The Sizewell C Project

9.67 Quantifying Uncertainty in Entrapment Predictions for Sizewell C

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Executive Summary

SZC Co, plans to build a new coastal nuclear power station (Sizewell C, SZC), adjacent to the operational Sizewell B (SZB) and decommissioned Sizewell A (SZA) sites in Suffolk. The station would be of a once-through design, abstracting large volumes of seawater for cooling the condenser steam. Fish and other biota may become drawn into the station in the abstracted cooling water. SZC has been designed with a suite of mitigation measures designed to reduce environmental impacts of abstraction and discharge of cooling water. Embedded mitigation measures to reduce impingement of fish and invertebrates at SZC include the installation of low velocity side entry (LVSE) intake heads and dedicated fish recovery and return (FRR) systems, coupled with a chlorination strategy that would prevent impinged biota being exposed to anti-fouling chemicals.

The FRR system incorporates filtration systems including drum and band screens, that are designed to protect the condensers and other essential cooling water systems from blockage. Fish large enough to be impinged by the mesh would be returned to the marine environment via the FRR outfalls. Smaller life-history stages including eggs, larvae and juvenile fish of some species may be susceptible to entrainment, whereby they pass through the mesh and thus through the stations cooling water system to be discharged at the outfalls.

As part of the Development Consent Order (DCO) application for the operation of the new station, the effects of water abstraction on fish have been evaluated. As different life-history stages of fishes may be impinged or entrained, total losses consider both pathways and are termed entrapment. The majority of fish entrapped are expected to be juvenile stages. To determine the potential for population level effects due to entrapment of these predominantly juvenile life history stages, losses of these fish in terms of equivalent adults has been apportioned by applying an equivalent adult value (EAV). These equivalent adult losses, expressed as an annual rate, can then be contextualised against an appropriate population comparison such as population size, spawning stock biomass (SSB) or fisheries landings relative to thresholds for population sustainability.

For marine fishes it is well established that populations can sustain annual losses of 10-20% or more of population size above natural mortality. For commercially exploited species, a 1% threshold for annual losses relative to population size has been applied in the Sizewell C assessments because this represents a value considerably lower than that known to be sustainable. For unexploited species, a threshold of 10% has been applied.

The assessment of impacts provided as part of the DCO Application includes assessment of entrapment impacts with and without mitigation measures. However, statutory stakeholders have questioned the assumptions regarding the effectiveness of mitigation measures and the sensitivity of the assessment to uncertainties. This paper considers the population level effects of entrapment and quantifies the sensitivity of the predicted impacts to uncertainty in the operational performance of the proposed fish mitigation measures. Further, by applying bootstrapping approaches the analyses incorporate the confidence intervals in impingement predictions and the variance in the baseline population that losses are compared with. This allows estimates of the mean and 95th percentile effects (1 in 20-year event) to be established.

The proposed LVSE intake heads is considered to provide some advantages over the current SZB intake head design in terms of reductions in fish entrapment per cumec of seawater abstracted but estimates of the effectiveness of the LVSE heads have not been agreed. Acknowledging that the effectiveness of the LVSE intake heads is not certain, the sensitivity analyses in this report assume no benefit of the LVSE heads beyond the SZB design.

The FRR system is designed to return robust species that are impinged onto the drum and band screens safely back to sea. As part of the Hinkley Point C Inquiry[1], the Environment Agency provided a technical report (Technical Brief: TB008 Fish Recovery and Return System Mortality Rates) to "*set a FRR mortality rate for each species and a range around the FRR mortality rate for each species. The range set accounts*

[1] The Hinkley Point C Water Discharge Activity (WDA) Appeal Inquiry on the Permit Variation Application Relating to Acoustic Fish Deterrent heard evidence during a 9-day hearing from 8th - 24th June 2021. Evidence included the effectiveness of mitigation measures including the FRR system.

for the uncertainty in the underlying evidence used to set the FRR mortality rate, and in the efficiency of the bespoke FRR system proposed for Hinkley Point C (HPC)." The Sizewell C project will replicate the design of HPC as much as possible. However, the reduced tidal range at Sizewell compared with Hinkley Point allows several design changes to incorporate site-specific improvements over the HPC design meaning the SZC FRR should afford higher survival rates for impinged fishes. The Environment Agency FRR mortality ranges have therefore been applied to SZC to provide a conservative estimate for the perceived uncertainty in the FRR efficiency.

The results of the uncertainty analysis show that for all species, effects are below the thresholds that would trigger further investigation for potential population level effects. The three most commonly impinged species at Sizewell are sprat, herring and whiting, whilst sand gobies are the most commonly entrained species. The mean annual entrapment effect for sprat is <0.03% of the SSB (upper 95^{th} percentile 0.04%), for herring entrapment is predicted to result in losses of 0.01% of SSB (upper 95^{th} percentile 0.02%), and for whiting mean losses are 0.08% of SSB (upper 95^{th} percentile 0.11%). Such losses are not significant at the population level.

Sea bass and sand gobies are the only species where entrapment exceeds the 1% threshold.

The mean annual losses of sea bass are 0.99% of SSB with an upper 95^{th} percentile estimate of 1.88%. Sea bass are not uniformly distributed with low catch rates observed in surveys offshore and 95% of bass caught in-shore of the Sizewell-Dunwich Bank suggesting that impingement predictions scaled-up from SZB may overestimate sea bass impingement at SZC. However, to provide the highest degree of confidence in the assessment a full International Council for Exploration of the Sea (ICES) stock assessment is being prepared for sea bass incorporating entrapment mortality as an additional mortality term.

The mean annual loss of sand gobies is 1.03% with an upper 95^{th} percentile estimate of 1.41%. Sand gobies are a short lived, fast maturing, highly fecund species with high degrees of natural variability. Because sand gobies are productive species with a short lifespan and early age of maturity, and because they are not fished, they will be able to sustain additional mortality rates greater than 10% of population size. The predicted level of losses of sand gobies is not regarded as significant at the population level.

Overall, this report provides further evidence that the proposed development of Sizewell C would not have significant effects on the population sustainability of any of the key species assessed.

1 Introduction

SZC Co. plans to build a new coastal nuclear power station (Sizewell C, SZC), adjacent to the operational Sizewell B (SZB) and decommissioned Sizewell A (SZA) sites in Suffolk. The station would be of a once-through design, abstracting large volumes of seawater for cooling the condenser steam. Fish and other biota may become drawn into the station in the abstracted cooling water. Biota large enough to be impinged on the 10x10mm fine mesh filtration systems (drum and/or band screens), that are designed to protect the condensers and other essential cooling water systems from blockage, would be returned to the marine environment via the fish recovery and return (FRR) system. Smaller life-history stages including eggs, larvae and juvenile fish of some species may be susceptible to entrainment, whereby they pass through the fine filtrations systems and passage through the stations cooling water system to be discharged at the outfalls.

As part of the Development Consent Order (DCO) application for the operation of the new station, the effects of water abstraction on fish populations have been evaluated. As different life-history stages of fishes may be exposed to either impingement or entrainment, total losses include both components which is herein termed entrapment. The basis for predictions of impingement by SZC is data collected at the operational SZB station. Impingement monitoring at that station consisted of a total of 205 sample visits in the period February 2009 to March 2013, and April 2014 to October 2017 (BEEMS Technical Report TR406.v7 [AS-238]). Entrainment predictions are derived from fish and invertebrate samples from the SZB forebay, taken on 40 occasions between May 2010 and May 2011 (BEEMS Technical Report TR318 [APP-324]). Due to the extremely high natural mortality rates of the very early life-history stages of fish, impingement rather than entrainment represents the primary route of impact for most fish species at the population level.

To determine the effects of entrapment of fish, two assessment approaches have been considered:

1. **Population level effects:** Annual losses due to entrapment are compared with the size of the relevant population to determine the potential for entrapment to have significant effects on population sustainability. This is to say that the rates and timing of increases and decreases in spawning population size, with and without the additional effects of SZC entrapment, would be almost indistinguishable.

2. **Local level effects:** Assessments consider the potential for the station to cause localised depletion in fish numbers at the scale of the Sizewell Bay. Local depletion assessments are independent but complement the assessment of population level effects and are used to assess the potential for food-web effects mediated through local reductions in prey availability.

This paper considers population level effects and the sensitivity of the predicted impacts to uncertainty in the assessment parameters. Local depletion is considered in detail in BEEMS Scientific Position Paper SPP103 (Rev 5), which will be provided at Deadline 6 responding to Deadline 2 comments from the **RSPB/Suffolk Wildlife Trust** [REP2-505] and **Natural England** [REP2-153].

SZC has been designed with a suite of cooling water mitigation measures designed to reduce environmental impacts of abstraction and discharge of cooling water, summarised in the **Marine Ecology and Fisheries Environmental Statement** (starting at **22.5.15** [APP-317]). Embedded mitigation measures proposed for SZC are the primary means to reduce impingement of fish and invertebrates and include the installation of low velocity side entry (LVSE) intake heads and dedicated fish recovery and return (FRR) systems coupled with a chlorination strategy that would prevent impinged biota being exposed to anti-fouling chemicals. A report provided as a **Supplementary Submission** at Deadline 5 [REP5-123], explained the fish protection measures proposed for SZC and, in particular, why an Acoustic Fish Deterrent (AFD) system is not part of the suite of mitigation measures.

Impingement predictions in the DCO submissions were structured to show the effects of no mitigation, the individual effect of each mitigation measure, and the effects of the mitigation measures in combination. This approach provided a full illustration of the consequences of different components of the mitigation and their predicted implications.

The Marine Management Organisation (MMO) in its **Written Representation** at Deadline 2 [REP2-140] indicated at paragraph 3.2.6:

> *"The assessment makes assumptions about the effectiveness of the LVSE system and FRR system. There is a lack of good evidence to support these assumptions and thus the scale of benefit is uncertain, however, the MMO understands that there isn't any further work that can sensibly be done to reduce this uncertainty*".

It is noteworthy that the MMO goes on to state at paragraph 3.2.7 [REP2-140]:

> *"Notwithstanding these uncertainties, the entrapment estimates indicate that even in the absence of LVSE and FRR mitigation measures, only 4 species exceed the 1% threshold: bass, for which density adjustment substantially reduces assessment of impact; sand goby, for which mortality rate >1% Spawning Stock Biomass (SSB) is not a concern at population level; thin-lipped mullet, for which value is an artefact of the low level of landings and absence of SSB; and eel, for which the applied Equivalent Adult Value (EAV) of 1 is unrealistically high, and is a species most likely to benefit from the FRR. On this basis, the MMO consider there is a good level of confidence that actual impacts to all fish species will not be significant. Therefore, the MMO support the conclusions of the ES."*

The aim of this report is to determine the sensitivity of entrapment assessments on fish populations to uncertainties in the operational performance of the proposed fish mitigation measures. The sensitivity analysis also accounts for the natural fluctuations of fish stocks as observed during impingement monitoring between 2009 and 2017 and the confidence intervals for the impingement predictions. The upper and lower estimates of entrainment rates for key species with life-history stages subject to entrainment were also factored into the quantitative analyses.

