The Sizewell C Project

6.3 Volume 2 Main Development Site

Chapter 22 Marine Ecology and Fisheries

Appendix 22G - Predictions of Entrainment by Sizewell C in Relation to Adjacent Fish and Invertebrate Populations

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Predictions of entrainment by Sizewell C in relation to adjacent fish and invertebrate populations

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Please note that the red line boundary was amended after this document was finalised, therefore figures in this document do not reflect the boundaries in respect of which development consent has been sought in this application. However, amendments to the red line boundary does not have any impact on the findings set out in this document and all other information remains correct.

Executive summary

This report provides an assessment of predicted entrainment losses in the proposed Sizewell C power station on the key fish and invertebrate zooplankton species at Sizewell C (SZC). These predictions are calculated using data on entrainment of species in the Sizewell B (SZB) station (abstraction 51.5 cumecs), scaled to the level of abstraction planned for SZC (131.86 cumecs i.e. 131.86 $m^3 s^{-1}$). The data come from the BEEMS Comprehensive Entrainment Monitoring Programme (CEMP), which sampled fish and invertebrates from the Sizewell B forebay on 40 occasions between May 2010 and May 2011, using coarse (500 µm) and fine (270 µm) mesh nets alternately throughout each of the 24-hour sampling periods. The average volume of water sampled per 24 hours was 713,470 l for the coarse nets and 682,340 l for the fine nets, equating to around 0.031 % of the full flow of the station.

Predicted entrainment effects on fish

A ranking of abundance by species for fish eggs and larvae from the entrainment data was similar to that obtained from the BEEMS offshore plankton surveys undertaken separately between 2008 and 2012 indicating that the entrainment data were representative of the wider Sizewell ichthyoplankton community.

The total estimated number of fish eggs entrained at SZB from May 2010 to May 2011 (unadjusted for entrainment survival) was 288.6 million and was dominated (76.4 %) by anchovy and sole. 92.4 million larval fish were estimated to be entrained, with gobies, sprat, herring and pilchard dominating (95.1 %). 19.5 million juvenile fish were estimated to have been entrained, with gobies and sprat dominating (83.7 %). The total predicted number of fish eggs, larvae and juveniles that would be entrained annually (before adjustment for entrainment survival and conversion to adult equivalents) at SZC is 738.9 million, 236.7 million and 49.9 million respectively. The location of the seawater intake structures at SZC will be offshore of the Sizewell Dunwich Bank whereas the intakes at SZB are inshore of the Bank. Results from near-shore BEEMS surveys (BEEMS Technical Reports TR315, TR326, and TR379) provide no statistical evidence that entrainment (per volume of cooling water abstracted) for fish or invertebrate species will be higher at SZC than SZB.

Whilst the predicted numbers of individual animals entrained as eggs, larvae or juveniles appears large, it must be borne in mind that the natural mortality these very early life-history stages suffer in the wild is very substantial. Consequently, the impact of entrainment mortality on adult wild populations and fisheries, for those species where fisheries currently exist, will be much lower than the simple numbers of individuals indicate. In the case of fish eggs, the impact of lost eggs on fish populations is assessed by expressing egg loss through entrainment in the context of the numbers of eggs produced by an “average” or typical spawning female (“equivalent spawning females”). This “adult reproductive equivalent” approach may underestimate the population loss due to egg entrainment because it assumes all the eggs were viable and newly laid, so to mitigate this the lower estimate of the number of eggs spawned was used wherever a range is given in the literature. In the case of fish larvae, the impact of lost larval fish is assessed by expressing larval loss through entrainment in the context of the numbers of larvae produced by an “average” or typical spawning female (“equivalent spawning females”). The numbers of larvae produced were estimated from the numbers of eggs spawned (above) and assuming upper (97 %) and lower (70 %) levels of natural egg mortality. This approach provides upper and lower estimates of the impact of larval loss through entrainment. In the case of juvenile fish, for most species an equivalent adult value (EAV) was derived. In the absence of data, a worst case EAV value of 1 was assumed, which will considerably over-estimate adult numbers for such species.

To put the predicted entrainment loss of fish eggs, larvae and juveniles at SZC into the context of populations, the estimated equivalent adult numbers were converted to weights and compared with the spawning stock biomass (SSB) of each species or the respective international landings, based on its stock assessment area. Twenty four key fish species have been selected at Sizewell (defined in the fish characterisation report, BEEMS Technical Report TR345 on the basis of conservation importance, ecological importance and socio-economic value) as representative of the local assemblage. Only eight of these 24 species have been detected in entrainment sampling at Sizewell. For seven of these eight key taxa the predicted entrainment losses are much less 1 % of the SSB or the international landings of that species in 2010. The highest predicted loss was 0.001% of SSB for sprat or 0.01% landings for dab. Gobies (predominantly sand goby) are the eighth key taxa detected in entrainment sampling. The species are short lived and commercially unexploited. The predicted entrainment loss is 1.4 % of the mean population numbers which is less than the highly conservative screening threshold of 10% for such unexploited species.

Considering the other key fish species at Sizewell identified in BEEMS Technical Report TR345 some species are considered not to be at risk or at negligible risk of entrainment at SZC because:

- They are not present at the vulnerable life stage/size e.g. the diadromous species which reproduce in freshwater and then do not enter the marine environment until they are too large to be entrained (twaite and allis shad, sea trout, salmon and sea lamprey). In theory, very early life stages of river lamprey and possibly cucumber smelt could be present in the marine environment at Sizewell at a sufficiently small size to be entrained. However, these species are readily identifiable, and none were detected in the Sizewell entrainment and plankton sampling programmes.
- They were not detected in entrainment sampling but were detected during offshore plankton surveys but in such low densities to have negligible effect on the species at the population level even if they had all been entrained at SZC e.g. larvae of mackerel, whiting and plaice with 1 larva of each species being caught in a total of 585 plankton samples from 2008-2015 (BEEMS Technical Report TR315).
- The species were not detected during entrainment nor plankton sampling at Sizewell and their juveniles do not come into the Sizewell Bay area until they are too large to be entrained e.g. cod, thin- lipped grey mullet, thornback ray and horse mackerel.
- The species does not have egg or larval stages and the juveniles are too large to be entrained e.g. tope.
- The European eel in its glass eel phase is theoretically vulnerable to entrainment at Sizewell C. The totality of data from an extensive sampling programme together with considerations of how glass eels migrate around the UK has led to the conclusion that whilst glass eels are present in Sizewell coastal waters, their density is very low at this location. In addition, glass eels make use of selective tidal stream transport (STST) to migrate to suitable estuaries at or near to the sea surface where they would be at low risk of entrainment from the deep seabed mounted SZC intakes. Even if a few glass eels are entrained, BEEMS entrainment simulations of SZC under planned operational conditions of pressure, temperature, chlorine dosing and exposure time showed 80% or greater survival. The entrainment risk to glass eels is, therefore, considered negligible.
- After consideration of the hydrodynamics in the southern North Sea and the results of previous modelling studies on the fate of Blackwater herring larvae it has been concluded that the proportion of Blackwater herring larvae that would be at risk of entrainment at Sizewell C would be negligible (Appendix C 6.6).

The predicted entrainment effects on the 24 key fish taxa are, therefore, considered negligible.

Predicted entrainment effects on invertebrate zooplankton

Forty-nine zooplankton taxa were recorded in the SZB entrainment sampling programme. The relative ranking of taxa from offshore and onshore sampling was similar, with 40 of the taxa found in the offshore plankton sampling also being found in the onshore entrainment sampling. Differences in relative abundance were found for some benthic or hyperbenthic species, which were detected in lower numbers in offshore sampling. This is possibly due to differences in efficiency of sampling gears; species such as mysids can avoid sampling gear with small apertures.

Copepods represented approximately 72 % of the measured invertebrate zooplankton abundance in the entrainment sampling at Sizewell and, together with bentho-pelagic (mainly gammarids and mysids) and benthic taxa (mostly barnacles) represent just over 90 % of the entrained community. It is concluded that for copepods the predicted loss of local biomass due to entrainment is negligible and, because of their behaviour, the bentho-pelagic and benthic taxa will be at low risk of entrainment at Sizewell C and the predicted entrainment effects on these populations will also be negligible. The predicted effect of SZC entrainment on the assessed invertebrate zooplankton groups is, therefore, considered to be negligible.

Table 1 provides an assessment of predicted entrainment effects for each of the key fishes and invertebrate zooplankton taxa at Sizewell (described in BEEMS Technical Reports TR345 and TR315).

Table 1 Predicted entrainment effects on key fishes and invertebrate zooplankton taxa at Sizewell

		Reason why key species				
Taxon		**Socio-economic**	**Ecological**	**Conservation**	**Detected in entrainment sampling**	**Predicted Entrainment effect on fish population**
Fishes						
European sprat	*Sprattus sprattus*		🟩		Y	Negligible
Atlantic herring	*Clupea harengus*	🟦	🟩	🟧	Y	Negligible
Whiting	*Merlangius merlangus*		🟩	🟧	N	Negligible
European sea bass	*Dicentrarchus labrax*	🟦	🟩		Y	Negligible
Sand gobies	*Pomatoschistus* spp.		🟩		Y	Negligible
Dover sole	*Solea solea*	🟦	🟩	🟧	Y	Negligible
Dab	*Limanda limanda*		🟩		Y	Negligible
Anchovy	*Engraulis encrasicolus*		🟩		Y	Negligible
Thin-lipped grey mullet	*Liza ramada*		🟩		N	Not at risk
European flounder	*Platichthys flesus*		🟩		Y	Negligible
Atlantic cod	*Gadus morhua*	🟦	🟩	🟧	N	Not at risk
European plaice	*Pleuronectes platessa*	🟦	🟩	🟧	N	Negligible
Smelt	*Osmerus eperlanus*			🟧	N	Not at risk
Thornback ray	*Raja clavata*	🟦	🟩		N	Not at risk
European eel	*Anguilla anguilla*			🟧	N [1]	Negligible
Horse mackerel	*Trachurus trachurus*			🟧	N	Not at risk
Twaite shad	*Alosa fallax*			🟧	N	Not at risk
River lamprey	*Lampetra fluviatilis*			🟧	N	Not at risk
Mackerel	*Scomber scombrus*			🟧	N	Negligible
Sea trout	*Salmo trutta*			🟧	N	Not at risk
Allis shad	*Alosa alosa*			🟧	N	Not at risk
Tope	*Galeorhinus galeus*			🟧	N	Not at risk
Atlantic salmon	*Salmo salar*			🟧	N	Not at risk
Sea lamprey	*Petromyzon marinus*			🟧	N	Not at risk
Invertebrate zooplankton						
Copepods	Copepoda		🟩		Y	Negligible
Gammarids	Gammaridae		🟩		Y	Negligible
Mysids	Mysida		🟩		Y	Negligible
Barnacles	Cirripedia		🟩		Y	Negligible

1.1 Revisions to entrainment assessments in Version 3 of this report

Since Version 2 of this report was released (03/06/2019) additional work has been undertaken to address issues raised by stakeholders. The main changes to the assessments that are included in this report are:

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[1] Glass eels were not detected in entrainment sampling but are known to migrate past the Sizewell site in very small numbers (BEEMS Technical Report TR356)

i. In each of the three fish life history stages (eggs, larvae and juveniles), some individuals were recorded as 'unidentified specimen', usually due to damage. These scaled numbers of unidentified eggs, larvae and juvenile groups were not included in the final assessment of impacts. To address this, the numbers of unidentified specimens have been re-allocated proportionately across all other taxa present. This exercise was undertaken monthly for each of the three developmental stages, to achieve maximum re-allocation of the unidentifiable component.

ii. In the larval stage, some specimens were simply recorded as 'herrings' (i.e. unidentified clupeids). Following the June 2019 MTF meeting, the larval clupeid samples were re-analysed to determine whether they could be better identified. A proportion of the larvae were identified as either herring, sprat or pilchard. The numbers of individuals in each of these groups was changed and all calculations were updated.

iii. For the 'herrings' that could still not be allocated to species, the numbers of 'herring' individuals were proportionately allocated to the identified clupeid species that were present, in the same way as the 'unidentified specimens' had been re-allocated (i.e. re-allocation was carried out monthly).

iv. Estimates of the sand goby population have been updated. Version 2 of this report incorrectly used the reported beam trawl efficiency for muddy sediments but in this report the 46% measured efficiency for sandy sediments appropriate to the east Anglian coast has been used.

v. Re-allocation of the *Gobiidae* group. All species of the *Gobiidae* were recorded together (i.e. not identified to genus or species). To allow comparisons with impingement data in which gobies are identified, the *Gobiidae* numbers were separated into a 'sand goby' group and an 'other gobies' group. Data from impingement sampling at SZB showed that of all gobies present, 87 % were *Pomatoschistus* sp. and the remaining 13 % were other goby species. Therefore, for the entrainment dataset, the numbers entrained in each developmental stage were allocated out in these proportions.

1.2 Revisions to entrainment assessments in Version 4 of this report

i. Detailed responses to stakeholder comments on the glass eel entrainment assessment have been added (Section 4.1.5).

ii. Results from Entrainment Mimic Unit experiments on glass eel using the HPC profile have been included in the report.

iii. Consideration of the risk to Blackwater herring larvae discussed (Appendix C6.6)

1.3 Revisions to entrainment assessments in Version 5 of this report

i. Inclusion of red line boundary information on page 13.

1.4 Revisions to entrainment assessments in Version 6 of this report

i. Information added on the risk to entrained organisms from the daily discharge of process waste hydrazine via the cooling water outfalls in Section 2, paragraph 3.

2 Introduction

Direct cooled coastal power stations use large volumes of seawater in their cooling systems to condense turbine steam. The current Sizewell B station (SZB) abstracts 51.5 $m^3\ s^{-1}$ (cumecs) of seawater and the proposed new nuclear build (NNB), Sizewell C (SZC) would abstract 131.86 $m^3\ s^{-1}$. Although the cooling water intakes are protected by coarse screens to prevent the intake of larger fish and debris, smaller organisms inevitably enter the cooling water system. Most fish and crustaceans that pass through the intake screens are removed through **impingement** on fine-mesh drum screens before the water enters the power station cooling system, to prevent them blocking the condenser tubes. Smaller planktonic organisms (fish eggs and larvae, invertebrate zooplankton and phytoplankton) are **entrained**, that is they pass through the power station cooling system before being discharged back into the environment. SZB uses 10mm mesh for its fine filtration systems as will the proposed SZC.

Entrained organisms in SZC would be subject to a variety of physical and chemical stresses before they are returned back to sea via the SZC cooling water outfalls. These stresses include changes in pressure (up to +2 atmospheres), potential mechanical damage due to contact with the fine filtration mesh, a rapid increase in temperature of about 11.6 °C and exposure to chlorine based anti-fouling agents which, when added to seawater, form oxidants (or Total Residual Oxidants, TROs) mainly consisting of hypobromous acid and hypobromite that have biocidal properties.

In addition to chlorination, small quantities of process waste hydrazine would be discharged into the cooling water flow at the seal pit in a single daily pulse of 2.32h per day resulting in an initial hydrazine concentration of 69 ng l^{-1} in the cooling water flow. (This discharge scenario is the worst case as far as entrainment risk is concerned and there is alternative daily discharge scenario of 4.6h of 34 ng l^{-1}, BEEMS Technical Report TR193). However, when hydrazine is added to chlorinated seawater the hydrazine is oxidized to nontoxic nitrogen, sodium chloride and water and the hydrazine concentration immediately decreases by approximately 90%. For example, in experiments described in BEEMS Technical Report TR363, an initial hydrazine concentration of 69 l^{-1} fell to 8.4 ng l^{-1} in the presence of chlorinated seawater at the planned TRO concentrations for SZC. To put these concentrations into an environmental risk context, the Canadian Federal Water Quality Guidelines for hydrazine indicate that concentrations below 200 ng l^{-1} have a low likelihood for adverse effects for marine life (Environment Canada 2013). Even at the planned SZC initial concentration of 69 l^{-1} the concentration of hydrazine for only 2.3h per day would be considered to present a very low risk for entrained organisms; at 8 ng l^{-1} the additional risk is considered negligible and is not considered further in this report.

It has sometimes been assumed that entrainment stresses cause sufficient damage that 100 % of all entrained organisms die during, or shortly after, passage through the power station, but experimental evidence shows significant levels of survival for some species (see section 3.6).

Most of the permanent members of the zooplankton (holoplankton) are species with rapid recruitment during their breeding season. It has therefore been previously assumed that holoplankton species are able to compensate for any losses as a consequence of cooling water entrainment (Coughlan, 1982). Of greater concern are species whose egg and larval stages are planktonic, such as many species of fin-fish, which only breed once each year and for which losses of the young stages could have negative impacts on their annual recruitment. Laboratory experiments on the effects of entrainment on ichthyoplankton have indicated that the development of some flatfish (Bamber and Seaby, 1993) and roundfish (Bamber and Seaby, 1995) eggs may be inhibited, and the larvae damaged, by entrainment through a power station cooling water circuit.

An assessment of the type and quantity of organisms impinged on the SZC drum screens before the water enters the power station cooling system is presented in BEEMS Technical Report TR406. Here, the type and quantity of planktonic organisms entrained at SZB are assessed and used as a basis for predicting the likely entrainment mortality at SZC, placed into the context of wider populations.

2.1 Characterisation of the Sizewell plankton community

Two methods have been used to assess the type and numbers of zooplankton organisms entrained at SZB as a basis for predicting the likely entrainment at SZC:

a. The BEEMS Comprehensive Entrainment Monitoring Programme (CEMP) at SZB. The CEMP sampling was undertaken by Pisces Conservation limited and involved taking pumped water samples from the SZB forebay for 24 hours on 40 occasions over a 12-month period between May 2010 and May 2011 (BEEMS Technical Report TR235). The pumped water samples were alternately passed through fine (270 µm) or coarse (500 µm) mesh nets. The CEMP was intended to last for more than one year, but operational safety issues prevented this from being realised.

b. Offshore plankton surveys were carried out using a Gulf VII high-speed plankton with a main net mesh size of 270 µm and a smaller “pup” net mesh size of 80 µm towed for 10 minutes for each sample. Initial surveys were targeted on obtaining a wide-area characterisation and employed an undulating sampling profile from 0.5 m below the sea surface to 2 m above the seabed to sample most of the water column (BEEMS Technical Reports TR069; TR069a; TR202). Once the location of the SZC intakes had been decided, subsequent surveys were focused on 3 or 4 locations (SZB intake, SZB outfall, SZC intake/outfall and later a reference location to the north of Sizewell, with the plankton sampler towed at the approximate depth of the power station intakes (BEEMS Technical Reports TR276; TR326; TR379).

Zooplankton populations are spatially patchy and subject to year to year fluctuations in abundance. They are composed of different types of organisms, some permanent members of the community and some transient: holoplankton are wholly pelagic and drift with tidal and wind induced currents, whilst meroplankton live in, on or near to the seabed, but either undertake vertical migrations into the water column or produce pelagic reproductive stages (eggs and larvae). Whilst many invertebrate species have low swimming speeds, some can control their depth in the water column and undertake daily vertical migrations; being at or close to the surface at night but deeper during daylight hours. Past experiments have shown that the species composition measured at approximately the same time from power station forebays and offshore were not the same for all species. These differences were not explained at the time but were potentially due to differences in the selectivity of the two sampling methods, the ability of some larval and juvenile zooplankton species to avoid small aperture samplers, differences in when samples were taken or the patchiness of the zooplankton communities (BEEMS Technical Report TR081).

These characteristics mean that two different sampling methods have different advantages and disadvantages.

The offshore zooplankton surveys enable:

- spatial variability in the plankton community to be determined;
- inter annual variability to be assessed (the BEEMS offshore dataset is multi-year);
- a range of organism sizes to be sampled (due the ability to deploy fine mesh nets with a 10-minute sampling profile without the sediment clogging that would result from longer sampling intervals); and
- short net deployments that facilitate easier identification (the smaller quantity of material sampled means that organisms tend to be less damaged in the nets).

But

- for safety and logistical reasons, sampling opportunities are limited; often to daylight and to fine weather;
- sampling for a whole year at shorter than monthly intervals is also unreasonably expensive; and
- there is previous experimental evidence of differences between the offshore and onshore (i.e. in the forebay) plankton communities.

The CEMP survey is advantageous because:

- it does not suffer from a tidal or day/night bias (by virtue of its 24 h samples); and
- the measured plankton community is that which is entrained in the power station (assuming that the forebay population can be determined accurately; the forebay is turbulent and well mixed).

But

- additional data are required to determine if the CEMP survey at SZB was representative of the likely plankton community abstracted at the SZC intakes (3 km offshore), hence the need for offshore surveys;
- a narrower size range of organisms was sampled (sampling was automated and unmanned at night and it was not possible to automatically reduce the sampling time if net clogging started to occur, so in order not to lose samples the minimum mesh size was set at 270µm); and
- samples were only taken for one year.

2.1.1 Adopted zooplankton characterisation protocol for entrainment assessment

The sampling protocol used to characterise the Sizewell plankton community for producing the SZC entrainment predictions was:

i. To use the CEMP survey to determine the zooplankton community at SZB

ii. To undertake simultaneous offshore sampling with the same design of pumped sampler used in the CEMP programme to understand any differences between the measured communities offshore at the SZB intakes and onshore (in the forebay).

iii. To use the multi-year offshore plankton characterisation data to understand any differences between the plankton communities at the SZB intakes and the location of the proposed SZC intakes.

2.2 Assessment of entrainment effects

Past entrainment survival experiments have indicated that there may be detrimental effects of entrainment on fish eggs and/or larvae. Such studies also provided evidence that indicates, for some species and some life-history stages, there can be significant survival after passage through a power station cooling system. Before the BEEMS programme there were few entrainment survival estimates for most of the species encountered at Sizewell, but experiments conducted on a range of species and life stages using the BEEMS entrainment mimic unit (EMU) have added to the entrainment mortality dataset. These experiments are complex because of the difficulty of obtaining and keeping specific species, the short duration of specific life stages, variability between different batches of experimental animals and the lengthy experimental time required to obtain statistically valid results. Nevertheless, the available dataset has been expanded from the pioneering work of Bamber and Seaby in the 1990s and, where suitable data exist (see Table 2), these were used these to adjust the predictions of entrainment mortality described in this report.

By its nature, entrainment involves the very youngest life-history stages of fish and invertebrates. In the wild, these early life-history stages usually suffer substantial natural mortality before recruiting to a fishery or an adult population, so any additional mortality attributable to power station entrainment will not have the same impact (numerically and in terms of biomass) on the population as had these organisms been adults.

2.2.1 Assessment of effects on fish

For many fish species, extensive data are available on the estimated size of adult populations and fisheries, particularly for commercially important species. To derive a realistic evaluation of entrainment mortality of adult populations and fisheries, methods have been developed for relating the numbers of the early life-history stages entrained to the abundance of adult populations. For those key taxa where suitable independent data exist, the impact of entrainment mortality on populations in the ICES-defined stock units of the species in question have been assessed.

2.2.2 Assessment of effects on invertebrate zooplankton

The invertebrate species found at Sizewell are common and widely distributed in the North Sea and further afield. No population estimates exist for any of these invertebrate species and therefore a different method of effects assessment was required. Extensive studies have established a relationship between the size and natural mortality (M) of fish that has been found to provide a good fit over many orders of magnitude of size range from larvae to adults; essentially the smaller the organism the higher the rate of natural mortality (Gislason et al., 2010; McGurk, 1986). Field studies on the natural mortality of invertebrate zooplankton have proved much more difficult to undertake. Nevertheless, values of M for some of the more common marine species are available. For example, the instantaneous natural mortality (M) of the common marine copepod *Acartia tonsa* has been estimated to lie between 0.7 and 0.8 d^{-1} (Rumrill, 1990). At an M of 0.7 a static population of *A. tonsa* would be reduced to 0.7 % of its initial value within 7 days. Unless the entrainment mortality in any given area is an appreciable fraction of M, then entrainment will not have any material effect on the population because its dynamics would be governed by the high natural mortality. As the benthic invertebrates found at Sizewell are geographically widely distributed, at a population level, even if 100 % entrainment mortality is assumed, the trivial volume of seawater abstracted by SZC per day compared with the volume of even just the Southern North Sea leads to a conclusion that at the population level the effect of entrainment of invertebrates is negligible (assuming that the species forms one population across the Southern North Sea).

An alternative assessment is to consider what the effect of entrainment might be locally i.e. within the zone in Sizewell Bay at risk of abstraction into SZC. However, SZC would be on an open coastal location with a daily exchange of water between the zone at risk of abstraction and the adjacent North Sea. BEEMS Technical report TR385 estimates that the SZC abstraction zone has an approximate volume of 8.45 10^8 m^3 and experiences a seawater exchange with the adjoining sea area of 10 % per day or 8.45 10^7 m^3 per day. SZC will abstract approximately 131.86 cumecs or 1.14 10^7 m^3 per day or 1.35 % of the abstraction risk zone. Assuming no water exchange, the abstraction risk zone would all be filtered through SZC in 74 d but, because of water exchange, the abstraction zone is refreshed by new water every 10 d. i.e. in practice in such a coastal location even with long lived plankton organisms (e.g. mysids with an estimated M of 0.06 d^{-1}; (Clutter and Theilacker, 1971)) any change in zooplankton community due to entrainment in SZC would not be detectable against the natural spatial and temporal variability in zooplankton abundance and with the measurement uncertainty inherent with available monitoring tools.

Nevertheless, whilst it may not be detectable in the field, the power station will increase local zooplankton mortality and this report provides estimates of the predicted effects in Sizewell Bay.

2.3 Relevant site features

SZB is a direct-cooled nuclear power station, using a pressurised water reactor design to generate an electrical output of about 1195 MW. The SZB intake and outfall structures are located inshore of the Dunwich-Sizewell Bank system (

Figure 1) and for SZB the volume of water extracted is nominally 51.5 cumecs.

The intake structure consists of two intake heads, on an approximately E-W axis with centres 30 m apart. Each intake is connected to its own tunnel, which then join to form a single tunnel. Each head is octagonal and ~11.5 m across and is omnidirectional. The structure sits ~1.5 m above the seabed and the intake aperture is 3 m high. The tidal flows in the region are highly rectilinear and peak at 1 m s^{-1} on spring tides (BEEMS Technical report TR311). The effective face velocity is $26/(3 \times 11) = 0.8$ m s^{-1} so, during peak tides, a tidal streamline the width of the intake enters the intake, whereas, at slack water, the water is drawn from a radius around the intake.

