age Classes (1 000 000 – 254 590).

YEAR A	
No. maturing fish impinged in Year A.	254 590
Total no. maturing fish that would be present in **Year A** had they not been impinged	**254 590**

In Year A+1, one million fish will again be impinged, of which 254 590 will be mature (just as in Year A).

In addition to these, by applying mortality rates to the number of immature fish impinged in Year A in each Age Class, we can calculate that 383 036 of these would have survived to Year A+1. Proportional maturity for each Age Class is then applied to calculate that 176 663 of these would have matured in Year A+1.

In total, 431 253 maturing fish will be missing from the population in Year A+1 as a result of impingement in Year A and Year A+1 (176 663 + 254 590).

YEAR A+1	
No. maturing fish impinged in Year A+1.	254 590
No. juveniles of all ages impinged in Year A that would have survived and matured in Year A+1	176 663
Total no. maturing fish that would be present in **Year A+1** had they not been impinged	**431 253**

<u>In Year A+2</u>, impingement will have continued and so, as in Year A and Year A+1, a further 254 590 mature individuals will have been lost from the one million fish impinged in Year A+2.
Survival and maturity for the one million fish impinged in Year A+1 will be as for those impinged in Year A. This means that 176 663 fish impinged in Year A+1 would have otherwise matured in Year A+2.

Mortality rates for each Age Class can again be applied to calculate that in total, 124 533 of the immature fish impinged in Year A, that survived to Year A+1 would again survive to Year A+2. By applying the proportional maturity for each Age Class to these survivors we can calculate that 82 892 of these (across all ages) would have matured in Year A+2.

The total number of maturing fish not present in Year A+2 as a result of impingement in Year A, Year A+1 and Year A+2 then is 82 892 + 176 663 + 254 590 = 514 144 fish.

Year A+2	
No. maturing fish impinged in Year A+2.	254 590
No. juveniles impinged in Year A+1 that would have survived and matured in Year A+2	176 663
No. juveniles impinged in Year A that matured in Year A+2	82 892
Total no. maturing fish that would be present in **Year A+2** had they not been impinged	**514 144**

Similar calculations can be carried out for subsequent years, to find the number of individuals maturing in each year (see tables below).

Year A+3	
No. maturing fish impinged in Year A+3	254 590
No. juveniles impinged in Year A+2 that would have survived and matured in Year A+3	176 663
No. juveniles impinged in Year A+1 that matured in Year A+3	82 892
No. juveniles impinged in Year A that matured in Year A+3	21 415
Total no. maturing fish that would be present in **Year A+3** had they not been impinged	**535 559**

Year A+4	
No. maturing fish impinged in Year A+4	254 590
No. juveniles impinged in Year A+3 that would have survived and matured in Year A+4	176 663
No. juveniles impinged in Year A+2 that matured in Year A+4	82 892
No. juveniles impinged in Year A+1 that matured in Year A+4	21 415
No. juveniles impinged in Year A that matured in Year A+4	5 876
Total no. maturing fish that would be present in **Year A+4** had they not been impinged	**541 436**

Year A+5	
No. maturing fish impinged in Year A+5	254 590
No. juveniles impinged in Year A+4 that would have survived and matured in Year A+5	176 663
No. juveniles impinged in Year A+3 that matured in Year A+5	82 892
No. juveniles impinged in Year A+2 that matured in Year A+5	21 415
No. juveniles impinged in Year A+1 that matured in Year A+5	5 876
No. juveniles impinged in Year A that matured in Year A+5	358
Total no. maturing fish that would be present in **Year A+5** had they not been impinged	**541 793**
Year A+6	
No. mature fish impinged in Year A+6	254 590
No. juveniles impinged in Year A+5 that would have survived and matured in Year A+6	176 663
No. juveniles impinged in Year A+4 that matured in Year A+6	82 892
No. juveniles impinged in Year A+3 that matured in Year A+6	21 415
No. juveniles impinged in Year A+2 that matured in Year A+6	5 876
No. juveniles impinged in Year A+1 that matured in Year A+6	358
No. juveniles impinged in Year A that matured in Year A+6	11
Total no. maturing fish that would be present in **Year A+6** had they not been impinged	**541 804**

The numbers of lost fish build year on year until an equilibrium value of maturing fish is reached. In the example above, in Year A+7, none of the fish impinged in Year A would still survive as they would have all reached the end of their natural lifespan. The table for Year A+7 would though be identical to that for Year A+6, except that following the established pattern, the bottom row of the table would be occupied by fish impinged in Year A+1, rather than Year A. These would in turn ‘drop off’ the following year, when the bottom row of the table would show the number of maturing fish that would have been present had they not been impinged in Year A+2,

For our example fish species, the core method settles at a value of 541 804 maturing fish that would have been present in any one year, had they not impinged in that year, or in previous years.

