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Cefas

Particle Tracking Study of Impinged Sprat from the Proposed Hinkley Point C Fish Recovery and Return

Particle Tracking Study of Impinged Sprat from the Proposed Hinkley Point C Fish Recovery and Return

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Version and Quality Control

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Executive Summary

As a result of the direct cooling of Hinkley Point C (HPC) with seawater, fish present at the intakes will be impinged and subsequently returned to the sea via the Fish Recovery and Return (FRR) system. The subsequent fate of the discharged fish will depend upon the species. Sprat are expected to have 100% mortality within the FRR system but demersal fish such as whiting and mullet have an expected mortality of 54% and benthic species such as eels, rockling and some flatfish only 20% (BEEMS Technical Report TR456). Discharged dead fish will be passively transported from the FRR outfall and due to the strong tidal currents at Hinkley Point, there is a potential for some fish to beach on a wide area of the intertidal mud flats and surrounding beaches and become a nuisance. In practice the discharged dead fish will have a more varied fate. Some will sink to the seabed before reaching land and be consumed by benthic organisms, and some will be consumed by foraging piscivorous birds (either whilst the fish are floating and also once any fish beach). Some dead fish may also be consumed by other fish whilst at sea but that additional source of predation has not been considered in this study.

Most fish impingement at Hinkley Point takes place in winter from November – January (BEEMS Technical Report TR456) corresponding to the period when 99% of sprat impingement occurs. In the CIMP data record this peak period was from 19 November 2009 to 14 January 2010. During this peak period sprat accounted for 76% of total fish impingement at HPB, the remainder being predominantly whiting (16%), with some mullet (3%) and small numbers of other species. The calculated discharge of dead fish from HPC consists of approximately 70% dead sprat and that species is, therefore, the focus of this report. The sprat discharge rate was overestimated in this study by a factor of approximately 1.6 which more than compensated for the other 30% of the discharge that are not sprat. The worst-case impingement month of December was also selected for the modelling in order to be conservative.

The aim of this study was to determine the fate of these dead sprat and in particular to assess the potential abundance and distribution of sprat that may beach on the surrounding coastline. This is assessed using particle tracking with the validated 25m resolution GETM 3D hydrodynamic model of Hinkley Point, including particle sinking behaviour and bird predation. Population densities, distributions and sizes of foraging seabirds in the vicinity of the HPC FRR were obtained from British Trust for Ornithology (BTO) wetland bird surveys (WeBS). Based on these numbers and the energy requirements, foraging rates were calculated to parameterise predation in the model. Predation rates were calculated for the black headed gull, common gull, great black backed gull, herring gull and lesser black backed gull.

To assess the buoyancy of impinged sprat, and parametrise the behavior in the model, sprat were collected during routine impingement sampling at the Sizewell B station by Cefas staff. Over several campaigns from summer and winter 2018, a total of 1,366 sprat were collected, of which 88.3 % sank immediately, with the rest sinking over time. Based on the observed buoyancy data of sprat, particle sinking behaviour was parameterised whereby 88.3% of particles sink immediately. An exponential decay rate with a half-life of 12 hours was then applied to the remaining particles and after 24 hours, any remaining particles were classified as sunk.

Results and Conclusions

During the peak impingement period of November to January a small number of dead fish are expected to beach on the shoreline over a 12.1 km stretch of coast from west of Lilstock to east of Stolford. Over the 14-day simulation, a total of 342 sprat beached, representing 0.12% of the 281,219 fish included in the model. At the end of the simulation, only 5 fish were on the beach, or 0.002% of the total number of released fish. The number of beached fish was maximum during night time hours due to the absence of bird predation but during day time hours the number of birds present meant fish were typically eaten within 1-2 hours of daybreak.

The predicted mean instantaneous number of fish on the beaches was 1.02 fish and the maximum instantaneous number of fish was 148 at daybreak, however, within 5 hours (i.e. by noon), all those beached fish had been eaten by birds. The 148 fish covered a total coastline length of 10.1 km, with an average linear distribution of one sprat every 68 m. The average daily rate of beaching was 24.4 sprat per 24 hours. The mean instantaneous number of beached fish over the 14 day simulation during daylight hours was 4.17 fish spread over a length of coastline of up to 12.1km or 1 fish every 2.9km.

Even during the peak impingement event (148 sprat in one night) the average density along the shoreline was only one sprat per 68 m, rapidly falling to zero within 5 hours once bird predation commenced. The mean instantaneous density was much lower. Such dead fish densities are not considered to represent a nuisance and would be unlikely to be discernable on the shoreline.

1 Introduction

As a result of the direct cooling of the Hinkley Point C (HPC) power station with seawater, fish will be impinged through the cooling water infrastructure. To avoid fish, invertebrates and other debris passing into the station condensers, cooling water from the intakes passes through rotating drum screens. Fish and invertebrates are washed from the drum screens and are returned to sea via the Fish Recovery and Return (FRR) outfall.

Based on the CIMP impingement data from Hinkley Point B (HPB), of the 64 species recorded, sprat (*Sprattus sprattus*) was the most abundant, representing approximately half of the impinged samples between February 2009-February 2010 (BEEMS Technical Report TR456).