The intake structure was designed to exclude any large superstructure that might attract fish and has a cap to limit drawdown from the surface. Trash bars are situated in the forebay to prevent large pieces of debris from damaging the drum screens. The intake tunnel consists of nine square precast concrete caissons, each are 4.82 m wide (internal) and a total of 702 m long. Flow velocities in the tunnel are approximately 2.44 m s^{-1}, giving a passage time through the tunnel of approximately 5 min. The capped intake design was intended primarily to ensure that warm, surface water is not drawn into the station, and to reduce the likelihood of there being a surface vortex. The capped design, by eliminating vertical water movement, also helps fish avoid entrapment into the intakes because fish are ill-equipped to respond to vertical water movements. Velocity caps are considered to be especially protective of pelagic species such as sprat and herring (Fleming et al., 1994). Studies undertaken in March/April 1994 concluded that SZB impinged significantly fewer fish than the previous Sizewell A station, which was not fitted with a velocity cap (Fleming et al., 1994). The SZB discharge is through two tunnels that point offshore and upward, with the discharge in the nearshore region ~150 m from the low tide mark (

Figure 1). The proposed SZC intakes will be 3 km offshore, located on the outer side of the Sizewell-Dunwich Bank in approximately 15 m (ODN) depth (

Figure 1). The preferred outfall locations 09a and 09b are contingent on final engineering geotechnical assessments but will be here or further offshore and in approximately 18 m depth.

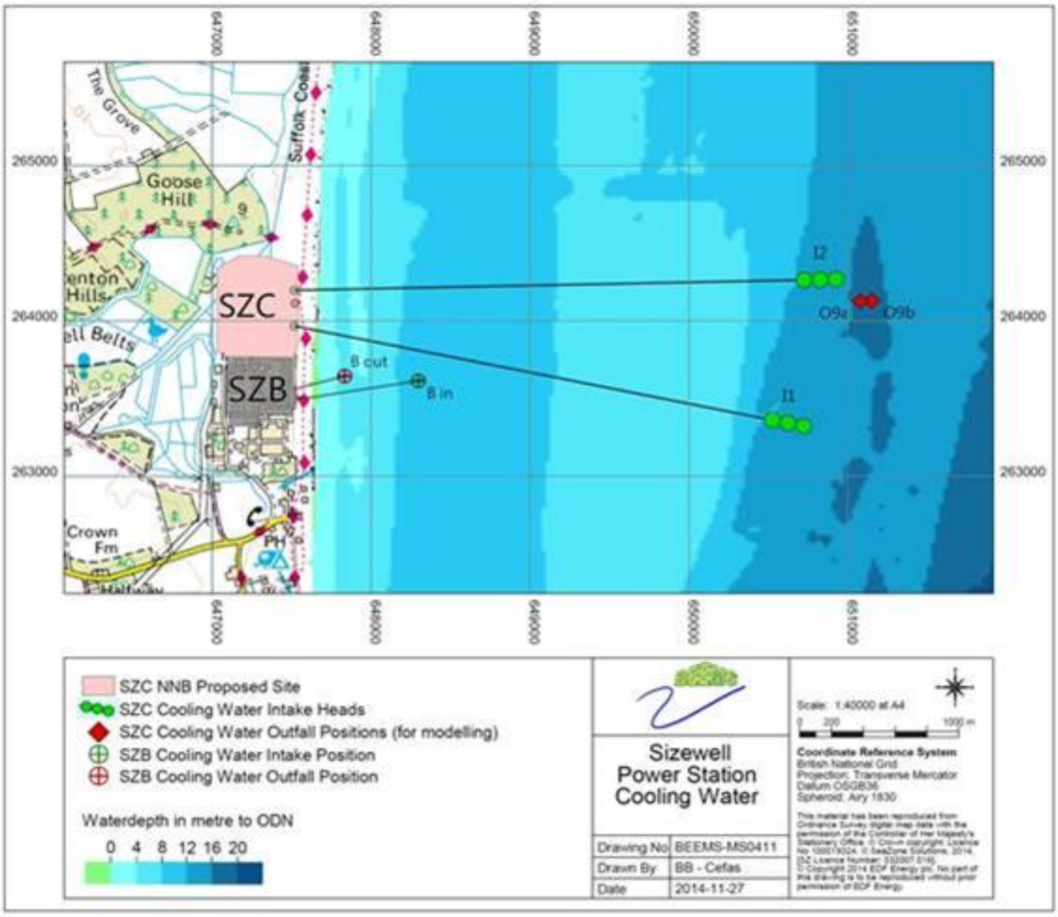

Figure 1 The Suffolk coast at Sizewell, showing the locations of the intake and outfall for SZB and the proposed intakes and outfalls for SZC

3 Entrainment sampling and predictions

Full details of the BEEMS Comprehensive Entrainment Monitoring Programme is provided in BEEMS Technical Report TR235. A summary is provided below.

3.1 Methods: equipment used

Entrainment sampling was achieved by pumping sea water from the forebay through the sampling equipment, known as the BEEMS Automated Entrainment Sampling Facility (AESF; Figure 2). The AESF was located on the lower level (+4.6 m level) walkway adjacent to the forebay. The pump was deployed in front of the station's cooling water drum screens so that any lost equipment would be captured on the screens and not pass into the power station cooling water system. The flow from the forebay during sampling was a very small percentage of the water taken in by the station (less than 0.1 %) and was returned via the adjacent fish return gulley to the outfall surge chamber.

The AESF was deployed for a period of one year. To facilitate 24-hour sampling, a series of 10 net reservoirs was installed, so that the equipment could operate unsupervised and the sampling crew did not need to remain on site throughout the sample period.

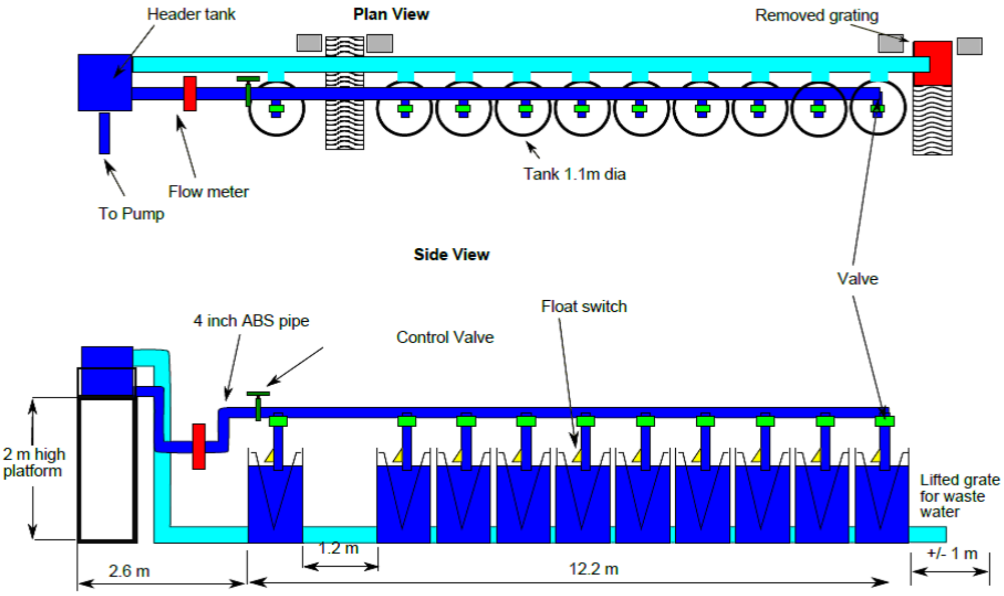

Figure 2 A schematic layout of the BEEMS Automated Entrainment Sampling Facility

The header tank was a 750-litre vented reservoir with a pumped seawater supply from the forebay and an overflow running to drain. The header tank maintained a constant positive head of water pressure to the net reservoirs. The header discharge pipe, from the bottom of the tank, was installed with a flow control valve to ensure the header tank was always overflowing, to maintain a constant head independent of tide conditions (where pump suction head and hence flow rate would vary).

Net reservoirs were installed with plankton nets which collected matter entrained in the seawater which had passed through the pump strainer. The plankton nets had a mouth diameter of 60 cm, supported in the reservoirs by frames (Figure 3), reducing the damage done to the sampled organisms by keeping them in suspension.

Figure 3 The main sampling tanks.

Seawater flowed through the nets and into the reservoir and then overflowed to drain. A float switch was fitted at the top of the reservoir that would cut off the water supply to the reservoir if the nets became blocked, preventing the passage of water through to the overflow drain. In this instance, the flow would simply be increased through the header tank overflow. The flow meter recorded the reduced seawater flow to a blocked net.

To allow pump and hose installation and removal, a scaffold lifting frame and electric hoist was installed. Between sample runs the pump, hose and electric hoist were disconnected, removed and stored in the sample equipment tent on the adjacent lower level walkway.

3.2 Methods: on-station entrainment sampling

The sampling programme consisted of forty 24-hour sampling periods between 17th May 2010 and 3rd May 2011, arranged in quarterly blocks of ten dates; the sampling dates randomly selected within each quarter.

Each sample run, lasting 24 hours, filtered between 15 and 18 l/s of sea water from the forebay through nets of alternating mesh size (500 µm and 270 µm) located in the net reservoirs. Each net reservoir was operated for 1 hour – providing 1 sample - before the sampling control system transferred the flow to the next net reservoir, i.e. the sea water flowed through one net only with the flow being completely diverted to the next net at the end of each 1 hour sample. Nets were removed, the contents washed out and preserved, and the net replaced prior to the reservoir being used again. The pump sampler was deployed by site contractors and sampling began at approximately 12:00 hrs and finished 24 hours later. This 24-hour sampling approach was used to eliminate diurnal and short-term (~13-hr cycle) tidal bias, longer-term tidal bias was eliminated by randomising sampling dates.

The plankton samples were initially fixed in the field in neutrally buffered 4 % formaldehyde and stored at Pisces' laboratories. The hourly samples from each 24-hour period were combined into 2 samples, one coarse mesh (500 µm) and one fine mesh (270 µm, giving in total 40 samples from the coarse mesh and 40 from the fine mesh. The samples were combined, as processing all samples (960 samples) would have been time consuming and costly. The samples were transported to the Cefas Lowestoft laboratory where the formaldehyde solution was replaced with an ‘observation fluid’ consisting of 0.5 % propylene phenoxetol, 5 % propane-1-2-diol in distilled water (Steedman, 1976).

3.3 Plankton sample processing

Aliquots of each sample were placed under low-power microscopes and all fish eggs and larvae, and larger zooplankton components were removed from all samples. Smaller zooplankton were removed from the 270 µm mesh samples only. Individuals were removed and counted, either from the whole sample or from a known volume sub-sample. Samples for the smaller zooplankton were often sub-sampled quite heavily because of the volume of plankton, sediment and debris present. Any sub-sampling was carried out using a Folsom splitter (McEwen et al., 1954) to divide, and often sub-divide, the samples. The proportions of samples analysed for ichthyoplankton (fish eggs and larvae) ranged from whole samples to 1/32nd of a sample on one occasion. For the larger zooplankton subsampling could be more extensive (between 1/4th and 1/64th of a sample) because of the greater abundance of some organisms. For the smaller zooplankton subsampling was even more extensive with a maximum subsample of 1/3200th of a sample). If subsampling was required, the total number of individuals of a given species was calculated by raising up by the subsampled counts to the total sample.

For each sample, the numbers of organisms in the sample were expressed as number per 10 m^3 of water filtered during the collection of that sample.

3.4 Entrainment estimates and predictions

Approximately 600,000 to 800,000 l of seawater from the forebay were filtered through both the coarse and fine plankton nets on each of the 40 sampling periods, with 55.8 million litres being filtered in total. Sample-by-sample details of the numbers of fish eggs, larvae and/or juveniles together the numbers of invertebrate zooplankton are given in BEEMS Technical Report TR235. In this report, the results have been consolidated into total entrainment estimates (for SZB) and predictions (for SZC) on a monthly and annual basis. Note however that the total estimates of entrainment for SZB provided in BEEMS Technical Report TR235 are slightly different from those presented here because the authors of BEEMS Technical Report TR235 (Pisces Conservation Ltd.) calculated total entrainment using a linear interpolation method to estimate entrainment between sampling dates. The method assigned each non-sampling day the numbers entrained from the closest sampled day. Thus, half of the non-sampled days between 2 sampled dates would be allocated the entrainment numbers from the first date, and half would be allocated the entrainment numbers from the second date, eventually allocating an estimate of entrainment numbers for each day of the year. In contrast, in this report, entrainment estimates have been obtained by grouping samples by month and calculating a monthly mean number and scaling to each month as appropriate before summing all month’s data, to provide an estimate of the numbers entrained per year when running at full capacity. This was considered more appropriate, as there is no basis for assuming that the numbers entrained on the non-sampled days were the same as the numbers entrained during the closest sampled day.

Entrainment estimates assume that the station runs at full load all year, i.e. with all 4 cooling water pumps running all year. At full load, SZB pumps 51.5 $m^3 s^{-1}$ while SZC will pump 131.86 $m^3 s^{-1}$. At these flows, SZB pumps 4,449,600 $m^3 day^{-1}$ while SZC will pump 11,392,704 $m^3 day^{-1}$.

To obtain estimates of total annual entrainment by species, all samples from a given month were summed and the average entrainment (number per 10 m^3) per day was calculated for each month. This number was then multiplied by 4,449,600 to provide estimated entrainment per day for SZB and by 11,392,704 to provide predicted entrainment per day for SZC. These numbers were then multiplied by the numbers of days in each month to give the total estimated and predicted entrainment by month. The 12 months were summed to give the annual numbers entrained. The process is illustrated below:

1. Calculate the abundance of each species in the sample (number per 10 m^3)
$$\frac{number\ of\ individuals\ of\ species\ in\ sample}{volume\ of\ water\ filtered\ during\ sample\ collection}$$
2. Calculate mean abundance of each species in each month (mean number per 10 m^3)
$$\frac{\sum species\ abundance\ per\ m3\ for\ all\ samples\ in\ the\ month}{number\ of\ samples\ in\ the\ month}$$
3. Calculate monthly total numbers entrained by SZB for each species
$$species\ mean\ monthly\ abundance\ \times \frac{SZB\ daily\ volume}{10} \times number\ of\ days\ in\ month$$
4. Calculate annual total numbers entrained SZB for each species
$$\sum monthly\ numbers\ entrained\ for\ 12\ months$$
5. Calculate annual total numbers entrained SZC for each species
$$annual\ number\ individuals\ entrained\ by\ SZB\ \times \frac{SZC\ daily\ volume}{SZB\ daily\ volume}$$

3.5 Adjustment for unidentifiable eggs, larvae and juveniles

Some eggs, larvae or juveniles could not be identified to species and were recorded as ‘unidentified’. In the case of eggs, this was because either the whole egg or the oil globules had ruptured had. In the case of larvae or juveniles, some specimens were too damaged to provide a species identification.

To ensure that the unidentified group was included in the estimates and predictions, the numbers of eggs, larvae and juveniles were apportioned to the known species groups using the proportion of each species group to the total (minus the unidentified portion). To account for seasonality, this apportioning process was carried out monthly.

For example, for eggs the process was as follows:

1. Sum the calculated monthly total numbers entrained by SZB for all identified species (calculated in step 3 above)
$$\sum Monthly\ number\ number\ of\ individuals\ entrained\ SZB\ (all\ known\ species)$$
2. Calculate the monthly proportion of each species to the known total entrained for that month
$$\frac{monthly\ species\ abundance}{monthly\ total\ numbers\ entrained\ (identified\ taxa)}$$
3. Add the unknown proportion to the known monthly number for each species
$$Known\ number\ entrained\ + (monthly\ proportion * \ monthly\ number\ unidentified)$$
4. Calculate the new monthly total (this should be the same as the original)

$$\sum all\ adjusted\ species\ numbers\ for\ the\ month$$

5. Calculate annual numbers entrained SZB (this should be the same as the original)

$$\sum adjusted\ monthly\ numbers\ entrained\ for\ 12\ months$$

The apportioning process was carried out for unidentified eggs, larvae and juveniles and in the case of larvae only, unidentified clupeids.

3.6 Entrainment survival

Given the large quantity of seawater pumped and the inevitable damage caused when attempting to catch planktonic organisms, it is considered inappropriate to attempt to assess entrainment passage survival by sampling on the power station itself. Instead, Entrainment Mimic Units (EMU), which simulate entrainment passage in a controlled way, have been used to investigate entrainment mortality. Table 2 shows EMU data relevant to Sizewell which were used to calculate predictions of entrainment mortality.

3.7 Placing entrainment losses of finfish species into a population context

For key finfish taxa (identified in BEEMS Technical Report TR345) equivalent adult losses were compared with international landings and the Spawning Stock Biomass (SSB) of each species, depending on their stock unit. A description of the stock unit areas is given in Appendix A.

Table 2 Predictions of entrainment mortality obtained from EMU experiments

Taxon	Estimated entrainment survival	Source	Notes
Sole eggs	20 % at ≥23°C	Bamber and Seaby, 1993	
Bass eggs	40 - 46 % at 11°C change in temperature, 62 % at 11.6°C change in temperature	Bamber and Seaby, 1995; BEEMS Technical Report TR261	
Glass eel	100 % up to 21.9°C, 37 % at 31.8°C	BEEMS Technical Report TR395	Laboratory experiments, not EMU experiments. SZC Temperature and chlorination profile only, not pressure.
Glass eel	80 % at HPC standard operating conditions for maximum discharge temperature of up to 28.8°C. 5mm mesh	BEEMS Technical Report TR273	HPC profile. Peak pressure change 4bar, chlorination applied, delta T 11.6°C. Intake lengths approx. 3km, 5mm mesh. This quoted survival rate is considered the more precautionary set of results for glass eel but SZC with a 10mm screen mesh is considered likely to produce greater survival.
Plaice yolk sac larvae	6.5 % at 11.6°C change in temperature, worst case experimental result	BEEMS Technical Report TR297 BEEMS Technical Report TR396	
Mysids (*Schistomysis sp.)*	70 % at 25°C, 0 % at >29°C	BEEMS Technical Report TR394	Present all year at Sizewell but with peaks in May and September - November
Copepod (*A. tonsa*)	80 % no temperature change 70 % at 11.6°C change in temperature	Bamber and Seaby, 2004; BEEMS Technical Report TR408	
Decapods (*C. crangon* first zoea larvae)	70 % (26 - 27°C), 2 % (29 - 31°C)	Bamber and Seaby, 2004; BEEMS Technical Report TR370	

4 Results

4.1 Fish species and life-history stages entrained

Over the twelve-month CEMP surveys, 23 fish taxa were recorded as present, as either eggs, larvae, and/or small juveniles (Table 3). Of these 23 taxa, 8 species (dab *Limanda limanda*, Dover sole *Solea solea*, anchovy *Engraulis encrasicolus*, flounder *Platichthys flesus*, sea bass *Dicentrarchus labrax*, herring *Clupea harrengus*, *Gobiidae*, and sprat *Sprattus sprattus* - indicated by green shading) are key taxa within the Greater Sizewell Bay area (BEEMS Technical Report TR345). Although some witch *Glyptocephalus cynoglossus* larvae were entrained, there are no self-sustaining witch stocks in the southern North Sea (Heessen et al., 2015) and these are considered to be vagrant larvae that have drifted from more distant populations and are not part of any southern North Sea witch stock. Consequently, entrainment of witch larvae is not considered further.

Table 3 Fish taxa by life history stage entrained at SZB. Key taxa (defined in BEEMS Technical Report TR345) are shaded in green

Fish species	**Present as:**		
	eggs	**larvae**	**juveniles**
Butter fish (*Pholis gunnellus*)			✓
Dab (*Limanda limanda*)			✓
Dover sole (*Solea solea*)	✓	✓	
Dragonets (Callionymidae)	✓	✓	
European anchovy (*Engraulis encrasicolus*)	✓		
European flounder (*Platichthys flesus*)		✓	
European sea bass (*Dicentrarchus labrax*)	✓		
Garfish (*Belone belone*)	✓		
Gobies (Gobiidae)		✓	✓
Gurnards (*Trigla* spp.)	✓		
Herring (*Clupea harengus*)		✓	✓
Lesser weever fish (*Trachinus vipera*)	✓		
Long rough dab (*Hippoglossoides platessoides*)	✓		
Pilchard (*Sardina pilchardus*)	✓	✓	
Pipe-fishes/seahorses (Syngnathidae)		✓	✓
Right eyed flatfish (Pleuronectidae)		✓	
Rocklings (*Gaidropsarus* spp./*Onos* spp.)	✓		
Sandeel (Ammodytidae)	✓	✓	✓
Sea snail (*Liparis liparis*)		✓	
Solenette (*Buglossidium luteum*)		✓	
Soles (Soleidae)		✓	
Sprat (*Sprattus sprattus*)	✓	✓	✓
Witch (*Glyptocephalus cynoglossus*)		✓	

Comparison of the entrainment data with those from the BEEMS offshore plankton characterisation surveys (see BEEMS Technical Report TR315) allowed us to ascertain whether entrainment predictions calculated from samples taken from the inshore SZB intake are relevant to the proposed SZC intake sited further offshore in deeper waters; if the two datasets are similar overall, then the SZB-generated data are applicable to SZC. Although more recent data are available from offshore sampling, caparison was made between the 2010-2011 CEMP data and the 2008-2012 offshore data to provide a consistent time period.

Six of the 10 most dominant fishes encountered as eggs in the entrainment samples (anchovy, Dover sole, sea bass, pilchard, sprat and rockling *Gaidropsarus* spp./*Onos* spp.) were also amongst the 10 most dominant fishes encountered as eggs in the offshore plankton sampling (Table 4 and BEEMS Technical Report TR315). Garfish *Belone belone* and long-rough dab *Hippoglossoides platessoides* were the only fishes encountered as eggs in the entrainment sampling but not encountered in the near-shore sampling. Meanwhile, several taxa (mackerel *Scomber scombrus*, gurnard *Trigla* spp., scaldfish *Arnoglossus laterna*, turbot *Scophthalmus maximus*, brill *Scophthalmus rhombus* and topknot) that were encountered as eggs in the plankton sampling off Sizewell were not encountered as eggs in the entrainment sampling. In general, these species were also rare in the offshore surveys, so their absence from the entrainment data set is likely to reflect their general low abundance near the SZB intakes.

Six of the 10 most dominant fish taxa encountered as larvae in the entrainment samples (gobies, herring, sprat, sandeel, pilchard and Dover sole) were also amongst the 10 most dominant fish taxa encountered as larvae in the near-shore surveys (Table 4 and BEEMS Technical Report TR315). Witch was the only fish species encountered as larvae in the entrainment sampling that was not encountered in the near-shore surveys. Meanwhile numerous taxa (anchovy, sand sole *Pegusa lascaris*, dab, plaice *Pleuronectes platessa*, rockling, sea bass, lesser weever *Trachinus vipera*, gurnard, bib *Trisopterus luscus*, whiting *Merlangius merlangus*, sea scorpion *Taurulus bubalis* and scaldfish) that were encountered as larvae in the plankton sampling off Sizewell were not encountered as larvae in the entrainment sampling, again, presumably because their position in the water column prevents them from being entrained. Dab were however encountered as juveniles in the entrainment sampling.

The overall similarity in both fish eggs and larvae between the entrainment data from SZB and the near-shore plankton characterisation surveys suggests that the ichthyoplankton of the Sizewell area form one community and entrainment predictions calculated from the SZB data are, indeed, applicable to SZC.

Table 4 Ranked comparison of the 10 most numerous fishes encountered as eggs or larvae during the BEEMS entrainment sampling (2010-2011) and offshore plankton surveys (2008-2012). Taxa in only the entrainment dataset are highlighted in green and those only in the offshore dataset are highlighted in yellow

	Fish eggs		**Fish larvae**	
Rank	Entrainment sampling 2010-2011	Plankton survey 2008-2012	Entrainment sampling 2010-2011	Plankton survey 2008-2012
1	Anchovy	Anchovy	Gobies	Gobies
2	Dover sole	Dover sole	Herring	Unidentified clupeids
3	Unidentified eggs	Sprat	Unidentified larvae	Herring
4	Pilchard	Rockling	Sprat	Sprat
5	Sprat	Sea bass	Sandeel	Dover sole
6	Rockling	Unidentified eggs	Dragonet	Anchovy
7	Sea bass	Solenette	Pilchard	Sandeel
8	Gurnards	Lesser weever	Dover sole	Unidentified larvae
9	Dragonet	Pilchard	Solenette	Sea bass
10	Garfish	Mackerel	Right eyed flatfish	Pilchard

Note: unidentified eggs are those that could not be speciated because of the whole egg or the oil globule(s) rupturing. Unidentified fish larvae are those that were too damaged to assign further. Unidentified clupeids are those larvae that could be assigned to this family only.

4.1.1 Entrainment of fish eggs

The eggs of 12 fish taxa were encountered in the water taken from the SZB forebay (Table 5). Of these, anchovy and Dover sole made up the overwhelming (>76 %) proportion. Overall, 13.8 % of the eggs could not be identified (either the egg or the oil globule was ruptured) and were re-allocated monthly to those species groups present (Table 5). Note that individual species' proportions and their rankings have changed due to the monthly apportioning process.

Fish eggs started to appear in February and March (Figure 4), but most could not be identified to species (Appendix B.1 and Appendix B.2). Maximum egg entrainment occurred in April (Figure 4), when Dover sole were dominant, with rocklings, dragonets and sprat also present. Anchovy eggs were entrained from May to August, with 97 % of these in June and July. Dover sole eggs were entrained from April to June, with 99 % of these in May and June. Egg entrainment remained high in May to July. From September onwards, no eggs were entrained (Appendix B.1 and Appendix B.2).

Few entrainment passage survival estimates exist for most of the species at Sizewell, but data are available for sole eggs (20 % survival Bamber and Seaby, 1993) and bass eggs (40-46 % survival, Bamber and Seaby, 1995; 62 % survival BEEMS Technical Report TR261). We have therefore assumed 20 % survival of sole eggs and 40 % survival of bass eggs in the estimates of entrainment mortality prior to converting to the number of "equivalent spawning females" (Table 6).

