HINKLEY POINT C PERMIT VARIATION

EPR/HP3228XT/V004

Technical Brief: TB010

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

The Estuarine and Coastal Monitoring and Assessment Service, Environment Agency.

National Fisheries Services, Environment Agency.

NNB HRA Team, Environment Agency.

Marine Contractor, APEM LTD.

2019 (DRAFT-03)

DRAFT

CONTENTS

DRAFT

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.

DRAFT

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.

DRAFT

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.

DRAFT

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.

DRAFT

---

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

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.

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.

Spawning 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.

DRAFT

---

[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 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.

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).

DRAFT

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.

DRAFT

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.

DRAFT

- 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.

DRAFT

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 species' Feature Templates and 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 0.13 will be used. Due to the salmon's complex life-cycle, the Environment Agency undertook a simplified EAV procedure for this species. Each individual impinged fish was assigned its own EAV factor, based on at-sea survival data for smolts, and the probability of kelts returning to spawn again. The mean of these EAV factors was then calculated and this value (0.13) 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. We recognise that this is a simplified EAV, which does not take into account the

DRAFT

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.

DRAFT

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.

DRAFT

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.

DRAFT

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.

DRAFT

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

DRAFT

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.

DRAFT

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.

DRAFT

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)

DRAFT

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

DRAFT

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

DRAFT

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°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

DRAFT

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

DRAFT

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^{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.

DRAFT

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).

DRAFT

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.

DRAFT

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.

DRAFT

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.

DRAFT

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.

DRAFT

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)

DRAFT

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)

DRAFT

Table 3. Conclusion Results

	EAV factor		
	Used in Applicant's assessment	Used in the Environment Agency's assessment	
Species		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	0.130	0.130 Mean, 0.310 SD
Sea trout	N/A	1.000	N/A
Brown Shrimp	1.000	N/A	N/A

DRAFT

REFERENCES

Aprahamian, M.W. (1988) The biology of the twaite shad, *Alosa fallax fallax* (Lacépède), in the Severn Estuary. J. Fish Biol. **33** (Issue sA): 141-152

BEEMS (2016) A new approach for calculating Equivalent Adult Value (EAV) metrics. Technical Report TR383. Cefas, Lowestoft.

BEEMS (2017) Hinkley Point - Equivalent Adult Value (EAV) metrics 2009-2010. Technical Report TR426. Cefas, Lowestoft.

BEEMS (2018) Revised Predictions of Impingement Effects at Hinkley Point C - 2018. Technical Report TR456 Edition 2, Revision 10. Cefas, Lowestoft.

Ciotti, B. J., Targett, T. E. and Burrows, M. T. (2013) Decline in growth rate of juvenile European plaice (Pleuronectes platessa) during summer at nursery beaches along the west coast of Scotland. Canadian Journal of Fisheries and Aquatic Science 70: 720-734.

EPRI (2004) Extrapolating Impingement and Entrainment Losses to Equivalent Adults and Production Foregone. EPRI (Electric Power Research Institute, Inc.) Technical Report 1008471 Final Report, July 2004

Environment Agency (2010) Cooling Water Options for the New Generation of Nuclear Power Stations in the UK. Environment Agency SC070015/SR3.

Environment Agency (2019) Nuclear power station cooling waters: evidence on 3 aspects. Environment Agency SC170021/R1

Gerritsen, H. D., Armstrong, M. J., Allen, M., McCurdy, W. J. and Peel, J. A. D. (2003) Variability in maturity and growth in a heavily exploited stock:whiting (Merlangius merlangus L.) in the Irish Sea. Journal of Sea Research 49: 69–82.

Gislason, H., Daan, N., Rice, J. C. and Pope, J. G. (2010) Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries 11: https://doi.org/10.1111/j.1467-2979.2009.00350.x

Goodyear, C. P. (1990) Spawning stock biomass per recruit: the biological basis for a fisheries management tool. ICCAT Col. Vol. Sci. Pap., Vol. XXXII (2): 487-497.

Goodyear, C. P. (1993) Spawning stock biomass per recruit in fisheries management: foundation and current use. p. 67-81. In S. J. Smith, J. J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

ICES (2017a) Report of the Working Group on Celtic Seas Ecoregion (WGCSE). ICES WGCSE REPORT 2017. ICES CM 2017/ACOM:13

DRAFT

ICES (2017b) Report of the Herring Assessment Working Group for the Area South of 62 deg N (HAWG). ICES HAWG REPORT 2017. ICES CM 2017/ACOM:07

ICES (2018) Report of the Joint EIFAAC/ICES/GFCM Working Group on Eels (WGEEL), 5–12 September 2018, Gdańsk, Poland. ICES CM 2018/ACOM:15. 152 pp.