Predicted values of FRR mortality applied in the impingement assessments reported in the DCO (in **BEEMS Technical Report TR406.v7** [AS-238]), were based on Environment Agency (2005) values, modified for passage through the SZC trash racks, band screens and drum screens by applying species-specific morphometrics of the fish samples at Sizewell B. As part of the HPC WDA Appeal Inquiry[2], the Environment Agency produced a technical report (Technical Brief: TB008 Fish Recovery and Return System Mortality Rates). This report detailed a range of FRR survival rates for different species. Where data were available, this report considers the Environment Agency best case and worst-case values.

Acknowledging that the effectiveness of the LVSE intake heads is not certain, the sensitivity analyses in this report assume no benefit of the LVSE heads. Impingement per cubic metre of water (cumec) extracted is therefore assumed to be the same as for SZB.

The assumed range of fish entrapment rates (both impingement and entrainment), together with uncertainty in FRR survival, was bootstrapped to predict the range of fish numbers that would be lost annually by SZC. The resulting distributions of mortalities were summarised by taking the mean, median, 5th and 95th percentile of the 5000 calculated values.

Most fish entrapped at SZC will be juveniles. High natural mortality of the young age classes impinged means that most of the impinged fishes would not survive to contribute to the adult spawning population even if they were not impinged. To determine the impact of losses of these fish from the adult population the losses are converted into equivalent adults (that is, the number of those juveniles impinged that would normally be expected to survive to maturity taking into account predation, disease etc). Equivalent adult value (EAV) factors are used to convert an annual rate of loss due to impingement of predominantly juvenile fish into an annual rate of loss of fish that would mature and join the spawning population.

The annual EAV losses are considered against relevant population comparators. Comparators might be fish numbers in the population or spawning stock biomass (SSB). Where direct population comparators are not available, losses are contextualised relative to commercial catches (landings). Variance in the population

[2] The Hinkley Point C Water Discharge Activity (WDA) Appeal Inquiry on the Permit Variation Application Relating to Acoustic Fish Deterrent heard evidence during a 9-day hearing from 8th - 24th June 2021. Evidence included the effectiveness of mitigation measures including the FRR system.

comparator was considered from the mean value and standard error using bootstrapping of 5,000 iterations and assuming a normal distribution. From the 5000 bootstrap iterations, drawing on all the uncertainty variables, a mean, median, lower 5th percentile and upper 95th percentile population impact on the population was calculated.

This approach quantifies uncertainty in the entrapment predictions for the following parameters:

- Upper and lower rate of entrainment.
- Upper and lower rate of impingement.
- Effects of LVSE mitigation, a worst-case of zero benefit has been applied.
- Effectiveness of the FRR system (by applying a range of values proposed by the Environment Agency for the similar, albeit more complicated[3], FRR design at HPC (TB008)).
- Baseline population comparator.

[3] The Hinkley Point C FRR system has an additional 'handling' element due to an Archimedes' screw which carries the fish to a sufficient elevation to drain back to see under gravity, as well as a longer route of return to sea.

2 Methodology of estimation of uncertainty

2.1 Sources of uncertainty

This section considers the uncertainty associated with each parameter used in the assessment of entrapment. Further, it considers the potential for unquantifiable uncertainties to influence the entrapment predictions.

2.1.1 Variability in impingement predictions.

Fish abundance and distribution is heterogeneous in space and time and many species show highly seasonal patterns of impingement. Impingement monitoring at SZB was designed in a pseudo-random fashion to eliminate tidal biases whilst sampling the full year to capture seasonal patterns. Samples consisted of six 1-hour samples during the day and an overnight bulk sample, thus providing a 24-hour impingement record. A total of 205 site visits were undertaken in the 8 years from 2009-2012, and 2014-2017.

Impingement monitoring methodologies at SZB and the statistical methodology for bootstrapping the 8 years of seasonal data to estimate an annual mean impingement prediction with 95% confidence intervals for SZB is detailed in **BEEMS Technical Report TR339** [AS-238]. Impingement estimates from SZB are scaled up to the greater flow rates to predict impingement rates at SZC following approaches detailed in **BEEMS Technical Report TR406.v7** [AS-238]. Impingement predictions for SZC provide a mean value along with upper and lower 95% confidence intervals.

Following comments from the Environment Agency during consultation on the WDA environmental permit, revised impingement estimated for SZB and SZC were estimated. The changes are detailed in BEEMS Scientific Position Paper SPP111.v2. The refinements in the impingement predictions resulted in minor changes in the absolute impingement numbers that were well within the confidence intervals of the **Environmental Statement** [APP-317] and had no bearing on the original conclusions. For full transparency, changes in the absolute numbers, along with a table comparing the latest figures with the DCO figures was provided in BEEMS Scientific Position Paper SPP111.v2 and summarised and submitted to the Examining Authority separately in response to Examining Authority Questions BIO.1.242 and BIO.1.243 (see **Appendix 7L** of [REP2-110]).

The uncertainty analyses apply the upper and lower confidence intervals of annual impingement. A normal distribution was fitted to the data in the uncertainty analysis and bootstrapping methods draw from the range covering 95% of the data. The unmitigated annual impingement rates along with confidence intervals for each of the key species at SZC are provided in Table 1.

Table 1. Mean and 95% confidence intervals of predicted annual unmitigated impingement at SZC. Numbers are not adjusted for equivalent adult values (EAV).

Common name	**Sizewell C Unmitigated Impingement numbers (SPP111.v2 and [REP2-110])**		
	Mean	Lower	Upper
Sprat	6,153,906	3,173,989	10,415,898
Herring	2,211,750	1,310,172	3,352,700
Whiting	1,495,192	1,095,717	1,954,416
European sea bass	641,398	296,862	1,113,750
Sand gobies	483,487	205,548	916,287
Dover sole	211,083	146,474	290,806
European anchovy	148,332	43,495	356,894
Dab	128,476	76,309	214,481
Thin-lipped grey mullet	107,602	33,386	207,685
Flounder	32,149	24,367	42,211

Common name	Sizewell C Unmitigated Impingement numbers (SPP111.v2 and [REP2-110])		
	Mean	Lower	Upper
Cucumber smelt (UK EA)	22,165	13,867	32,370
European plaice	21,956	14,135	32,723
Atlantic cod	16,505	5,716	30,807
Thornback ray	6,700	4,172	9,833
Twaite shad - Elbe mean	2,693	1,340	4,691
Twaite shad - Scheldt	2,693	1,340	4,691
River lamprey	2,607	1,430	4,393
European eel	2,463	1,530	3,628
Horse-mackerel	1,560	488	1,560
Mackerel	277	14	277
Tope	55	0	55
Sea Trout	8	0	8
Sea lamprey	4	0	4
Allis shad	0	0	0

2.1.1.1 Potential for diurnal bias

Impingement monitoring personnel cannot remain on the nuclear facility site outside normal working hours due to site security restrictions. Restricted site access at operational nuclear power stations means it is not possible to collect hourly samples nor monitor the collection of overnight bulk samples, and overnight bulk samples may overflow when the sample net becomes clogged.

In summer months, overflow typically arises due to large numbers of ctenophores clogging the nets. Overflows may also result due to ingress of weed and/or mud, or in the winter months due to inundation with pelagic species, primarily sprat and herring, and demersal whiting. A bulk sample is considered invalid if water overflows the top of the trash bins, as this could potentially result in underestimates of impingement. All bulk samples that may have overflowed were removed from the impingement record. The causes of overflow, and changes in the rate of overflow through time, were detailed in BEEMS Scientific Position Paper SPP111.v2.

When bulk samples are considered to be invalid, the six hourly samples are extrapolated to estimate 24-h impingement. Of the 205 impingement samples collected seasonally over 8 years, there were a total of 100 valid bulk samples. As such, there are 105 occasions where the daytime hourly samples were extrapolated to establish a 24-hour estimate of impingement. The incidence and seasonality of invalid samples are tabulated in BEEMS Scientific Position Paper SPP111.v2.

Depending on the species-specific diurnal behaviour there is the potential that the greater number of daily samples could over- or underestimate impingement. To investigate the potential for any diurnal bias to propagate into the impingement predictions, further analyses were reported in **BEEMS Technical Report TR339: Appendix F** [AS-238]. A total of 22 sampling visits with full 6 hourly samples and a valid bulk sample in the period 2014 – 2017 were analysed to determine if there were differences in the hourly impingement rates between the daytime hourly and overnight bulk samples. The species investigated included herring *Clupea harengus*, sea bass *Dicentrarchus labrax*, cucumber smelt *Osmerus eperlanus* and sand gobies *Pomatoschistus spp*. The results showed a high degree of variability but no significant difference between hourly and bulk impingement rates and no consistent sampling bias between the hourly and bulk samples. Thus, it was concluded that there was no significant misrepresentation of impingement rates as a result of any sampling bias (**BEEMS Technical Report TR339: Appendix F** [AS-238]).

The **Environment Agency** [REP2-135] suggest that, by only including valid bulk samples, the analyses in **BEEMS Technical Report TR339** [AS-238]. did not consider periods of maximum abundance when diurnal behaviour may be different. The Environment Agency point to data collected from SZA that indicate greater impingement rates during periods of darkness (Turnpenny, 1988). Periods of darkness occur during the period when bulk samples were collected at SZB, but the actual period of darkness varies throughout the year.

The study at SZA demonstrated that fish impingement on the drum screens was highly dependent on tidal activity and peaked on the mid-ebb and mid-flood tides when the velocity became maximal (Turnpenny, 1988; Environment Agency, 2005). Furthermore, fish entrapment rates are highly seasonal in most species, particularly in herring and sprat that represent nearly 70% of the annual impingement (BEEMS Scientific Position Paper SPP111.v2; Table 1). It is not clear from Turnpenny (1988) what the underlying factors driving the observed night-time increase in impingement rates at SZA are, and to what degree the data were influenced by seasonal sporadic impingement events of shoaling species such as herring and sprat.