Table 5 Total annual estimated (SZB) and predicted (SZC) entrainment of fish eggs. Values for sole and bass are unadjusted for entrainment survival.

SZB	Species	SZC	% of total	Cumulative %
Numbers entrained prior to re-allocation of the unidentified egg group				
121,942,026	European anchovy	312,218,941	42.3	42.3
98,677,999	Dover sole	252,653,999	34.2	76.4
39,757,299	Unidentifiable specimen	101,794,124	13.8	90.2
10,129,108	Pilchard	25,934,450	3.5	93.7
5,889,729	Sprat	15,079,993	2.0	95.8
5,431,629	Rocklings	13,907,079	1.9	97.7
4,546,540	European seabass	11,640,908	1.6	99.2
1,021,511	Gurnards	2,615,465	0.4	99.6
744,391	Dragonets	1,905,931	0.3	99.8
341,358	Garfish	874,009	0.1	100.0
36,000	Lesser weever fish	92,174	0.0	100.0
32,416	Long rough dab	82,998	0.0	100.0
32,307	Sandeels	82,718	0.0	100.0
288,582,312	**Total**	**738,882,789**		
Numbers entrained following re-allocation of the unidentified egg group				
124,143,767	Dover sole	317,856,254	43.0	43.0
123,239,720	European anchovy	315,541,543	42.7	85.7
12,352,555	Sprat	31,627,339	4.3	90.0
11,294,574	Rocklings	28,918,497	3.9	93.9
10,357,745	Pilchard	26,519,849	3.6	97.5
4,694,916	European seabass	12,020,809	1.6	99.1
1,026,768	Gurnards	2,628,925	0.4	99.5
1,016,354	Dragonets	2,602,262	0.4	99.8
352,887	Garfish	903,529	0.1	100.0
36,116	Lesser weever fish	92,471	0.0	100.0
33,511	Long rough dab	85,801	0.0	100.0
33,398	Sandeels	85,512	0.0	100.0
288,582,312	**Total**	**738,882,789**		

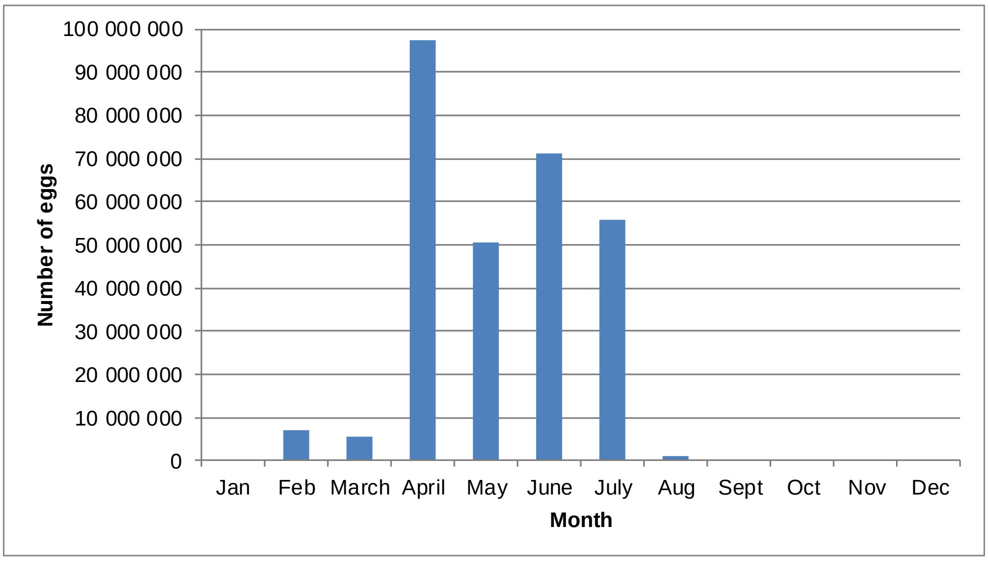

Figure 4 Total estimated numbers of fish eggs entrained at SZB each month.

While the numbers of eggs entrained seems large, it must be borne in mind that the natural mortality of eggs in the wild is substantial. Consequently, the impact of entrainment mortality at SZB or SZC on adult wild populations and fisheries (for those species where fisheries currently exist), will be very much lower than the simple numbers of eggs indicate. In the case of fish eggs, it is possible to make a rough assessment of the impact on fish populations by expressing egg entrainment in the context of the numbers of eggs produced by an “average” or typical spawning female – the “equivalent spawning female”. However, estimates of annual egg production for a given species vary widely, even within studies, which can produce quite different estimates of the number of typical spawning females. Therefore, while the “equivalent spawning females” estimation provides a pragmatic method for scaling egg entrainment to the adult population, it should only be regarded as indicative.

In this analysis, the annual estimated (SZB) and predicted (SZC) egg entrainment has been divided by the number of eggs produced by a spawning female (Table 6). Where the source data provided a range, the lower value has been used to give a worst-case evaluation. Estimates of monthly entrainment of fish eggs by taxon are presented for SZB in Appendix B.1 (initial estimates) and Appendix B.2 (following apportioning of the unidentified eggs group) and predictions for SZC in Appendix B.3 (initial) and Appendix B.4 (apportioned). The numbers of males were not considered, as an individual male can spawn with many females, making the effective reproductive output of a typical male difficult to assess.

Table 6 Total annual estimated (SZB) and predicted (SZC) entrainment of fish eggs in relation to the egg production of a typical spawning female. **Note: the equivalent numbers of spawning females for sole and bass have first been adjusted to account for entrainment passage survival of 20 % and 40 %, respectively and therefore differ from the values given in Table 5**. Where the source data provided a range of number of eggs per female, the lower value has been used in the calculations of equivalent spawning females

Species	Number of eggs per female	Number of eggs, SZB	Number of eggs, SZC	Equivalent number of spawning females, SZB	Equivalent number of spawning females, SZC	Source of egg production data
Dover sole	432,428	99,315,013	254,285,003	230	588	Witthames et al. (1995)
European anchovy	110,000-350,000	123,239,720	315,541,543	1,120	2,869	Motos (1996)
Sprat	8,700-46,600	12,352,555	31,627,339	1,420	3,635	Silva (1973)
Rocklings	3,000-14,000	11,294,574	28,918,497	3,765	9,639	Badsha and Sainsbury (1978)
Pilchard	8,500-11,200	10,357,745	26,519,849	1,219	3,120	Zwolinski et al. (2001)
European seabass	200,000-2,500,000	2,816,950	7,212,486	14	36	Mayer et al. (1990)
Gurnards	2,000-200,000	1,026,768	2,628,925	513	1,314	İşmen et al. (2004)
Dragonets	7,226	1,016,354	2,602,262	141	360	King et al. (1994)
*Garfish	2,193-10,804	352,887	903,529	161	412	Dorman (1991)
Lesser weever fish	No data available	36,116	92,471			
Long rough dab	25,000-250,000	33,511	85,801	1	3	Bagenal (1957)
*Sandeel	5,000-20,000	33,398	85,512	7	17	Macer (1966)
Total		**261,875,592**	**670,503,215**	**8,590**	**21,995**	

** indicates eggs are usually laid on or in a substrate and should not be floating free in the water column, are most likely unviable.*

4.1.2 Entrainment of fish larvae

The larvae of 15 fish taxa were encountered in the SZB forebay (Table 7). Of these, gobies and clupeids (unidentified clupeids, sprat, herring and pilchard) made up 77.0 % of the larvae entrained. Overall, 40.4 % of the larvae present could not be identified due to damage (unidentified specimens = 20.8 %; unidentified clupeids = 19.6 %). The unidentified specimens were first re-allocated monthly to all other species groups, before the unidentified clupeid group was re-allocated monthly to the clupeid species present (Table 7). Note that individual species' proportions and their rankings have changed due to the monthly apportioning process. However, not all unidentified specimens could be re-allocated. In January, there were no species groups identified, so the unidentified specimens group could not be re-allocated. Similarly, in October, no clupeid species were recorded, and the unidentified group could not be re-allocated. Finally, the newly-raised 'Gobies' group was separated into a 'Sand goby' group (to represent *Pomatoschistus* sp.) and an 'Other gobies' group for all other goby species in the proportions 87%:13%.

Larvae appeared in low numbers from January to March and abundance increased up to September (Figure 5). Goby larvae, the most prevalent species, were entrained in all months except January, February and April (Appendix B.5). Although entrainment was highest in September, it was mostly gobies. May was the most species-rich month, with all but two of the species present as larvae (sprat and witch) being entrained.

Table 7 Total annual estimated (SZB) and predicted (SZC) entrainment of fish larvae

SZB	Species	SZC	% of total	Cumulative %
Numbers entrained prior to re-allocation of the unidentified larval groups				
44,698,663	Gobies	114,445,936	48.3	48.3
19,254,719	Unidentifiable specimen	49,299,558	20.8	69.2
18,149,697	Unidentified clupeids	46,470,273	19.6	88.8
5,644,515	Sprat	14,452,150	6.1	94.9
1,103,461	Dragonets	2,825,287	1.2	96.1
979,742	Pilchard	2,508,520	1.1	97.2
1,785,373	Herring	4,571,249	1.9	99.1
233,732	Sandeels	598,445	0.3	99.3
203,189	Dover sole	520,242	0.2	99.6
172,613	Solenette	441,956	0.2	99.7
66,624	Right eyed flatfish	170,584	0.1	99.8
37,128	Pipe-fishes	95,062	0.0	99.9
33,435	European flounder	85,605	0.0	99.9
33,145	Soles	84,865	0.0	99.9
31,719	Sea snail	81,212	0.0	100.0
31,265	Witch	80,050	0.0	100.0
92,459,018		**236,730,994**		
Numbers entrained following re-allocation of the unidentified larval groups and the Gobiidae				
52,073,218	Sand goby	133,327,662	56.3	56.3
17,434,255	Sprat	44,638,462	18.9	75.2
7,781,056	Other gobies	19,922,524	8.4	83.6
6,999,619	Herring	17,921,743	7.6	91.2
3,611,703	Pilchard	9,247,363	3.9	95.1
1,644,325	Unidentified clupeids	4,210,111	1.8	96.8
1,108,154	Dragonets	2,837,305	1.2	98.0
777,113	Unidentifiable specimen	1,989,712	0.8	98.9
262,523	Sandeels	672,162	0.3	99.2
217,835	Dover sole	557,742	0.2	99.4
185,055	Solenette	473,813	0.2	99.6
128,393	Right eyed flatfish	328,736	0.1	99.7
90,581	Witch	231,922	0.1	99.8
39,804	Pipe-fishes	101,914	0.0	99.9
35,845	European flounder	91,776	0.0	99.9
35,535	Soles	90,982	0.0	100.0
34,005	Sea snail	87,066	0.0	100.0
92,459,018		**236,730,994**		

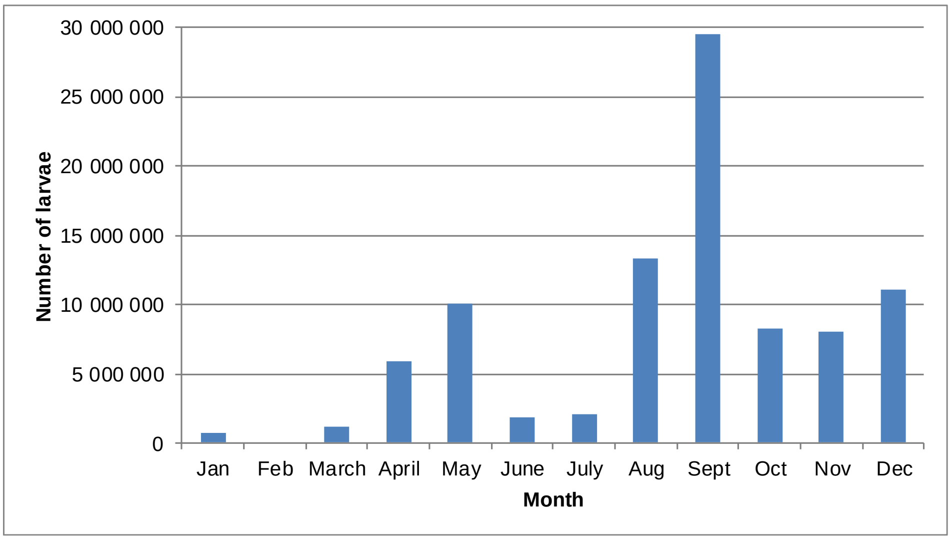

Figure 5 Total estimated numbers of fish larvae entrained at SZB each month.

Like fish eggs (in Section 4.1.1 above), the natural mortality of larvae in the wild is substantial and so the impact of larval entrainment mortality on adult wild populations and fisheries, where they currently exist, will be very much lower than the simple numbers of larvae would suggest. It is not as straightforward as it is for eggs to make an assessment of the impact on fish populations by expressing larval mortality in the context of the numbers of eggs produced by an “average” or typical spawning female, because egg mortality itself is very high so the number of eggs does not equal the number of larvae (for example, a female Dover sole will produce 432 428 eggs (Table 6), but significantly fewer larvae because many of the eggs will die). The method can be applied but requires a prior adjustment to the number of eggs per female to account for egg mortality before the larval phase. This weighting is achieved by estimating the upper and lower number of eggs, by species, that would survive to become larvae, using a generalised (across species) egg mortality range (for pelagic fish, 97 % - 70 %; (Dahlberg, 1979, c.f. Table 1 therein).

In this analysis, an estimate of “equivalent spawning females” (Table 8) has been derived by (i) calculating the numbers of larvae produced by an “average” female (by adjusting the number of eggs produced by an “average” female by the upper (97 %) and lower (70 %) egg mortality rates) and then (ii) dividing the annual estimated (SZB) and predicted (SZC) larval entrainment by these upper and lower estimates of the number of larvae. Again, as with the case for eggs, where the source data provided a range, the lower value has been used to give a worst-case evaluation and this analysis again assumes that all eggs are fertilised and recently spawned.

Estimates of monthly entrainment of fish larvae by taxon are presented for SZB in Appendix B.5 (initial estimates) and Appendix B.6 (following apportioning of the unidentified eggs group) and predictions for SZC in Appendix B.7 (initial) and Appendix B.8 (apportioned).

It was not possible to identify all right eyed flatfish larvae to species; sometimes because the samples were damaged. Three right-eyed flatfish species were identified at Sizewell as larvae or juveniles (flounder, dab and witch) and plaice is the only other right-eyed flatfish that is likely to be found at Sizewell. Juvenile plaice were found in offshore 2m beam trawl samples (BEEMS Technical Report TR201) but at 65-90mm minimum length the juveniles were too large to have been entrained. No plaice larvae were identified in the entrainment sampling and only 1 plaice larva was found in offshore plankton sampling (BEEMS Technical Report TR315) and therefore, although unlikely, the unidentified flatfish could have been plaice. Spawning of plaice in the North Sea occurs in late winter and early spring, with peak spawning activity between January and March and a smaller late spawning activity continuing through to April and May. The unidentified right eyed flatfish larvae were found in May and June. If they had all been plaice, the estimated numbers of spawning female fish would have been between 2 and 20 (based upon fecundity estimates of 100,000 to 130,000 eggs/female from Heessen et al. (2015) representing a negligible impact on the estimated SSB of 549 923 t in 2010 for North Sea plaice (ICES, 2018a).

A single Soleidae larvae was recorded in May that was too badly damaged to identify to species. Of the four Soleidae species present in northwestern European waters (Wheeler, 1978), three (Dover sole, sand sole *Pegusa lascaris* and solenette) have been identified in the Sizewell area either during impingement sampling or in 2 m beam trawl surveys (BEEMS Technical Report TR345). Dover sole spawn in coastal waters in the spring and early summer, while solenette spawn in the summer. Sand sole spawn in the western Channel in July (Wheeler, 1978). If the larvae had been a Dover sole, the estimated numbers of spawning fish would have been between 1 and 7 (based upon fecundity estimates of 432,429 eggs/female from Witthames et al. (1995), in addition to the estimated 4-43 identified Dover sole

Table 8 Estimates (SZB) and predictions (SZC) of the number of “equivalent spawning females” lost through entrainment of fish larvae at an assumed 97 % and 70 % egg mortality. Where the source data provided a range of number of eggs per female, the lower value has been used in the calculations

						Equivalent number of spawning females				
		No. larvae/female		**Number of larvae**		**SZB**		**SZC**		
Species	**Number of eggs per female**	**97% egg mortality**	**70% egg mortality**	**SZB**	**SZC**	**97% egg mortality**	**70% egg mortality**	**97% egg mortality**	**70% egg mortality**	**Source of egg production data**
Sand goby	2,303 - 5,603	69	691	52,073,218	133,327,662	753,701	75,370	1,929,768	192,977	Claridge et al. (1985)
Sprat	8,700-46,600	261	2,610	17,434,255	44,638,462	66,798	6,680	171,029	17,103	Silva (1973)
Other gobies	2,303 - 5,603	69	691	7,781,056	19,922,524	112,622	11,262	288,356	28,836	Claridge et al. (1985)
Herring	24,900-41,700	747	7,470	6,999,619	17,921,743	9,370	937	23,992	2,399	Jennings and Beverton (1991)
Pilchard	8,500-11,200	255	2,550	3,611,703	9,247,363	14,164	1,416	36,264	3,626	Zwolinski et al. (2001)
Unidentifiable clupeids				1,644,325	4,210,111					
Dragonets	7,226	217	2,168	1,108,154	2,837,305	5,112	511	13,088	1,309	King et al. (1994)
Unidentifiable specimen				777,113	1,989,712					
Sandeels	5,000-20,000	150	1,500	262,523	672,162	1,750	175	4,481	448	Macer (1966)
Dover sole	432,428	12,973	129,728	217,835	557,742	17	2	43	4	Witthames et al. (1995)
Solenette	No data			185,055	473,813					
Right eyed flatfish	100,000-130,000	3,000	30,000	128,393	328,736	43	4	110	11	Heessen et al. (2015)
Witch				90,581	231,922					
Pipe-fishes	100-400	3	30	39,804	101,914	13,268	1,327	33,971	3,397	Heessen et al. (2015)
European flounder	2,000,000	60,000	600,000	35,845	91,776	1	0	2	0	Muss and Nielsen (1999)
Unidentified soles				35,535	90,982					
Sea snail	No data			34,005	87,066					
Total				**92,459,018**	**236,730,994**	**976,845**	**97,685**	**2,501,103**	**250,110**	

4.1.3 Entrainment of juvenile fish

Juveniles of 7 fish taxa were entrained in SZB (Table 9). Of these, gobies and sprat made up the overwhelming proportion (~79 %) of the juvenile fish entrained. As with the larval component, the 'Gobies' group was separated into a 'Sand goby' group and an 'Other gobies' group in the proportions 87%:13%.

Inspection of the size range of fish impinged on the drum screens at SZB (BEEMS Technical Report TR339) indicates that few fish below 30 mm are impinged. As the entrainment sampling pump was fitted with a strainer with 8 mm x 18 mm slots (to remove coarse debris from the pumped water; (BEEMS Technical Report TR235), it was concluded that that there is very little overlap, by species, between the juvenile fish detected in the impingement monitoring and the entrainment monitoring programmes. Thus, it is appropriate to calculate impingement and entrainment predictions separately.

Juvenile fish appeared in most months of the year (Figure 6) but varied by taxon across the year. Gobies and sprat juveniles were recorded throughout the year, but not in all months; May, August and November were the months of highest goby entrainment while almost half of the entrained sprat were recorded in August (Appendix B.9). In contrast, juvenile herring were entrained only in May, butterfish and dab only in September, and only one juvenile sandeel was recorded in December.

Table 9 Total annual estimated (SZB) and predicted (SZC) entrainment of entrained juvenile fish

SZB	Species	SZC	% of total	Cumulative %
Numbers entrained prior to re-allocation of the unidentified juvenile group				
8,707,566	Gobies	22,294,750	44.6	44.6
6,828,612	Sprat	17,483,898	35.0	79.6
1,969,535	Dab	5,042,775	10.1	89.7
986,334	Butter fish	2,525,399	5.1	94.8
812,165	Unidentifiable specimen	2,079,458	4.2	99.0
120,269	Pipe-fishes	307,935	0.6	99.6
50,379	Sandeels	128,990	0.3	99.8
33,788	Herring	86,511	0.2	100.0
19,508,648		**49,949,716**		
Numbers entrained following re-allocation of the unidentified juvenile group and the Gobiidae				
7,602,995	Sand goby	19,466,620	39.0	39.0
7,584,699	Sprat	19,419,776	38.9	77.9
1,969,535	Dab	5,042,775	10.1	87.9
1,136,080	Other gobies	2,908,805	5.8	93.8
986,334	Butter fish	2,525,399	5.1	98.8
144,512	Pipe-fishes	370,006	0.7	99.6
50,379	Sandeels	128,990	0.3	99.8
34,114	Herring	87,346	0.2	100.0
19,508,648		**49,949,716**		

Note: The number of entrained juvenile fish caught during the monitoring programme was very small for some species and the scaled-up numbers must therefore be treated with caution. For example, only 1 juvenile sandeel and 1 herring was caught in the 40 samples. The calculated annual catches differ due to the volumes of water filtered during the collection of the two samples.

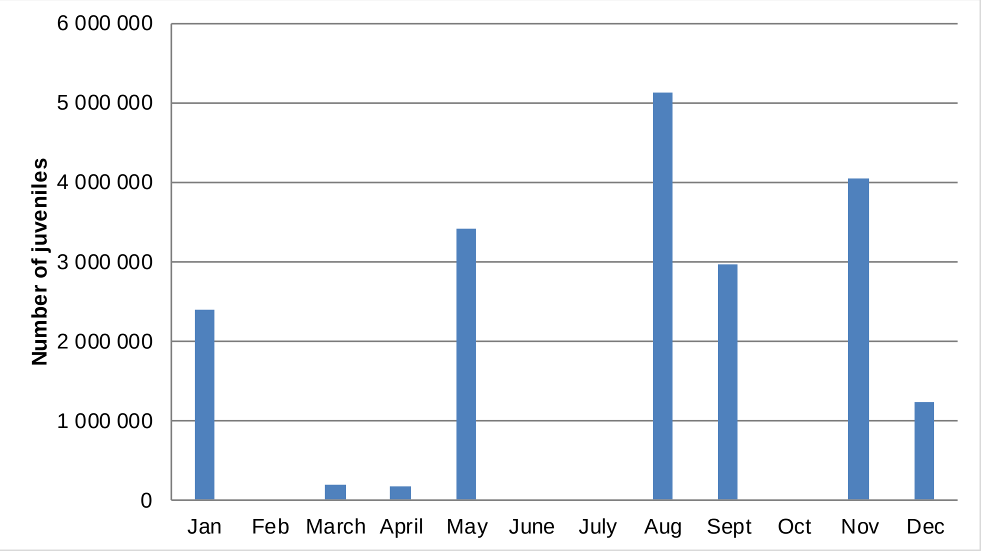

Figure 6 Total estimated numbers of juvenile fish entrained at SZB each month.

Like fish eggs and larvae (see Sections 4.1.1 and 4.1.2 above), juvenile fish also experience significant natural mortality and so entrainment mortality at the population level is not a straightforward mirror of the numbers of juveniles entrained. The natural mortalities of juvenile fish will be lower than for eggs or larvae, but it is currently difficult to assess this, since size distribution data were not available for entrained larvae. However, inspection of the size range of fish impinged on the drum screens at SZB (BEEMS Technical Report TR339) indicates that few are below 30 mm it is assumed that entrained juveniles are no larger than 30 mm. Consequently, and where the necessary ancillary biological data exist (i.e. an age-length key and the von Bertalanffy growth parameters L_∞ and k), an “worst case” equivalent adult value (EAV) has been calculated for entrained juvenile fish, assuming size at entrainment of 30 mm (BEEMS Technical Report TR383). For pipe-fish, where biological and other data cannot be obtained, a worst case (and unrealistic) EAV of 1 was used (Table 10).

Table 10 Estimates (SZB) and predictions (SZC) of the number of “adult equivalent” fish lost through entrainment of juvenile fish. (The use of EAV of 1 in yellow generates considerable overestimates in equivalent adults). EAV calculations are given in BEEMS Technical Report TR383

Species	Number of juveniles, SZB	Number of juveniles, SZC	EAV	Equivalent number of Adults, SZB	Equivalent number of Adults, SZC
Sand goby	7,602,995	19,466,620	0.049	375,892	962,430
Sprat	7,584,699	19,419,776	0.00129	9,784	25,052
Dab	1,969,535	5,042,775	0.004325	8,518	21,810
Other gobies	1,136,080	2,908,805	0.049	56,168	143,811
Butter fish	986,334	2,525,399	0.01345	13,266	33,967
Pipe-fishes	144,512	370,006	1.00	144,512	370,006
Sandeels	50,379	128,990	0.112	5,663	14,501
Herring	34,114	87,346	0.00000006	0	0
Total	**19,508,648**	**49,949,716**		**613,804**	**1,571,576**

Estimates of monthly entrainment of fish larvae by taxon are presented for SZB in Appendix B.9 (initial estimates) and Appendix B.10 (following apportioning of the unidentified eggs group) and predictions for SZC in Appendix B.11 (initial) and Appendix B.12 (apportioned).

4.1.4 Combined entrainment of fish eggs, larvae and juveniles

The overall estimated (SZB) and predicted (SZC) entrainment losses for fish (eggs, larvae and juveniles combined), with no adjustments for entrainment survival of bass or sole eggs or for equivalent females, are given in Table 11. The calculated equivalent numbers of adults (spawning females for eggs and larvae, EAV for juveniles) that are predicted to be lost at SZC as a result of entrainment are given in Table 12, along with (for commercially-important species) the stock unit landings and stock unit SSB (Spawning Stock Biomass).