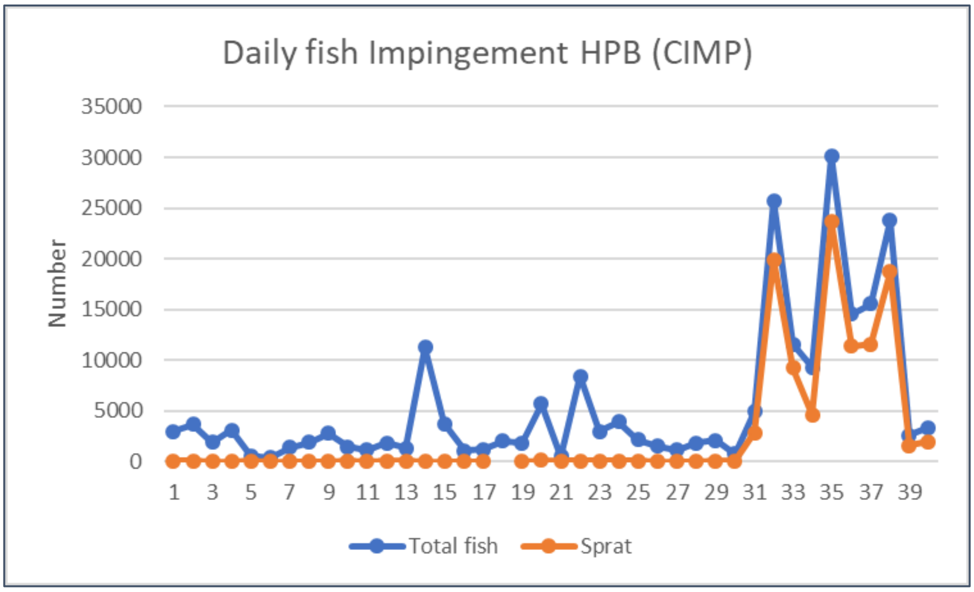

Figure 1 Measured daily fish impingement at HPB during the period February 2009 to end January 2010 (The horizontal axis is the measurement day in the 40 * 24-hour measurement periods in the programme)

Most fish impingement at Hinkley Point takes place in winter from November – January (BEEMS Technical Report TR456) corresponding to the period when 99% of sprat impingement occurs. In the CIMP data record this peak period was from 19 November 2009 to 14 January 2010. If the window was widened to 13th November to 28th January, the total sprat impingement numbers only increased by 3%. During this peak period sprat accounted for 76% of total fish impingement at HPB, the remainder being predominantly whiting (16%), with some mullet (3%) and small numbers of other species (Appendix A,Table 8).

At HPC all of the impinged fish will be recovered in the FRR system and returned to sea via the dedicated subtidal FRR outfall. The subsequent fate of the discharged fish will depend upon the species. Sprat are expected to have 100% mortality within the FRR system but demersal fish such as whiting and mullet have an expected mortality of 54% and benthic species such as rockling and flatfish only 20% (TR456). Discharged dead fish will be passively transported from the FRR outfall and due to the strong tidal currents at Hinkley Point, there is a potential for some fish to beach on a wide area of the intertidal mud flats and surrounding beaches and become a nuisance. In practice the discharged dead fish will have a more varied fate. Some will sink to the seabed before reaching land and be consumed by benthic organisms, some will be consumed by foraging piscivorous birds (either whilst the fish are floating and also once any fish beach). The calculated discharge of dead fish from HPC consists of approximately 70% dead sprat (Appendix A, Table 10) and that species is, therefore, the focus of this report.

The aim of this study is to track where these dead sprat travel and assess the potential abundance and distribution of sprat that may beach on the surrounding coastline. This is assessed using particle tracking with the validated 25m resolution GETM 3D hydrodynamic model of Hinkley Point, including particle sinking behaviour and bird predation.

2 Data Sources

2.1 Marine Birds

2.1.1 Number of marine birds present at Hinkley Point

Data on bird counts in the vicinity of Hinkley Point were acquired from the British Trust for Ornithology (BTO) on the 17th April 2018. These data held counts from the wetland bird surveys (WeBS) which is collected with the intention of providing data on waterbird population densities, distributions and sizes. Detailed methodologies for these surveys can be found as part of the WeBS data request guidance[1]. Survey data for the years 2013-2015 were acquired for the BTO survey areas[2]:

- Steart Marshes
- Pawlett Hams
- Severn – Berrow Flats
- Bridgwater Bay
- Severn – R Parrett at Combwich and Pawlett
- Berrow.

These areas were deemed appropriate due to their proximity to the discharge area of the FRR outlet. Bird counts were extracted for the following gulls which are all opportunistic feeders whose diets include fish (caught near to the sea surface), fish discards and carrion as well as other prey.

Common name	Scientific Name
Black headed gull	*Chroicocephalus ridibundus*
Common gull	*Larus canus*
Great black backed gull	*Larus marinus*
Herring gull	*Larus argentatus*
Lesser black backed gull	*Larus fuscus*

Dead sprat would provide a high energy food source which gulls could readily predate whilst the fish were floating or beached. Table 1 provides a summary of the gull counts from the WeBS data.

[1] WeBS guidance note can be found; https://www.bto.org/volunteer-surveys/webs/data/overview-data
[2] WeBS survey areas can be found; http://blx1.bto.org/websonline/public/

Table 1: WeBS nesting counts for seabirds in proximity to HPC.