The design and inshore location of SZA intakes and the species impinged needs to be considered when drawing comparisons to SZB. In the Environment Agency 'Screening for intake and outfalls: a best practice guide' report (2005), they point to the "*considerable progress was made and continues to be made"* by the power industry in relation to improving intake technologies to reduce fish catches. Specifically in relation to SZA and B, the report describes design changes to reduce fish impingement by:

- reduction of intake velocities;
- fitting a velocity cap to the intake to eliminate vertical flow components;
- elimination of any intake superstructure (which tend to act as artificial reefs that attract fish);
- location of the intakes further offshore where juvenile densities are lower;
- installation of a fish return system.

Following comments from the Environment Agency during consultation on the Sizewell C WDA environmental permit application, and concerns relating to the incidence of bulk samples, all the bulk samples were reviewed, and 18 samples removed where there was an indication that overflowing may have occurred (resulting in 100 bulk samples from 118). Analyses of the effects of removing and including these additional samples was provided in BEEMS Scientific Position Paper SPP111.v2. The difference in predicted annual impingement numbers at SZC following the removal of the 18 bulk samples was very minor and bi-directional i.e. some species saw minor increases whilst others had minor decreases. The mean change was a 0.7% increase for the eight species contributing to the top 95% of impingement. The only key species where impingement rates changed more than 2.5% in either direction was cucumber smelt, with an 8.4% increase in predicted impingement following the removal of the 18 bulks.

There are two plausible hypotheses to explain the increase in smelt impingement following the removal of overflowing bulks:

a) Assuming smelt are equally susceptible to impingement throughout the day, the removal of the additional bulks could simply represent the fact that smelt were underestimated in the overflowing bulk samples previously used in the analyses. Removing these samples thereby increases impingement predictions. This explanation seems unlikely given the modest and bi-directional changes in other species.

b) Smelt are impinged in greater numbers during the day, thus the removal of bulk samples and extrapolation of raised hourly samples to determine 24-hour estimates, increases impingement predictions.

No significant differences in mean smelt impingement rates between hourly and bulk samples were observed in the analyses described in **BEEMS Technical Report TR339** [AS-238], however, maximum impingement did occur during daylight hours. There is no evidence of smelt movements in the sea that helps to assess whether impingement records from hourly and bulk samples are displaying an unexpected pattern. Some information on diurnal patterns of distribution is available for fresh and brackish waters, but results are not consistent. In one shallow freshwater lake in the Netherlands, smelt were found in the upper parts of the water column by day and tended to disperse to deeper water at night (Gastauer *et al.,* 2013). In an entirely freshwater Finnish lake the reverse was seen whereby smelt migrated from deeper areas in the day to the surface at night (Horppila *et al.,* 2000). In freshwater and estuaries smelt are more active and migrate at night, but it is not known if this is also true in the sea (Moore, 2016; Moore *et al.,* 2016). In inshore waters of the Baltic Sea (depths ~ 15-20 m) smelt was found to feed in the water column and on the same food as herring (Mustamäki *et al*., 2016). Herring and sprat in the Baltic Sea disperse during the night at the surface and aggregate during the day at the bottom; it is possible smelt follow a similar behavioural pattern as herring and sprat do, following their prey (Cardinale *et al.,* 2003; Nilsson *et al.,* 2003). On the evidence available, there is no indication that the impingement records underestimate smelt. Conversely, if smelt are more susceptible to impingement during daylight hours the impingement predictions may overestimate impingement adding a degree of precaution to the assessment.

The Environment Agency also raised concerns relating to the potential for higher rates of impingement of eel at night, and that impingement estimates may be underestimated due to the greater proportion of daily samples. During their main spawning migration over deeper water, silver eels exhibit diel vertical migrations, moving from deeper water during the day into shallower water at night (Righton *et al.,* 2016). Tracking of yellow and silver eels in the southern North Sea show that selective tidal stream transport was used day and night when it occurred. Some evidence of the use of shallower water by silver eels during the night exists, but during the study one yellow eel was in shallower water during the day (McCleave and Arnold, 1999). Other studies have shown midwater movements by night and low levels of movement on the seabed by day (Westerberg, 1979; Westerberg *et al.,* 2007). In a Baltic study, most silver eel swimming at night was within just 1m of the water surface (Westerberg *et al.,* 2007). Use of the seabed by day in the early stages of silver eel migration may be a predator avoidance strategy (Lennox *et al.,* 2018). It is feasible that a greater proportion of daylight samples may result in an underestimate of impingement of yellow eels at SZB. However, the assessment of eel losses is precautionary in that it all impinged yellow eels have been given a theoretical maximum EAV for a semelparous (breeds once in a lifetime) species of 1, despite no adult silver eels having been impinged.

The most commonly impinged species at SZB are sprat and herring, accounting for 69% of impingement by numbers. In offshore waters with depths > 40m herring undertake diurnal vertical migrations, moving closer to the sea surface at night, which is linked to the changing distribution of their prey (Munk *et al.,* 1989; Heath *et al.,* 1991; Huse and Korneliussen, 2000; Beare *et al.,* 2009). Herring also tend to school more tightly by day and to disperse at dusk (Cardinale *et al.,* 2003; Nilsson *et al.,* 2003). Since the capacity for vertical migration is constrained in shallow waters, an element of offshore movement at night and/or less marked day to night changes in abundance in the upper few metres of the water column are expected than would be observed offshore. In shallow (10m) and turbid waters of Zeeschelde, with low transparency as might be expected at intake heads of SZC (~15m), there was no statistical difference between day and night herring catches, and both day and night juvenile herring were aggregated in the upper water layer without diel migrations (Maes *et al.,* 1999). The mean recorded numbers of impinged herring per hour was more than twice as high by day than by night, and that maximum numbers recorded per hour were more than ten times higher by day than by night (**BEEMS Technical Report TR339**, [see **Appendix F** AS-238]). However, the mean differences were not statistically significant, owing to high variance in impingement rates associated with shoaling species. The removal of 18 bulk samples from the SZB impingement monitoring resulted in a minor decrease in herring impingement predictions of 1.3%, indicating that the removed bulk samples had, on average, very subtly more herring (BEEMS Scientific Position Paper SPP111.v2). In the deeper waters of SZC it is likely that (per volume) herring impingement at night would be lower than at SZB. It is unlikely that impingement sampling significantly underestimates pelagic herring sampling due to diurnal samples biases. This is because the impingement predictions are driven to a greater degree by the incidence of sporadic high impingement rates (Figure 1). Such variability in impingement rates, influences the confidence intervals (Table 1) in impingement predictions and is thus incorporated into the uncertainty analyses.

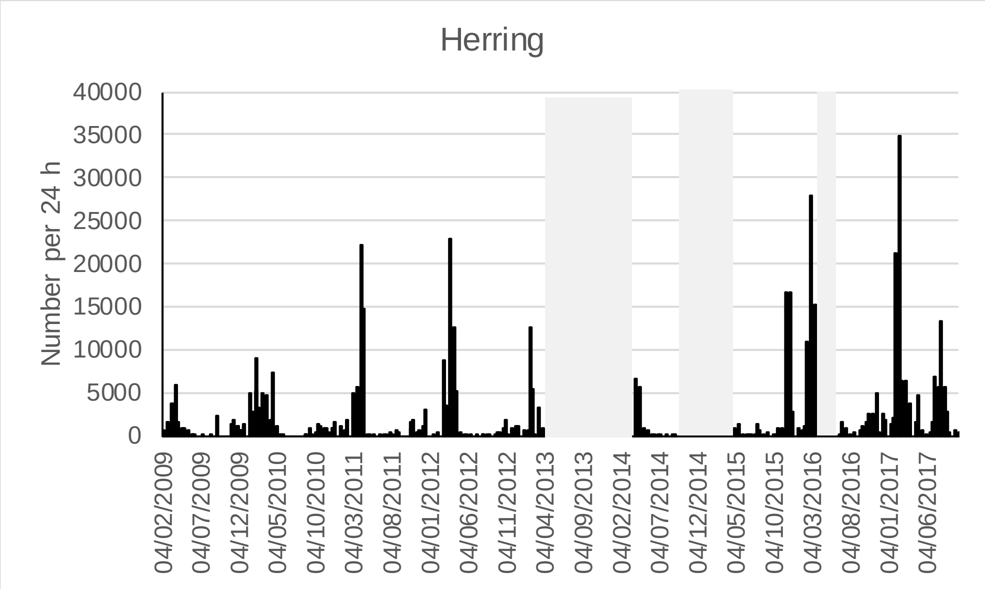

Figure 1 Observed number of herring impinged per 24 hour period at Sizewell B (from TR339 [AS-238]).

In the case of sea bass, adults using offshore areas are known to spend the day in deeper water and ascend at night, but this behaviour is not so pronounced or consistent inshore and in the summer months (Quayle *et al.,* 2009; de Pontual *et al.,* 2019). Experimental (tank) studies have indicated that sea bass occupy the surface layer at night and swim deeper in the water column during the day (Schurmann *et al.,* 1989). Limited data from tracking with acoustic tags during periods of summer inshore residency in Ireland show sea bass are most active at dawn and dusk (O'Neill, 2017). Another study for juvenile sea bass showed that detection probabilities varied among estuaries, with more daytime detections in one location and more night-time detections in another. The effects were relatively small, however (changes less than 20%) (Stamp, 2021). The evidence from studies of sea bass ecology do not provide any counter evidence to the impingement records from hourly and bulk samples presented in **BEEMS Technical Report TR339** [see **Appendix F** AS-238]. These impingement records show that both the mean recorded numbers and the maximum numbers of impinged sea bass recorded per hour were marginally lower in the bulk (predominantly night-time) samples, than in the hourly (exclusively daytime) samples, and that these differences were not significant (**BEEMS Technical Report TR339** [see **Appendix F** AS-238]). A minor increase in sea bass impingement predictions (1.5%) was also observed when bulk samples were removed (BEEMS Scientific Position Paper SPP111.v2). Literature evidence and impingement data therefore points to the fact that impingement predictions may, if anything, marginally overestimate sea bass impingement due to a higher incidence of daily samples.

In conclusion, any diurnal bias resulting from a higher proportion of day-time samples than predominantly night-time bulk samples would be species-specific and bi-directional. Therefore, the sampling would not introduce a consistent bias. Given that there were 100 valid bulk samples, and that bulk samples have a greater weighting when present, any species-specific diurnal bias is not predicted to significantly alter the results. Diurnal bias is not considered further in the uncertainty analysis.

2.1.2 Ranges in entrainment prediction

Entrainment primarily impacts the early life-history stages of fish including eggs, larvae and post-larvae and, for some species, juvenile stages. The occurrence of these early life-history stages is highly seasonal and is directly related to the timing of spawning events. Between May 2010 and May 2011, 3-4 samples per month were collected.