4.1.5 Entrainment of fish species of conservation interest

Six fish species that have formal conservation status are known to migrate in the vicinity of the Suffolk coast. Five of these species (twaite shad (*Alosa fallax*), Allis shad (*Alosa alosa*), river lamprey (*Lampetra fluviatilis*), cucumber smelt (*Osmerus eperlanus*) and sea trout (*Salmo trutta*) are anadromous (i.e. migrate from the sea into freshwater to spawn). The 0 group of twaite shad, allis shad and sea trout are not at risk of entrainment at Sizewell C as that part of their lifecycle is spent in rivers until they are too large to be entrained. In theory, very early life stages of river lamprey and possibly cucumber smelt could be present in the marine environment at Sizewell at a sufficiently small size to be entrained. However, these species are readily identifiable, and none were detected in the Sizewell entrainment and plankton sampling programmes.

The European eel (*Anguilla anguilla*) is catadromous, migrating as glass eels from the marine environment into estuaries and freshwater to feed and grow as yellow eels, then migrating back to sea as silver eels, ultimately to spawn in the Sargasso Sea. The glass eel phase of the eel lifecycle is potentially at risk from entrainment at Sizewell C. Glass eels enter estuaries all year round, with migration peaks depending on latitude and the variability of oceanic factors. In southwest Spain, highest densities occur between late autumn and spring with two migration peaks observed, whereas peak glass eel migration in the UK is later, typically occurring from February to May.

Glass eels that contribute to UK populations first arrive in the Western Approaches and then transit with the tidal currents either through the English Channel into the southern North Sea or from the north, following currents that flow around Scotland and southwards into the southern North Sea. The time to reach the southern North Sea is dependent on met-ocean conditions over Northern Europe and the relative strength of the Gulf Stream and associated currents around the British Isles. However, little is known about the residence times of glass eels in the southern North Sea. It is considered that glass eels reach the coast and then seek a salinity or other chemical cue to commence migrations up estuaries and then, for a large proportion of their number, to freshwater. The time spent in the open North Sea will, therefore, be dependent on the tidal currents and when the eels sense estuarine cues. In the journey from the Western Approaches to the southern North Sea the density of glass eels in coastal waters will be reduced progressively and substantially as large proportions of the eels migrate up estuaries encountered on route. In particular, eels travelling through the Channel and then heading north will encounter the very large Thames freshwater signal followed by signals from Essex and Suffolk rivers before they reach the coast in the vicinity of Sizewell. Residual hydrodynamic flows will also tend to carry a proportion of eels passing through the Straits of Dover towards the Dutch Coast. Eels migrating from the north will also encounter freshwater signals at for example the Humber, the Wash, North Norfolk coast rivers and the Broads at Yarmouth. Thereafter residual flows will tend to carry eels towards continental Europe. The net result of these tidal flow patterns is that the expected glass eel density in the vicinity of Sizewell would be expected to be the amongst the lowest in the UK (on their migration route).

Given their morphology of typically 4 mm width (and up to 8mm width for 130mm long elvers), it is likely that most glass eels (and elvers) will pass through the 10 mm mesh on the SZB (and proposed SZC) cooling water screens and only rarely appear in impingement samples. In the BEEMS CIMP programme from 2009 to 2017 only two glass eels were sampled; 1 in March 2013 and 1 in January 2017 with both of length of approximately 67.5mm. The BEEMS targeted glass eel surveys in April and May 2015 (BEEMS Technical Report TR356) only detected 1 glass eel in 105 valid tows using a methodology which successfully sampled many glass eels in the Bristol Channel. No glass eels or elvers have been detected in water drawn from the SZB forebay during the 12 month BEEMS Comprehensive Entrainment Monitoring Programme at Sizewell in 2011 (BEEMS Technical Report TR235) nor in any of the 620 plankton tows in surveys conducted at

Sizewell between 2008 to 2017. The totality of data from this extensive sampling programme led to the conclusion that whilst glass eels are present in Sizewell coastal waters, their density is very low at this location.

In addition, glass eels are considered to make use of selective tidal stream transport to migrate to suitable estuaries at or near to the sea surface where they would not be at risk of entrainment from the deep SZC intakes except possibly for a short period at slack water.

The potential effect of glass eel entrainment in SZC has, therefore, been assessed as negligible, especially given the high measured survival (80% or higher) in laboratory studies that simulated the physical and chemical conditions and time of exposure and that any entrained glass eels would encountered within Sizewell C (Table 2).

4.1.5.1 Consideration of stakeholder comments on the glass eel entrainment assessment.

During stakeholder engagement on the effects of SZC on fish, the Environment Agency (EA) has questioned whether the BEEMS surveys would have adequately detected glass eels. In particular, the EA have suggested that:

1. the glass eel specific surveys targeted the surface waters during daylight when glass eels would have been seeking refuge near the seabed.
2. all the glass eels sampled in the entrainment monitoring programme could have crawled out of the sampling nets before the nets were emptied.

These points have been carefully considered. In relation to point 1, the eel behaviour that the EA have described is from upper estuaries not in lower estuaries or coastal waters (Harrison *et al.,* 2014). At Hinkley Point (i.e. in the lower estuary) large numbers of glass eels were successfully sampled using the same methodology employed at Sizewell whereby the upper part of the water column is sampled during the daytime on the flood tide. As expected virtually no glass eels were detected on the ebb tide which is the behaviour that would be expected from fish using selective tidal stream transport (STST) to migrate on all of the available flood tides. Therefore, glass eels do migrate during daylight hours on flood tides at such locations (not just at night). This is supported by Lambert *et al.,* 2007 where 30% of glass eels were found to migrate on the flood by day in the lower section of the Gironde estuary. Glass eels have poor swimming abilities and STST is the most energy efficient means of transport. Based upon the relative timings of eel arrivals in UK estuaries it is considered likely that glass eels employ STST on flood tides in coastal waters during day and night, particularly where underwater light levels are low due to high suspended sediment concentrations such as on the UK east coast. The question of whether the BEEMS surveys were too late could also be posed. The sample timings were determined from known glass eel arrival times on the UK east coast. For example, EA monitoring at Beeleigh Cut on the Blackwater (to the south of Sizewell where glass eel densities would be expected to be higher than off Sizewell assuming their likely southern migration route around the UK) showed that peak glass eels numbers were detected in May with substantial numbers in April and June but very low numbers of arrivals in March which would imply that the BEEMS survey timing was appropriate. The year 2015 could also have been a year of anomalously low glass eel recruitment but Figure 7 shows that this was not the case and in fact 2015 was a year that reflected the increase in glass eel recruitment observed across Europe from 2011 onwards described in Section 6.6.4.1. The BEEMS targeted glass eel surveys are, therefore, not considered invalid and if substantial number of glass eels were present at Sizewell the surveys would have detected them.

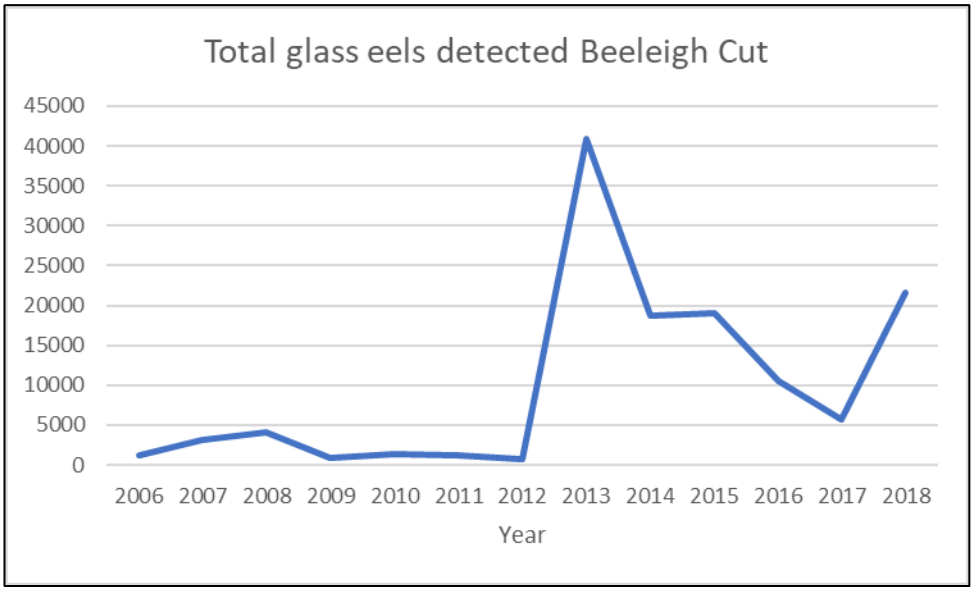

Figure 7 EA monitoring data for upriver glass eel migration from the Blackwater in Essex.

In relation to the EA's second point, glass eels are indeed known to crawl to overcome barriers but this is reported behaviour from upper estuaries:

"*Although STST is the primary mechanism facilitating migratory passage through estuaries, where tidal effects become weaker in upper estuarine zones, a behavioural shift to active swimming is necessitated to effect further dispersion upstream at the freshwater interface or more certainly from the point where they accumulate glass eels change their behavioural pattern and actively migrate counter current. Such an active migration is revealed in the 'crawling' behaviour that glass eels display on trapping ladders*." Harrison *et al.*, 2014.

The crawling behaviour described is a behavioural change associated with the tidal interface not necessarily in the coastal zone. Assuming glass eels in the marine environment could climb barriers, the net sides in the entrainment tanks were very steep and Cefas considers it highly unlikely that, if any eels had been caught, that they would all have climbed out of all of the many nets deployed. In particular, the type of pump used to sample the SZB forebay for the entrainment sampling would have been likely to have compromised the likelihood of glass eel survival, further reducing the possibility of 100% escapement from the sampling nets.

In conclusion, the glass eel migration pattern around the UK, the strength and direction of coastal currents and the large number of freshwater rivers that the eels would encounter on route would mean that glass eel densities at Sizewell would be expected to be very low and amongst the lowest on the UK coast (on the eel migration route). This low-density conclusion is supported by monitoring data. However, that monitoring data does confirm that a few glass eels do transit past Sizewell whilst seeking freshwater signals. On energy efficiency grounds this migration is most likely to use a form of STST in near surface waters. When the tide is in the 'wrong' direction the evidence suggests that glass eels are stationary on, or even buried in the bottom sediments to avoid being carried away from their preferred migration course. Such a migration strategy will mean that there is a low risk of abstraction into power stations with bottom mounted intakes which do not abstract surface water except minimally at slack water. The deeper the intakes, the lower the risk of abstraction. It would therefore be expected that glass eel abstraction at SZB would be greater than at SZC due to substantially deeper water at the proposed SZC intakes. The abstraction risk zone for the SZC intake heads depends on the swimming ability of the species. Glass eels are weak swimmers and can sustain approximately 0.25 m/s for only 3 minutes before exhaustion and have a sustained swimming speed of no more than 0.05 m/s for long periods (McCleave 1980). Glass eels resting on the seabed would be unlikely to be abstracted as the SZC intake surfaces would be 1.5 to 3.5m above the bed. The only times that glass eels would be at risk is when they were settling towards or moving off the seabed. In which case, only those individuals that were within a worst case 7 m of the intakes would be entrained (BEEMS Scientific Position Paper SPP099). This represents a very small volume of water at the SZC intakes compared to the potential volume that the eels could settle in within Sizewell Bay and the abstraction risk is, therefore, considered minimal. The same argument would apply at SZB (whilst recognising that the risk would probably be larger due to the shallower water at the SZB intakes) and combined with the expected low glass eel densities at the site and their migration pattern in surface waters would provide a coherent explanation of the absence of glass eels in the SZB entrainment monitoring surveys.

The targeted glass eel surveys only detected 1 individual from which it is not possible to deduce anything about their spatial distribution in Sizewell Bay and, in particular, whether the expected density would be lower or higher at the SZC intakes than at the SZB intakes. However, it is known that glass eels are seeking a freshwater signal as a cue to migrate up estuary. Due to dilution and the effects of tidal advection, the probability of detecting such signals will reduce rapidly with distance from the coast especially given the very strong shore parallel tidal currents along the Suffolk coast and the presence of offshore sandbanks. Many of the freshwater discharges on the East Anglian coast are relatively small, especially in the vicinity of Sizewell e.g. the Blyth and discharges from the Minsmere sluice, and such small signals in combination with the effects of dilution and tidal advection would indicate that a close to shore migration strategy would be the most likely to be allow the eels to find estuaries. On that basis, the working hypothesis is that glass eels migrating on the coast will preferentially swim close to the coast and that their density offshore at the location of the SZC intakes would be lower than at the SZB intakes. Some evidential support for this hypothesis is provided by glass eel behaviour in lower estuaries where it is known that they occur in the highest densities closest to the estuary shorelines when migrating up the estuary (For example at Hinkley Point).

Considering the totality of the monitoring evidence and the implications of glass eel migration pattern around the UK, it is considered that the conclusions that the density of glass eels off Sizewell was very low and that the risk of any significant entrainment effects on glass eel recruitment would be negligible are supported by the evidence.

4.1.6 Entrainment of fish eggs, larvae and juveniles in relation to fish populations

To put the entrainment loss of fish eggs, larvae and juveniles of the 8 key taxa into context, the adult equivalent estimates given in the previous section for each life history stage were summed, and converted to fish weights using, where possible, the mean weights of adult fish landed from commercial catches (calculated from data given in ICES Working Group reports). These total weights were related to the international landings and spawning stock biomass (SSB) information from ICES stock assessments and presented in Appendix C. The resulting estimates of loss to populations and fisheries are given in Table 12.

In BEEMS Technical Report TR406 the scientific rationale for considering 1% of SSB (or international landings) as a precautionary screening threshold has been described. For unexploited stocks this threshold is considered unrealistically conservative and for many unexploited species that occur at UK latitudes, a sustainable level of mortality is considered to be equal to the natural mortality (M) of the species (implying a sustainable harvesting rate of 10%-20% for such species, BEEMS Technical Report TR406). This formula is not conservative for very short lived (or tropical species) where the sustainable value of fishing mortality is less than M, typically 0.25 to 0.5 M (Caddy and Csirke 1983). Gobies are such a short-lived species reproducing within the first year of life. They are a very abundant species that is 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 that would indicate the possibility of separate stock identities over large geographic areas. Sand gobies have an estimated M of 3.3 (Fishbase) implying a sustainable harvesting rate of greater than 50%. The 10% threshold for unexploited stocks proposed in BEEMS Technical Report TR406 is, therefore, highly conservative for this species.

For the seven of the 8 key taxa entrained at Sizewell the predicted entrainment losses are much less 1 % of the SSB or the international landings of that species in 2010 (year of sampling). The highest predicted loss was 0.001% of SSB for sprat or 0.01% landings for dab. Gobies are an unexploited species and the predicted entrainment loss is 1.4 % of the mean population numbers which is less than the highly conservative screening threshold of 10% for that species.

Losses of sand eels are compared with SBB and landings, even though these do not fulfil the key taxa criteria in the fish characterisation report (BEEMS Technical Report TR345). Sandeel losses at 0.0001% SSB were significantly less than the 1 % screening threshold and are considered an overestimate due to the use of an EAV of 1 for juveniles.

Table 11 Summary of estimated entrainment losses (unadjusted for entrainment survival or equivalent adults) by life history stage at SZB (upper) and SZC (lower) (taken from Table 5, Table 7 and Table 9). Key taxa are shaded green.

Species	Eggs	Larvae	Juveniles	Total
Predicted entrainment loss (unadjusted numbers) for SZB				
Butter fish			986,334	986,334
Dab			1,969,535	1,969,535
Dover sole	124,143,767	217,835		124,361,602
Dragonets	1,016,354	1,108,154		2,124,509
European anchovy	123,239,720			123,239,720
European flounder		35,845		35,845
European seabass	4,694,916			4,694,916
Garfish	352,887			352,887
Gurnards	1,026,768			1,026,768
Herring		6,999,619	34,114	7,033,733
Lesser weever fish	36,116			36,116
Long rough dab	33,511			33,511
Pilchard	10,357,745	3,611,703		13,969,448
Pipe-fishes		39,804	144,512	184,316
Right eyed flatfish		128,393		128,393
Rocklings	11,294,574			11,294,574
Sandeels	33,398	262,523	50,379	346,300
Sand goby		52,073,218	7,602,995	59,676,213
Sea snail		34,005		34,005
Solenette		185,055		185,055
Sprat	12,352,555	17,434,255	7,584,699	37,371,509
Witch		90,581		90,581
Unidentifiable clupeids		1,644,325		
Unidentifiable gobies		7,781,056	1,136,080	
Unidentifiable soles		35,535		
Unidentifiable specimen		777,113		
Total	**288,582,312**	**92,459,018**	**19,508,648**	**398,093,006**
Predicted entrainment loss (unadjusted numbers) for SZC				
Butter fish			2,525,399	2,525,399
Dab			5,042,775	5,042,775
Dover sole	317,856,254	557,742		318,413,996
Dragonets	2,602,262	2,837,305		5,439,567
European anchovy	315,541,543			315,541,543
European flounder		91,776		91,776

Species	Eggs	Larvae	Juveniles	Total
European seabass	12,020,809			12,020,809
Garfish	903,529			903,529
Gurnards	2,628,925			2,628,925
Herring		17,921,743	87,346	18,009,088
Lesser weever fish	92,471			92,471
Long rough dab	85,801			85,801
Pilchard	26,519,849	9,247,363		35,767,211
Pipe-fishes		101,914	370,006	471,920
Right eyed flatfish		328,736		328,736
Rocklings	28,918,497			28,918,497
Sandeels	85,512	672,162	128,990	886,664
Sand goby		133,327,662	19,466,620	152,794,282
Sea snail		87,066		87,066
Solenette		473,813		473,813
Sprat	31,627,339	44,638,462	19,419,776	95,685,577
Witch		231,922		231,922
Unidentifiable clupeids		4,210,111		
Unidentifiable gobies		19,922,524	2,908,805	
Unidentifiable soles		90,982		
Unidentifiable specimen		1,989,712		
Total fish	**738,882,789**	**236,730,994**	**49,949,716**	**1,019,272,695**

Table 12 Predicted entrainment losses by life history stage at SZC adjusted to give equivalent numbers of spawning females and equivalent numbers of adults (where species data are available to make estimates). For key taxa (green shading), losses are shown in relation to stock landings and SSB (or for sand gobies, an estimate of population abundance – given in red).

	Entrainment loss (equivalent spawning females or EAV)				**Total entrainment loss (as adults)**								
Species	**Eggs**	**Larvae (97 % egg mortality)**	**Larvae (70 % egg mortality)**	**Juvenile**	**Lower estimate**	**Upper estimate**	**Fish wt (kg)**	**Total wt (t) upper estimate**	**Stock landings (t)**	**Stock SSB (t)**	**% of landing**	**% of SSB**	**Source of fishery data**
Dab				21,810	21,810	21,810	0.040	0.872	8,279	NA	0.011	NA	ICES (2018)
Dover sole	588	43	4		592	631	0.227	0.143	12,603	31,358	0.001	0.000	ICES (2018)
European anchovy	2,869				2,869	2,869	0.021	0.060	727	NA	0.008	NA	ICES catch download
European flounder		2	0		0	2	0.082	0.000	3,365	NA	0.000	NA	ICES (2018)
European seabass	36				36	36	1.365	0.049	4,768	20,780	0.001	0.000	ICES (2018b)
Herring		23,992	2,399	0	2,399	23,992	0.174	4.175	187,600	2,023,720	0.002	0.000	ICES (2018c)
Sprat	3,635	171,029	17,103	25,052	45,790	199,715	0.010	1.997	143,500	225,041	0.001	0.001	ICES (2018c)
Sand gobies		1,929,768	192,977	962,430	1,155,406	2,892,198				205,882,353		1.40	Rogers and Millner (1996)
Butterfish				33,967	33,967	33,967							
Dragonets	360	13,088	1,309		1,669	13,449							
Garfish	412				412	412							
Gurnards	1,314				1,314	1,314							
Long rough dab	3				3	3							
Pilchard	3,120	36,264	3,626		6,746	39,384							
Pipe-fishes		33,971	3,397	370,006	373,403	403,977							
Right eyed flatfish		110	11		11	110							
Rocklings	9,639				9,639	9,639							
Sandeel	17	4,481	448	14,501	14,966	18,999	0.007	0.127	300,893	124,742	0.00004	0.00010	ICES (2018c)
Unidentified gobies		288,356	28,836		28,836	288,356							
Total	**21,995**	**2,501,103**	**250,110**	**1,571,576**	**1,843,681**	**4,094,674**							

Notes to Table 12

1. For the Gobies stock estimate see Appendix C.9.3
2. For pipefish, an EAV of 1 was used, which unrealistically overestimates entrainment mortality

4.2 Entrainment of invertebrate zooplankton

Forty-nine invertebrate zooplankton taxa were encountered in the SZB cooling water (Table 13). These have been arranged into groups for the purposes of the environmental impact assessment. The groups are based on similarities in planktonic life habit, taxonomy or form using the list of key taxa reported for the offshore surveys (BEEMS Technical Report TR315). Of these groups, copepods made up 72.1 % of the total zooplankton entrained while bentho-pelagic taxa (mainly gammarids and mysids) and primarily benthic taxa (mostly barnacles) comprised a further 18.0 % (Table 14).

Zooplankton were entrained in all months of the year, but only in low numbers in January through to March, with March being the minimum (Figure 8). Peak zooplankton entrainment occurred in May and then declined gradually through the summer and autumn. Details of monthly entrainment of zooplankton by taxon are presented in Appendices B.13 and B.14.

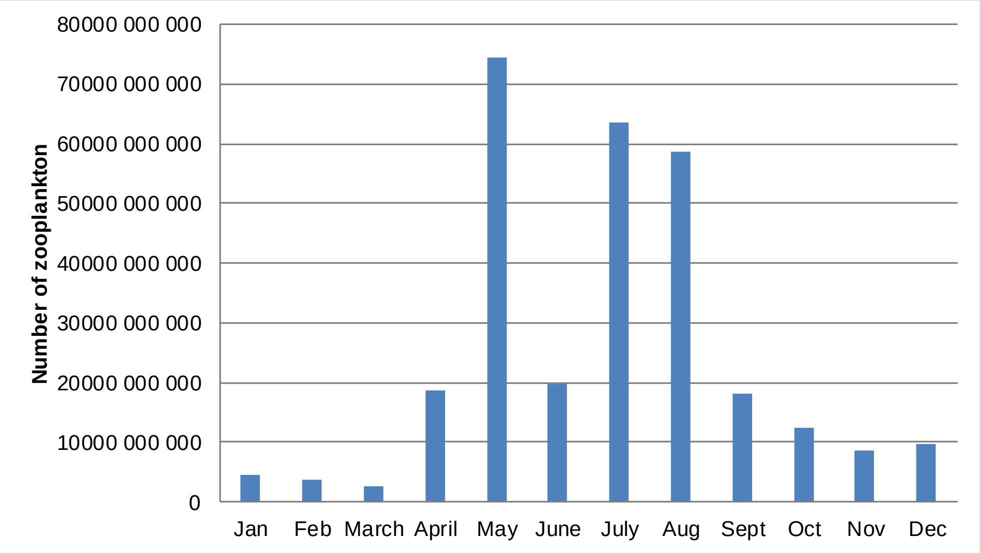

Figure 8 Total estimated numbers of invertebrate zooplankton entrained at SZB each month

During the CEMP survey, simultaneous pumped water samples were taken from the SZB forebay and from near to the SZB intakes at the intake depths. There was little difference in fish egg and larval densities between the two sampling methods. For the invertebrate macro zooplankton, the onshore sampling caught many more mysids and gammarids than did the offshore sampling. This is not unexpected as it is known that both taxa have the ability to actively avoid small aperture sampling devices (Mees and Jones, 1997). Mysids and gammarids live in the hyperbenthic or epibenthic zone close to or on the seabed where they are difficult to sample without the use of purpose-designed sledges. More generally, mysids form dense shoals and therefore repeat samples are prone to produce highly variable density estimates. Both groups are only likely to become vulnerable to pumped or net samplers located 2 m above the bed when they either engage in diel vertical migrations or are temporarily moved off the bottom by sediment resuspension under wave action.

Table 13 Total annual estimated (SZB) and predicted (SZC) invertebrate entrainment. Taxa are arranged into “assessment groups” as follows: 1=copepods, 2=bentho-pelagic taxa, 3=primarily benthic taxa and larvae of benthic taxa, 4=invertebrate eggs, 5=foraminifera, 6=gelatinous plankton, 7=tunicates, 8=nematodes, 9=non-determinate taxa and 10=other non-key taxa[2].