Species	Average Abundance in November	Average Abundance in December
Black Headed Gull	546	233
Common Gull	10	32
Great Black Backed Gull	24	8
Herring Gull	92	126
Lesser Black Backed Gull	20	2

2.1.2 Bird consumption rates

To best calculate the consumption rate of available sprat the number of sprat per day per gull were calculated for each of the bird species. This was achieved by first calculating the basal metabolic rates (BMR) per gull using the calculation reported in Garthe *et al.*(1996), where 'body mass' was taken as average body mass of each gull species as reported in Table 2;

$$BMR\ (kJ\ d^{-1}) = 2.3(body\ mass(g))^{\ 0.774}$$

Equation (1)

The BMR was then translated to the field metabolic rate (FMR) to represent the energy demands of active gulls, which takes into account thermoregulation, digestion, moult, reproduction and activity/ movement. Garthe *et al.* (1996) report, that for periods outside of the breeding season, the FMR should be calculated as;

$$FMR\ (kJ\ d^{-1}) = 2.5(BMR)$$

Equation (2)

The FMR was then divided by the average available energy per sprat to give the required number of sprat per day per gull, where the available average energy per sprat was calculated using an assimilation efficiency of 75%, as reported in Garth *et al.* (1996);

$$Available\ energy\ per\ sprat = 0.75(energy\ per\ sprat)$$

Equation (3)

To estimate the average energy per sprat the reported Clupeid energetic equivalent (6.5 kJ g^{-1}) was used, as reported in Garthe *et al.* (1996). Using data collected as part of the comprehensive impingement monitoring programme (CIMP) (BEEMS Technical Report TR129) sprat tail length (TL) and weights were calculated for the 50%ile, as 8.3 cm and 4.38 g respectively. The average energy per sprat was, therefore, calculated by multiplying the clupeid energy equivalent of 6.5 kJ g^{-1} by the average impinged sprat weight at HPB (collected from the CIMP) of 4.38 g, resulting in each sprat representing 21.36 kJ.

$$Energy\ per\ sprat = Clupeid\ equivalent\ energy * average\ weight\ of\ sprat$$

Equation (4)

2.1.3 Results

Table 2 presents the results of energy demands and how many sprat per day each bird species would need to consume, as calculated by their field metabolic rate divided by the available energy per sprat (assuming that their energy needs are met only by sprat).

Table 2: Energy demands and how many sprat per day each bird species would need to consume.

Species	Average Size (g)		BMR (kJ/day)	FMR (kJ/day)	Sprat/ day/ gull
Black Headed Gull	300	*Chroicocephalus ridibundus*	190	475	22
Common Gull	385	*Larus canus*	230.4	576	27
Great Black Backed Gull	1,525	*Larus marinus*	669.2	1,673	79
Herring Gull	900	*Larus argentatus*	444.8	1,112	52
Lesser Black Backed Gull	785	*Larus fuscus*	400.4	1,001	47

Combining the data in Table 1 and Table 2 shows that the gull population in the vicinity of Hinkley Point would have to consume the equivalent of 13,268 sprat per day to meet their daily energy requirements.

2.2 Sprat

2.2.1 Source term

To derive a sprat source term for the model, i.e. the number of fish released per hour from the HPC FRR outfall, the number of sprat that are likely to be impinged at HPC was determined from the Comprehensive Impingement Monitoring Program (CIMP) data from Hinkley Point B (HPB) in 2009/10.

In the CIMP programme each 24-hour sample consisted of an 18-hour overnight bulk sample, followed by six consecutive hourly samples in daylight. Impingement of schooling species such as sprat is highly variable with time and therefore to construct a sprat impingement source term it was decided not to use the 18-hour bulk sample as this would have averaged out temporal variability and to only use the 6 hourly records. It is worth considering the impact of this decision. The daylight sampling was done on the ebb tide and HPB has an ebb tidal sampling bias of approximately 1.6 (TR456). By using the hourly samples the assumption has been made that these daylight samples are fully representative of the full 24 hours which is incorrect and examination of the relatively short impingement record during the peak impingement period shows that the measured impingement rate was a factor of 1.69 greater during the 6 hourly samples than during the bulk sample (Appendix A, Table 7).

The CIMP data between 19 November 2009 to 14 January 2010 comprised 42 hourly measurements of impingement (Appendix A, Table 7). The impingement numbers from HPB were then scaled to those at HPC using the approach detailed in Section 5 of TR456 for pelagic species. The peak periods for impingement were in December followed by November and so December was selected for modelling as a worst case. It was assumed that all of the sprat discharged from the FRR outfall were dead and their fate was modelled via particle tracking over a spring neap cycle using the first 14 days of December with a time interval of 1 hour.

The HPC sprat impingement data were not normally distributed (there was one large outlier), however once the data were transformed by taking the natural logarithm they were then normally distributed (Shipiro Wilk Test) with a mean (natural logarithm) of 6.479 and standard deviation 0.7352. A 14-day hourly record was then generated using the Microsoft EXCEL function (NORM.INV(RAND(),mean, standard deviation) which generates random numbers from a normal distribution. The random number function generated a total of 281,219 sprat (particles in the model) for the 14-day period in December (Figure 2). Scaling of the measured CIMP data for December predicted 177,482 sprat in the period i.e. the source term has been overestimated by a calculated factor of 1.58. As noted in Section 1, sprat account for approximately 70% of the dead fish discharge at HPC i.e. the number of dead fish discharged would be underestimated by a factor of approximately 1.43 if only sprat is modelled. However, by using a source term overestimated by a factor 1.58 it is considered that the final modelling predictions are precautionary.