Entrained fishes are typically in the early stages of the life cycle with very low EAV. Gobies are an exception, with all life stages susceptible to entrainment. The earlier the life stage and the lower the EAV, the smaller the impact of a given rate of entrapment mortality on the population. The vast majority of early life stages would not survive if they had not been entrained. For example, egg mortality rates in pelagic spawners (e.g. herring, anchovy, mackerel, horse mackerel, plaice) is between 70-97%, with a total survival from eggs to juvenile stages being <0.1% (Dahlberg, 1979).

Entrainment mimic unit (EMU) studies provide estimates of the survival of entrained sea bass and Dover sole eggs as well as survival of a range of invertebrates (**BEEMS Technical Report TR318** [APP-324]). EMU studies have also demonstrated high survival rates of entrained glass eels. Where specific entrainment survival data are available it has been applied (Table 2), in all other instances mortality of early stages has been assumed to be 100%. This is considered precautionary as studies at other power plants has demonstrated variable but higher survival. Observed survival rates as low as 3-5% have been reported in anchovy, whereas 59-97% survival has been shown in striped bass (ecological and morphological analogue of sea bass). Survival rates of entrained larvae of different blennies and gobies at Calver Cliffs Nuclear Power Plant ranged from 37 to 97% (Mayhew *et al.,* 2000). Whilst entrainment effects are minor for most species, assuming 100% mortality ensures our analyses are conservative.

The range of entrainment predictions is provided in Table 2. The numbers presented herein represent the number of equivalent adults summed from the egg, larval and juvenile stages of the key species entrained and the range represents the variability in natural egg mortality rates (full details are provided in **BEEMS Technical Report TR318 [**APP-324]). In the **ES** [APP-317], entrapment estimates were based on the upper EAV numbers (Table 2). The uncertainty analysis in this report are also based on the range of EAV numbers. For all species except sand gobies, entrainment losses converted to EAV represent a small proportion of impingement losses (see Section 2.1.3).

Table 2. Range in annual equivalent adults predicted to be entrained at SZC for the key species entrained during monitoring at SZB. Numbers of eggs, larvae and juveniles that are entrained annually have been converted to equivalent adult values (EAV) numbers. Numbers included predicted entrainment survival for life stages with data available from entrainment mimic unit (EMU) studies. Where no data is available, 100% mortality is assumed.

Common name	Entrainment survival (TR318)	Entrainment EAV numbers (TR318) or weight in kg of equivalent silver eels (SPP104)	
		Lower	Upper
Sprat	0% precautionarily assumed.	45,790	199,715
Herring	0% precautionarily assumed.	2,399	23,992
Whiting	0% precautionarily assumed.	0	0
European sea bass	40% survival of eggs based on EMU studies.	36	36
Sand gobies	0% precautionarily assumed.	1,155,406	2,892,198
Dover sole	20% survival of eggs based on EMU studies. 0% precautionarily assumed of other stages.	592	631
European anchovy	0% precautionarily assumed.	2,869	2,869
Dab	0% precautionarily assumed.	21,810	21,810
European eel (glass eel converted to silver eel biomass)	80% survival of glass eels based on EMU studies.	5.6kg	18.9kg

2.1.3 Equivalent adult value (EAV)

Equivalent adult value (EAV) factors are used to convert an annual rate of loss due to impingement of predominantly juvenile fish into an annual rate of loss of fish that are maturing and joining the spawning population. High natural mortality of the young age classes impinged means that most of the impinged fishes would not survive to contribute to the adult spawning population in the absence of the station. The Cefas EAV method involves a forward projection of annual impingement mortalities, accounting for natural mortality, to give an equivalent annual rate of loss of mature fish. It is a straightforward adjustment to reflect the likelihood of impinged fish reaching maturity and contributing to the spawning population.

EAV factors are multiplied by numbers of impinged fish to estimate the number of equivalent adults that are lost (the EAV number) or multiplied by numbers of impinged fish and the individual body weight of mature fish in the population to give an EAV biomass. EAV numbers and biomass are expressed as annual rates.

Estimates of annual EAV numbers or biomass as a proportion of spawning population size can be used to assess if the annual rate of impingement mortality pose a risk to the population sustainability relative to pre-defined thresholds (see Section 2.2). An advantage of the EAV method is that it is not so data-demanding as more complex methods of population assessment (e.g. stock assessment). This advantage allows it to be applied to many species to screen for risks, as done by Cefas when assessing the effects of impingement.

During correspondence with SZC Co. regarding the scope of sensitivity analyses (23/07/2021), the Environment Agency requested that impingement predictions be updated to include repeat spawning, applying an extension proposed by the Environment Agency termed “Spawning Production Foregone” (SPF). The Environment Agency also requested the underlying parameters used in the EAV calculations be checked to ensure they are suitably precautionary and apply the latest information. Whilst Cefas has checked the underlying parameters used in the EAV calculations, the SPF factor has not been calculated as this measure does not estimate an annual rate of loss from the spawning population and therefore cannot be assessed against the population comparator. The concerns with the SPF method are briefly considered below and are detailed in a Technical Note prepared for issue at Deadline 6 (Doc Ref 9.63; Appendix F).

2.1.3.1 Is the EAV approach precautionary

Cefas EAV factors are calculated for each species based on the length distributions on the fish in the impingement record. Age at length keys are used to determine the ages of impinged fishes. Species maturity at age and age specific natural mortality rates from the literature are applied to determine the number of fish that would have been expected to survive to first maturity, had they not been impinged.

Fishing mortality has not been included when calculating the EAV. This means EAV numbers for first time spawners are overestimated, as in most species fishing mortality is recorded before the age of maturity in directed fisheries and as bycatch. By assuming no fishing mortality before maturity, the EAV assessment overestimates the chance of survival to maturity and is therefore precautionary, particularly for species such as cod, whiting and sea bass.

In repeat spawning fish populations that are subject to sustainable rates of additional mortality, the year in which a year-class of fish matures and recruits to the spawning population is not the year in which the egg production of the year-class is greatest. This is because the fecundity of fishes increases rapidly with size, thus age. But, at the age of first maturity there will be more fish present in any given year-class than at any subsequent age, because mortality will occur after first maturity. This means that an estimate of the number of entrapped equivalent adults (EAV number) that would have reached the age at first maturity will be greater than the number that would have reached any subsequent age. Thus, when an EAV number at the age of first maturity is expressed as a percentage of spawning population numbers it provides a conservative estimate of impact. This is because every fish contributing to the EAV number has a value of one, which is the same as the value of one that is given to older, larger and more fecund fish in the spawning population.

An EAV number may be compared to a population number (as is the case for twaite shad where losses are compared to an estimated population number from a given river system, Table 5).

In most cases, the EAV number is converted into an EAV biomass for comparison with the Spawning Stock Biomass (SSB), by multiplying the EAV number of first-time spawners by the mean adult fish weight from the spawning population. The individual weight at the age at first maturity will be lower than the individual weight of older and more fecund fish in the spawning population. Multiplying lost numbers at the age of first maturity by mean individual biomass in the spawning population will upweight losses of spawners due to entrapment and their effective contribution to the spawning population biomass. This results in a precautionary rate of EAV biomass loss as a percentage of spawning population biomass for repeat spawning species.

For species where there are very low numbers recorded in impingement samples or there are insufficient biological data to determine an EAV, a precautionary EAV of 1 has been assumed. Notably, this assumption was made for Twaite shad, river lamprey and European eel. This assumes all fish of these species would contribute to the spawning population. EAV values and comments on the degree of precaution assumed are provided in Table 3.

Cefas has reviewed the EAV input parameters and is satisfied they account for the latest evidence on species maturation and age specific mortality. Cefas recognises that the Environment Agency concern may pertain to whiting, for which recent ICES evidence indicated a lower age at first maturation in the south-western stock. However, the south-western whiting stock is separate from the North Sea stock and the maturation data applied to calculate EAV correctly applied the average values for the period of observed impingement. Maturation data are updated by the ICES Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK) every year, the years 2009-2017 remain unchanged.

EAVs used in this sensitivity analysis are consistent with those applied in the **Environmental Statement** [APP-317] and detailed in **BEEMS Technical Report TR406.v7** [AS-238] and are provided in **Table 3.**

Table 3. Equivalent adult values.

Common name	EAV	Comment
Sprat	0.751	
Herring	0.715	
Whiting	0.356	
European sea bass	0.224	
Sand gobies	1.000	
Dover sole	0.213	
European anchovy	0.974	
Dab	0.445	
Thin-lipped grey mullet	0.083	
Flounder	0.462	
Smelt (cucumber)	0.761	
European plaice	0.345	
Atlantic cod	0.359	
Thornback ray	0.193	
Twaite shad	1.000	The assessment is precautionary as 46% of impinged fish are between 1- and 3-year-olds with very low maturity rates at this age range (<1%). Up to 76% of fish in the impingement record may not have reached maturation.
River lamprey	1.000	River lamprey metamorphose into adults at a length of 90-120mm and at around 130mm they migrate to the sea (Maitland, 2003). 14.0% in the impingement record are below 130mm, some as small as 6.5-9.5mm have been recorded which may be washouts from river systems. River lamprey are semelparous (breed once then die) therefore an EAV of 1 represents the theoretical maximum value.
European eel	1.000	No silver eels (adults) have been impinged at Sizewell. The yellow eel stages would continue to mature in coastal waters before migrating to the Sargasso Sea to spawn. Eel are semelparous therefore an EAV of 1 represents the theoretical maximum value.
Horse-mackerel	1.000	Negligible impingement.
Mackerel	1.000	Negligible impingement.
Tope	1.000	Low impingement numbers.
Sea Trout	1.000	Single impingement record.

Common name	EAV	Comment
Sea lamprey	1.000	Negligible impingement. Sea lamprey are semelparous therefore an EAV of 1 represents the theoretical maximum value.
Allis shad	1.000	Single impingement record.

2.1.3.2 Spawning Production Foregone (SPF)

The SPF extension attempts to build upon the EAV by adding the probability of repeat spawning whereby a fish may spawn more than once over a number of years. By adopting this approach, the assessment necessarily estimates a multiannual rate of impingement losses and not an annual one. Such an approach would necessarily give inflated estimates of annual loss and annual loss as a percentage of spawning population size. This is because it would involve projecting and summing the future numbers of mature fish over several years (a multi-annual rate of loss) rather than estimating it for a single year.