Total SZB	Species/taxon	Total SZC	% of total	Functional group
90,804,418,404	*Centropages* spp. (Copepod)	232,494,574,966	30.84	1
66,308,863,895	*Temora* spp. (Copepod)	169,776,442,588	22.52	1
24,350,227,027	*Acartia* spp. (Copepod)	62,346,037,588	8.27	1
10,420,353,589	*Isias* spp. (Copepod)	26,680,151,928	3.54	1
7,972,319,840	Copepoda (including damaged specimens)	20,412,234,837	2.71	1
3,672,057,749	*Pseudocalanus elongatus* (Copepod)	9,401,893,879	1.25	1
2,126,577,765	*Paracalanus* spp. (Copepod)	5,444,864,934	0.72	1
1,840,744,205	Harpacticoida (Copepod)	4,713,020,017	0.63	1
1,579,451,480	Calanoid (Copepod)	4,044,009,169	0.54	1
1,466,827,275	*Parapontella brevicornis* (Copepod)	3,755,647,465	0.50	1
792,911,584	*Pseudocalanus* spp. (Copepod)	2,030,161,582	0.27	1
301,634,997	*Calanus* spp. (Copepod)	772,302,732	0.10	1
246,460,852	*Temora longicornis* (Copepod)	631,035,494	0.08	1
227,624,900	*Cyclopoida* (Copepod)	582,808,141	0.08	1
68,472,730	*Siphonostomatoida* (Copepod)	175,316,780	0.02	1
10,756,173	*Stephos* spp. (Copepod)	27,539,979	0.00	1
7,332,268	*Oithona* spp. (Copepod)	18,773,455	0.00	1
8,235,550	*Eurytemora* spp. (Copepod)	21,086,207	0.00	1
4,357,372	*Caligus* spp. (Parasitic copepod)	11,156,565	0.00	1
3,639,878	*Paramisophria* spp. (Copepod)	9,319,501	0.00	1
25,692,326,281	*Gammaridae* (Amphipoda)	65,782,332,882	8.72	2
9,984,663,956	*Mysidacea* (Opposum shrimps)	25,564,617,267	3.39	2
3,904,094,049	Cumacea	9,995,996,919	1.33	2
9,935,084,259	Cirripedia (Barnacles)	25,437,673,989	3.37	3
2,224,775,897	Lamellibranch (Bivalves)	5,696,290,288	0.76	3
631,094,661	Polychaeta (Bristle worms)	1,615,847,418	0.21	3
294,241,382	Echinodermata (Starfish/sea urchins)	753,372,206	0.10	3
211,782,628	*Ectoprocta/ bryozoa* (Sea mats)	542,245,774	0.07	3
82,877,137	*Arachnida (Mites)*	212,197,657	0.03	3
7,300,734,045	Invertebrate eggs	18,692,714,391	2.48	4
7,244,971,221	Foraminifera	18,549,939,907	2.46	5
1,909,675,639	Cnidaria	4,889,511,256	0.65	6
1,022,820,221	Medusae (Jellyfish)	2,618,816,978	0.35	6
456,648,741	Hydrozoa	1,169,198,116	0.16	6
294,032,753	Ctenophora (Sea gooseberries)	752,838,035	0.10	6
320,803,358	Appendicularia (Pelagic tunicates)	821,381,179	0.11	7
23,257,796	Urochordata (Tunicates)	59,548,989	0.01	7
170,041,982	Nematode (Roundworm)	435,373,510	0.06	8
4,191,096,572	Gastropoda	10,730,834,834	1.42	9
2,048,644,042	Isopoda (Isopod)	5,245,324,337	0.70	9
982,201,666	Decapoda	2,514,817,702	0.33	9
741,011,536	Shrimps and prawns-like decapods	1,897,277,305	0.25	9

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[2] Non-determinate taxa are those not identified to a sufficient taxonomic level to place them into one of the assessment groups (e.g. isopods, which can be either benthic or pelagic); other non-key taxa are those found in the plankton locally but not sufficiently common or abundant to be defined as key taxa.

Total SZB	Species/taxon	Total SZC	% of total	Functional group
503,976,628	Unidentified specimen	1,290,375,887	0.17	9
1,909,975,229	Chaetognatha (Arrow worms)	4,890,278,324	0.65	10
67,226,840	Hydroida	172,126,817	0.02	10
50,065,510	Brachyura (True crabs)	128,187,148	0.02	10
24,359,982	Hyperiidae (Amphipoda)	62,371,015	0.01	10
17,568,000	*Podon* spp. (Cladocera)	44,980,903	0.01	10
15,044,202	Pycnogonid (Sea Spider)	38,519,000	0.01	10
294,468,363,746	**Total**	**753,953,367,837**		

Table 14 Entrained invertebrate zooplankton functional groups

Functional group	% of total
Copepods	72.07
Bentho-pelagic taxa	13.44
Primarily benthic taxa and their larvae	4.54
Invertebrate eggs	2.48
Foraminifera	2.46
Gelatinous plankton	1.25
Tunicates	0.12
Nematodes	0.06
Non-determinate taxa	2.88
Other non-key taxa	0.71

Zooplankton have high rates of natural mortality due to predation. Entrainment into SZC will increase the rate of local mortality and could, therefore, have localised effects on food availability for other species in the food web. The invertebrates entrained at Sizewell are all common and widely distributed and any calculation of the effect of SZC at the population level (e.g. by calculating the ratios of entrained seawater volumes to the volumes occupied by the relevant population over the period of the animal's pelagic life stage) will have negligible impact, as discussed in Section 2.2.2. Instead, we have undertaken calculations to determine what the effect of SZC would be at a local level i.e. within the volume of seawater at risk of abstraction into the power station.

As set out in Section 2.2.2, BEEMS Technical Report TR385 estimates that the zone at risk of abstraction has a volume of $8.45\ 10^{8}\ m^{3}$ and experiences a seawater exchange with the adjoining sea area of 10 % per day or $8.45\ 10^{7}\ m^{3}$. SZC will abstract 131.86 cumecs or $1.14\ 10^{7}\ m^{3}$ per day, i.e. 1.35 % of the abstraction risk zone per day. However, given that the daily exchange between the SZC abstraction risk zone and adjoining sea areas is 7.8 x the SZC daily abstraction rate, even the effect of 100 % entrainment mortality for relatively long lived species such as mysids would not be detectable against the natural variability in zooplankton abundance (natural mortality estimates are given in Table 15). Nevertheless, even though it is considered that increases in mortality may not be detectable, there will be a localised reduction in zooplankton abundance and this report has attempted to derive worst case estimates for the size of the effect for the most dominant groups (copepods, bentho-pelagic taxa and the primarily benthic taxa).

Table 15 Estimates of natural mortality for invertebrate zooplankton

Species	Group	Estimated natural mortality M d^{-1}	Source
Acartia tonsa	Copepod	0.70	McGurk (1986)
Acartia tonsa	Copepod	0.70	Rumrill (1990)
Acartia tonsa	Copepod	0.82	Rumrill (1990)
Centropages typicus	Copepod	0.24	Rumrill (1990)
Balanus sp.	Benthic taxa	0.145	Rumrill (1990)
Mysid juveniles (*Metamysidopsis elongata*)	Bentho-pelagics	0.06	Clutter and Theilacker (1971)

Note: Natural mortality (M) of invertebrate larvae is dominated by predation (Hirst and Kiørboe, 2002) and therefore estimates of M are typically derived by following populations in their environment over time. Such studies are difficult, and time consuming to undertake and estimates of zooplankton mortality rates are therefore scarce. The difficulties of following populations in coastal areas, which are spatially variable and subject to advection in and out of the study area, also mean that the published estimates of M can be variable e.g. for barnacle larvae estimates of M range from 0.33 to 0.06. Also note that the value given for *Centropages typicus* is for nauplii only.

The estimated entrainment mortality in SZC, derived from EMU experiments where possible, is shown in Table 16. Because mysid mortality is temperature-dependant, a further calculation was made to derive their total annual entrainment mortality using the profile of mysid numbers collected at SZB during the 1-year CEMP (BEEMS Technical Report TR235) and the measured mortality with temperature from SZC EMU experiments (BEEMS Technical Report TR394). This is presented in Table 17.

Table 16 Estimates of entrainment mortality in Sizewell C (copepod and mysid data are from Table 2)

Assessment group	Estimated entrainment mortality SZC
Copepods	30 %
Bentho-pelagic (gammarids)	Unknown – a worst case of 100 % has been assessed
Bentho-pelagic (mysids)	30 % - 100 % dependent upon temperature
Benthic (barnacles)	Unknown – a worst case 100 % has been assessed.

Table 17 Estimate of total mysid entrainment mortality at Sizewell C

SZC outfall temperature °C (=ambient temperature + 11.6°C)	% of mysids caught at SZB at corresponding ambient seawater temperature	EMU entrainment survival	% survival
<=25	72.8%	70 %	50.94 %
<=26	10.4%	60 %	6.26 %
<=27	1.2%	50 %	0.58 %
<=28	11.4%	44 %	5.03 %
<=29	0.3%	7 %	0.02 %
>29	3.9%	0 %	0.00 %
Total	100 %		**62.83 %**
Mortality			**37.2 %**

To estimate the effects of local entrainment mortality the following assumptions were made:

a. Abstraction risk zone is 8.46 10^8 m^3 (BEEMS Technical Report TR385), SZC CW abstraction rate 131.86 cumecs (1.14 10^7 m^3 d^{-1}) i.e. plume abstraction = 1.35 % of the abstraction risk zone. This is precautionary as it underestimates the tidal volume.
b. Percentage seawater exchange with adjacent area is 10 % per day (BEEMS Technical Report TR385).
c. Planktonic larvae of each invertebrate taxon are present at uniform spatial density within the Sizewell area.
d. For calculation purposes, the young of each taxon are assumed to emerge into the plankton at the same time.
e. The larvae are vulnerable to entrainment at the same rate throughout each day.
f. Natural mortality is not density dependent.
g. Natural mortality is uniform across the Sizewell Bay area i.e. predation risk is constant and that abstraction rates are equivalent to *in-situ* densities.

Abundance of larvae within the plume risk zone after time interval t is given by:

$N_t = N_0 e^{-Mt}$ With no power station (Equation 1)

$N_t = N_0 e^{-Mt} (1 - P_{ex} * E_{mort})$ With power station

Where M = natural mortality of species (d^{-1}), P_{ex}= power station abstraction per day as a percentage of the plume abstraction risk area, E_{mort} = entrainment mortality of the species, N_0 is the original abundance.

The effect of seawater exchange (E_x) is:

$N_t = N_t$ – number of individuals in volume advected out + number in water advected in. i.e.

$$N_t = N_0 e^{-Mt} (1 - P_{ex} * E_{mort}) - E_x * N_0 e^{-Mt} (1 - P_{ex} * E_{mort}) + E_x * N_0 e^{-Mt}$$

or

$N_t = N_0 e^{-Mt} (1 - P_{ex} * E_{mort} * (1 - E_x))$ With power station and water exchange (Equation 2)

Comparing the integrals of equations 1 and 2 over a time period representative of the taxon’s lifetime in the plankton enables the effect of SZB entrainment in that period to be estimated (the selected assessment interval for each species was the time taken for the number of individuals in a population to fall to approximately 5 % of the initial number in the absence of any additional mortality caused by a power station). The calculated entrainment effects are given in Table 18. These calculations cannot be directly applied to gammarids, because there are no estimates of entrainment mortality or natural mortality. It is known that gammarids are more tolerant of temperature than mysids (upper lethal temperatures of 34°C; (BEEMS Scientific Advisory Report SAR008) *versus* approximately 29°C (BEEMS Technical Report TR394), so a reasonable though conservative first approximation is that the predicted local loss of gammarids would be similar to that predicted for mysids in Table 18, at approximately 6 %; a worst case estimate using the same calculation but assuming 100 % entrainment mortality (instead of the 37 % assumed for mysids) would be a local loss of 14 %.

Table 18 Estimated entrainment effects on local invertebrate zooplankton numbers at Sizewell

Taxon	M (d^{-1})	Entrainment mortality	Change in abundance within the abstraction zone of SZC	Assessment interval (time taken for population to fall to 5% of its initial level)	Expected population level with no power station as a % of N_0

Acartia tonsa	0.7	30 %	-0.42 %	5 d	3.0 %
Centropages typicus	0.24	30 %	-1.27 %	13 d	4.4 %
Barnacles	0.145	No data. Worst case 100 % assumed	-6.75 %	21 d	4.8 %
Mysids	0.06	37.2 %	-5.97 %	50 d	5.0 %
Gammarids	Unknown 0.06 assumed	Unknown 37% - 100% assumed	-5.9% to -14.7% (see below for further analysis)	50d	5.0 %

Table 18 column 4 demonstrates that the local impact on copepod abundance (which represented 72 % of the invertebrate zooplankton numbers from the CEMP) is negligible. For mysids and barnacle larvae, the predicted local reduction in abundance is low at approximately 6 %, but does warrant further consideration.

This simple analysis probably overestimates entrainment effects, for a number of reasons. It ignores the effects of zooplankton behaviour and assumption e. above, that organisms are equally vulnerable to entrainment throughout the day is not valid and is likely to lead to overestimates of entrainment mortality. Many herbivorous and omnivorous mesozooplankton[3] feed predominantly near the surface at night to minimise the risk of predation from fish and then undertake diel vertical migration to deeper water during the day. There is also evidence that many smaller mesozooplankton arrive at the surface earlier and leave later than larger forms (Hayes, 2003). Many species of copepods behave in this manner and as such are most at risk of entrainment only during daylight hours, thereby reducing potential entrainment effects.

Of more significance, several of the common species found in the plankton at Sizewell are actually benthic or bentho-pelagic (gammarids, mysids and cumacea) and only become vulnerable to entrainment if they are mobilised off the seabed by wave action or if they undertake diel vertical migration (DVM). For mysids, a significant proportion of the total population remain in the hyperbenthic layer during darkness thereby even further reducing their vulnerability to entrainment (Mees and Jones, 1997). For those mysid species that do undertake DVM, their vulnerability to entrainment will not be constant in time; they will largely only be vulnerable as they transit past the intake apertures which, in the relatively deep water (15 m) at the SZC intakes, will be a small percentage of each 24 h period. We have calculated this percentage assuming:

- Organisms are at risk of entrainment when their vertical position is within 2 * the 2 m aperture of the intake i.e. 4 m (out of 15 m water depth)
- The organisms make 2 vertical transitions per day (i.e. to the surface and then back)
- Mysids can maintain a vertical swimming speed of 0.2 cm s^{-1} (similar sized mysids (*Neomysis integer)* to the *Schistomysis sp.* found at Sizewell have been observed to be capable of sustained horizontal swimming speeds of ≈ 6 - 8 cm s^{-1} (Roast et al., 1998).

Using these assumptions, it would take mysids approximately 2.1 h to make each transition from the seabed to the sea surface and they would be at risk of entrainment for a total of 4.6 % of each day. This would change the predicted entrainment loss of mysids to -0.27 %.

In addition, there are not likely to be as many mysids around SZC as around SZB, because mysids occur in greater densities inshore in shallow water (Mauchline, 1967; Mees and Jones, 1997) and the SZC intakes would be located 3 km offshore. The exposure of benthic and bentho-pelagic organisms to wave remobilisation in the deeper water of the SZC intake location will also be less than at SZB.

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[3] Planktonic animals in the size range 0.2-20 mm

Gammarids spend most of the time buried in the sediment and are largely invulnerable to entrainment. For example, for the related commonly occurring marine amphipod *Corophium volutator*, it has been estimated that less than 0.1 % of the population at any given time is present in the hyperbenthic layer where, even so, it forms a significant part of the diet of demersal and even some pelagic species (Mees and Jones, 1997). Even making the unlikely assumption that 100 % of the population undertakes DVM; the period of entrainment risk would only be approximately 10 % of each 24 h period as they transit past the SZC intakes (See above calculation for mysids which, after adjusting for the reduced size, and consequent reduced swimming speed of gammarids, gives a calculated period of entrainment risk of approximately 9.6 % of each 24h period). The worst-case estimate of entrainment mortality (using mysid data and assuming 100 % entrainment mortality) would be a local loss of 14 %. However, once the entrainment exposure factor of 10 % of each 24 h period is included, the predicted loss would be approximately 1.4 % (Table 19).

In contrast, recently hatched barnacle larvae have a positive phototactic response and are attracted to the sea surface and it has been estimated that 90 % of all later stage barnacle nauplii are found near the surface at any given time in a 24 h period (Tapia and Pineda, 2007). As such, barnacle larvae will be at much reduced risk of entrainment than if they were only found at the depth of the SZC intakes. The revised prediction of entrainment loss is approximately -0.68% (Table 19).

Table 19 Revised estimates of SZC entrainment effects on local invertebrate zooplankton numbers after considering the behaviour of mysids, gammarids and barnacle larvae

Taxon	**M (d^{-1})**	**Entrainment mortality**	**Reduction in abundance within the abstraction zone of SZC**
Acartia tonsa	0.7	30 %	-0.42 %
Centropages typicus	0.24	30 %	-1.27 %
Barnacles	0.145	Worst case 100 % assumed	-0.68 %
Mysids	0.06	37%	-0.27 %
Gammarids	0.06 assumed	100% assumed	-1.5 %

Copepods represent approximately 72 % of the measured invertebrate zooplankton abundance at Sizewell and together with bentho-pelagic (mainly gammarids and mysids) and benthic taxa (mostly barnacles) represent just over 90 % of the entrained community. It is concluded that, for copepods, the predicted loss due to entrainment is negligible and, because of their behaviour, the others will be at low risk of entrainment at SZC and the effects on these populations will also be negligible. The predicted effect of SZC entrainment on these groups of invertebrate zooplankton is therefore considered to be negligible.

5 Discussion and conclusion

The total estimated number of fish eggs entrained annually at SZB (unadjusted for entrainment survival) was 288.6 million, dominated (76.4 %) by anchovy and sole. 92.4 million larval fish were estimated to be entrained, with gobies, sprat, herring and pilchard dominating (95.1 %). 19.5 million juvenile fish were estimated to have been entrained, with gobies and sprat the most abundant (83.7 %) species. The total predicted (unadjusted) numbers of fish eggs, larvae and juveniles that would be entrained annually at SZC are 738.9 million, 233.7 million and 49.9 million, respectively. However, it is estimated that 20 % of sole and 40 % of bass eggs would survive their passage through the cooling water systems.

While the numbers of individual animals entrained as either eggs, larvae or small juveniles seems large, it must be borne in mind that the natural mortality these very early life-history stages suffer in the wild is very substantial. Consequently, the impact of entrainment mortality at SZB or SZC on adult wild populations and fisheries will be very much lower than the simple numbers of individuals may seem to indicate. In the case of fish eggs, assessment was made on fish populations by expressing egg loss through entrainment in the context of the numbers of eggs produced by an “average” or typical spawning female (“equivalent spawning females”). Males were not taken into account since an individual male can spawn with many females so the effective reproductive output of a typical male is difficult to assess. This “adult reproductive equivalent” approach probably underestimates the population losses due to egg entrainment because it assumes all the eggs were viable and newly laid; to counter a precautionary approach was used of using the lower estimate of the number of eggs spawned wherever a range is given in the literature. In the case of fish larvae, assessment was made by expressing larval loss through entrainment in the context of the numbers of larvae produced by an “average” or typical spawning female (“equivalent spawning females”). For this we have estimated the numbers of larvae produced from the numbers of eggs spawned (above) assuming upper (97 %) and lower (70 %) levels of natural egg mortality. This approach provides upper and lower estimates of the impact of larval loss through entrainment. In the case of juvenile fish, a calculated equivalent adult value (EAV; Table 10) was used. If the required biological information to calculate an EAV was not available, an EAV of 1 was assumed. Such an assumption overestimates fish mortality; sometimes substantially.

To put the predicted entrainment loss of fish eggs, larvae and juveniles at SZC into the context of populations, the estimated equivalent adult numbers were converted to weights and compared with the spawning stock biomass (SSB) of each species or the respective international landings, based on its stock assessment area. Twenty four key fish species have been selected at Sizewell (defined in the fish characterisation report, BEEMS Technical Report TR345 on the basis of conservation importance, ecological importance and socio-economic value) as representative of the local assemblage. Only eight of these 24 species have been detected in entrainment sampling at Sizewell. For seven of these eight key taxa the predicted entrainment losses are much less 1 % of the SSB or the international landings of that species in 2010. The highest predicted loss was 0.001% of SSB for sprat or 0.01% landings for dab. Gobies (predominantly sand goby) are the eighth key taxa detected in entrainment sampling. The species are short lived and commercially unexploited. The predicted entrainment loss is 1.4 % of the mean population numbers which is less than the highly conservative screening threshold of 10% for such unexploited species.

Considering the other key fish species at Sizewell identified in BEEMS Technical Report TR345 some species are considered not to be at risk or at negligible risk of entrainment at SZC because:

a. They are not present at the vulnerable life stage/size e.g. the diadromous species which reproduce in freshwater and then do not enter the marine environment until they are too large to be entrained (twaite and allis shad, sea trout, salmon and sea lamprey). In theory, very early life stages of river lamprey and possibly cucumber smelt could be present in the marine environment at Sizewell at a sufficiently small size to be entrained. However, these species are readily identifiable, and none were detected in the Sizewell entrainment and plankton sampling programmes.

b. They were not detected in entrainment sampling but were detected during offshore plankton surveys but in such low densities to have negligible effect on the species at the population level even if they had all been entrained at SZC e.g. larvae of mackerel, whiting and plaice with 1 larva of each species being caught in a total of 585 plankton samples from 2008-2015 (BEEMS Technical Report TR315).

c. The species were not detected during entrainment nor plankton sampling at Sizewell and their juveniles do not come into the Sizewell Bay area until they are too large to be entrained e.g. cod, thin- lipped grey mullet, thornback ray and horse mackerel.

d. The species does not have egg and larval stages and the juveniles are too large to be entrained e.g. tope.

e. The European eel in its glass eel phase is theoretically vulnerable to entrainment at Sizewell C. The totality of data from an extensive sampling programme together with considerations of how glass eels migrate around the UK has led to the conclusion that whilst glass eels are present in Sizewell coastal waters, their density is very low at this location. In addition, glass eels make use of selective tidal stream transport (STST) to migrate to suitable estuaries at or near to the sea surface where they would be at low risk of entrainment from the deep seabed mounted SZC intakes. Even if a few glass eels are entrained, BEEMS entrainment simulations of SZC under planned operational conditions of pressure, temperature, chlorine dosing and exposure time showed 80% or greater survival. The entrainment risk to glass eels is, therefore, considered negligible.

f. After consideration of the hydrodynamics in the southern North Sea and the results of previous modelling studies on the fate of Blackwater herring larvae it has been concluded that the proportion of Blackwater herring larvae that would be at risk of entrainment at Sizewell C would be negligible (Appendix C 6.6).

The predicted entrainment effects on the 24 key fish taxa are, therefore, considered negligible.

Entrainment presents a similarly low risk to the assessed groups of invertebrate zooplankton as it does to egg, larval or juvenile fishes. Copepods represented approximately 72 % of the measured invertebrate zooplankton abundance in the entrainment sampling at Sizewell and, together with bentho-pelagic (mainly gammarids and mysids) and benthic taxa (mostly barnacles) represent just over 90 % of the entrained community. For copepods, predicted local losses due to entrainment is negligible and, because of their behaviour, the bentho-pelagic and benthic taxa will be at low risk of entrainment at SZC and the predicted entrainment effects on these populations will also be negligible.

Table 20 provides an assessment of predicted entrainment effects for each of the key fishes and invertebrate zooplankton taxa at Sizewell described in BEEMS Technical Reports TR345 and TR315 . All species in Table 20 are either not at risk from entrainment or the predicted entrainment levels are negligible.

Table 20 Predicted entrainment effects on key fishes and invertebrate zooplankton taxa at Sizewell

		Reason why key species				
Taxon		**Socio-economic**	**Ecological**	**Conservation**	**Detected in entrainment sampling**	**Predicted Entrainment effect on fish population**
Fishes						
European sprat	*Sprattus sprattus*		🟩		Y	Negligible
Atlantic herring	*Clupea harengus*	🟦	🟩	🟧	Y	Negligible
Whiting	*Merlangius merlangus*		🟩	🟧	N	Negligible
European sea bass	*Dicentrarchus labrax*	🟦	🟩		Y	Negligible
Sand gobies	*Pomatoschistus* spp.		🟩		Y	Negligible
Dover sole	*Solea solea*	🟦	🟩	🟧	Y	Negligible
Dab	*Limanda limanda*		🟩		Y	Negligible
Anchovy	*Engraulis encrasicolus*		🟩		Y	Negligible
Thin-lipped grey mullet	*Liza ramada*		🟩		N	Not at risk
European flounder	*Platichthys flesus*		🟩		Y	Negligible
Atlantic cod	*Gadus morhua*	🟦	🟩	🟧	N	Not at risk
European plaice	*Pleuronectes platessa*	🟦	🟩	🟧	N	Negligible
Smelt	*Osmerus eperlanus*			🟧	N	Not at risk
Thornback ray	*Raja clavata*	🟦	🟩		N	Not at risk
European eel	*Anguilla anguilla*			🟧	N [4]	Negligible
Horse mackerel	*Trachurus trachurus*			🟧	N	Not at risk
Twaite shad	*Alosa fallax*			🟧	N	Not at risk
River lamprey	*Lampetra fluviatilis*			🟧	N	Not at risk
Mackerel	*Scomber scombrus*			🟧	N	Negligible
Sea trout	*Salmo trutta*			🟧	N	Not at risk
Allis shad	*Alosa alosa*			🟧	N	Not at risk
Tope	*Galeorhinus galeus*			🟧	N	Not at risk
Atlantic salmon	*Salmo salar*			🟧	N	Not at risk
Sea lamprey	*Petromyzon marinus*			🟧	N	Not at risk
Invertebrate zooplankton						
Copepods	Copepoda		🟩		Y	Negligible
Gammarids	Gammaridae		🟩		Y	Negligible
Mysids	Mysida		🟩		Y	Negligible
Barnacles	Cirripedia		🟩		Y	Negligible

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[4] Glass eels were not detected in entrainment sampling but are known to migrate past the Sizewell site in very small numbers (BEEMS Technical Report TR356)

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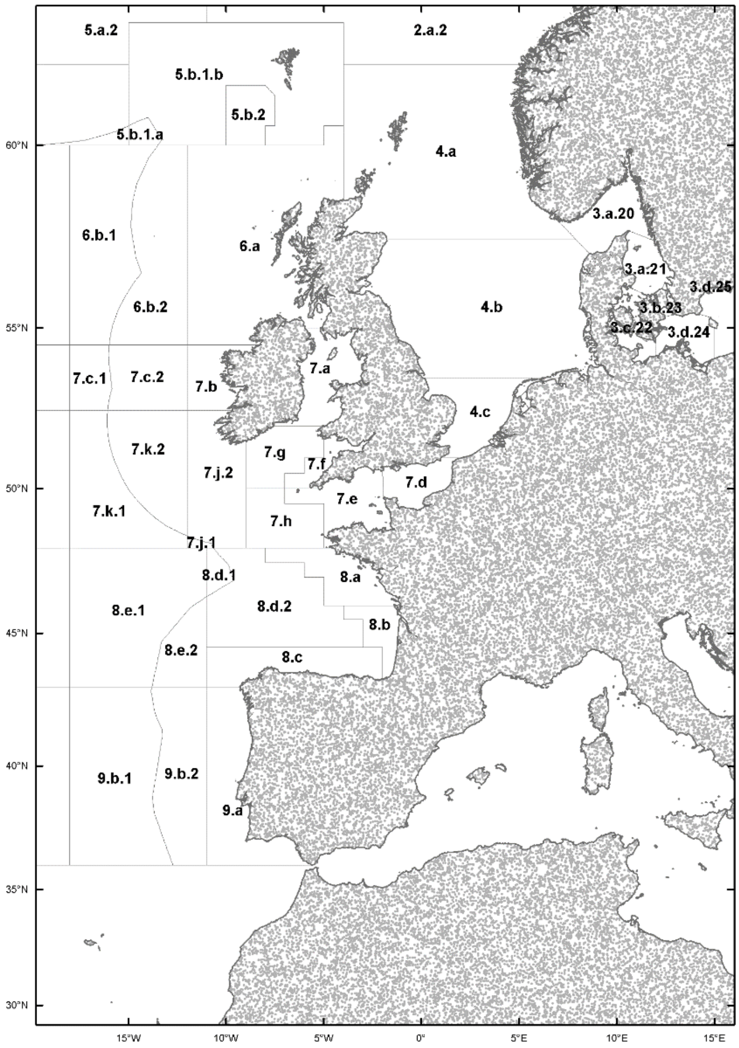
Appendix A ICES stock unit areas