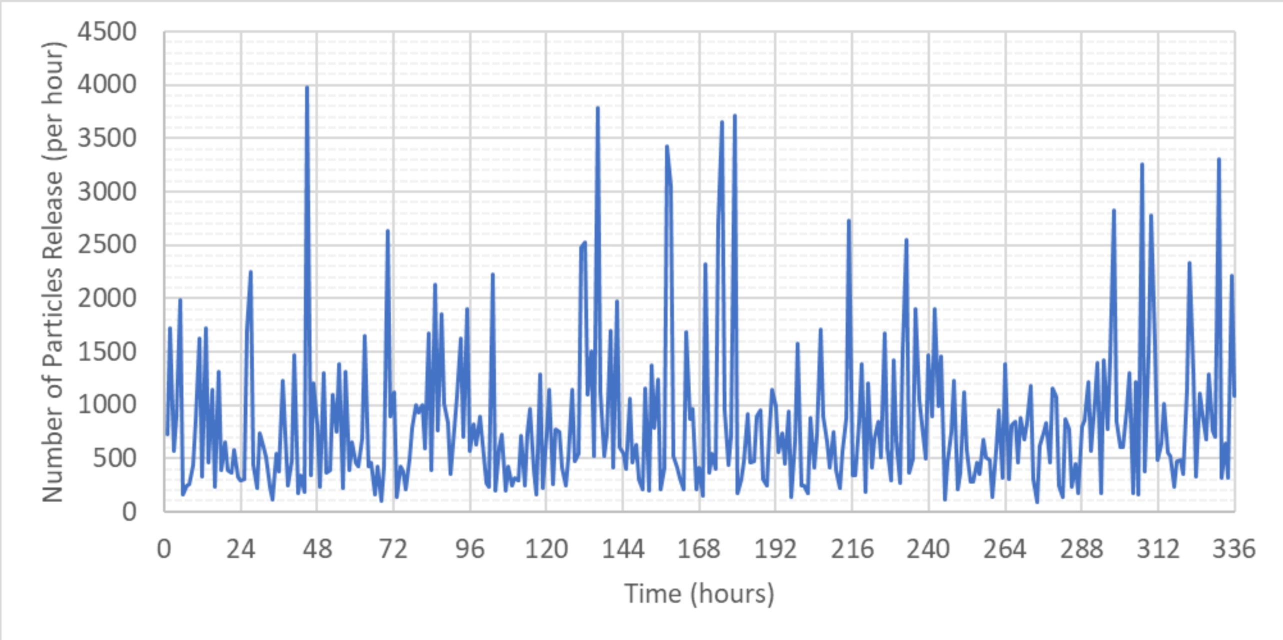

Figure 2. Number of particles released per hour via the Hinkley Point C Fish Recovery and Return outfall. Each particle represents one sprat.

2.2.2 Sinking behavior

To assess the buoyancy of impinged sprat and parametrise the behavior in the model, sprat were collected during routine impingement sampling at the Sizewell B station by Cefas staff. During normal station operations, cooling water passes from the forebay area to four rotating drum screens of 10 mm mesh size that prevent fish, invertebrates and other debris (generally larger than approximately 3 cm) from passing into the station cooling system. The fish and invertebrates are washed from the drum screens and pass back to the sea via the cooling water seal pit and the cooling-water discharge. When impingement sampling is underway, the cooling water discharge is diverted into a trash bin for collection in a specially-designed net. During the day when the sampling team are on site, the net is emptied hourly and the contents are sorted to species. Each fish species is weighed individually and then either the whole or a subsample of each fish species is measured.

To investigate their buoyancy, once the sprat sample had been measured, it was returned to a container of seawater to determine whether they would float or sink. Two approaches were used.

In the first round of experiments (generally conducted over the summer 2018 when sprat was scarce), the fish were placed in a container and the time was recorded. The number of fish that did not sink immediately was recorded. Those that did not float were classed as ‘sank immediately’. The fish remained in the container for as long as possible while the sampling team continued their normal work, and when time allowed, the number of fish still on the surface was recounted and recorded. At the end of the sampling day, the number of fish that remained floating was recorded, along with their individual lengths. These fish were designated as ‘remained floating’. The fish that did not sink immediately but did so at some point between the start and the end of the experiment were designated as ‘slowly sinking’.

Several samples were observed on each sampling visit, and samples from different hourly sample collections were placed in individual containers. Due to sampling limitations, each experiment was stopped at around 1600h, when the sampling team was preparing to leave the site overnight – giving a maximum immersion time of approximately 5 hours for the samples collected during the first sample of the day and only around 45 minutes for the last sample of the day. The resulting dataset consisted of 457 sprat of the length classes 2.5 -2.9 cm TL to 15.0-15.4 cm TL, and is presented in Figure 3. 376 of the 457 sprat, or 82%, sank immediately. 68 of the 457 sprat, or 15%, remained floating at the end of the 5-hour experiment.