Jennings, S., Reynolds, J. D. and Mills, S. C.(1998) Life history correlates of responses to fisheries exploitation. Proc. R. Soc. London B 265:333-339.

Lochet, A., Maury-Bachet, R., Poirier, C., Tomas, J., Lahaye, M., Aprahamian, M. and Rochard, E. (2008) Mercury contamination and life history traits of Allis shad *Alosa alosa* (Linnaeus, 1758) and Twaite shad *Alosa fallax* (Lacepede, 1803) in the Gironde estuary (South West France). Hydrobiologia 602: 99-109.

Maitland, P.S. (2003) Ecology of the river, brook and sea lamprey. Conserving Natura 2000 Rivers Ecology Series No. 5. English Nature, Peterborough.

Maitland, P. S. and Hatton-Ellis, T. W. (2003) Ecology of the Allis and Twaite Shad. Conserving Natura 2000 Rivers Ecology Series No. 3. English Nature, Peterborough.

Maitland, P. S. and Lyle, A. A. (2005) Ecology of Allis Shad Alosa alosa and Twaite Shad Alosa fallax in the Solway Firth, Scotland. Hydrobiologia 534: 205-221.

Pereira, T. G., Batista, I., Bandarra, N. M., Ferreira, J., Fradinho, N. and Afonso, F. (2013) Chemical composition and nutritional value of raw and fried allis shad (*Alosa alosa*). International Journal of Food Science and Technology 48: 1303-1308.

Peterson, I. and Wroblewski, J. S. (1984) Mortality rate of fishes in the pelagic ecosystem. Canadian Journal of Fisheries and Aquatic Science 41:1117-1120.

Ryland, J. S. and Ajayi, T. O. (1984) Growth and population dynamics of three Raja species (Batoidei) in Carmarthen Bay, British Isles. ICES Journal of Marine Science 41: 111–120.

Thorpe, R. B., LeQuesne, W. J. F., Luxford, F., Collie, J. S. and Jennings, S. (2014) Evaluation and management implications of uncertainty in a multispecies size-structured model of population and community responses to fishing. Methods in Ecology and Ecolution 6: https://doi.org/10.1111/2041-210X.12292

Turnpenny, A.W.H. (1988) Fish impingement at estuarine power stations and its significance to commercial fishing. J. Fish Biol. **33** (Supplement A), 103-110.

Turnpenny, A. W. H. & Henderson, P. A. 1992 Sizewell: Reappraisal of fish impingement at the 'A' Station, and implications of multiple plant operation: Fawley.

Whittamore, J. M. and McCarthy, I. D. (2005) The population biology of the thornback ray, Raja clavata in Caernarfon Bay, north Wales. Journal of the Marine Biological Association of the United Kingdom 85: 1089-1094.

WHO (World Health Organization), 1990. Environmental health criteria, 101. Methylmercury. WHO/ICPS, Geneva.

DRAFT

DRAFT

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	***

DRAFT

* 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.

DRAFT

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

DRAFT

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.

DRAFT

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**

DRAFT

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

DRAFT

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

DRAFT

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

DRAFT

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

DRAFT

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.

DRAFT

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)

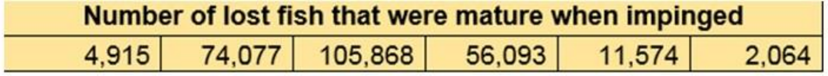
DRAFT

	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	For each age group this is: ∑(no. in each size class * length))/(no. fish in age group)]
Natural mortality	0.80	0.57	0.34	0.29	0.28	0.26	0.24	For each age group this is: ∑(no. in each size class * M of that size class))/(no. fish in age group)]
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
of which, this number reach maturity		66739	52839	20058	3377	269		
			59257	22495	1178	2175		
				40174	6764	148		Number of fish that were immature in Year A that would have survived to Year A+5 and matured this year
					9483	757		Number of fish that were immature in Year A that would have survived to Year A+4 and matured this year
						926		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

DRAFT

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:

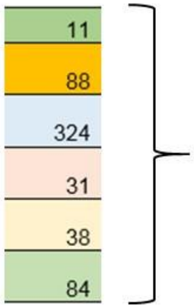


Number of lost fish that were mature when impinged					
4,915	74,077	105,868	56,093	11,574	2,064

Total = 254,590

From Step 6:

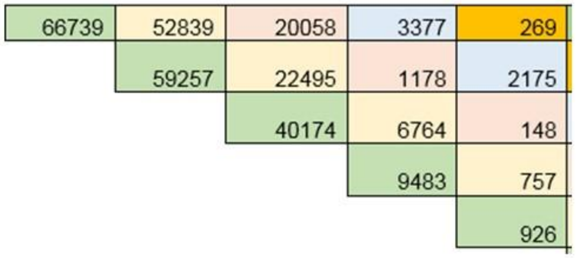
No. that would have survived to Age 6



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

DRAFT

	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	For each age class this is: ∑(no. in each size class * M of that size class))/(no. fish in Age Group)]
		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

DRAFT

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.

DRAFT

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

DRAFT

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**

DRAFT

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	992	45,035	110,424	77,725	18,493			252,670
								1,164,689

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	992	45,035	110,424	77,725	18,493			252,670
FSP of Year A fish	446	25,469	78,597	58,159				162,670
								1,327,359

DRAFT

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	992	45,035	110,424	77,725	18,493			252,670
FSP of Year A+1 fish	446	25,469	78,597	58,159				162,670
FSP of Year A fish	200	14,403	55,943					70,546
								1,397,905

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	992	45,035	110,424	77,725	18,493			252,670
FSP of Year A+2 fish	446	25,469	78,597	58,159				162,670
FSP of Year A+1 fish	200	14,403	55,943					70,546
FSP of Year A fish	90	8,145						8,235
								1,406,141

DRAFT

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	992	45,035	110,424	77,725	18,493			252,670
FSP of Year A+3 fish	446	25,469	78,597	58,159				162,670
FSP of Year A+2 fish	200	14,403	55,943					70,546
FSP of Year A+1 fish	90	8,145						8,235
FSP of Year A fish	40							40
								1,406,181

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	992	45,035	110,424	77,725	18,493			252,670
FSP of Year A+4 fish	446	25,469	78,597	58,159				162,670
FSP of Year A+3 fish	200	14,403	55,943					70,546
FSP of Year A+2 fish	90	8,145						8,235
FSP of Year A+1 fish	40							40
FSP of Year A fish								0
								1,406,181

DRAFT

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	992	45,035	110,424	77,725	18,493			252,670
FSP of Year A+5 fish	446	25,469	78,597	58,159				162,670
FSP of Year A+4 fish	200	14,403	55,943					70,546
FSP of Year A+3 fish	90	8,145						8,235
FSP of Year A+2 fish	40							40
FSP of Year A+1 fish								0
FSP of Year A fish								0
								1,406,181

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.

DRAFT

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) = 1,406,181

Spawner Production Foregone EAV = 1.41

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

DRAFT

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	
	843,444	67,553,019	298,145,773	272,037,142	73,973,100		
	378,984	38,202,951	212,211,313	203,555,482			
	170,288	21,604,740	151,045,715				
	76,515	12,218,030					
	34,381						
Total reproductive output	7,558,335	470,253,161	1,668,785,288	1,325,019,329	301,351,784	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	1,538	3,340	7,656	9,545	9,308	7,970	4,750

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

- (1,538 + 3,340 +7,656 + 9,545 + 9,308 + 7,970 + 4,750) / 7 **= 6,301 eggs**

DRAFT

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	1,538	3,340	7,656	9,545	9,308	7,970	4,750
(Average no. eggs deposited per fish maturing at age) / (overall average lifetime fecundity)	0.24	0.53	1.22	1.51	1.48	1.26	0.75

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	1,538	3,340	7,656	9,545	9,308	7,970	4,750	
(Average no. eggs deposited per fish maturing at age) / (overall average lifetime fecundity)	0.24	0.53	1.22	1.51	1.48	1.26	0.75	**Total**
Value of each Age Class	1,200	74,633	264,849	210,291	47,827	8,019	433	607,252

DRAFT

Step 13

The sum of the values of each Age Class (607,252), divided by the number of fish impinged (1,000,000) gives:

Lifetime Fecundity Value Factor = 0.61

DRAFT