For stock assessment purposes, the northeast Atlantic is divided in to various statistical areas (see map below). Species are assessed over different statistical areas depending on their life histories, population distributions and fisheries. Data from all countries fishing in that stock unit area are aggregated to carry out the stock assessment. This includes international landings, data from market sampling programmes and from research surveys. The key taxa in the Sizewell area are



Species	**Stock unit area**
Dab	Subarea 4 (North Sea) and Division 3.a (Kattegat and Skagerrak)
Dover sole	Subarea 4 (North Sea)
European anchovy	No stock area defined. Genetic studies suggest that the North Sea and English Channel populations are genetically homogenous. Therefore, losses are compared with landings of anchovy from Subarea 4 (North Sea) and English Channel (Divisions 7.d and 7.e)
European flounder	Subarea 4 (North Sea) and Division 3.a (Kattegat and Skagerrak)
European seabass	Divisions 4.b–c (Central and southern North Sea), 7.a (Irish Sea), and 7.d–h (Bristol Channel and Celtic Sea)
Herring	Subarea 4 (North Sea), Division 3.a (Kattegat and Skagerrak) and Division 7.d (Eastern Channel)
Sprat	Subarea 4 (North Sea)

Appendix B Monthly estimates (SZB) and predictions (SZC) of entrainment

B.1 Estimated entrainment of fish eggs at SZB – including unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Dover sole	0	0	0	66,844,990	30,812,580	1,020,429	0	0	0	0	0	0	**98,677,999**
Dragonets	0	0	0	744,391	0	0	0	0	0	0	0	0	**744,391**
European anchovy	0	0	0	0	2,056,945	64,041,009	54,817,464	1,026,608	0	0	0	0	**121,942,026**
European seabass	0	0	0	0	4,376,844	169,696	0	0	0	0	0	0	**4,546,540**
Garfish	0	0	0	0	341,358	0	0	0	0	0	0	0	**341,358**
Gurnards	0	0	0	0	64,479	957,032	0	0	0	0	0	0	**1,021,511**
Lesser weever fish	0	0	0	0	0	36,000	0	0	0	0	0	0	**36,000**
Long rough dab	0	0	0	0	32,416	0	0	0	0	0	0	0	**32,416**
Pilchard	0	0	0	0	6,415,560	3,713,548	0	0	0	0	0	0	**10,129,108**
Rocklings	0	0	774,495	2,609,882	1,641,904	405,347	0	0	0	0	0	0	**5,431,629**
Sandeels	0	0	0	0	32,307	0	0	0	0	0	0	0	**32,307**
Sprat	0	1,003,452	0	1,107,631	3,037,043	741,603	0	0	0	0	0	0	**5,889,729**
Unidentifiable specimen	0	5,953,191	4,852,667	26,051,925	1,648,636	228,695	1,022,186	0	0	0	0	0	**39,757,299**
Total	**0**	**6,956,643**	**5,627,162**	**97,358,819**	**50,460,072**	**71,313,359**	**55,839,650**	**1,026,608**	**0**	**0**	**0**	**0**	**288,582,312**

B.2 Estimated entrainment of fish eggs at SZB – following monthly re-allocation of unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Dover sole	0	0	0	91,266,761	31,853,293	1,023,712	0	0	0	0	0	0	124,143,767
Dragonets	0	0	0	1,016,354	0	0	0	0	0	0	0	0	1,016,354
European anchovy	0	0	0	0	2,126,420	64,247,043	55,839,650	1,026,608	0	0	0	0	123,239,720
European seabass	0	0	0	0	4,524,675	170,242	0	0	0	0	0	0	4,694,916
Garfish	0	0	0	0	352,887	0	0	0	0	0	0	0	352,887
Gurnards	0	0	0	0	66,657	960,111	0	0	0	0	0	0	1,026,768
Lesser weever fish	0	0	0	0	0	36,116	0	0	0	0	0	0	36,116
Long rough dab	0	0	0	0	33,511	0	0	0	0	0	0	0	33,511
Pilchard	0	0	0	0	6,632,249	3,725,496	0	0	0	0	0	0	10,357,745
Rocklings	0	0	5,627,162	3,563,400	1,697,361	406,651	0	0	0	0	0	0	11,294,574
Sandeels	0	0	0	0	33,398	0	0	0	0	0	0	0	33,398
Sprat	0	6,956,643	0	1,512,303	3,139,621	743,988	0	0	0	0	0	0	12,352,555
Total	**0**	**6,956,643**	**5,627,162**	**97,358,819**	**50,460,072**	**71,313,359**	**55,839,650**	**1,026,608**	**0**	**0**	**0**	**0**	**288,582,312**

B.3 Predicted entrainment of fish eggs at SZC – including unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Dover sole	0	0	0	171,149,133	78,892,170	2,612,695	0	0	0	0	0	0	**252,653,999**
Dragonets	0	0	0	1,905,931	0	0	0	0	0	0	0	0	**1,905,931**
European anchovy	0	0	0	0	5,266,578	163,969,853	140,353,995	2,628,515	0	0	0	0	**312,218,941**
European seabass	0	0	0	0	11,206,421	434,487	0	0	0	0	0	0	**11,640,908**
Garfish	0	0	0	0	874,009	0	0	0	0	0	0	0	**874,009**
Gurnards	0	0	0	0	165,092	2,450,373	0	0	0	0	0	0	**2,615,465**
Lesser weever fish	0	0	0	0	0	92,174	0	0	0	0	0	0	**92,174**
Long rough dab	0	0	0	0	82,998	0	0	0	0	0	0	0	**82,998**
Pilchard	0	0	0	0	16,426,324	9,508,126	0	0	0	0	0	0	**25,934,450**
Rocklings	0	0	1,983,009	6,682,311	4,203,913	1,037,847	0	0	0	0	0	0	**13,907,079**
Sandeels	0	0	0	0	82,718	0	0	0	0	0	0	0	**82,718**
Sprat	0	2,569,227	0	2,835,966	7,776,009	1,898,791	0	0	0	0	0	0	**15,079,993**
Unidentifiable specimen	0	15,242,480	12,424,711	66,703,046	4,221,147	585,547	2,617,193	0	0	0	0	0	**101,794,124**
Total	**0**	**17,811,707**	**14,407,720**	**249,276,387**	**129,197,380**	**182,589,892**	**142,971,188**	**2,628,515**	**0**	**0**	**0**	**0**	**738,882,789**

B.4 Predicted entrainment of fish eggs at SZC – following monthly re-allocation of unidentified proportion

Species	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	Dec	Total
Dover sole	0	0	0	233,678,352	81,556,801	2,621,101	0	0	0	0	0	0	317,856,254
Dragonets	0	0	0	2,602,262	0	0	0	0	0	0	0	0	2,602,262
European anchovy	0	0	0	0	5,444,460	164,497,379	142,971,188	2,628,515	0	0	0	0	315,541,543
European seabass	0	0	0	0	11,584,925	435,885	0	0	0	0	0	0	12,020,809
Garfish	0	0	0	0	903,529	0	0	0	0	0	0	0	903,529
Gurnards	0	0	0	0	170,668	2,458,257	0	0	0	0	0	0	2,628,925
Lesser weever fish	0	0	0	0	0	92,471	0	0	0	0	0	0	92,471
Long rough dab	0	0	0	0	85,801	0	0	0	0	0	0	0	85,801
Pilchard	0	0	0	0	16,981,133	9,538,715	0	0	0	0	0	0	26,519,849
Rocklings	0	0	14,407,720	9,123,689	4,345,903	1,041,186	0	0	0	0	0	0	28,918,497
Sandeels	0	0	0	0	85,512	0	0	0	0	0	0	0	85,512
Sprat	0	17,811,707	0	3,872,084	8,038,649	1,904,899	0	0	0	0	0	0	31,627,339
Total	**0**	**17,811,707**	**14,407,720**	**249,276,387**	**129,197,380**	**182,589,892**	**142,971,188**	**2,628,515**	**0**	**0**	**0**	**0**	**738,882,789**

B.5 Estimated entrainment of fish larvae at SZB - including unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Dover sole	0	0	0	0	203,189	0	0	0	0	0	0	0	**203,189**
Dragonets	0	0	0	0	65,116	0	1,038,345	0	0	0	0	0	**1,103,461**
European flounder	0	0	0	0	33,435	0	0	0	0	0	0	0	**33,435**
Gobies	0	0	387,248	0	202,380	193,142	1,022,186	10,244,802	19,715,267	4,106,742	8,047,038	779,859	**44,698,663**
Herring	0	0	0	0	1,594,956	190,417	0	0	0	0	0	0	**1,785,373**
Herrings	0	0	0	535,158	6,278,467	196,162	0	0	0	1,027,468	0	10,112,442	**18,149,697**
Pilchard	0	0	0	0	979,742	0	0	0	0	0	0	0	**979,742**
Pipe-fishes	0	0	0	0	37,128	0	0	0	0	0	0	0	**37,128**
Right eyed flatfish	0	0	0	0	35,412	31,212	0	0	0	0	0	0	**66,624**
Sandeels	0	0	0	165,947	67,785	0	0	0	0	0	0	0	**233,732**
Sea snail	0	0	0	0	31,719	0	0	0	0	0	0	0	**31,719**
Soles	0	0	0	0	33,145	0	0	0	0	0	0	0	**33,145**
Solenette	0	0	0	0	172,613	0	0	0	0	0	0	0	**172,613**
Sprat	0	0	0	4,466,349	0	0	0	0	983,201	0	0	194,965	**5,644,515**
Witch	0	0	0	0	0	31,265	0	0	0	0	0	0	**31,265**
Unidentifiable specimen	777,113	0	781,738	744,391	701,725	1,218,386	0	3,072,254	8,876,707	3,082,404	0	0	**19,254,719**
Total	**777,113**	**0**	**1,168,985**	**5,911,845**	**10,436,810**	**1,860,584**	**2,060,531**	**13,317,056**	**29,575,176**	**8,216,614**	**8,047,038**	**11,087,266**	**92,459,018**

B.6 Estimated entrainment of fish larvae at SZB – following monthly re-allocation of unidentified proportions

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Dover sole	0	0	0	0	217,835	0	0	0	0	0	0	0	217,835
Dragonets	0	0	0	0	69,810	0	1,038,345	0	0	0	0	0	1,108,154
European flounder	0	0	0	0	35,845	0	0	0	0	0	0	0	35,845
Gobies	0	0	1,168,985	0	216,967	559,572	1,022,186	13,317,056	28,170,321	6,572,289	8,047,038	779,859	59,854,274
Herring	0	0	0	0	5,879,616	1,120,003	0	0	0	0	0	0	6,999,619
Unidentified clupeids	0	0	0	0	0	0	0	0	0	1,644,325	0	0	1,644,325
Pilchard	0	0	0	0	3,611,703	0	0	0	0	0	0	0	3,611,703
Pipe-fishes	0	0	0	0	39,804	0	0	0	0	0	0	0	39,804
Right eyed flatfish	0	0	0	0	37,965	90,428	0	0	0	0	0	0	128,393
Sandeels	0	0	0	189,853	72,671	0	0	0	0	0	0	0	262,523
Sea snail	0	0	0	0	34,005	0	0	0	0	0	0	0	34,005
Soles	0	0	0	0	35,535	0	0	0	0	0	0	0	35,535
Solenette	0	0	0	0	185,055	0	0	0	0	0	0	0	185,055
Sprat	0	0	0	5,721,993	0	0	0	0	1,404,855	0	0	10,307,407	17,434,255
Witch	0	0	0	0	0	90,581	0	0	0	0	0	0	90,581
Unidentifiable specimen	777,113	0	0	0	0	0	0	0	0	0	0	0	777,113
	777,113	**0**	**1,168,985**	**5,911,845**	**10,436,810**	**1,860,584**	**2,060,531**	**13,317,056**	**29,575,176**	**8,216,614**	**8,047,038**	**11,087,266**	**92,459,018**

‘Gobies’ (59.8 million individuals) were further separated into ‘sand gobies’ (52.0 million) and ‘other gobies’ (7.7 million) by the proportions 87 % and 13 %, respectively.

B.7 Predicted entrainment of fish larvae at SZC - including unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Dover sole	0	0	0	0	520,242	0	0	0	0	0	0	0	520,242
Dragonets	0	0	0	0	166,722	0	2,658,566	0	0	0	0	0	2,825,287
European flounder	0	0	0	0	85,605	0	0	0	0	0	0	0	85,605
Gobies	0	0	991,504	0	518,170	494,517	2,617,193	26,230,672	50,478,741	10,514,853	20,603,542	1,996,742	114,445,936
Herring	0	0	0	0	4,083,707	487,542	0	0	0	0	0	0	4,571,249
Herrings	0	0	0	1,370,211	16,075,314	502,251	0	0	0	2,630,717	0	25,891,779	46,470,273
Pilchard	0	0	0	0	2,508,520	0	0	0	0	0	0	0	2,508,520
Pipe-fishes	0	0	0	0	95,062	0	0	0	0	0	0	0	95,062
Right eyed flatfish	0	0	0	0	90,669	79,915	0	0	0	0	0	0	170,584
Sandeels	0	0	0	424,890	173,555	0	0	0	0	0	0	0	598,445
Sea snail	0	0	0	0	81,212	0	0	0	0	0	0	0	81,212
Soles	0	0	0	0	84,865	0	0	0	0	0	0	0	84,865
Solenette	0	0	0	0	441,956	0	0	0	0	0	0	0	441,956
Sprat	0	0	0	11,435,587	0	0	0	0	2,517,377	0	0	499,186	14,452,150
Witch	0	0	0	0	0	80,050	0	0	0	0	0	0	80,050
Unidentifiable specimen	1,989,712	0	2,001,552	1,905,931	1,796,688	3,119,541	0	7,866,164	22,727,817	7,892,152	0	0	49,299,558
Total	**1,989,712**	**0**	**2,993,056**	**15,136,620**	**26,722,287**	**4,763,817**	**5,275,758**	**34,096,836**	**75,723,935**	**21,037,723**	**20,603,542**	**28,387,707**	**236,730,994**

B.8 Predicted entrainment of fish larvae at SZC – following monthly re-allocation of unidentified proportions

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Dover sole	0	0	0	0	557,742	0	0	0	0	0	0	0	557,742
Dragonets	0	0	0	0	178,740	0	2,658,566	0	0	0	0	0	2,837,305
European flounder	0	0	0	0	91,776	0	0	0	0	0	0	0	91,776
Gobies	0	0	2,993,056	0	555,521	1,432,722	2,617,193	34,096,836	72,126,960	16,827,613	20,603,542	1,996,742	153,250,186
Herring	0	0	0	0	15,054,101	2,867,642	0	0	0	0	0	0	17,921,743
Unidentified clupeids	0	0	0	0	0	0	0	0	0	4,210,111	0	0	4,210,111
Pilchard	0	0	0	0	9,247,363	0	0	0		0	0	0	9,247,363
Pipe-fishes	0	0	0	0	101,914	0	0	0	0	0	0	0	101,914
Right eyed flatfish	0	0	0	0	97,205	231,531	0	0	0	0	0	0	328,736
Sandeels	0	0	0	486,096	186,065	0	0	0	0	0	0	0	672,162
Sea snail	0	0	0	0	87,066	0	0	0	0	0	0	0	87,066
Soles	0	0	0	0	90,982	0	0	0	0	0	0	0	90,982
Solenette	0	0	0	0	473,813	0	0	0	0	0	0	0	473,813
Sprat	0	0	0	14,650,523	0	0	0	0	3,596,975	0	0	26,390,965	44,638,462
Witch	0	0	0	0	0	231,922	0	0	0	0	0	0	231,922
Unidentifiable specimen	1,989,712	0	0	0	0	0	0	0	0	0	0	0	1,989,712
Total	**1,989,712**	**0**	**2,993,056**	**15,136,620**	**26,722,287**	**4,763,817**	**5,275,758**	**34,096,836**	**75,723,935**	**21,037,723**	**20,603,542**	**28,387,707**	**236,730,994**

‘Gobies’ (153.3 million individuals) were further separated into ‘sand gobies’ (133.3 million) and ‘other gobies’ (19.9 million) by the proportions 87 % and 13 %, respectively.

B.9 Estimated entrainment of juvenile fish at SZB - including unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Butter fish	0	0	0	0	0	0	0	0	986,334	0	0	0	**986,334**
Dab	0	0	0	0	0	0	0	0	1,969,535	0	0	0	**1,969,535**
Herring	0	0	0	0	33,788	0	0	0	0	0	0	0	**33,788**
Gobies	0	0	194,306	0	3,267,240	0	0	2,052,500	0	0	2,025,711	1,167,810	**8,707,566**
Pipe-fishes	48,570	0	0	0	71,699	0	0	0	0	0	0	0	**120,269**
Sandeels	0	0	0	0	0	0	0	0	0	0	0	50,379	**50,379**
Sprat	1,559,278	0	0	165,947	0	0	0	3,077,676	0	0	2,025,711	0	**6,828,612**
Unidentifiable specimen	779,639	0	0	0	32,526	0	0	0	0	0	0	0	**812,165**
Total	**2,387,486**	**0**	**194,306**	**165,947**	**3,405,254**	**0**	**0**	**5,130,176**	**2,955,870**	**0**	**4,051,421**	**1,218,189**	**19,508,648**

B.10 Estimated entrainment of juvenile fish at SZB - following monthly re-allocation of unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Butter fish	0	0	0	0	0	0	0	0	986,334	0	0	0	**986,334**
Dab	0	0	0	0	0	0	0	0	1,969,535	0	0	0	**1,969,535**
Herring	0	0	0	0	34,114	0	0	0	0	0	0	0	**34,114**
Gobies	0	0	194,306	0	3,298,749	0	0	2,052,500	0	0	2,025,711	1,167,810	**8,739,075**
Pipe-fishes	72,121	0	0	0	72,391	0	0	0	0	0	0	0	**144,512**
Sandeels	0	0	0	0	0	0	0	0	0	0	0	50,379	**50,379**
Sprat	2,315,365	0	0	165,947	0	0	0	3,077,676	0	0	2,025,711	0	**7,584,699**
Total	**2,387,486**	**0**	**194,306**	**165,947**	**3,405,254**	**0**	**0**	**5,130,176**	**2,955,870**	**0**	**4,051,421**	**1,218,189**	**19,508,648**

‘Gobies’ (8.7 million individuals) were further separated into ‘sand gobies’ (7.6 million) and ‘other gobies’ (1.1 million) by the proportions 87 % and 13 %, respectively.

B.11 Predicted entrainment of juvenile fish at SZC - including unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Butter fish	0	0	0	0	0	0	0	0	2,525,399	0	0	0	**2,525,399**
Dab	0	0	0	0	0	0	0	0	5,042,775	0	0	0	**5,042,775**
Herring	0	0	0	0	86,511	0	0	0	0	0	0	0	**86,511**
Gobies	0	0	497,498	0	8,365,402	0	0	5,255,197	0	0	5,186,606	2,990,047	**22,294,750**
Pipe-fishes	124,357	0	0	0	183,578	0	0	0	0	0	0	0	**307,935**
Sandeels	0	0	0	0	0	0	0	0	0	0	0	128,990	**128,990**
Sprat	3,992,356	0	0	424,890	0	0	0	7,880,046	0	0	5,186,606	0	**17,483,898**
Unidentifiable specimen	1,996,178	0	0	0	83,280	0	0	0	0	0	0	0	**2,079,458**
Total	**6,112,892**	**0**	**497,498**	**424,890**	**8,718,772**	**0**	**0**	**13,135,243**	**7,568,174**	**0**	**10,373,212**	**3,119,036**	**49,949,716**

B.12 Predicted entrainment of juvenile fish at SZC - following monthly re-allocation of unidentified proportion

Species	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
Butter fish	0	0	0	0	0	0	0	0	2,525,399	0	0	0	**2,525,399**
Dab	0	0	0	0	0	0	0	0	5,042,775	0	0	0	**5,042,775**
Herring	0	0	0	0	87,346	0	0	0	0	0	0	0	**87,346**
Gobies	0	0	497,498	0	8,446,078	0	0	5,255,197	0	0	5,186,606	2,990,047	**22,375,425**
Pipe-fishes	184,657	0	0	0	185,349	0	0	0	0	0	0	0	**370,006**
Sandeels	0	0	0	0	0	0	0	0	0	0	0	128,990	**128,990**
Sprat	5,928,234	0	0	424,890	0	0	0	7,880,046	0	0	5,186,606	0	**19,419,776**
	6,112,892	**0**	**497,498**	**424,890**	**8,718,772**	**0**	**0**	**13,135,243**	**7,568,174**	**0**	**10,373,212**	**3,119,036**	**49,949,716**

Gobies’ (22.3 million individuals) were further separated into ‘sand gobies’ (19.5 million) and ‘other gobies’ (2.9 million) by the proportions 87 % and 13 %, respectively.

B.13 Estimated entrainment of zooplankton at SZB

Species/taxon	Jan	Feb	March	April	May	June	July
Gammaridae (Amphipoda)	554,054,802	325,230,131	290,337,600	128,558,889	1,440,688,178	3,926,355,716	4,281,516,786
Hyperiidae (Amphipoda)	7,332,268	5,988,330	0	0	0	0	0
Appendicularia (Pelagic tunicates)	0	0	0	0	0	62,117,140	167,031,009
Arachnida (Mites)	18,199,389	24,115,242	0	0	0	0	0
Brachyura (True crabs)	0	0	0	50,065,510	0	0	0
Chaetognatha (Arrow worms)	3,267,696	50,934,045	13,065,317	0	34,407,306	47,829,090	0
Cirripedia (Barnacles)	36,661,342	20,992,396	1,557,882	4,535,127,627	4,462,654,704	600,695,427	173,111,946
Cnidaria	152,396,628	40,174,139	25,857,055	50,065,510	560,513,106	872,946,768	23,257,796
Copepoda (including damaged specimens)	73,650,144	90,148,793	40,112,645	497,845,481	3,183,633,583	799,940,294	2,136,260,853
Calanoid (Copepod)	41,191,028	48,230,484	20,240,127	124,082,769	268,452,656	58,022,494	373,708,127
Cyclopoida (Copepod)	76,178,430	4,771,576	7,338,957	75,364,664	0	0	23,257,796
Harpacticoida (Copepod)	149,442,112	144,961,504	103,911,406	234,650,224	68,814,611	0	356,531,268
Acartia spp (Copepod)	58,221,358	192,855,453	289,159,616	1,082,298,440	3,304,586,922	889,499,715	4,943,572,494
Calanus spp (Copepod)	0	0	0	0	0	0	0
Caligus spp (Parasitic copepod)	0	0	0	4,357,372	0	0	0
Centropages spp (Copepod)	449,439,462	621,033,885	475,847,042	5,243,774,539	38,351,757,771	3,620,032,319	24,718,373,612
Eurytemora sp (Copepod)	0	6,677,668	1,557,882	0	0	0	0
Isias spp (Copepod)	0	0	0	0	0	0	310,015,676
Oithona spp (Copepod)	7,332,268	0	0	0	0	0	0
Paracalanus spp (Copepod)	19,978,356	11,976,660	10,059,627	26,429,981	158,298,830	0	0
Paramisophria spp (Copepod)	3,639,878	0	0	0	0	0	0
Parapontella brevicornis (Copepod)	0	0	0	0	0	0	103,338,559
Pseudocalanus spp (Copepod)	32,758,900	125,754,926	98,407,610	501,582,842	34,407,306	0	0
Pseudocalanus elongatus (Copepod)	128,220,542	124,022,901	30,914,097	52,288,465	1,531,101,815	268,156,695	103,338,559
Siphonostomatoida (Copepod)	7,279,756	0	3,170,480	0	0	58,022,494	0
Stephos spp (Copepod)	0	0	10,756,173	0	0	0	0
Temora spp (Copepod)	1,223,404,170	652,083,613	246,326,996	3,743,312,685	14,838,756,969	4,541,683,954	20,733,632,068

Species/taxon	Jan	Feb	March	April	May	June	July
Temora longicornis (Copepod)	0	0	246,460,852	0	0	0	0
Ctenophora (Sea gooseberries)	0	0	0	0	0	294,032,753	0
Cumacea	24,042,929	30,792,910	74,827,225	56,302,021	0	16,552,946	667,335,490
Decapoda	0	0	6,642,411	0	240,851,140	0	190,288,805
Echinodermata (Starfish/ sea urchins)	3,639,878	4,771,576	9,143,575	50,065,510	34,407,306	169,798,473	0
Ectoprocta/ bryozoa (Sea mats)	0	0	0	0	0	0	23,257,796
Foraminifera	494,706,712	180,825,001	50,171,628	87,433,190	137,629,223	58,022,494	229,934,913
Gastropoda	0	0	0	50,065,510	68,814,611	694,787,382	760,366,672
Hydroida	0	0	0	0	0	49,658,839	0
Hydrozoa	13,880,404	65,938,110	0	0	0	0	23,257,796
Invertebrate eggs	150,743,221	147,395,012	69,413,886	91,997,587	1,634,926,466	682,764,229	2,336,857,033
Isopoda (Isopod)	10,175,269	6,677,668	8,062,990	50,262,982	178,968,438	707,245,683	299,708,300
Lamellibranch (Bivalves)	311,979,259	249,329,584	310,705,155	90,108,895	228,645,594	499,897,946	0
Medusae (Jellyfish)	13,880,404	5,988,330	4,113,761	0	0	300,566,658	310,015,676
Mysidacea (Opposum shrimps)	421,193,135	345,586,981	244,230,903	1,920,733,843	2,952,474,738	0	0
Shrimps and prawns-like decapods	18,199,389	0	0	0	318,129,813	203,078,729	0
Nematode (Roundworm)	7,332,268	0	3,115,765	8,714,744	34,407,306	16,552,946	0
Podon spp (Cladocera)	0	0	0	0	0	0	0
Polychaeta (Bristle worms)	24,872,435	18,126,912	10,400,006	0	103,221,917	80,934,983	316,885,159
Pycnogonid (Sea Spider)	0	4,771,576	1,557,882	8,714,744	0	0	0
Urochordata (Tunicates)	0	0	0	0	0	0	23,257,796
Unidentified specimen	10,207,898	6,677,668	0	0	228,645,594	207,173,375	0
Total	**4,547,501,731**	**3,556,833,073**	**2,707,466,551**	**18,764,204,022**	**74,399,195,902**	**19,726,369,541**	**63,628,111,983**