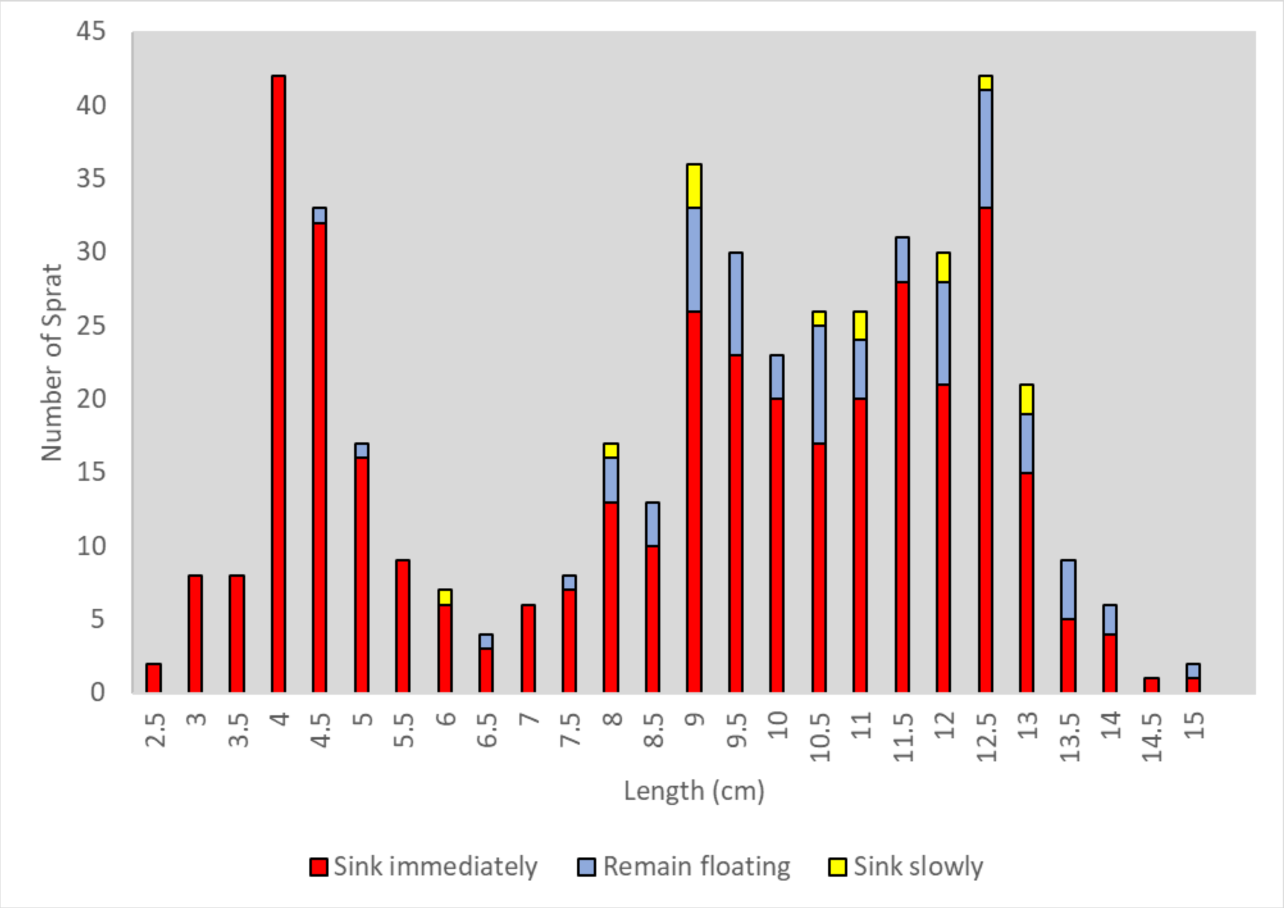

Figure 3: Observed sinking behaviour of impinged sprat, sorted by length, held in buckets for a maximum of 5 hours.

In the second set of experiments on 18th December 2018 (when sprat were more abundant), a known number of unmeasured fish was placed in the container and the number that did not immediately sink was recorded. The number that remained on the surface was recorded each hour until the end of the sampling day. The fish were left overnight and the number that remained on the surface when the sampling team arrived the next day was recorded. This allowed for an immersion time of up to 23 hours to be observed. Table 3 summarises the proportion of the sprat that sank immediately and the total that had sunk by the next morning. Only sprat from sample 1 and 2 were measured, with lengths ranging from 9 – 13 cm.

Table 3: Observed sinking behaviour of impinged sprat, held in buckets overnight.

	Number of sprat	Duration (hrs)	% that sank immediately	% that had sunk by the next morning
Sample 1	140	23	87.9	94.3
Sample 2	269	22	84.0	90.3
Sample 6	500	18	96.2	98.8

Overall, a total of 1,366 sprat were collected, of which 88.3% sank immediately, with the rest sinking over time.

3 Model Description

3.1 GETM model

The particle tracking study was conducted using the validated 3D Hinkley Point 25 m resolution GETM model. The model setup, calibration and validation are described in BEEMS Technical Report TR267 Edition 2. As with the 100 m resolution Hinkley Point GETM model (BEEMS Technical Report TR177) the surface is forced with reanalysed data from a meteorological model (ERA40 interim from ECMWF). The boundary conditions were forced by a broader 3D GETM domain, described in BEEMS Technical Report TR177. In this study, the GETM model domain used a discrete grid with dimensions of 25 m by 25 m and 15 vertical layers in a sigma co-ordinate system in which the layer thickness changed with water depth.

The model domain extends an area from -3.485300 to -3.054002 °E and 51.156 to 52.22 °N. The particle tracking is conducted independently of the GETM computation, as a post process. Therefore, to reduce the computational run time, the hydrodynamic forcing of the GETM model was limited to an area from -3.418891 to -2.987593 °E and 51.17745 to 51.26273 °N, as shown in Figure 4. The particle tracking was conducted over a spring neap cycle using the first 14 days of December 2008 (the year selected as the representative year for modelling in HPC studies) with a time interval of 1 hour.

Particles are released into the model domain, at the sea surface, from the HPC FRR outfall, located at 320230 mE, 146685 mN (BNG).