Critically, rates that compile losses of spawning fish over several years and report these as a percentage of spawning population size cannot be related to the thresholds for an annual rate of loss (such as annual rates of fishing mortality that are known to be sustainable), because the rates would be multiannual. Accounting for repeat spawning would, in effect, generate a crude estimate of accumulated numbers of missing fish over many years.

A second important issue with the application of the SPF extension is the need to deal with fishing mortality. The Cefas EAV approach is already precautionary in that is assumes no mortality of the juvenile stages. To extend this assumption to the adult stages introduces over-precaution. For example, sustainable fishing mortality reference values vary in well studied commercial fish species between 19% for sea bass to 36% for plaice above natural mortality for the stocks of relevance to Sizewell (**Table 10** in **BEEMS Technical Report TR406.v7** [AS-238]). In their **Relevant Representations** [RR-0744], the MMO raise this point regarding the appropriate application of EAV approaches, acknowledging that both methods are precautionary but that *"care needs to be taken to avoid an over-precautionary approach"*. In their review of the EAV approaches, the MMO conclude [RR-0744]:

> *"The MMO consider the core method [Cefas EAV method] is the better in that the end-point age is more likely to be reflective of reality in the context of currently fished seas, and because the MMO consider the extension method, while very precautionary, has conceptual challenges for EAV>1[4] and problems for comparing to SSB. The MMO is comfortable that all due efforts have been made to secure data at an appropriate scale."*

Cefas is confident in the precautionary nature of EAV-based risk assessment and maintain that the SPF method proposed by the Environment Agency is not fit for purpose because it does not estimate an annual rate of loss from the spawning population. Rather than being a precautionary measure accounting for repeat spawning, SPF introduces further uncertainty and cannot directly be compared with estimates of annual rates of mortality that are known to be sustained (e.g., annual rates of fishing mortality). The SPF is therefore not considered further in this report.

If annual rates of EAV biomass were to exceed pre-defined thresholds for population sustainability, further detailed analyses or understanding of the species biology may be undertaken. A powerful analytical tool available for data rich species is to run a full ICES stock assessment whereby annual impingement from the station can be added as a source of mortality of the stock over multiple years to determine if the long-term impact of the station could affect population trends. Such data demanding approaches are not available for many of the species assessed at Sizewell and are restricted to data rich, typically commercially exploited species.

[4] For many of the conservation species, and those impinged in low numbers a precautionarily EAV of 1 has been applied (Table 3).

To provide the highest level of confidence available in the assessment of no significant effects, Cefas will undertake a full ICES stock assessment for sea bass based on precautionary assumptions which will be provided at Deadline 8. Sea bass was selected for the stock assessment on the basis that it is a data rich species with a well-established stock model available. Sea bass is the 4th most impinged species at Sizewell B and has been subject of stakeholder concerns pertaining to the stock area. Furthermore, when the distribution of the species within the Greater Sizewell Bay is not accounted for it is also the species with the highest predicted effect percentage due to Sizewell C (see below).

2.1.4 Uncertainty in the performance of the LVSE mitigation

The LVSE intakes are designed to minimise impingement[5] by:

1. Reducing vertical velocities, which fish are ill equipped to resist, by means of velocity caps on the intakes.

2. Limiting the intercept area of the intake surfaces to the tidal stream and in so doing reduce the risk of impingement for fish swimming with the tidal stream i.e. to reduce the cross-sectional area of the intake to the prevailing tidal directions by mounting the head parallel with the tidal flow.

3. Reducing intake velocities into the head to a target velocity of 0.3m/s over as much of the length of the intake surface as possible to maximise the possibility of most fish avoiding abstraction.

Statutory consultees have questioned the effectiveness of the LVSE in the absence of an AFD. In its response to **Examining Authority question Bio.1.245** [REP2-140] the MMO state that

> *"It is recognised that the LVSE design has been put forward by the Environment Agency as a mitigation measure for cooling water abstractions (in its good practice guidance), although this tends to be accompanied by Acoustic Fish Deterrent (AFD) systems (which are not currently proposed for SZC). While it is feasible that the LVSE design, on its own, will provide some benefit in terms of reductions in fish impingement, even if the benefit was zero, the MMO does not believe this would not materially change the conclusions of the overall fish entrapment assessment."*

In acknowledgement of the lack of certainty in the current assessment of the effectiveness of the LVSE heads, the sensitivity analyses in this report assume no benefit of the LVSE. Impingement per cumec is therefore assumed to be no different than the current SZB head which, unlike SZC, which has a velocity cap but is not LVSE by design. A value of 1.0 has been applied in the sensitivity assessment (Table 4).

2.1.5 Uncertainty in the performance of the FRR mitigation

The fish recovery and return (FRR) system is designed to return robust species (particularly flatfish, eels, lampreys and crustacea, and to a lesser extent demersal species such as bass, cod and whiting) that are impinged onto the station drum and band screens safely back to sea. The FRR system has been designed and, following intensive design scrutiny, has received regulatory approval for HPC.

The predicted values of FRR mortality applied in the impingement assessments at DCO were based on Environment Agency guidance for species specific survival through FRR systems, modified for the SZC specific trash racks, band screens and drum screens. A description of the approach is provided in **BEEMS Technical Report TR406.v7** [AS-238]. Table 4 shows the predicted FRR mortality for each of the key species.

In Technical Brief: TB008 Fish Recovery and Return System Mortality Rates) the Environment Agency states "*The Technical Brief recommends a method to set a FRR mortality rate for each species and a range around the FRR mortality rate for each species. The range set accounts for the uncertainty in the underlying evidence used to set the FRR mortality rate, and in the efficiency of the bespoke FRR system proposed for Hinkley Point C (HPC).*"

[5] Small life-history stages typically entrained are not predicted to benefit significantly from the head design due to reduce swimming capabilities.

Sizewell C will replicate the design of Hinkley Point C as much as possible. However, the reduced tidal range at Sizewell compared with Hinkley allows several design changes that are improvements over the HPC design:

a) The reduced tidal range means that the drum screens can be smaller – the diameter will be 4m less than at Hinkley Point C which means that the rotation time (and time that fish and biota will be in the bucket will be shorter than at Hinkley Point C);

b) Due to the reduced tidal range, and the elevations of buildings on the power station platform, the debris recovery building is at a suitable elevation to drain back to sea under gravity directly from its floor. At Hinkley Point C due to the large tidal range the material needs to be elevated to platform level by use of an Archimedes screw – which introduces an additional element of "fish handling" (i.e., manipulation) within the FRR. An Archimedes screw is not required at Sizewell.

c) The reduced tidal range and lack of the need for an Archimedes screw, allows each UKEPR unit to have its own, dedicated FRR tunnel to return fish to sea from the debris recovery building which is more direct and therefore reduces transit time for fish through the system.

Furthermore, at Hinkley Point C the trash rack would be fitted with 50mm spacing, whereas a 75mm spaced trash rack would be fitted at SZC. This increase in trash rack size reduces the impediment of the largest size fish (with the highest EAVs).

In summary, the FRR system at Sizewell C is predicted to have greater efficiency than that at Hinkley Point C. Therefore, for this sensitivity analysis, it is considered appropriately precautionary to apply the Environment Agency (TB008) Hinkley Point C FRR uncertainty ranges.

The Environment Agency best and worst case values from TB008 have been used in the sensitivity analysis. Where worst-case ranges are lower than the FRR efficiency applied by in **BEEMS Technical Report TR406.v7 [**AS-238], the higher values are used. The uncertainty analysis is completed twice, once with the FRR efficiency fixed to the values applied in **BEEMS Technical Report TR406.v7** [AS-238] in the 'impingement assessment' and once with the Environment Agency TB008 range in the 'entrapment assessment'. The bootstrapping approach for the entrapment assessment draws from the FRR range assuming a normal distribution (Table 4).

Table 4. Mitigation parameters applied in uncertainty analyses. Where the predicted FRR efficiency is greater than the Environment Agency worst case, the FRR efficiency value from **BEEMS Technical Report TR406.v7** [AS-238] is applied as the worst-case. Sensitivity analyses apply the FRR efficiency (impingement assessment) and TB008 best and worst-case range (entrapment assessment).

Common name	**LVSE**	**FRR efficiency (TR406.v7 [AS-238])**	**FRR mitigation range applied in uncertainty analysis based on Environment Agency HPC values (TB008)**		
			TB008 predicted	**Realistic best case**	**Realistic worst case**
Sprat	1.000	1.000	1.000	0.950	1.000
Herring	1.000	1.000	1.000	0.900	1.000
Whiting	1.000	0.551	0.552	0.410	1.000
European sea bass	1.000	0.551	0.608	0.300	0.950
Sand gobies	1.000	0.206	0.200	NA	NA
Dover sole	1.000	0.206	0.200	0.050	0.206+
European anchovy	1.000	1.000	NA*	*0.900*	*1.000*
Dab	1.000	0.535	NA*	*0.206*	*0.535*
Thin-lipped grey mullet	1.000	0.551	NA	NA	NA
Flounder	1.000	0.231	0.200	0.050	0.231
Smelt (cucumber)	1.000	1.000	NA*	*0.900*	*1.000*
European plaice	1.000	0.206	0.200	0.020	0.206+
Atlantic cod	1.000	0.553	0.563	0.180	0.560
Thornback ray	1.000	0.206	0.545	*0.206*‡	0.550
Twaite shad	1.000	1.000	1.000	0.960	1.000
River lamprey	1.000	0.206	0.200	0.110	0.206+
European eel	1.000	0.206	0.200	0.110	0.206+
Horse-mackerel	1.000	1.000	NA*	*0.900*	*1.000*
Mackerel	1.000	1.000	NA*	*0.900*	*1.000*
Tope	1.000	0.206	NA	NA	NA
Sea Trout	1.000	1.000	1.000	NA	NA
Sea lamprey	1.000	0.206	0.407	NA	NA
Allis shad	1.000	1.000	1.000	NA	NA

* Where there is no FRR information of the species from the Environment Agency TB008 report a range has been applied for similar species groups, ranges are shown in italics. + Where the TB008 values are lower than those predicted in TR406 Rev 7, the TR406 values are applied. The lower value for best case FRR efficiency applies the TR406 Rev 7 predicted value rather than the Environment Agency TB008 reported value of 0.41, this is a result of the larger trash rack spacing between HPC and SZC.