The total number of fish that would have matured over time from the fish impinged in any one year is also 541 804, but it can be seen that the full effect of one year’s impingement losses (for example, Year A) does not occur in that year alone, but is instead spread over seven years (Year A to Year A+6).

The core method EAV is calculated by dividing the equilibrium number by the total number of fish impinged in a year (541 804 / 1 000 000 = 0.54).

EXAMPLE E.II

Demonstration of how the extension to the core method for EAV calculation exerts an influence across multiple years.

As in Example E.I, one million of our hypothetical fish species (Environment Agency, 2019) are predicted to be impinged annually. Length-at-age data and proportional maturity-at-age data are applied on order to calculate the number of individuals that would have been mature in the first year of operation of a power station (Year A)

<u>In Year A</u>, 254 590 of the one million impinged individuals would have been mature, or would have reached age-of-first-maturity in that year. The mature individuals would have been comprised of Age 0 = 4 915 fish, Age 1 = 74 077 fish, Age 2 = 105 868 fish, Age 3 = 56 093 fish, Age 4 = 11 574 fish and Age 5 = 2 064 fish (from Table 2 in Example E.I).

The number of individuals lost in Year A that would otherwise have contributed to the spawning population in Year A is therefore 254 590.

YEAR A	
No. adults impinged in Year A.	254 590
Total no. adults that would be present in **Year A** had they not been impinged	**254 590**

Figures in blue are counted in the core method and its extension.

<u>In Year A+1</u>, one million fish will again be impinged, of which 254 490 will be mature or will have matured that year (just as in Year A). This is the same as for the core method.

In addition to these, by applying mortality rates to the number of immature fish impinged in Year A in each Age Class, we can calculate that 176 663 of the fish that were immature when impinged in Year A would have survived and become mature in Year A+1. This again, is the same as the core method.

In the extension, mortality rates for each Age Class are applied to the 254 590 fish that were mature when impinged in Year A, to calculate that 171 765 of these would have survived to spawn again in Year A+1. Had they not been impinged in Year A, these 171 765 fish would have been present and would have formed part of the spawning population in Year A+1. It is therefore valid to include these fish in a comparison with the Spawning Stock Biomass. These 171 765 repeat spawners are not accounted for in the core method.

YEAR A+1	
No. adults impinged in Year A+1.	254 590
No. adults impinged in Year A that would have survived and spawned again in Year A+1	171 765
No. juveniles of all ages impinged in Year A that would have survived and matured in Year A+1	176 663
Total no. adults that would be present in **Year A+1** had they not been impinged	**603 018**

Figures in blue are counted in the core method and its extension, figures in red are counted in the extension only.

In Year A+2, one million fish will again be impinged, of which 254 490 will be mature (just as in Year A and Year A+1).

Applying the core method's assumption of constant impingement and constant SSB, the numbers of immature fish impinged in Year A+1 that survive and mature in Year A+2 will be the same as were impinged in Year A and would otherwise have matured in Year A+1 (n = 176 663). Similarly, the number of fish that were mature when impinged in Year A+1 that would have survived to Year A+2 will be the same as the number that were mature when impinged in Year A and survived to Year A+1 (n = 171 765).

By applying mortality rates for each Age Class to the 171 765 fish that were mature when impinged in Year A and survived to spawn again in Year A+1, we can calculate that 125 917 would have survived to spawn again in Year A+2.

Similarly, mortality rates are applied to each Age Class for the 176 663 fish that were impinged in Year A that matured in Year A+1 to calculate that 117 862 of these would have survived to spawn again in Year A+2.

In Year A+2 then, a total of 415 544 repeat spawners would have been present in the spawning population had they not been impinged in Year A or Year A+1 (shown in red font in the table below). None of these repeat spawners would have been accounted for in the core method (see table immediately below).