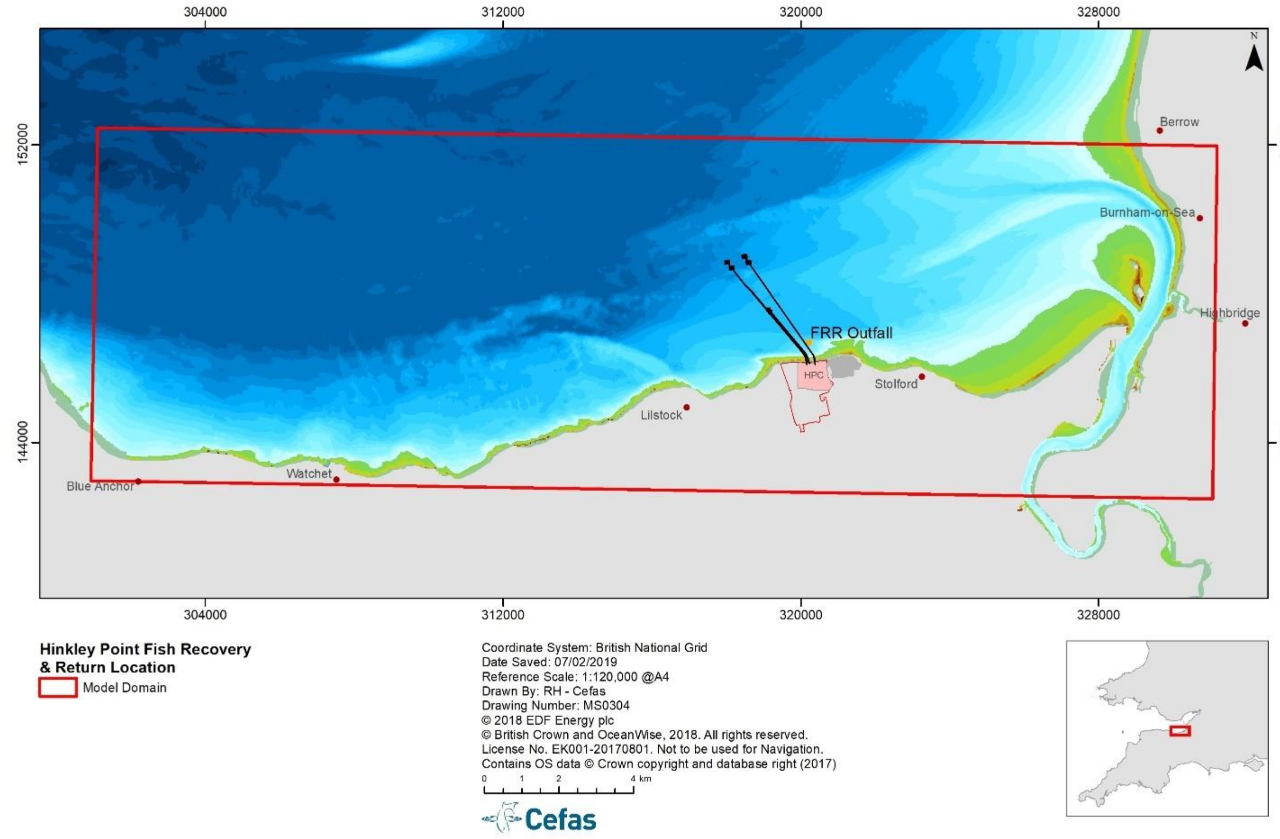

Figure 4: Plan of Hinkley Point C infrastructure and the location of the FRR outfall overlaying local bathymetry. The red rectangle indicates the area modelled in the particle tracking simulation.

3.2 Particle Model

The particle tracking model has been used for modelling the movement both of passive particles and fish subject to the three-dimensional currents as modelled by the GETM model, and was previously used for determining the optimal position of the FRR outfall (BEEMS Technical Report TR197). The particles are subject to three sets of processes: advection by the hydrodynamics, random diffusion and probabilistic ‘mortality’ processes, whereby particles are removed from the system.

The data used from the GETM model consisted of:

a) The raw non-tidal bathymetry as an x – y grid.
b) Water depth.
c) u, v and w vector of currents in 3 dimensions for all cells and all layers over time.

In the model, diffusion is set to a minimal level as the particles are assumed to be passive but a small amount of physical diffusion is used to avoid numerical convergence of modelled sprat arriving at the same position. There is a particle upward movement of 5 cm/s which pushes the buoyant sprat towards the surface, consistent with a partially buoyant particle with high drag in the water column but is still small compared to the most extreme vertical advection.

There are three processes modelled in which a particle is removed from the system: beaching, sinking and predation by seabirds. Beaching occurs when the particles end up in locations where the water depth in all 15 depth bands are zero or the particle reaches a designated land grid cell. Once the particle is beached, for example in the intertidal region, it cannot be resuspended but is available to be predated,by birds even if the water depths increase again. Furthermore, predation on the seabed from benthic scavangers such as crustaceans (not included in the model) will also occur.

Based on the observed sprat buoyancy data, particle sinking behaviour has been included whereby 88.3% of particles sink immediately. An exponential decay curve with a half-life of 12 hours was applied to the remaining particles, whereby 50% of the remaining particles have sunk after 12 hours, to simulate a gradual sinking behaviour. After 24 hours, any remaining particles are classified as sunk. Once a particle has sunk, it is removed from the system and cannot be moved or predated by birds.

3.3 Predation

The predation is parameterised into the particle tracking model as a Holling type 2 functional response (Pianka, 1994), whereby the rate of predation (sprat eaten per time interval), C, is calculated by:

$$C = n\left(\frac{aP}{1+ahP}\right) \qquad \text{Equation (5)}$$

where n is the population of birds, P is the dead spat population, a is the rate at which a predator locates prey, known as the attack rate and h is the time taken for a predator to consume its prey known as the handling time. The type 2 functional response has been used as it is more appropriate than the type 1 functional response. A type 1 functional response assumes a linear relationship whereby the rate of consumption linearly increases with the prey availability. The type 2 response is a decelerating intake rate where foraging and eating are mutually exclusive behaviours. If the prey density increases for a static population of predators, the rate of predation will increase but then level off.