2.1.6 Interannual variability in the population comparators

Rates of entrapment of fish at Sizewell are influenced by the abundance of fish of different life stages in the coastal waters. Recruitment drives the abundance of larvae and juvenile fish at Sizewell and the distribution of age classes which may be entrapped. Many juveniles inhabit inshore nursery areas. Older fish occur in the Greater Sizewell Bay during seasonal migrations. Most of the fishes impinged at SZB are juveniles. To assess the risks posed by the annual losses of these fish an EAV number or biomass, as described in Section 2.1.3, is compared to the relevant population comparator (Table 5). The stock unit comparators and justification for their application is described in greater detail in (**BEEMS Scientific Position Paper SPP103 (Rev 5)** [Doc Ref. 6.14A]).

To account for interannual variability in abundance, impingement monitoring was conducted for eight years and an annual mean and confidence interval for impingement rates was estimated. Entrapment predictions were compared to the mean population comparator during the impingement monitoring period (2009-2017), whether it be SSB, landings or a population estimate.

To account for the interannual variability in the population comparator, the sensitivity assessment accounts for the variance in the population comparator over the years of the impingement monitoring. From the 5000 bootstrap iterations drawing on all the variables a mean, median, lower 5th percentile and upper 95th percentile population impact on the population can be calculated.

2.2 Statistical treatment

The uncertainty analyses were computed twice, once focusing on the ‘uncertainty in impingement predictions’ where the FRR mitigation values were fixed to those applied in **BEEMS Technical Report TR406.v7** [AS-238]. This first run only considered the uncertainty in the impingement predictions and population comparators and provided a direct comparison to the DCO assessments in the **Environmental Statement** with the latest results reported in **Appendix 7L** [REP2-110]. The second analysis ‘uncertainty in entrapment predictions’ included the full suite of parameters:

- Upper and lower rate of entrainment.
- Rates of impingement.
- Effects of LVSE mitigation, a worst-case of zero benefit has been applied.
- Effectiveness of the FRR systems (by applying a range of values proposed by the Environment Agency for the similar FRR design at HPC (TB008)).
- Baseline population comparator.

The resulting distributions of impingement and entrapment were summarised by taking the mean, median, 5th and 95th percentile of the 5000 calculated values. This analysis was carried out in the software R v4.0.2 (R Core Team, 2020) using the packages readxl (v1.3.1) for reading in the input file and dplyr (v1.0.0) for data handling. The detailed calculation steps are shown below.

The comparators to be used in the assessment of impact might be population numbers or biomass (e.g. SSB or catch /landings.

Respectively, scaled impinged numbers (N_{SZC}) or biomass at SZC (B_{SZC}) were calculated from impinged numbers at SZB (N_{SZB}) as:

$N_{SZC} = N_{SZB} \times 2.326 \times 1 \times EAV$,

where 2.326 is SZB to SZC scaling factor, 1 is the LVSE scaling factor, and EAV is Equivalent Adult Value factor. N_{SZC} is subsequently expressed as a proportion of population numbers.

$B_{SZC} = N_{SZB} \times 2.326 \times 1 \times EAV \times W/1000$,

where 2.326 is SZB to SZC scaling factor, 1 is the LVSE scaling factor, EAV is Equivalent Adult Value factor, W is the mean weight of a mature fish in kg. B_{SZC} is subsequently expressed as a proportion of biomass in tonnes.

To include uncertainty in entrainment, iterations were drawn from a uniform distribution between the lower and upper values of the range of estimated entrained EAV numbers (Table 2), or weight in the case of eels. If the population comparator was expressed in weight (SSB or catch), entrainment numbers were multiplied by weight of a mature individual. Entrainment losses were added to the impingement losses described above to provide a total entrapment number or weight.

Uncertainty in entrapment accounted for the total uncertainty in impingement and entrainment. Uncertainty of the comparators was assessed from their mean values and standard errors assuming normal distributions. For each of the 5000 iterations, a separate value of the comparator was generated from the normal distribution. For comparators without annual values (e.g. river lamprey), and for European anchovy that had highly variable landings, the mean was taken as a fixed value and applied to each iteration (Table 5.). In each case, the annual entrapment rate as a percentage of the population comparator was then calculated.

From the resulting 5000 estimates of % effect, the average (mean and median), lower (5th percentile), and upper (95th percentile) % effect values were calculated.

2.3 The threshold for effects

To have a negligible impact on the dynamics of a fish population, any predicted annual mortality rate must be considerably less than the rate of mortality that would prevent it from replacing itself on a year-to-year basis. For species where there are limited data available, other than those with very low rates of productivity, annual mortality rates of 10%-20% of SSB are considered sustainable in international fisheries management practice. Sustainable fishing mortality reference values, using precautionary approaches, vary in well studied commercial fish species between 19% for sea bass to 36% for plaice above natural mortality for the stock of relevance to Sizewell. The coefficient of variation of the SSB in species fished around Sizewell (e.g. herring, bass, whiting and others) is estimated by ICES to be 12-58% (**Table 10** in **BEEMS Technical Report TR406.v7** [AS-238]).

Given these relatively high rates of mortality are known to be sustainable, a precautionary threshold of 1% annual mortality as a proportion of population size has been adopted to assess the risks posed by entrapment. It is important to note that this is not a threshold for changes in spawning population size attributed to impingement. It is a threshold linked to annual rates of mortality which are deemed to be sustainable. The threshold is justified on the basis that it relates to losses of spawning fish that are an order of magnitude lower than those observed to be sustained by fished populations.

For non-exploited stocks, a 1% threshold is highly precautionary based on fish population dynamics and any observed variation or trend in stock numbers would therefore be due to other factors other than SZC impingement. This is to say that the rates and timing of increases and decreases in spawning population size, with and without the additional effects of SZC entrapment, would be almost indistinguishable.

Table 5. Stock comparators and interannual variability between 2009-2017 used in uncertainty analyses. The stock areas are described in **BEEMS Technical Report TR406.v7** [AS-238] and further justification is provided in BEEMS Scientific Position Paper SPP103 (Rev 5).

Common name	Comparator	Biomass (t) or <u>numbers</u>									
		2009	2010	2011	2012	2013	2014	2015	2016	2017	Mean
Sprat	SSB (t)	184,795	185,165	164226	132,853	107,152	216,858	346,972	222,571	175,080	**192,852**
Herring	SSB (t)	2,043,590	2,164,870	2,583,390	2,746,510	2,517,680	2,450,220	2,275,330	2,684,890	2,331,180	**2,421,962**
Whiting	SSB (t)	130,622	154,317	142,719	147,948	139,669	132,966	141,379	148,121	156,088	**143,759**
European sea bass	SSB (t)	18,451	18,252	16,815	15,582	13,877	11,333	12,085	10,173	9,395	**13,996**
Sand gobies	Population numbers	NA	NA	NA	NA	NA	NA	NA	NA	NA	**<u>205,882,353</u>**
Dover sole	SSB (t)	30,520	29,091	26,402	28,880	32,536	28,413	27,390	33,144	30,612	**29,665**
European anchovy	Landings (t)	1,045	1,205	633	842	207	1,042	8,954	1,041	13,039	**3,112**
Dab	Landings (t)	6,561	7,240	6,824	6,095	5,214	4,344	3,595	4,070	2,751	**5,188**
Thin-lipped grey mullet	Estimated SSB (t) based on landings	650.2	739.5	722.1	712.4	584.7	593.6	416.4	378.3	271.7	**563.2**
Flounder	Landings (t)	3,088	3,365	3,193	2,310	1,876	2,067	1,913	1,739	1,262	**2,313**
Cucumber smelt (UK EA)	Estimated SSB (t) based on landings	NA	NA	20.2	70.4	88.9	69.1	60.4	60.3	8.1	**53.9**
European plaice	SSB (t)	643,553	792,570	824,392	874,478	990,616	1,148,875	1,069,940	1,147,047	1,213,531	**967,222**
Atlantic cod	SSB (t)	16,460	16,333	12,178	11,004	8,591	10,552	10,302	8,539	6,156	**11,124**
Thornback ray	Landings (t)	532.0	490.8	624.8	661.9	752.7	744.0	663.9	717.6	905.0	**677.0**
Twaite shad - Elbe mean	Population estimate	<u>12,946,294</u>	<u>1,659,773</u>	<u>385,132</u>	<u>52,052</u>	<u>117,650</u>	<u>270,258</u>	<u>8,475,065</u>	<u>17,128,995</u>	<u>5,081,855</u>	**<u>5,124,119</u>**
Twaite shad - Scheldt	Population estimate	NA	NA	NA	<u>66,385</u>	<u>8,904</u>	<u>30,300</u>	<u>29,281</u>	<u>198,705</u>	<u>NA</u>	**<u>66,715</u>**
River lamprey	RDB (t)	NA	NA	NA	NA	NA	NA	NA	NA	NA	**62**
European eel	Landings (t)	NA	NA	87.9	88.1	94.6	61.8	71.6	67.8	NA	**78.6**

Common name	Comparator	Biomass (t) or <u>numbers</u>									
		2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Mean**
Horse-mackerel	Landings (t)	44,533	24,046	27,619	21,023	18,628	13,370	9,354	12,186	13,344	**20,456**
Mackerel	Landings (t)	3,230,003	3,579,017	4,063,019	3,730,890	4,123,080	5,161,009	5,148,898	4,884,807	4,747,484	**4,296,467**
Tope	Landings (t)	649.9	564.4	511.5	466.1	483.3	462.4	500.8	453.7	460.2	**505.8**
Sea Trout	Population numbers	NA	NA	NA	NA	NA	NA	NA	NA	NA	**<u>39,795</u>**
Sea lamprey	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**NA**
Allis shad	Estimated adult numbers migrating upriver	NA	NA	NA	NA	NA	NA	NA	NA	NA	**<u>27,397</u>**

3 Results & Discussion

3.1 Uncertainty in impingement predictions

The uncertainty analysis was run initially with impingement data and predicted FRR mitigation values as applied in **BEEMS Technical Report TR406.v7** [AS-238] (**Table 4**). Permutations accounted for variation in the predictions of impingement and in the relevant population comparator over the impingement monitoring period. The results can therefore be compared to those in the DCO assessments in the Environmental Statement with the latest results reported in **Table 5** of **Appendix 7L** [REP2-110]. The simulation also allows the performance of the uncertainty analyses to be understood prior to the full entrapment run.

For the key species at Sizewell, the mean impingement rates are below 1% of the relevant population comparators and corresponded to previous results. The exception is twaite shad where mean impingement rates are compared to the estimated Elbe and Scheldt populations as requested by Natural England, this is explored in more detail in Section 3.1.1.

Sprat and herring are the most frequently impinged species accounting for 69% of total annual impingement numbers. Losses at the population level due to impingement at SZC, assuming no benefit from the LVSE heads or FRR mitigation, are predicted to be 0.03% for sprat and 0.01% for herring. In both cases upper 95th percentile losses, representing a 1 in 20-year event, are less than 0.05% of the population. Whiting is the third most impinged species at SZB and impingement losses with the predicted level of FRR mortality equate to 0.06% of the population as a mean and 0.07% as an upper 95th percentile (Table 6).