Year A+2	
No. adults impinged in Year A+2.	254 590
No. adults impinged in Year A+1 that would have survived and spawned again in Year Y+2	171 765
No. juveniles impinged in Year A+1 that would have survived and matured in Year A+2	176 663
No. adults impinged in Year A that would have survived and spawned in Year A+2	125 917
No. juveniles impinged in Year A that matured in Year Y+1 and survived to Year A+2	117 862
No. juveniles impinged in Year A that matured in Year A+2	82 892
Total no. adults that would be present in **Year A+2** had they not been impinged	**929 689**

Figures in blue are counted in the core method and its extension, figures in red are counted in the extension only.

Similar calculations can be carried out for subsequent years, to find the numbers of individuals maturing in each year and the number of mature fish surviving to spawn again in each year (see tables below).

Year A+3	
No. adults impinged in Year A+3	254 590
No. adults impinged in Year A+2 that would have survived and spawned again in Year A+3	171 765
No. juveniles impinged in Year A+2 that would have survived and matured in Year A+3	176 663
No. adults impinged in Year A+1 that would have survived and spawned again in Year A+3	125 917
No. juveniles impinged in Year A+1 that matured in Year A+2 and survived to Year A+3	117 862
No. juveniles impinged in Year A+1 that matured in Year A+3	82 892
No. adults impinged in Year A that would have survived and spawned again in Year A+3	90 274
No. juveniles impinged in Year A that matured in Year A+1 and survived to Year A+3	86 669
No. juveniles impinged in Year A that matured in Year A+2 and survived to Year A+3	60 136
No. juveniles impinged in Year A that matured in Year A+3	21 415
Total no. adults that would be present in **Year A+3** had they not been impinged	**1 188 184**

Figures in blue are counted in the core method and its extension, figures in red are counted in the extension only.

Year A+4	
No. adults impinged in Year A+4	254 590
No. adults impinged in Year A+3 that would have survived and spawned again in Year A+4	171 765
No. juveniles impinged in Year A+3 that would have survived and matured in Year A+4	176 663
No. adults impinged in Year A+2 that would have survived and spawned again in Year A+4	125 917
No. juveniles impinged in Year A+2 that matured in Year A+3 and survived to Year A+4	117 862
No. juveniles impinged in Year A+2 that matured in Year A+4	82 892
No. adults impinged in Year A+1 that would have survived and spawned again in Year A+4	90 274
No. juveniles impinged in Year A+1 that matured in Year A+2 and survived to Year A+4	86 669
No. juveniles impinged in Year A+1 that matured in Year A+3 and survived to Year A+4	60 136
No. juveniles impinged in Year A+1 that matured in Year A+4	21 415
No. adults impinged in Year A that would have survived and spawned again in Year A+4	50 386
No. juveniles impinged in Year A that matured in Year A+1 and survived to Year A+4	61 471
No. juveniles impinged in Year A that matured in Year A+2 and survived to Year A+4	44 805
No. juveniles impinged in Year A that matured in Year A+3 and survived to Year A+4	16 013
No. juveniles impinged in Year A that matured in Year A+4	5 876
Total no. adults that would be present in **Year A+4** had they not been impinged	**1 366 735**

Figures in blue are counted in the core method and its extension, figures in red are counted in the extension only.

Year A+5	
No. adults impinged in Year A+5	254 590
No. adults impinged in Year A+4 that would have survived and spawned again in Year A+5	171 765
No. juveniles impinged in Year A+4 that would have survived and matured in Year A+5	176 663
No. adults impinged in Year A+3 that would have survived and spawned again in Year A+5	125 917
No. juveniles impinged in Year A+3 that matured in Year A+4 and survived to Year A+5	117 862
No. juveniles impinged in Year A+3 that matured in Year A+5	82 892
No. adults impinged in Year A+2 that would have survived and spawned again in Year A+5	90 274
No. juveniles impinged in Year A+2 that matured in Year A+3 and survived to YearA+5	86 669
No. juveniles impinged in Year A+2 that matured in Year A+4 and survived to Year A+5	60 136
No. juveniles impinged in Year A+2 that matured in Year A+5	21 415
No. adults impinged in Year A+1 that would have survived and spawned again in Year A+5	50 386
No. juveniles impinged in Year A+1 that matured in Year A+2 and survived to Year A+5	61 471
No. juveniles impinged in Year A+1 that matured in Year A+3 and survived to Year A+5	44 805
No. juveniles impinged in Year A+1 that matured in Year A+4 and survived to Year A+5	16 013
No. juveniles impinged in Year A+1 that matured in Year A+5	5 876
No. adults impinged in Year A that would have survived and spawned again in Year A+5	13 505
No. juveniles impinged in Year A that matured in Year A+1 and survived to Year A+5	33 584
No. juveniles impinged in Year A that matured in Year A+2 and survived to Year A+5	31 078
No. juveniles impinged in Year A that matured in Year A+3 and survived to Year A+5	12 030
No. juveniles impinged in Year A that matured in Year A+4 and survived to Year A+5	4 230
No. juveniles impinged in Year A that matured in Year A+5	358
Total no. adults that would be present in **Year A+5** had they not been impinged	**1 461 519**