Species/taxon	Aug	Sept	Oct	Nov	Dec	Total
Gammaridae (Amphipoda)	8,735,800,923	2,636,535,491	1,167,191,221	885,705,212	1,320,351,332	**25,692,326,281**
Hyperiidae (Amphipoda)	0	0	0	0	11,039,384	**24,359,982**
Appendicularia (Pelagic tunicates)	0	51,552,583	22,534,625	0	17,568,000	**320,803,358**

Species/taxon	Aug	Sept	Oct	Nov	Dec	Total
Arachnida (Mites)	0	0	17,761,572	11,912,520	10,888,414	**82,877,137**
Brachyura (True crabs)	0	0	0	0	0	**50,065,510**
Chaetognatha (Arrow worms)	173,627,909	1,338,378,596	79,841,178	152,140,503	16,483,591	**1,909,975,229**
Cirripedia (Barnacles)	0	22,415,065	36,863,757	22,925,346	22,078,768	**9,935,084,259**
Cnidaria	84,172,449	0	22,534,625	38,110,795	39,646,769	**1,909,675,639**
Copepoda (including damaged specimens)	721,231,464	56,119,158	103,127,021	61,036,140	209,214,266	**7,972,319,840**
Calanoid (Copepod)	189,629,329	109,827,619	177,443,928	30,068,223	138,554,697	**1,579,451,480**
Cyclopoida (Copepod)	0	0	17,761,572	11,912,520	11,039,384	**227,624,900**
Harpacticoida (Copepod)	84,172,449	130,086,806	141,331,389	201,589,973	225,252,463	**1,840,744,205**
Acartia spp (Copepod)	7,893,263,543	2,813,399,136	1,918,681,590	383,767,193	580,921,566	**24,350,227,027**
Calanus spp (Copepod)	105,456,881	138,965,138	19,102,184	38,110,795	0	**301,634,997**
Caligus spp (Parasitic copepod)	0	0	0	0	0	**4,357,372**
Centropages spp (Copepod)	10,988,646,006	2,194,747,478	2,517,572,299	1,263,035,910	360,158,081	**90,804,418,404**
Eurytemora sp (Copepod)	0	0	0	0	0	**8,235,550**
Isias spp (Copepod)	9,746,987,971	363,349,942	0	0	0	**10,420,353,589**
Oithona spp (Copepod)	0	0	0	0	0	**7,332,268**
Paracalanus spp (Copepod)	1,206,912,284	201,806,748	228,798,640	95,276,986	167,039,653	**2,126,577,765**
Paramisophria spp (Copepod)	0	0	0	0	0	**3,639,878**
Parapontella brevicornis (Copepod)	357,974,226	817,450,576	144,012,612	44,051,302	0	**1,466,827,275**
Pseudocalanus spp (Copepod)	0	0	0	0	0	**792,911,584**
Pseudocalanus elongatus (Copepod)	489,998,551	220,073,047	221,172,567	228,362,092	274,408,419	**3,672,057,749**
Siphonostomatoida (Copepod)	0	0	0	0	0	**68,472,730**
Stephos spp (Copepod)	0	0	0	0	0	**10,756,173**
Temora spp (Copepod)	12,126,930,106	2,235,557,666	2,766,983,602	1,887,922,728	1,312,269,339	**66,308,863,895**
Temora longicornis (Copepod)	0	0	0	0	0	**246,460,852**
Ctenophora (Sea gooseberries)	0	0	0	0	0	**294,032,753**
Cumacea	2,284,847,924	255,770,027	196,546,112	208,732,850	88,343,615	**3,904,094,049**
Decapoda	357,974,226	141,375,833	45,069,251	0	0	**982,201,666**
Echinodermata (Starfish/ sea urchins)	0	22,415,065	0	0	0	**294,241,382**

Species/taxon	Aug	Sept	Oct	Nov	Dec	Total
Ectoprocta/ bryozoa (Sea mats)	0	188,524,833	0	0	0	**211,782,628**
Foraminifera	89,455,460	322,923,396	41,636,809	1,474,152,142	4,078,080,253	**7,244,971,221**
Gastropoda	568,887,988	1,611,161,499	391,162,218	45,850,691	0	**4,191,096,572**
Hydroida	0	0	0	0	17,568,000	**67,226,840**
Hydrozoa	189,629,329	101,112,278	62,830,823	0	0	**456,648,741**
Invertebrate eggs	1,236,832,179	152,501,870	247,890,852	334,643,573	214,768,135	**7,300,734,045**
Isopoda (Isopod)	463,431,107	148,098,287	79,841,178	61,036,140	35,136,001	**2,048,644,042**
Lamellibranch (Bivalves)	0	172,669,230	0	193,524,226	167,916,007	**2,224,775,897**
Medusae (Jellyfish)	84,172,449	157,231,436	106,569,435	34,837,866	5,444,207	**1,022,820,221**
Mysidacea (Opposum shrimps)	400,543,091	1,324,607,708	1,591,670,862	633,246,910	150,375,785	**9,984,663,956**
Shrimps and prawns-like decapods	89,455,460	0	0	95,276,986	16,871,159	**741,011,536**
Nematode (Roundworm)	0	22,415,065	35,523,145	41,980,743	0	**170,041,982**
Podon spp (Cladocera)	0	0	0	0	17,568,000	**17,568,000**
Polychaeta (Bristle worms)	0	22,415,065	19,102,184	0	35,136,001	**631,094,661**
Pycnogonid (Sea Spider)	0	0	0	0	0	**15,044,202**
Urochordata (Tunicates)	0	0	0	0	0	**23,257,796**
Unidentified specimen	0	33,704,093	0	0	17,568,000	**503,976,628**
Total	**58,670,033,304**	**18,007,190,733**	**12,420,557,252**	**8,479,210,365**	**9,561,689,289**	**294,468,363,746**

B.14 Predicted entrainment of zooplankton at SZC

Species/taxon	Jan	Feb	March	April	May	June	July
Gammaridae (Amphipoda)	1,418,595,460	832,715,440	743,377,009	329,160,681	3,688,721,226	10,052,995,431	10,962,345,698
Hyperiidae (Amphipoda)	18,773,455	15,332,450	0	0	0	0	0
Appendicularia (Pelagic tunicates)	0	0	0	0	0	159,044,001	427,664,249
Arachnida (Mites)	46,597,504	61,744,384	0	0	0	0	0
Brachyura (True crabs)	0	0	0	128,187,148	0	0	0
Chaetognatha (Arrow worms)	8,366,570	130,410,935	33,452,284	0	88,096,065	122,461,044	0
Cirripedia (Barnacles)	93,867,274	53,748,685	3,988,784	11,611,687,939	11,426,129,113	1,538,013,573	443,233,809
Cnidaria	390,194,551	102,861,398	66,204,102	128,187,148	1,435,131,226	2,235,082,735	59,548,989
Copepoda (including damaged specimens)	188,572,970	230,815,918	102,703,949	1,274,677,768	8,151,338,334	2,048,157,808	5,469,657,399
Calanoid (Copepod)	105,465,029	123,488,769	51,822,585	317,700,075	687,343,054	148,560,117	956,837,933
Cyclopoida (Copepod)	195,046,365	12,217,087	18,790,581	192,962,808	0	0	59,548,989
Harpacticoida (Copepod)	382,629,843	371,157,747	266,053,553	600,795,701	176,192,129	0	912,858,504
Acartia spp (Copepod)	149,069,287	493,784,855	740,360,912	2,771,104,317	8,461,025,855	2,277,464,706	12,657,465,419
Calanus spp (Copepod)	0	0	0	0	0	0	0
Caligus spp (Parasitic copepod)	0	0	0	11,156,565	0	0	0
Centropages spp (Copepod)	1,150,739,564	1,590,087,924	1,218,353,223	13,426,099,236	98,195,393,780	9,268,688,575	63,288,635,814
Eurytemora sp (Copepod)	0	17,097,424	3,988,784	0	0	0	0
Isias spp (Copepod)	0	0	0	0	0	0	793,760,526
Oithona spp (Copepod)	18,773,455	0	0	0	0	0	0
Paracalanus spp (Copepod)	51,152,349	30,664,900	25,756,551	67,671,016	405,306,480	0	0
Paramisophria spp (Copepod)	9,319,501	0	0	0	0	0	0
Parapontella brevicornis (Copepod)	0	0	0	0	0	0	264,586,842
Pseudocalanus spp (Copepod)	83,875,507	321,981,448	251,961,698	1,284,246,864	88,096,065	0	0
Pseudocalanus elongatus (Copepod)	328,294,381	317,546,791	79,152,094	133,878,776	3,920,215,248	686,585,279	264,586,842
Siphonostomatoida (Copepod)	18,639,002	0	8,117,661	0	0	148,560,117	0
Stephos spp (Copepod)	0	0	27,539,979	0	0	0	0
Temora spp (Copepod)	3,132,389,784	1,669,587,285	630,692,769	9,584,334,187	37,992,980,464	11,628,474,683	53,086,149,989

Species/taxon	Jan	Feb	March	April	May	June	July
Temora longicornis (Copepod)	0	0	631,035,494	0	0	0	0
Ctenophora (Sea gooseberries)	0	0	0	0	0	752,838,035	0
Cumacea	61,559,234	78,841,808	191,586,754	144,155,040	0	42,381,971	1,708,638,014
Decapoda	0	0	17,007,152	0	616,672,452	0	487,213,238
Echinodermata (Starfish/sea urchins)	9,319,501	12,217,087	23,411,102	128,187,148	88,096,065	434,750,032	0
Ectoprocta/ bryozoa (Sea mats)	0	0	0	0	0	0	59,548,989
Foraminifera	1,266,641,301	462,982,226	128,458,852	223,862,921	352,384,258	148,560,117	588,722,673
Gastropoda	0	0	0	128,187,148	176,192,129	1,778,925,519	1,946,833,970
Hydroida	0	0	0	0	0	127,145,914	0
Hydrozoa	35,539,225	168,827,170	0	0	0	0	59,548,989
Invertebrate eggs	385,961,187	377,388,472	177,726,506	235,549,551	4,186,046,677	1,748,141,576	5,983,261,523
Isopoda (Isopod)	26,052,640	17,097,424	20,644,385	128,692,753	458,228,703	1,810,823,607	767,369,640
Lamellibranch (Bivalves)	798,788,061	638,380,562	795,525,859	230,713,764	585,421,516	1,279,932,876	0
Medusae (Jellyfish)	35,539,225	15,332,450	10,532,826	0	0	769,567,369	793,760,526
Mysidacea (Opposum shrimps)	1,078,417,995	884,836,880	625,325,959	4,917,824,553	7,559,481,923	0	0
Shrimps and prawns-like decapods	46,597,504	0	0	0	814,535,867	519,960,411	0
Nematode (Roundworm)	18,773,455	0	7,977,568	22,313,129	88,096,065	42,381,971	0
Podon spp (Cladocera)	0	0	0	0	0	0	0
Polychaeta (Bristle worms)	63,683,092	46,411,935	26,628,055	0	264,288,194	207,224,987	811,349,069
Pycnogonid (Sea Spider)	0	12,217,087	3,988,784	22,313,129	0	0	0
Urochordata (Tunicates)	0	0	0	0	0	0	59,548,989
Unidentified specimen	26,136,182	17,097,424	0	0	585,421,516	530,444,295	0
Total	**11,643,370,452**	**9,106,873,962**	**6,932,165,813**	**48,043,649,367**	**190,490,834,401**	**50,507,166,750**	**162,912,676,623**

Species/taxon	Aug	Sept	Oct	Nov	Dec	Total
Gammaridae (Amphipoda)	22,367,042,908	6,750,554,754	2,988,462,803	2,267,749,305	3,380,612,167	**65,782,332,882**
Hyperiidae (Amphipoda)	0	0	0	0	28,265,110	**62,371,015**
Appendicularia (Pelagic tunicates)	0	131,994,633	57,697,392	0	44,980,903	**821,381,179**

Species/taxon	Aug	Sept	Oct	Nov	Dec	Total
Arachnida (Mites)	0	0	45,476,523	30,500,678	27,878,567	**212,197,657**
Brachyura (True crabs)	0	0	0	0	0	**128,187,148**
Chaetognatha (Arrow worms)	444,554,875	3,426,768,966	204,424,421	389,538,771	42,204,394	**4,890,278,324**
Cirripedia (Barnacles)	0	57,391,271	94,385,533	58,697,788	56,530,221	**25,437,673,989**
Cnidaria	215,514,157	0	57,697,392	97,578,434	101,511,124	**4,889,511,256**
Copepoda (including damaged specimens)	1,846,632,638	143,686,837	264,045,223	156,276,222	535,669,770	**20,412,234,837**
Calanoid (Copepod)	485,524,725	281,201,357	454,325,365	76,986,327	354,753,831	**4,044,009,169**
Cyclopoida (Copepod)	0	0	45,476,523	30,500,678	28,265,110	**582,808,141**
Harpacticoida (Copepod)	215,514,157	333,072,741	361,863,242	516,148,619	576,733,782	**4,713,020,017**
Acartia spp (Copepod)	20,209,820,015	7,203,394,371	4,912,569,991	982,593,050	1,487,384,810	**62,346,037,588**
Calanus spp (Copepod)	270,010,569	355,804,719	48,909,010	97,578,434	0	**772,302,732**
Caligus spp (Parasitic copepod)	0	0	0	0	0	**11,156,565**
Centropages spp (Copepod)	28,135,201,211	5,619,405,872	6,445,962,784	3,233,862,429	922,144,555	**232,494,574,966**
Eurytemora sp (Copepod)	0	0	0	0	0	**21,086,207**
Isias spp (Copepod)	24,956,074,444	930,316,958	0	0	0	**26,680,151,928**
Oithona spp (Copepod)	0	0	0	0	0	**18,773,455**
Paracalanus spp (Copepod)	3,090,164,151	516,703,648	585,813,372	243,946,086	427,686,382	**5,444,864,934**
Paramisophria spp (Copepod)	0	0	0	0	0	**9,319,501**
Parapontella brevicornis (Copepod)	916,553,038	2,092,990,930	368,728,215	112,788,439	0	**3,755,647,465**
Pseudocalanus spp (Copepod)	0	0	0	0	0	**2,030,161,582**
Pseudocalanus elongatus (Copepod)	1,254,586,581	563,472,465	566,287,663	584,695,640	702,592,120	**9,401,893,879**
Siphonostomatoida (Copepod)	0	0	0	0	0	**175,316,780**
Stephos spp (Copepod)	0	0	0	0	0	**27,539,979**
Temora spp (Copepod)	31,049,650,560	5,723,895,803	7,084,552,579	4,833,815,359	3,359,919,126	**169,776,442,588**
Temora longicornis (Copepod)	0	0	0	0	0	**631,035,494**
Ctenophora (Sea gooseberries)	0	0	0	0	0	**752,838,035**
Cumacea	5,850,098,004	654,870,598	503,234,374	534,437,158	226,193,962	**9,995,996,919**
Decapoda	916,553,038	361,977,037	115,394,785	0	0	**2,514,817,702**
Echinodermata (Starfish/sea urchins)	0	57,391,271	0	0	0	**753,372,206**

Species/taxon	Aug	Sept	Oct	Nov	Dec	Total
Ectoprocta/ bryozoa (Sea mats)	0	482,696,785	0	0	0	**542,245,774**
Foraminifera	229,040,718	826,809,300	106,606,402	3,774,401,969	10,441,469,168	**18,549,939,907**
Gastropoda	1,456,574,176	4,125,199,130	1,001,527,186	117,395,576	0	**10,730,834,834**
Hydroida	0	0	0	0	44,980,903	**172,126,817**
Hydrozoa	485,524,725	258,886,699	160,871,308	0	0	**1,169,198,116**
Invertebrate eggs	3,166,770,701	390,464,012	634,696,848	856,817,505	549,889,830	**18,692,714,391**
Isopoda (Isopod)	1,186,563,607	379,189,128	204,424,421	156,276,222	89,961,807	**5,245,324,337**
Lamellibranch (Bivalves)	0	442,100,286	0	495,497,174	429,930,189	**5,696,290,288**
Medusae (Jellyfish)	215,514,157	402,573,536	272,859,139	89,198,466	13,939,284	**2,618,816,978**
Mysidacea (Opposum shrimps)	1,025,545,863	3,391,510,144	4,075,295,532	1,621,358,011	385,020,407	**25,564,617,267**
Shrimps and prawns-like decapods	229,040,718	0	0	243,946,086	43,196,719	**1,897,277,305**
Nematode (Roundworm)	0	57,391,271	90,953,046	107,487,005	0	**435,373,510**
Podon spp (Cladocera)	0	0	0	0	44,980,903	**44,980,903**
Polychaeta (Bristle worms)	0	57,391,271	48,909,010	0	89,961,807	**1,615,847,418**
Pycnogonid (Sea Spider)	0	0	0	0	0	**38,519,000**
Urochordata (Tunicates)	0	0	0	0	0	**59,548,989**
Unidentified specimen	0	86,295,566	0	0	44,980,903	**1,290,375,887**
Total	**150,218,069,737**	**46,105,401,361**	**31,801,450,082**	**21,710,071,431**	**24,481,637,857**	**753,953,367,837**

Appendix C Predictions of entrainment for specific species

This section presents the information that has been used to evaluate entrainment in population terms. For sole, bass, herring, sprat and sandeel, annual stock assessments carried out by ICES provide estimates for mortality, total international catch and SSB (ICES, 2018a, 2018b, 2018c). For dab and flounder, although ICES provides information on stock landings and relative abundance, full stock assessments cannot be completed due to a lack of data (ICES, 2018a). For these species the mean weight of individuals used in Table 12 was calculated from the catch numbers at age and catch weights at age given in the relevant Working Group Reports.

C.1 Dab

C.1.1 Distribution and fisheries

The dab (*Limanda limanda*) is distributed in coastal waters of the northeast Atlantic from the White Sea to the Bay of Biscay and is common on muddy or sandy sea beds around Britain to a depth of 100 m. As with many other flatfish species, small dab tend to be found in shallower waters than larger fish, but some quite large dab are caught in shallow bays and estuaries in autumn (Kennedy, 1969). Its centre of distribution in the North Sea appears to be located in the southern North Sea (Daan et al., 1990). Dab are not targeted by commercial fisheries and are taken mainly as a bycatch in trawls.

C.1.2 Spawning and nursery areas

Dab spawn mainly between March and May, in water 20–40 m deep (Rijnsdorp et al., 1992). Metamorphosis tends to take place in deeper water than for plaice or flounder, from whence the 0-groups migrate to nearby nursery grounds, showing a general preference for sheltered areas, though not for particular depth or salinity zones (Bolle et al., 1994; Riley et al., 1981). Dab mature at around 22 cm and 2−3 years old (Deniel and Tassel, 1986).

C.1.3 Migrations and population structure

Information from fisheries suggests that adult dab spend the winter in relatively deep water, returning inshore from May onwards. Tagging studies indicate that dab spawning in the German Bight may aggregate from the entire southern North Sea (Rijnsdorp et al., 1992), and that seasonal migrations between spawning grounds, nursery areas and adult feeding grounds are triggered by changes of water temperature (Saborowski and Buchholz, 1997). Rijnsdorp et al. (1992) provide age- and length-at-maturity and fecundity information for dab in the southern North Sea.

C.1.4 Stock status and catch and population estimates

ICES considers dab in the southern North Sea to be part of a stock unit that covers Subarea 4 (North Sea) and Division 3.a (Skagerrak, Kattegat). In 2016, a benchmark assessment was carried out on this stock for the first time, to fully investigate the data sets available to conduct a full stock assessment (ICES, 2018a). The stock is data poor, and the benchmark agreed on the use of a survey-based assessment model to inform stock status of North Sea dab, which provides relative estimates of the spawning stock, recruitment, and total mortality, rather than absolute values. The assessment indicated that relative spawning stock biomass (SSB) has been increasing since 2006, total mortality has declined since 2003 and that recruitment showed an increasing trend until 2014, but declined in the latest two years of the time-series (ICES, 2017a). The stock has not be re-assessed since that time (ICES, 2018a).

C.1.5 Conclusions

The dab encountered at Sizewell are part of a stock covering the North Sea and Skagerrak. Given the lack of absolute SSB estimates for this stock, we consider that the most appropriate comparison for dab is with the international landings for this stock in 2010 (the year of the CEMP programme), which were **8,279 t** (compared with catches of 50,765 t if the discarded catch is also included)

No dab eggs or larvae were detected in the CEMP survey; only juvenile dab were entrained.

The entrainment prediction for dab at SZC, rescaled to the number of adults and converted to weight, suggests that the impact would be 21,810 adults, equivalent to 0.872 t, or 0.011 % of North Sea/Skagerrak landings (Table 12).

C.2 Dover sole

C.2.1 Distribution and fisheries

Sole (*Solea solea*) are found in shelf waters from Iceland south to the northwest coast of Africa and the Mediterranean (Wheeler, 1978). They inhabit sandy and muddy areas in water down to 150 m, and tend to be inactive during daylight, when they may be partially buried in the seabed (Heessen et al., 2015). Sole are caught mainly in directed beam-trawl fisheries in the North Sea and in fixed trammel- or gillnets fished inshore. Discard rates of sole are low in these fisheries, which use a mesh size compatible with the minimum landing size of 24 cm.

C.2.2 Spawning areas

Sole spawning starts when the water temperature rises above 7 °C, and takes place from late February until late June in the seas around England and Wales (Fonds, 1979; van Beek, 1988). In the North Sea, the main spawning areas for sole are in coastal waters south of Flamborough Head, along the Dutch coast, and across the Southern Bight, from March to May (Coull et al., 1998).

C.2.3 Larvae and juveniles

Sole larvae are pelagic for up to 6 weeks (Fonds, 1979), during which time they move inshore and recruit to shallow inshore nurseries at metamorphosis (around 15–18 mm long; Marchand and Masson, 1988). Sole nurseries tend to be in estuaries, tidal inlets and shallow (<20 m) sandy bays along the coast (Millner and Whiting, 1990; Riley et al., 1986). There is a general movement up the estuary during May and June, with a return migration towards the sea in October and November. After 2 or 3 years, juvenile sole move into deeper water to join the adult stock (Dorel et al., 1991).

C.2.4 Migrations and population structure

Sole undertake their most extensive migrations as maturing juveniles. For example, sole tagged as 2-year-old juveniles in the eastern English Channel began to emigrate from the release areas as 3-year-olds, and a proportion of sole tagged on the French coast of the eastern Channel moved to the English side of the western Channel (ICES, 1989). The seasonal distribution of tag returns and catch rates in the sole fishery suggested that these movements are permanent and that, once fully mature, adult sole make short migrations into deeper offshore water in autumn and return to distinct spawning grounds inshore or on shallower offshore banks in spring. Sole appear to continue to use the spawning ground to which they first recruit (Kotthaus, 1963).

C.2.5 Stock status and catch and population estimates

The analytical age-based assessment for sole in the North Sea is based on landings (no discards are included) and one commercial fishery and three survey catch per unit effort series which provide standardised indices of abundance index (ICES, 2018d). The latest assessment shows that SSB has increased since 2007, fishing mortality has declined since 1999 and recruitment has fluctuated without trend since the early 1990s (ICES, 2018d).

C.2.6 Conclusions

The sole at Sizewell are part of the North Sea stock and the most valid comparison for sole is with international landings (**12,603 t**) and SSB (**31,358 t**) for this area in 2010 (ICES, 2018a).

Only sole eggs and larvae were detected in the CEMP survey, no juvenile sole were entrained. The entrainment prediction for sole at SZC, rescaled to the number of adults and converted to weight, suggests that the impact would be no more than a loss of about 631 adults, equivalent to 0.143 t, or 0.001 % of the North Sea landings and about 0.0005 % of the SSB (Table 12).

C.3 Anchovy

C.3.1 Distribution and fisheries

Anchovy *Engraulis encrasicolus* are concentrated in two well-defined areas in Atlantic European waters; the Bay of Biscay and the Gulf of Cádiz (ICES, 2018e). The main international fishery for anchovy is by French and Spanish purse-seiners in the Bay of Biscay (ICES Subarea VIII). In the north of its Atlantic distribution, anchovy are traditionally caught in small numbers as a bycatch in Division VIIh (Western Approaches). However, since the 2000s, variable but increasing numbers of anchovy have been landed in the western English Channel (Division VIIe) by the inshore fisheries targeting sprat and sardine.

C.3.2 Spawning areas

The main spawning area for anchovy is in the central and southern part of the Bay of Biscay, on the continental shelf from the 100 m isobath out to beyond the shelf break (ICES, 2018e). North of their main spawning areas, smaller spawning locations are known from the estuarine and coastal waters in the southern North Sea (Wallace and Pleasants, 1972).

C.3.3 Juveniles

Anchovy were one of the most abundant species impinged at SZB, when impingement samples (see BEEMS Technical Report TR339) suggested that age groups 0 and 1 dominated. In the Bay of Biscay (there is very little information for the species in British waters), anchovy are fully mature at 1 year old, in the spring following that in which they hatched (Motos, 1996).

C.3.4 Stock assessment and status

Although time-series of data on anchovy in peripheral areas such as the North Sea are insufficient to identify abundance trends of the anchovy population as a whole, the population in the northern areas appear to have increased in recent years (Beare et al., 2004; ICES, 2018e). Studies have shown that this increase is due to an expansion of local remnant populations (Petitgas et al., 2012) which are genetically distinct from the Bay of Biscay anchovy (Zarraonaindia et al., 2012). Data for anchovy elsewhere in northern Europe are scarce and not routinely reported to ICES. Consequently, there are no assessments for anchovy in the North Sea.