The estimated annual losses of sea bass with the predicted level of FRR mortality is 0.87% of SSB with an upper 95th percentile estimate of 1.41% and a 5th percentile of 0.44% (Table 6). However, these figures do not account for any benefit afforded by the LVSE heads or the distribution of sea bass within the Greater Sizewell Bay. Sea bass are not uniformly distributed across the site with evidence suggesting juvenile sea bass are more abundant inshore and may be attracted to the warm water effluents of SZB in winter when the vast majority are impinged at SZB. Sea bass distribution surveys were completed off Sizewell in February 2016. Low catch rates were observed at all offshore survey stations with 95% of bass caught in-shore of the Sizewell-Dunwich Bank suggesting the inshore distribution of juvenile bass was a wider phenomenon on the Suffolk coast and not just related to the immediate area of the plume. This corresponds to the established behaviour of juvenile bass utilising inshore coastal waters, where other factors such as food availability and predation threat are likely to drive distribution. Therefore, the impacts of SZC based on scaled up impingement estimated from SZB are likely to substantially overestimate sea bass impingement (further details are provided in **BEEMS Technical Report TR406.v7** [AS-238]). On this basis, no significant effects on the dynamics of the population are predicted.

Smelt in the coastal waters around Sizewell and in Suffolk are considered to belong to a population associated with the Norfolk Broads and the estuarine and brackish waters around Great Yarmouth and Lowestoft (Maitland, 2003b). Comparative genomic analyses concluded that smelt from Sizewell and from the River Thames, Waveney, and Great Ouse are genetically homogeneous with no genetic structuring seen within the region (BEEMS Technical Report TR423). It is considered probable, but not yet proven, that the smelt impinged at SZB originate from a southern North Sea population and very large numbers have been observed in the River Elbe in Germany (BEEMS Scientific Position Paper SPP100). For the purposes of assessing impacts on smelt populations, an ‘Anglian’ smelt population SSB has been estimated based on Environment Agency landings data from the Anglian Region. The Environment Agency manages the licensing of smelt fisheries and a precautionary assumption is made that the regulated landings represent the maximum sustainable harvesting rate for the species of approximately 16% (**BEEMS Technical Report TR406.v7** [AS-238]). Given the restrictive licensing practices this is likely to be highly precautionary and underestimate the SSB. For the years with catch data the mean landings in the Anglian Region between 2009-2017 were 8.63t resulting in an SSB of 53.9t. Losses of the proposed SZC station with no mitigation benefits represent 0.52% as a mean and 0.87% at a 95th percentile. Such losses, relative to a precautionary estimate of SSB, will not have a significant effect on smelt population dynamics.

The latest ICES advice points to growing evidence that cod in the North Sea may form two separate populations: the northern ‘Viking’ population, and the southern ‘Dogger’ population. Impingement at Sizewell would cause losses of the Dogger population. The SSB of the two populations remains unresolved, therefore the comparator applied for determine losses of the Dogger population is based on precautionary landings estimates from areas within the Dogger cod range (further details are provided in BEEMS Scientific Position Paper SPP103 (Rev 5). Losses of cod relative to conservative landings estimates are 0.08% as a mean and 0.14% as a 95th percentile. Such low losses relative to fisheries landings would have no significant impacts on the population of cod (Table 6).

3.1.1 Twaite shad

In the case of twaite shad, losses have been compared relative the estimated population of two European rivers where twaite shad spawn. The Shadow Habitats Regulations Assessment (HRA) addendum [AS-178]. has scoped in European sites designated for twaite shad where the site is recorded as having breeding populations. These sites and the distances from Sizewell C are listed in BEEMS Scientific Position Paper SPP103 (Rev 5). Fish monitoring programmes in German and Belgian estuaries are undertaken to determine trends in fish populations. However, to the best of our knowledge, absolute population estimates are not available for the designated sites. In the absence of population estimates for the designated sites, Cefas estimated the twaite shad population of the Elbe and Scheldt based on data provided by European organisations. The population estimate methodology and limitations of the approach are described in BEEMS Scientific Position Paper SPP100 [AS-238]. Natural England and the Environment Agency comments on the methodologies and assumptions applied in the population estimate are acknowledged in BEEMS Scientific Position Paper SPP103 (Rev 5). It would not be proportional to attempt to determine the population estimates for all twelve additional designated sites screened into the HRA when data is not available, and the predicted impacts are very low.

Given the distance of the proposed development from the spawning rivers (hundreds of kilometres) and the fact the development is in an open coastal environment, it is highly unlikely all fish impinged at Sizewell would come from any given riverine system. However, such a scenario is considered for two European systems where the population estimates have been made: the Elbe, approximately 500km from SZC, and the Scheldt approximately 200km away. The justification behind apportioning all losses to a single river is examined in BEEMS Scientific Position Paper SPP103 (Rev 5).

In both cases the mean impingement effect is highly skewed by the variance in the estimated population size. This statistical artefact is exemplified by the fact that the mean of the population effect for the Elbe (0.89%) is greater than the 95th percentile population effect (0.18%). Therefore, in cases where there is large variance in the comparator, the median is a more reliable value and shows effects of 0.05% for the Elbe and approximately 4% for the Scheldt (Table 6).

In the case of the Scheldt, the average population size following recovery of a breeding population in 2012 was estimated at 66,715 fish between 2012 and 2017 (BEEMS Technical Report SPP100). If all the twaite shad predicted to be impinged by SZC were from the Scheldt alone, the losses would account for 4% of the estimated Scheldt population. Impingement monitoring at SZB has recorded twaite shad throughout the monitoring period (2009-2017), recovery in the Scheldt occurred in 2012 with no spawning adults recorded in 2011. Therefore, it is not possible that all the twaite shad impinged at Sizewell originate from this single river.

The number of twaite shad observed in the Scheldt Estuary varies greatly from year to year, both the number of migratory adults in the spring and the number of juveniles in summer and autumn. Adults are now found every year. Recruitment of juveniles was observed in 2012, 2015, 2017, 2018, 2019 and 2020 (INBO, 2021). This establishing population, which just began to reproduce every year, at least to some extent, is probably still largely dependent on the arrival of fish from elsewhere. It is likely that the Scheldt breeding population is becoming re-established from fish from surrounding systems such as the Elbe. It is acknowledged that it is not possible to determine exactly what river system the twaite shad impinged at Sizewell originate from. However, genetic information from North Sea twaite shad demonstrate mixing which is consistent with the assumption that the Weser and Scheldt population recoveries have been seeded from fish originating in the Elbe. The predicted scale of losses from SZC is therefore considered to have negligible impacts on the breeding populations of shad in European rivers.

Table 6. Uncertainty analysis for impingement with fixed predicted FRR rates for key fish species at SZC. Cells in green are below the initial 1% screening threshold. Cells in red indicate values in exceedance of the 1% threshold.

Common name	Impingement, FRR fixed (% of Comparator)				Comparator
	Lower 5%	Median	Mean	Upper 95%	
Sprat	0.014	0.024	0.025	0.041	SSB
Herring	0.008	0.012	0.012	0.018	SSB
Whiting	0.045	0.058	0.058	0.073	SSB
European sea bass	0.443	0.829	0.869	1.407	SSB
Sand gobies	0.023	0.046	0.048	0.082	Population estimate
Dover sole	0.005	0.007	0.007	0.009	SSB
European anchovy	0.033	0.082	0.096	0.209	Landings
Dab	0.015	0.023	0.024	0.038	Landings
Thin-lipped grey mullet	0.177	0.435	0.461	0.816	Estimated SSB
Flounder	0.009	0.012	0.012	0.016	Landings
Cucumber smelt (UK EA)	0.312	0.510	0.542	0.867	Estimated SSB
European plaice	<0.001	<0.001	<0.001	<0.001	SSB
Atlantic cod	0.033	0.074	0.078	0.135	Landings
Thornback ray	0.084	0.123	0.126	0.176	SSB
Twaite shad - Elbe	0.023	0.052	0.885*	0.179	Population estimate
Twaite shad - Scheldt	1.671	3.953	8.445*	25.01	Population estimate
River lamprey	0.041	0.065	0.069	0.106	Humber population
European eel	0.142	0.209	0.213	0.301	RDB
Horse-mackerel	0.000	0.001	0.001	0.002	Landings
Mackerel	<0.001	<0.001	<0.001	<0.001	SSB
Tope	0.000	0.013	0.016	0.049	Landings
Sea Trout	0.000	0.0000	0.020	0.080	Population estimate
Sea lamprey	NA	NA	NA	NA	NA
Allis shad	0.000	0.0000	0.0000	0.0000	Population estimate

* High mean values are a statistical artefact of extreme outputs generated due to the variance in the population estimate. In such a case the median is a more reliable comparator. In the case of the Scheldt, where population recovery only occurred in 2012, these estimates are not realistic worst-case as described in Section 3.1.1.

3.2 Uncertainty in Entrapment Predictions: Full analysis

The uncertainty in entrapment predictions presented in Table 7 provide a more comprehensive analysis of the effects of uncertainty including upper 95th percentile and lower 5th percentile estimates than was provided in the DCO assessments in the **Environmental Statement** [APP-317].

Sand gobies are the species most influenced by the addition of entrainment data in the overall entrapment assessment. This is because the vast majority of sand gobies are entrained rather than impinged (Table 2). As entrainment is the primary factor determining population level effects, FRR efficiency is less important for this species. The uncertainty analysis showed the mean annual entrapment is predicted to be 1% of the population estimate with a 95th percentile of 1.41% (Table 7). The 95th percentile is comparable with the DCO estimates which only considered the upper EAV numbers (the uncertainty analysis considers the range of entrainment values). Sand gobies are a short lived, fast maturing, highly fecund species with high degrees of natural variability. They are ubiquitous in European coastal areas to at least a depth of 20m. The species produces pelagic larvae which are dispersed by tidal currents resulting in a lack of genetic diversity over the southern North Sea (BEEMS Scientific Position Paper SPP103 (Rev 5)). The entrapment losses for sand gobies are considered precautionary as the small impingement fraction is assigned an EAV of 1 and 100% mortality is assumed for the entrainment fraction. Survival rates of entrained larvae of different blennies and gobies at Calver Cliffs Nuclear Power Plant ranged from 37 to 97% (Mayhew *et al.,* 2000). Because of the absence of a fishery, their short lifespan and early age of maturity, sand gobies have a sustainable harvesting rate of far greater than the precautionary 10% SSB threshold applied (Section 5.1.1 of **BEEMS Technical Report TR406.v7** [AS-238]). 10% thresholds for non-exploited species have previously been applied for major DCO projects. For example, the Thames Tideway Strategy Group comprising representatives from the Environment Agency, Port of London Authority, Thames Water and other stakeholders considered annual mortality rates of up to 10 % (due to hypoxia) to be sustainable for all species not subject to fishing mortality (further details are available in **Section 5.1.4** of **BEEMS Technical Report TR406.v7** [AS-238]). Therefore, the predicted level of losses of sand gobies is not regarded as significant at the population level.