Predation from all five species, as identified in the WeBS data, were modelled. The attack rate is calculated as the maximum search time allowable per sprat divided by a 10 hour period, assuming foraging is limited to only occur during the day, including twilight, between 7am and 5pm (for Hinkley Point in December). For example, a herring gull requires 52 sprat per day, allowing a maximum search time of 0.19 hours per sprat during 10 hours of daylight, resulting in an attack rate of 0.019. Hudson (1987) measured an average handling rate for a herring gull eating a 28 cm whiting at 4 seconds. As a sprat is smaller, the handling rate is likely to be shorter. However, for this model, the handling rate is not a limiting factor. A handling rate of 4 seconds was applied uniformly to each bird species. Table 4 summaries the different parameters used for each bird species to calculate the rate of predation.

Table 4: Parameters used for each bird species to calculate rate of predation.

Bird Species	Population of Birds	Attack Rate, a	Handling Rate, h (sec)
Black Headed Gull	233	0.045	4
Common Gull	32	0.037	4
Great Black Backed Gull	8	0.013	4
Herring Gull	126	0.019	4
Lesser Black Backed Gull	2	0.021	4

The mean number of dead sprats discharged from HPC in the model was 651 per hour or 15,636 per day. With 88% sinking immediately only a mean of 1876 fish per day are avaialable to be predated by birds whereas the population energy requirement is the equivalent of 13,268 sprats per day (Section 2.1.3). Bird predation was, therefore, expected to be a relatively minor factor in the model, with considerable excess capacity avaialable to rapidly predate any fish that do become beached

4 Results

To show how the distribution of the particles varies with time, Figure 5 shows the distribution of the particles at daily intervals from day 6 to 14. As particles can still be predated after beaching, Figure 5 shows the instantaneous distribution of active particles (red) but the cumulative distribution of beached (green) and eaten (blue) through time. This is in order to show the total spatial extent of beaching, independent of the actual instantaneous numbers of beached particles at any one time. Furthermore, the cumulative distribution of eaten particles represent only the particles eaten prior to beaching and does not include the particles eaten after beaching. Figure 6 shows the distribution of the particles at the last timestep in more detail.

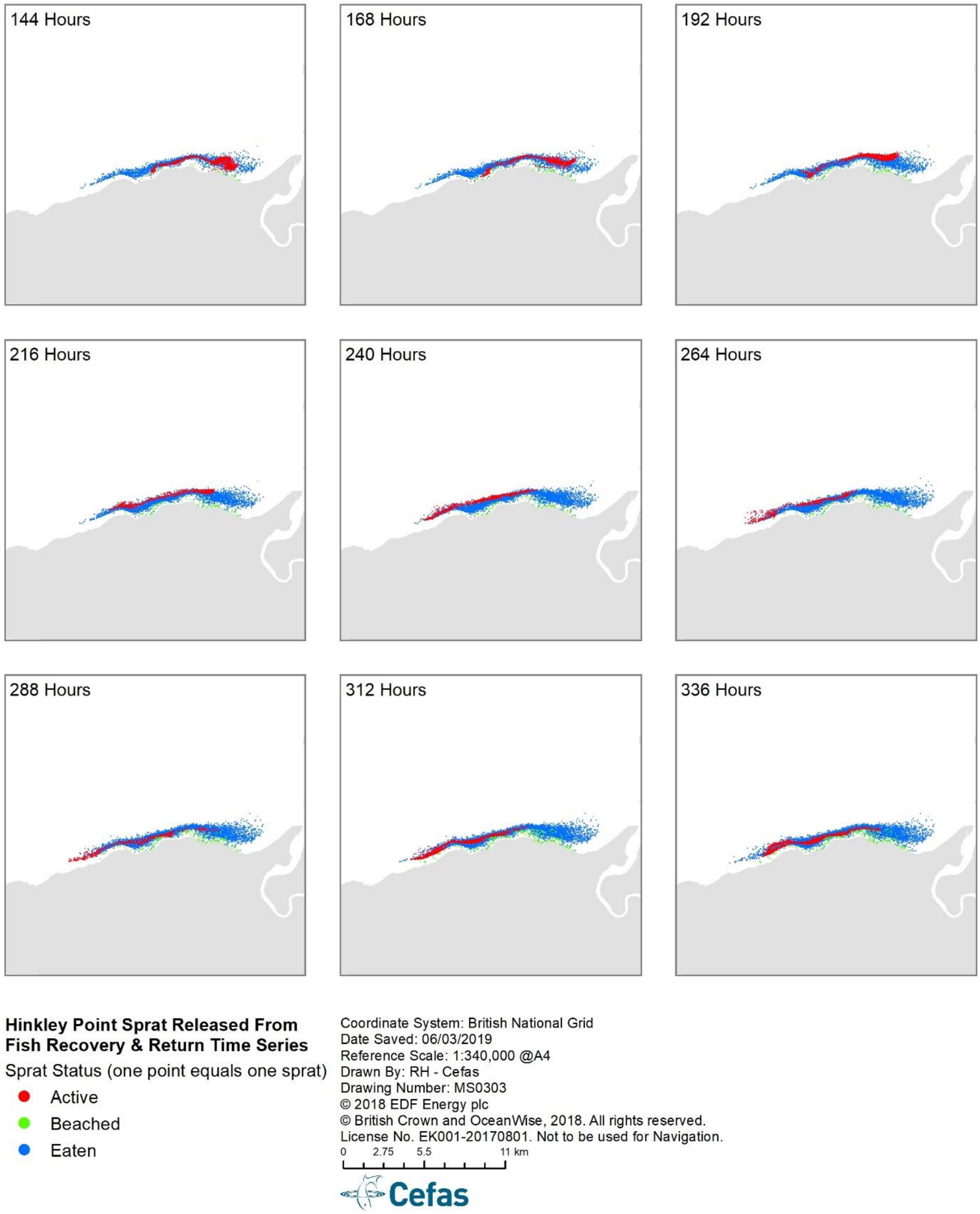

Figure 5: Instantaneous positions of active particles (red) and the cumulative distribution of beached (green) and eaten (blue) particles, at daily intervals from day 6 to 14. All particles are released from the HPC FRR outfall, with each particle representing 1 sprat.