C.3.5 Conclusions

Ongoing genetic work suggests that anchovy encountered at Sizewell are part of a southern North Sea population that migrates into the English Channel in the autumn (van der Kooij, pers. Comm). Genetic analysis suggests that North Sea and English Channel samples are genetically homogenous (ICES, 2018e). Given that there is no assessment of the species outside the main population in the Bay of Biscay, we consider that the most useful comparison for anchovy is with landings data for all vessels fishing in the North Sea and English Channel (ICES Subarea 4 and Divisions 7.d and 7.e in 2010 (**727 t**).

Only anchovy eggs were detected in the CEMP survey, no larval or juvenile anchovy were entrained. The entrainment prediction for anchovy at SZC, rescaled to the number of adults and converted to weight, suggests that the local impact equates to 2,869 fish or 0.06 t., equivalent to 0.008 % of landings (Table 12).

C.4 Flounder

C.4.1 Distribution

The flounder (*Platichthys flesus*) is widely distributed in shelf waters of the Northeast Atlantic from the White Sea and the Baltic south to the Mediterranean and Black Sea (Wheeler, 1969). It is common around the British Isles, and is unusual for a flatfish in that juveniles and adults are found in both marine and freshwater, often well above the tidal limit. Flounders are usually associated with soft, muddy or sandy mud substrata (Kennedy, 1969). The flounder is not an important species for commercial fisheries in the North Sea, but helps to provide an income for fishers in the Sizewell area.

C.4.2 Spawning areas, larvae and juveniles

Flounder spawn in the sea, at depths of 25−40 m, between February and April, at which time they tend to appear more in trawl catches than at other times of the year (Wheeler, 1969). The most important spawning grounds in the North Sea are situated along the continental coast, and small areas off the English and Scottish coasts are less important (van der Land, 1991). The larvae drift into shallow bays and estuaries where they metamorphose at a length of 8–10 mm during April and May (van der Veer and Groenewold, 1987). The juveniles either stay in the brackish environment or brackish water or migrate farther up rivers, and flounder of 2–3 cm are often seen well into freshwater some tens of km above the tidal limit (Vethaak, 1992). Male flounder mature at ~10 cm, and females at ~25 cm.

C.4.3 Adult migrations and population structure

During autumn, flounder withdraw from the inshore and estuarine and freshwater feeding areas into coastal areas, where immature fish spend the winter and adults move farther offshore to the spawning grounds, where they arrive by February. Spent flounder begin to appear inshore from April, and are found in shallow water along sandy beaches and in estuaries between May and November (Kennedy, 1969).

C.4.4 Stock assessment and status

ICES considers flounder in the southern North Sea to be part of a stock unit that covers Subarea 4 (North Sea) and Division 3.a (Skagerrak, Kattegat)(ICES, 2018a). The stock is data poor, and, like dab, the benchmark agreed on the use of a survey-based assessment model. The assessment indicated that landings have been decreasing since 2006 and are stable in the most recent years, and that the available survey information indicates no clear trend in stock biomass (ICES, 2017b).

C.4.5 Conclusions

The flounder encountered at Sizewell are part of a population in the North Sea. We consider that the most appropriate comparison would be with international landings from that stock area in 2010 (**3,365 t**).

Only flounder larvae were detected in the CEMP survey, no flounder eggs or juvenile flounder were entrained. The entrainment prediction for flounder at SZC, rescaled to the number of adults and converted to weight, suggests that the impact would be 2 fish each year, which would be negligible (Table 12).

C.5 Bass

C.5.1 Distribution and fisheries

Sea bass (*Dicentrarchus labrax*) are distributed in Northeast Atlantic shelf waters from southern Norway through the North Sea, Irish Sea and Bay of Biscay to northwest Africa, and in the Mediterranean and Black Seas (Pickett and Pawson, 1994).

They are caught in the North Sea mainly between April and November, from small boats using a variety of fishing methods close to shore and by recreational anglers operating from boats and the shore (Pawson et al., 2007). Commercial rod-and-line fishing takes place near warm-water discharges from power stations on the Scottish east coast and in northeast England, where landings of trawl-caught bass have increased significantly since 2003. Along the English coast in Division IVc, from Norfolk south, sea bass may be targeted in estuaries and around wrecks and offshore banks, in a mixed fishery using driftnets, fixed nets, trawls, longlines and rods and line (Walmsley and Pawson, 2007). Until recently, sea bass were not a target species for other nations' commercial fisheries in the North Sea, and were taken mainly as a bycatch in trawls. However, the fishery now attracts some directed effort from, for instance, Dutch beam trawlers, fly-seine and twin-rig trawl fishers, and professional rod-and-line fishers.

C.5.2 Spawning areas

A study in the 1980s described sea bass as starting to spawn in March offshore in the western Channel, when the temperature range associated with their egg distributions was 8.5–11 °C, then moving eastwards into the southern North Sea as the surface water temperature exceeds 9 °C (Thompson and Harrop, 1987). There is no contemporary information on bass spawning in the North Sea, but other evidence indicates that reproductive success and production of the sea bass population there has been much higher in the 1990s and 2000s (Colman et al., 2009).

C.5.3 Larvae and juveniles

Sea bass larvae move inshore over a period of 2−3 months and, at around 15 mm long, actively swim into coastal creeks, estuaries, backwaters and shallow bays from June on (Jennings and Pawson, 1992; Reynolds et al., 2003). Juvenile sea bass remain in these nursery areas through their first and second years, after which they migrate to overwintering areas in deeper water, and may return in summer to the larger estuaries for 3–5 years, depending on growth, until they are around 36 cm long (Pawson et al., 1987). In contrast to the regular migrations of adult sea bass (see below), a substantial proportion of the juvenile population emigrates from its respective stock areas and disperses throughout large parts of the population's distribution range (Pickett et al., 2004).

Climate and environment effects on the early life history of sea bass have significant implications for their distribution and abundance. There is a positive relationship between seawater temperature and the growth of the 0-group in summer (Pawson, 1992; Reynolds et al., 2003), and survival through the first winter is reduced at temperatures below 5–6 °C (Kelley, 2002; Lancaster, 1991). This may well explain the attraction for first-year sea bass of warm water effluents from coastal power station cooling systems, especially in autumn and winter (Kelley, 1986; Pawson and Eaton, 1999). This is likely to affect survival near Sizewell, where the warmed water might promote a longer growth season than elsewhere in the North Sea (without thermal warming), and also serve to retain juvenile sea bass in water that may be used for cooling. In British waters, male sea bass mature at a length of 31–35 cm and an age of 4–7 years, and females at 40–45 cm and 5–8 years (Pawson and Pickett, 1996).

C.5.4 Adult migrations

Tagging studies around England and Wales have demonstrated that adult sea bass migrate between well-defined (usually inshore) feeding areas and pre-spawning and spawning areas that tend to be offshore to the south and west (Pawson et al., 2007, 1987). Movement between the respective areas appears to be relatively rapid and takes place as the water cools from October to December, when adult females seek out water above approximately 9 °C. Many adult sea bass tagged in the southern North Sea spend the winter in the English Channel, and tagging off Guernsey in autumn (Quayle et al., 2009) showed that these fish migrate to summer feeding areas along the coasts of the eastern English Channel and southern North Sea at the end of spawning in April/May.

C.5.5 Stock status and catch and population estimates

Prior to 2012, the sea bass assessment areas used by ICES were based on consideration of the patterns of seasonal movements of sea bass in the exploited populations (i.e. >36 cm) as indicated by tag recaptures (e.g. (Pawson et al., 2007), and the characteristics of the seasonal fisheries taking them. Despite movement of both juvenile and adult sea bass between the North Sea and the English Channel, the North Sea was considered to be an assessment unit (ICES, 2004), along with separate units for the Eastern Channel (Area VIId), Western Channel & Western Approaches (Areas VIIe & h), and the Irish Sea & Celtic Sea (Area VIIa, f & g).

At the Inter-Benchmark Protocol meeting of October 2012 (ICES, 2012), however, the status of bass was assessed for a much larger area, combining these four stock units, using a dataset that included French commercial fishery data, as well as England and Wales data. An age- and length-based analytical assessment used commercial landings data and two survey indices, and this was updated in 2014 to include estimates of recreational catches (ICES, 2014). ICES now consider that estimates of fishing mortality, biomass, recruitment and biological reference points are robust and show a general trend of declining biomass since 2010 due to poor recruitment and sustained exploitation levels. The most recent advice is that SSB has been declining since 2005, fishing mortality has increased over the time-series, peaking in 2013 before a rapid decline, and that recruitment has been poor since 2008, with the exception of the 2013 and 2014 year-class estimates which show average recruitment (ICES, 2018f).

C.5.6 Conclusions

The sea bass encountered at Sizewell are part of a population that occupies an extensive area in the North Sea, the English Channel and western UK coastal waters. For the present purposes, we consider comparisons with international landings (**<u>4,768 t</u>**) and SSB (**<u>20,780 t</u>**) of the stock area in 2010.

Only bass eggs were detected in the CEMP survey, no larval or juvenile bass were entrained. The entrainment prediction for bass at SZC, rescaled to the number of adults, corrected for entrainment survival of 50 % and converted to weight, suggests that the impact will be approximately 36 fish equivalent to 0.049 t which represents 0.001 % of the landings and 0.0002 % of the SSB (Table 12).

C.6 Herring

C.6.1 Distribution and fisheries

The Atlantic herring (*Clupea harengus*) is widespread throughout northeast Atlantic shelf waters from the White Sea and Iceland in the north to the Bay of Biscay in the south (Wheeler, 1978). In the North Sea, herring are caught mainly in a directed fishery that takes place mostly in late spring and summer in the central and northern parts, and in autumn and winter in the southern North Sea (ICES, 2018c).

C.6.2 Spawning areas

Herring are benthic spawners, depositing masses of sticky eggs onto gravel substrata in well-established sites (Wheeler, 1978). There are four main spawning components of the North Sea herring population (Postum et al., 1977). The most northerly of the components spawns in summer in the Orkney/Shetland area, the “Buchan” component spawns in late summer off the Scottish east coast, the “Banks” component (which used to spawn around the western edge of the Dogger Bank) now spawns in autumn along the English east coast, and the “Downs” component spawns in late autumn through February in the southern

Bight and eastern English Channel. A small, discrete stock in the Thames Estuary spawns in spring on the Eagle Bank in the River Blackwater, Essex.

C.6.3 Larvae and juveniles

The movements of larvae hatching from spawning areas in the North Sea have been the subject of major investigations, and (Burd, 1985) showed that the larvae of Downs herring drift north-eastwards to nursery areas along the Dutch coast and into the German Bight. Nursery areas for fish spawned in the northern North Sea tend to be along the east coast of Scotland, across the North Sea and into the Skagerrak and Kattegat, whereas juvenile Banks herring are found along the east coast of England down to the Wash, and off the west coast of Denmark.

C.6.4 Adult migrations and population structure

Migrations of herring have been largely inferred from the seasonal distributions of directed fisheries and the biological characteristics of the fish caught. Herring that use different spawning sites may be distinguished on the basis of spawning time, mean egg size and fecundity (Blaxter and Hunter, 1982; Hempel and Blaxter, 1967; Zijlstra, 1973), vertebral counts (Cushing and Burd, 1957; Parrish and Saville, 1965) and variations in life history parameters such as growth and age or size at maturity that are attributable to environmental influences rather than genetic differences (Jennings and Beverton, 1991; Smith and Jamieson, 1986). However, they have been little studied by tagging, and their movements when they disperse after spawning are less well known. At certain times of the year, individuals from the four main North Sea stock units may mix and are caught together as juveniles and adults, and cannot be readily separated in the commercial catches (Bierman et al., 2010; Clausen et al., 2007). Consequently, North Sea autumn-spawning herring are managed as a single unit with the understanding that they consist of many spawning components. It is likely that two herring stocks are found off the Suffolk coast; the Downs herring, which occupies the southern North Sea and the Blackwater stock (also called Thames herring) that spawns in spring in the northern part of the Thames Estuary and tends to remain inshore, The two stocks mix seasonally in the southern half of the Thames Estuary.

C.6.5 Stock status and catch and population estimates

The ICES age-based assessment of herring in Subarea IV and Divisions IIIa and VIId (North Sea autumn spawners) uses commercial landings and four survey index series of catch per unit effort, and includes discards. The most recent benchmark for this stock was conducted in 2018 (ICES, 2018c). ICES considers that SSB and fishing mortality are reliably estimated, and that the stock is at full reproductive capacity with SSB above the precautionary reference point (B_{pa} = 900,000 t) (ICES, 2018g) The year classes from 2002 onwards are estimated to be among the weakest since the late 1970s, with the two lowest year classes falling within the recent four of the last 30 years. The poor survival of the larvae (Payne et al., 2009) is thought to be due to the current low productivity regime in the North Sea (Gröger et al., 2010).

C.6.6 Conclusions

The herring encountered at Sizewell are a mix of the Downs stock that chiefly occupies the southern North Sea and potentially some from a separate population that spawns mainly on Eagle Bank in the Blackwater Estuary, both of which move into adjacent inshore waters at times. While Blackwater herring are identified as a distinct “stock” for management purposes, there is no convincing genetic evidence that indicates that the Blackwater population is biologically separate from the much larger Downs stock. Previous modelling studies have concluded that the hydrodynamics of the estuary will tend to retain the majority of early stage Blackwater herring larvae within the estuary (Fox and Aldridge 2000). Modelling of the transport of Downs herring (Dickey-Collas *et al* 2009) demonstrated that the north easterly flow of the residual current in the southern North Sea will transport most larvae to the German Bight and this modelled circulation pattern is in good agreement with the results of larval surveys. However, given the size of the larval production in the eastern Channel, modelling shows a percentage of Downs herring larvae are likely to reach the coast at Sizewell, whereas the proportion of the Blackwater herring that will reach Sizewell is considered to be negligible. We have therefore compared entrainment estimates with abundance estimates for the Downs stock.

The herring encountered at Sizewell are part of a population that occupies an extensive area in the North Sea. For the present purposes entrainment is compared with international landings (**187,600 t**) and SSB (**2,023,720 t**) of the stock area in 2010.

Only larvae and juvenile herring were detected in the CEMP survey, no herring eggs were entrained. This is to be expected because herring lay their eggs on gravel substrate (above), so any entrained eggs would most likely have been dead. Based on the scaled-up CEMP dataset suggests that the impact would be a loss of a maximum of 23,992 fish or 14.175 t, equivalent to 0.002 % of the North Sea landings and 0.0002 % of the SSB (Table 12).

C.7 Sprat

C.7.1 Distribution and fisheries

Sprat (*Sprattus sprattus*) is distributed in Northeast Atlantic shelf waters from northern Norway and the northern Baltic south to the Mediterranean and Black Seas (Wheeler, 1978; Whitehead et al., 1984). It is particularly abundant in the central and southern North Sea, overlapping with populations in the English Channel and to a lesser extent in the Kattegat, although a genetic study by (Limborg et al., 2009) does not support the separation of sprat into the three stock areas currently employed by ICES (i.e. Subarea IV, Division VIId and Division IIIa). The species is short-lived in the North Sea, and the fishery is dependent on each year's incoming year class at age 1, which is itself dependent on the zooplankton community structure (Beaugrand, 2003; Reid et al., 2003).

Most of the sprat landings from the central and southern North Sea are taken in the Danish industrial small-meshed trawl fishery, and are used for reduction to meal and oil (ICES, 2018c). The UK lands small quantities of sprat, which are occasionally taken in mid-water trawls and in gillnets along the Suffolk coast (BEEMS Technical Report TR123).

C.7.2 Spawning areas

Sprat eggs have been recorded in the North Sea throughout the year (Milligan, 1986), although (Coull et al., 1998) indicate that spawning takes place chiefly between May and August offshore in the southern and central North Sea.

C.7.3 Larvae and juveniles, and adult migrations

Given the widespread spawning in the North Sea, sprat larvae are also widely distributed, although 0-group sprat are found chiefly in coastal waters (Coull et al., 1998) and have been reported in August and September from shallow inshore sites and estuaries in the southern North Sea (Riley et al., 1986). In contrast, older sprat are rarely found in shallow water, but fishing effort is largely targeted on large overwintering concentrations, and it is impossible to assess the distribution of adult fish when they spawn during their second summer. There is little known about the movements of sprat on the Suffolk coast.

C.7.4 Stock assessment

The ICES age-based assessment of sprat in Subarea 4 (North Sea) uses commercial landings and three survey index series of catch per unit effort but does not include discards (they cannot be quantified). A benchmark for this stock was conducted in 2013 (ICES, 2018c). ICES considers that the stock is at full reproductive capacity with SSB above the precautionary reference point (B_{pa} = 125,000 t) since 2005, though there is some uncertainty in the advice as the SSB consists of recruits for which abundance and proportion mature is unknown. Recruitment has fluctuated around the long-term mean, with occasional large year classes (ICES, 2019).

C.7.5 Conclusions

It seems likely that the sprat encountered at Sizewell are part of a population that is widespread throughout the North Sea and we consider that that the most appropriate comparisons for sprat is with landings (**143,500 t**) and SSB (**225,041 t**) in 2010.

Eggs, larvae and juveniles of sprat were detected in the CEMP survey. The entrainment prediction for sprat at SZC, rescaled to the number of adults, and converted to weight, suggests that the impact will be a maximum of 199,715 fish or 1.997 t which would be equivalent to a maximum of 0.001 % of the fishery and 0.0009 % of SSB (Table 12).

C.8 Sandeel

C.8.1 Species and distribution

Five species of sandeels are found in the North Sea:

- Lesser sandeel (*Ammodytes tobianus*). This is a small, common inshore species which reaches a maximum length of 20 cm, and is found along sandy shores from the mid-tide level to 30 m water depth. The species spawns from late March to early April throughout its range, depositing it's eggs on the sandy substrate.
- Greater sandeel (*Hyperoplus lanceolatus*) attains a length of approximately 32 cm. It is found in sand from the inter-tidal to 150 m depth. The species spawns in April and May at depths of 20-100 m. It forms only a small component of commercial fisheries.
- Raitts sandeel (*Ammodytes marinus*) reaches a maximum length of 24 cm. The species is found in sand and fine gravel. It is most abundant down to 50 m water depth, but can be found up to 150 m. The species spawns in winter (November-February) in the English Channel.
- Corbin's sandeel, (*Hyperoplus immaculatus*) is principally an offshore species with spawning in the English Channel taking place in January-April. It may reach up to 40 cm in length.
- Smooth sandeel (*Gymnammodytes semisquamatus*), an offshore (20-200 m) species which grows up to 23.5 cm, appears to have a preference for shell gravel grounds. In the North Sea, the species spawns in March-August, laying its eggs over shell gravel.

The first three species are distributed over fine sand and gravel from inshore down to approximately 100 m depth, with the last two species being predominantly offshore species (Wheeler, 1978). Sandeels make daily vertical shifts between inactive stages, during which they stay in the sand, and active stages, during which they forage. Sandeels hibernate for periods in winter buried in sand at depths of 20 to 50 cm.

Lesser, Greater, and Corbin's sandeels were all caught in BEEMS 2 m beam trawl surveys off Sizewell, but their presence and abundance was highly variable (BEEMS Technical Report TR201). Five greater sandeel were recorded from sampling sites off the Sizewell station complex and off Orford Ness in May 2008 and September 2011. The species was not abundant in the impingement dataset (only 332 individuals recorded in the 4 year period from February 2009 to February 2013) but occurred in 50 % of samples with the majority of individuals caught between July-October each year (BEEMS Technical Report TR345).

Four lesser sandeels were recorded in the 2 m beam trawl samples, all relatively close to the Sizewell station complex and over three different surveys. Lesser sandeels were caught more frequently than greater sandeels in impingement sampling but the numbers were low with 366 individuals recorded during the 4 years monitoring, and the species was less common than the greater sandeel, occurring in only 28 % of samples - also in contrast to the greater sandeel, the majority of records were from December-February (BEEMS Technical Report TR345). A single Corbin's sandeel was caught by the 2 m beam trawl in September 2011, off Thorpeness, and the species was not recorded during the impingement monitoring.

The two sandeel species found in the impingement sampling represented less than 0.04% of the total fish numbers caught.

Sandeels are ecologically important and are the target of large-scale industrial fisheries. In areas where they are abundant sandeels are an important prey species for many predators, including fish, marine mammals and seabirds.

C.8.2 Spawning

The species tends to spawn over sand and gravel with the eggs adhering to the substrate.

C.8.3 Fisheries and Stock Assessment

Sandeels are taken by trawlers using small-meshed demersal gear for non-human consumption (i.e. fishmeal). The fishery is seasonal, taking place mostly in the spring and summer. Sandeel are largely sedentary after settlement and form a complex of local (sub-) stocks in the North Sea (ICES, 2018c). To avoid local depletion, ICES advice for sandeel is provided separately for seven areas in Division 3a and Subarea 4, and of these, SA 1r is of relevance to the Sizewell area. The most recent advice for sandeel in SA 1r is that SSB at the start of 2019 (97,636 t) is below B_{pa} (145,000 t) and that the stock is at reduced reproductive capacity.

C.8.4 Conclusions

It seems likely that the sandeels encountered at Sizewell are part of a population that is widespread throughout the southern North Sea and we consider that that the most appropriate comparisons for sandeels would be with the landings (**300,893 t**) and SSB (**124,742 t**) in 2010 (landings are higher than the SSB indicating that the fishery takes a proportion of the juvenile part of the population).

Eggs, larvae and juveniles of sandeels were detected in the CEMP survey. The entrainment prediction for sandeel at SZC, rescaled to the number of adults, and converted to weight, suggests that the impact will be a maximum of 18,999 fish or 0.127 t which would be equivalent to a maximum of 0.00004 % of the fishery and 0.0001 % of SSB (Table 12).

C.9 Gobies

C.9.1 Distribution and life history

Sand gobies (*Pomatoschistus* spp.) are widely distributed in north eastern Europe and are found throughout the Mediterranean Sea, in the Bay of Biscay and around the UK coast and throughout the North Sea to Norway. The species is extremely common inshore from the mid-tide line to around 20 m depth over sandy substrates, and may be caught in large quantities in shrimp nets and trawls (Wheeler, 1978). Data from fisheries surveys shows that in the North Sea, the species tends to be present off the south and eastern coasts (Belgium and the Netherlands), but that its presence becomes less on the English north east and Scottish North eastern coasts (Heessen et al., 2015).

The species spawns between March and July and the female lays her eggs in nesting sites, which are guarded by territorial males (Heessen et al., 2015; Wheeler, 1978). Adults may move offshore from coastal habitats to reach suitable nesting sites, and they are believed to spawn throughout their distribution range. The species is fast growing and short-lived with most individuals dying after their first full spawning season. However, the maximum age given for the species is approximately 32 months (Heessen et al., 2015). Sand gobies feed on small crustaceans such as copepods and amphipods and young brown shrimp (Wheeler, 1978), and in turn are an important prey for many predators (Heessen et al., 2015).

C.9.2 Population assessment

Few data are available on sand goby abundance. In Cefas Young Fish Surveys (YFS) of the east and south coasts of England, gobies were the dominant species throughout the survey area, with highest densities recorded in the area from Flamborough to Winterton (region 1), followed by the area between Winterton and North Foreland (region 2), and the lowest densities between North Foreland and Portland Bill (region 3) (Rogers and Millner, 1996). For region 2, estimated densities in September of each year were approximately 41 individuals/1000 m^2, which is comparable with the abundances observed in the June BEEMS offshore survey (BEEMS Technical Report TR345). Population estimates for *Pomatoschistus* spp. in the region 2 ranged between 36 – 197 million individuals between 1973 and 1995 (mean = 94.7 million, st dev = 41.3 million individuals).

C.9.3 Conclusions

The sand gobies encountered at Sizewell are most likely to be part of populations that extend throughout the North Sea and eastern English Channel. However, their short pelagic larval stage before the post larvae settle to the seabed suggests that the individuals at Sizewell are part of more local populations (Heessen et al., 2015). Given the lack of any stock assessment for the population, the most appropriate comparison of impingement of sand goby at Sizewell is considered the mean abundances observed in region 2 of the Cefas YFS between 1973 and 1995 (94.7 million individuals). However, studies on the catching efficiency of 2 m beam trawls off the German coast showed that the gear is only 46% efficient at catching *Pomatoschistus* spp. over coarse sand (Reiss et al., 2006). The push net used for the Young Fish Surveys was chosen under the assumption that its selectivity was similar to that of the 2 m beam trawl (Rogers and Millner, 1996). Taking the trawl efficiency data, this would suggest that only 46 % of the gobies present in the areas surveyed during the YFS were recorded, leading to an underestimation of their abundance. To calculate the total abundance if the gear was 100 % efficient, the mean annual estimate was raised by a factor of (1/0.46) = **205.8 million** individuals.

Larvae and juvenile gobies were detected in the CEMP survey. The entrainment prediction for gobies at SZC, rescaled to the number of adults, suggests that the impact will be a maximum of 3,324,365 fish. However, due to the difficulties associated with identification of juveniles and larvae to species, individuals were only identified as gobies. In addition to *Pomatoschistus* spp. several other goby species (e.g. the transparent goby *Aphia minuta*) are present in the Sizewell area. Impingement data for SZB indicates that of the total gobies present, approximately 13 % is of species that are not *Pomatoschistus* spp. (BEEMS Technical Report TR406). To account for these other taxa and to allow a total entrapment assessment (impingement + entrainment) to be conducted for *Pomatoschistus* spp. (a key species), the gobies in the entrainment dataset were apportioned into a ‘sand goby’ group and an ‘other gobies’ group in the proportions 87 % and 13 % respectively. The apportioning process was carried out for the larval and juvenile stage separately (there were no goby eggs identified).

On this basis, the estimated number of sand gobies that would be entrained by SZC would represent 1.4 % of the abundance. Gobies are not a commercially-exploited species and as such, a precautionary harvesting rate threshold of 10% SSB is considered appropriate as a screening threshold for potentially significant effects that may affect the sustainability of the stock (see full discussion in BEEMS Technical Report TR406).