Entrapment losses due to SZC remain relatively unchanged for sprat and herring following the addition of the entrapment values and FRR uncertainty ranges, with mean losses of 0.03% and 0.01% of SSB, respectively and upper 95th percentile losses below 0.05% (Table 7).

The addition of the FRR uncertainty ranges with upper estimates for survival below those predicted in the DCO assessments (**BEEMS Technical Report TR406.v7** [AS-238]) caused small increases in predicted losses for a number of species including whiting, sea bass, and thornback ray. The upper uncertainty range for the FRR mitigation results in no benefit (100% mortality) for impinged whiting and only 5% reductions in mortality for sea bass. In these cases, the upper impingement estimates reported in Table 7, represent a highly precautionary scenario with effectively no mitigation.

Whiting is subject to negligible entrainment, but the uncertainty analyses incorporate the Environment Agency ranges in FRR effectiveness from 59% survival as a best case to 0% survival as a worst-case (Table 4). The predicted losses of whiting increase from 0.06% of the population SSB as a mean (Table 6) to 0.08% of the SSB and 0.11% as an upper 95th percentile (Table 7). Despite the precautionary uncertainty assessment, the impact of the station is not significant at the population level.

The predicted mitigation efficiency for sea bass was 0.551 indicating approximately 45% survival. The Environment Agency uncertainty data for FRR mitigation ranges from 70% survival to just 5% survival (Table 4). The mean annual loss of sea bass in the uncertainty analysis is 0.99% of SSB with an upper 95th percentile estimate of 1.88% (Table 7). These figures do not account for the distribution of sea bass within the Greater Sizewell Bay and are likely to overestimate bass impingement at SZC (see Section 3.1). Whilst the effects of the station do not pose a risk to the sustainability of the population, a full ICES stock assessment has been completed for this species incorporating losses from the station as an additional mortality term. The assessment will be provided at Deadline 8 to provide the highest degree of confidence in the assessment. Sea bass was selected for the stock assessment on the basis that it is a data rich species with a well-established stock model available. Sea bass is the 4th most impinged species at Sizewell B and has been subject of stakeholder concerns pertaining to the stock area. Furthermore, when the distribution of the species within the Greater Sizewell Bay is not accounted for it is also the species with the highest predicted effect percentage due to Sizewell C.

For many species including European eel and river lamprey, and for the epi-benthic species such as dab, flounder, plaice and sole, the range in FRR mortality proposed by the Environment Agency in TB008 indicates that the FRR may be more effective than assumed by in the DCO assessments (**BEEMS Technical Report TR406.v7** [AS-238]). Consequently, for these species' estimates of annual entrapment losses were lower in the uncertainty analysis (Table 7).

Table 7. Full uncertainty analysis for entrapment of key fish species at SZC. Cells in green are below the initial 1% screening threshold. Cells in red indicate values in exceedance of the 1% threshold.

Common name	Entrapment, FRR range (% of Comparator)				Comparator
	Lower 5%	Median	Mean	Upper 95%	
Sprat	0.014	0.024	0.026	0.041	SSB
Herring	0.008	0.012	0.012	0.017	SSB
Whiting	0.044	0.073	0.075	0.111	SSB
European sea bass	0.391	0.904	0.987	1.871	SSB
Sand gobies	0.653	1.025	1.026	1.410	Population estimate
Dover sole	0.002	0.004	0.005	0.007	SSB
European anchovy	0.034	0.080	0.093	0.201	Landings
Dab	0.024	0.033	0.034	0.048	Landings
Thin-lipped grey mullet	0.177	0.435	0.461	0.816	Estimated SSB
Flounder	0.003	0.007	0.007	0.013	Landings
Cucumber smelt (UK EA)	0.296	0.484	0.514	0.824	Estimated SSB
European plaice	0.000	<0.001	<0.001	<0.001	SSB
Atlantic cod	0.018	0.047	0.052	0.103	Landings
Thornback ray	0.117	0.221	0.230	0.376	SSB
Twaite shad - Elbe	0.023	0.051	0.867*	0.175	Population estimate
Twaite shad - Scheldt	1.637	3.859	8.275*	24.362	Population estimate
River lamprey	0.028	0.050	0.052	0.087	Humber population
European eel	0.111	0.173	0.179	0.266	RDB
Horse-mackerel	<0.001	0.001	0.001	0.001	Landings
Mackerel	<0.001	<0.001	<0.001	<0.001	SSB
Tope	0.000	0.013	0.016	0.049	Landings
Sea Trout	0.000	<0.001	0.020	0.080	Population estimate
Sea lamprey	NA	NA	NA	NA	NA
Allis shad	0.000	0.0000	0.0000	0.0000	Population estimate

* High mean values are a statistical artefact of extreme outputs generated due to the variance in the population estimate. In such a case the median is a more reliable comparator. In the case of the Scheldt, where population recovery only occurred in 2012 these estimates are not realistic worst-case as described in Section 3.1.1.

3.3 In built precaution in the assessments

The uncertainty analysis has assumed no benefit from the LVSE head mitigation and considered a range of FRR effectiveness values produced by the Environment Agency for HPC (TB008).

With the exception of sea bass and goby, all the predicted effects of entrapment are well below the threshold considered to indicate any population level effects. Once the life-history biology of sand gobies and the distribution of sea bass in the Sizewell Bay relative to the proposed SZC intakes is accounted for, no significant effects on their population dynamics are predicted.

The uncertainty analysis has quantified the degree of uncertainty in the various input parameters. It is acknowledged that there remains a degree of uncertainty for other parameters, for example the potential for reduced sampling efficiency for juvenile stages too small to be impinged (Section 2.1.2) and the potential for diurnal bias arising from a greater proportion of daylight samples, which may lead to over- or underestimation of impingement for different species depending on their diurnal behaviour (Section 2.1.1.1). However, it is necessary to consider that the magnitude of such uncertainties in relation to the magnitude of impacts, species by species, against the already inbuilt precaution in the entrapment assessments.

The precautionary steps in the entrapment assessments include:

- **Fishing mortality has not been included when calculating the Equivalent Adult Value (EAV) factor.** This results in EAV numbers and EAV biomass being overestimated i.e., the juvenile fish entrapped would have less chance of surviving to contribute to the spawning population had fishing mortality during juvenile stages been considered (Section 2.1.3.1).
- **Precautionary EAV biomass.** The EAV biomass is calculated by multiplying the EAV number by the mean adult fish weight from the spawning population. The individual weight at the age at first maturity will be lower than the individual weight of older and more fecund fish in the spawning population. Multiplying lost numbers at the age of maturity by mean individual biomass in the spawning population will upweight apparent losses of spawners due to entrapment and their potential contribution to the spawning population biomass. This correctly results in a precautionary higher rate of annual EAV biomass loss as a percentage of spawning population biomass for repeat spawning species (Section 2.1.3.1).
- **For many species, an EAV of 1 has been assumed.** Notably these species include twaite shad, river lamprey and European eel. This assumes all fish impinged would have survived to contribute to the spawning population (Section 2.1.3.1).
- **No benefit of the LVSE head has been assumed** (Section 2.1.4)**.**
- **The FRR mortality is likely to be precautionary due to improved design features.** The uncertainty range in the FFR efficiency is based on Environment Agency values for HPC with a fine trash rack spacing and a greater tidal range. In addition, Sizewell has dedicated FRR tunnels for each EPR without the requirement for an Archimedes screw to raise the fish. Therefore, SZC FRR mortality rates would be expected to be lower than at HPC (Section 2.1.5).
- **Single river estimates:** Losses of conservation species such as twaite shad are considered precautionary as the losses are apportioned to single river systems hundreds of kilometers from Sizewell individually. The likelihood is the fish originate from a number of sources.

Considering the low level of predicted effects (Table 7), and the in-built precaution in the assessment, the conclusions in the **Environmental Statement** [APP-317] of no significant effects on population stability can confidently be determined.

4 Conclusions

This report describes the population level effects of entrapment and quantifies the sensitivity of the predicted impacts to uncertainty in the operational performance of the proposed fish mitigation measures. The analyses incorporate the confidence intervals in impingement predictions and the variance in the baseline population that losses are compared against. This allows estimates of the mean and 95th percentile (1 in 20-year event) for annual entrapment losses as a proportion of population size (or other comparators) to be established.

The results of the uncertainty analysis show that for all species the annual entrapment losses as a proportion of population size are below the threshold that would pose a risk and therefore trigger further investigation for potential population level effects. The three most commonly impinged species at Sizewell are sprat, herring and whiting. The mean entrapment effect for sprat is <0.03% of the SSB (upper 95th percentile 0.04%), for herring entrapment is predicted to result in losses of 0.01% of SSB (upper 95th percentile 0.02%), and for whiting mean losses are 0.08% of SSB (upper 95th percentile 0.11%). Such losses are not significant at the population level.

Sea bass and sand gobies are the only species that exceed the 1% threshold for annual entrapment losses as a proportion of population size. The mean annual losses of sea bass in the uncertainty analysis is 0.99% of SSB with an upper 95th percentile estimate of 1.88%. Sea bass are not uniformly distributed with low catch rates observed in surveys offshore and 95% of bass caught inshore of the Sizewell-Dunwich Bank suggesting that impingement predictions scaled-up from SZB may overestimate sea bass impingement at SZC. As such, the results are precautionary and no significant effects on population sustainability are predicted.

The uncertainty analysis also showed sand gobies exceed the 1% threshold with a mean impingement rate of 1.03% and an upper 95th percentile effect of 1.41% of the population estimate. Because sand gobies are productive species with a short lifespan and early age of maturity, and because they are not fished, they will be able to sustain additional mortality rates greater than 10% of population size. The predicted level of losses of sand gobies is not regarded as significant at the population level.

Overall, the results of the uncertainty analysis, and the in-built precaution in the assessment methodologies provide a high degree of confidence in the predictions of no significant effects at the population level.

5 References

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