Figures in blue are counted in the core method and its extension, figures in red are counted in the extension only.

Year A+6	
No. adults impinged in Year A+6	254 590
No. adults impinged in Year A+5 that would have survived and spawned again in Year A+6	171 765
No. juveniles impinged in Year A+5 that would have survived and matured in Year A+6	176 663

No. adults impinged in Year A+4 that would have survived and spawned again in Year A+6	125 917
No. juveniles impinged in Year A+4 that matured in Year A+5 and survived to Year A+6	117 862
No. juveniles impinged in Year A+4 that matured in Year A+6	82 892
No. adults impinged in Year A+3 that would have survived and spawned again in Year A+6	90 274
No. juveniles impinged in Year A+3 that matured in Year A+4 and survived to Year A+6	86 669
No. juveniles impinged in Year A+3 that matured in Year A+5 and survived to Year A+6	60 136
No. juveniles impinged in Year A+3 that matured in Year A+6	21 415
No. adults impinged in Year A+2 that would have survived and spawned again in Year A+6	50 386
No. juveniles impinged in Year A+2 that matured in Year A+3 and survived to Year A+6	61 471
No. juveniles impinged in Year A+2 that matured in Year A+4 and survived to Year A+6	44 805
No. juveniles impinged in Year A+2 that matured in Year A+5 and survived to Year A+6	16 013
No. juveniles impinged in Year A+2 that matured in Year A+6	5 876
No. adults impinged in Year A+1 that would have survived and spawned again in Year A+6	13 505
No. juveniles impinged in Year A+1 that matured in Year A+2 and survived to Year A+6	33 584
No. juveniles impinged in Year A+1 that matured in Year A+3 and survived to Year A+6	31 078
No. juveniles impinged in Year A+1 that matured in Year A+4 and survived to Year A+6	12 030
No. juveniles impinged in Year A+1 that matured in Year A+5 and survived to Year A+6	4 230
No. juveniles impinged in Year A+1 that matured in Year A+6	358
No. adults impinged in Year A that would have survived and spawned again in Year A+6	388
No. juveniles impinged in Year A that matured in Year A+1 and survived to Year A+6	11 714
No. juveniles impinged in Year A that matured in Year A+2 and survived to Year A+6	16 400
No. juveniles impinged in Year A that matured in Year A+3 and survived to Year A+6	8 746
No. juveniles impinged in Year A that matured in Year A+4 and survived to Year A+6	1 968
No. juveniles impinged in Year A that matured in Year A+5 and survived to Year A+6	208
No. juveniles impinged in Year Y that matured in Year Y+6	11
Total no. adults that would be present in **Year A+6** had they not been impinged	**1 500 953**

Figures in blue are counted in the core method and its extension, figures in red are counted in the extension only.

As for the core method, numbers of lost fish build until an equilibrium value is reached. In the example above, in Year A+7, no fish impinged in Year A would survive as they would have all reached the end of their natural lifespan. The table for Year A+7 would though be identical to that for Year A+6, except that following the established pattern, the lower seven rows of the table would be occupied by fish impinged in Year A+1 (instead of those impinged in Year A). These would in turn ‘drop off’ the following year, when the bottom seven rows of the table then featuring fish impinged in Year A+2,

The extension settles at a value of 1 500 953 spawning fish that would have been present and would have formed part of the Spawning Stock Biomass in any year had they not been impinged.

The extension EAV factor is calculated by dividing the equilibrium number by the total number of fish impinged in a year (EAV factor = 1 500 953 / 1 000 000 = 1.50).

For comparison, the equilibrium value for the core method is 541 804 maturing fish that would have been present and part of the spawning population had they not previously been impinged, working through to an EAV factor of 0.54.