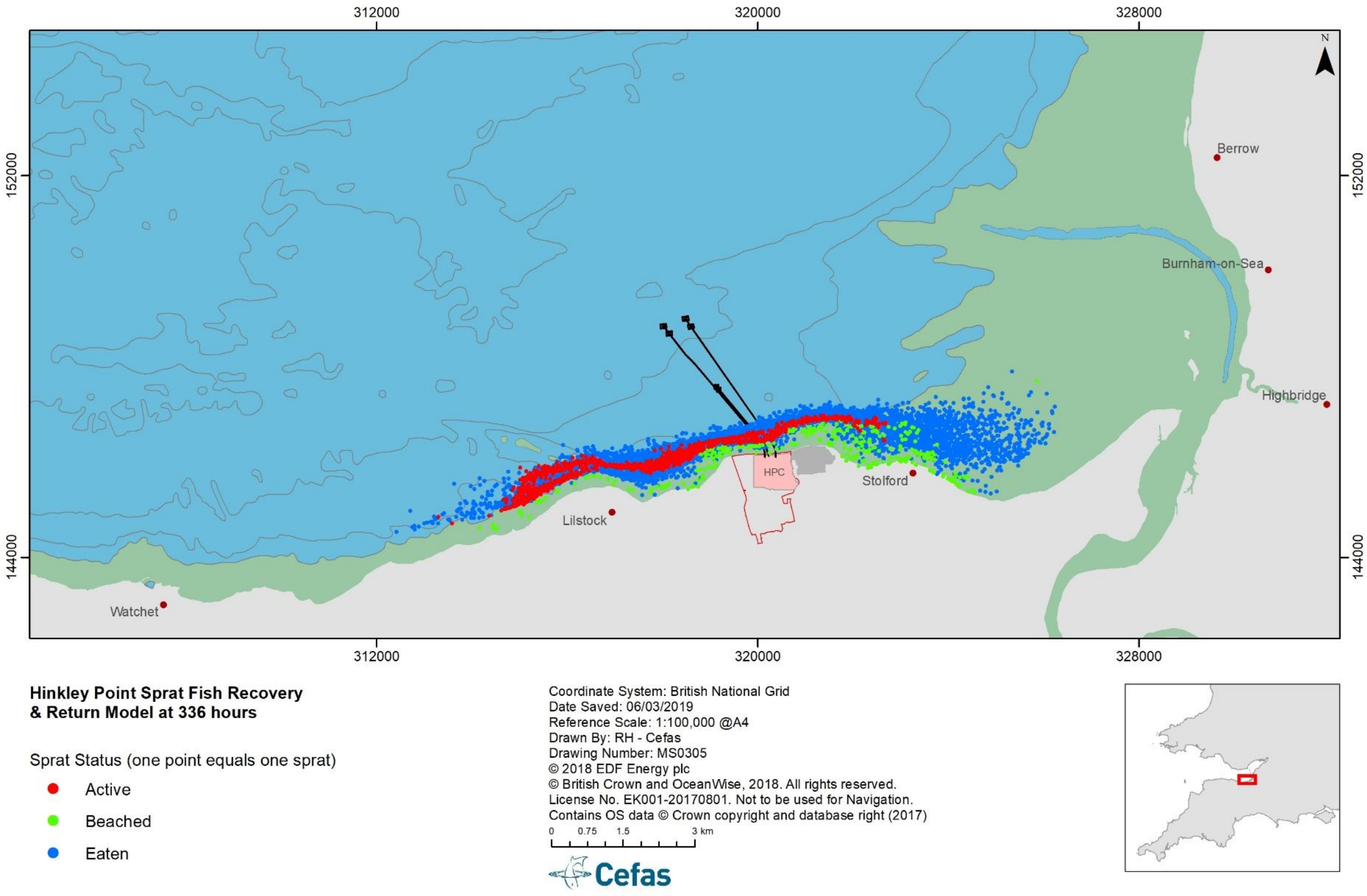

Figure 6: Final positions of active particles (red) and the cumulative distribution of beached (green) and eaten (blue) particles over the 14-day simulation. Each particle represents 1 sprat.

Results show that during the spring tides, the particles follow a trajectory parallel to the coastline, moving south west to north east, with sprat beaching to the west of Lilstock to the east of Stolford. However, as the tide transitions to the neap phase, with neap peak on 7th December, the particles are moved closer to the shoreline further south and east and more become deposited on the intertidal beach in front of Stolford to the east of the outflow. There is limited movement of particles to the north. The total extent of the beached particles was 12.1 km, with particles beaching 6.4 km west of the FRR outfall and 5.7 km east. Table 5 provides a summary of the proportion of sprat for five particles states (alive, sink immediately, sink within 24 hours eaten, beached) at the end of the 14-day simulation.

Table 5: Summary of the proportion of sprat, for each status, at the end of the 14-day simulation.

Status	Number of Particles	% of Population
Active (i.e. still at the sea surface)	1,224	0.44
Sink immediately	249,242	88.63
Sink within 24 hrs	23,967	8.52
Eaten at sea (i.e. doesn't include fish eaten once beached)	6,444	2.29
Beached (This is the total number of fish that beach over the 14 days but most were then consumed rapidly by birds)	342	0.12
Total	**281,219**	**100**

Figure 7 shows the instantaneous and cumulative number of particles beached over the 14-day simulation, along with the tidal elevations at Hinkley Point. Table 6 summarises the total number of beached particles per day.

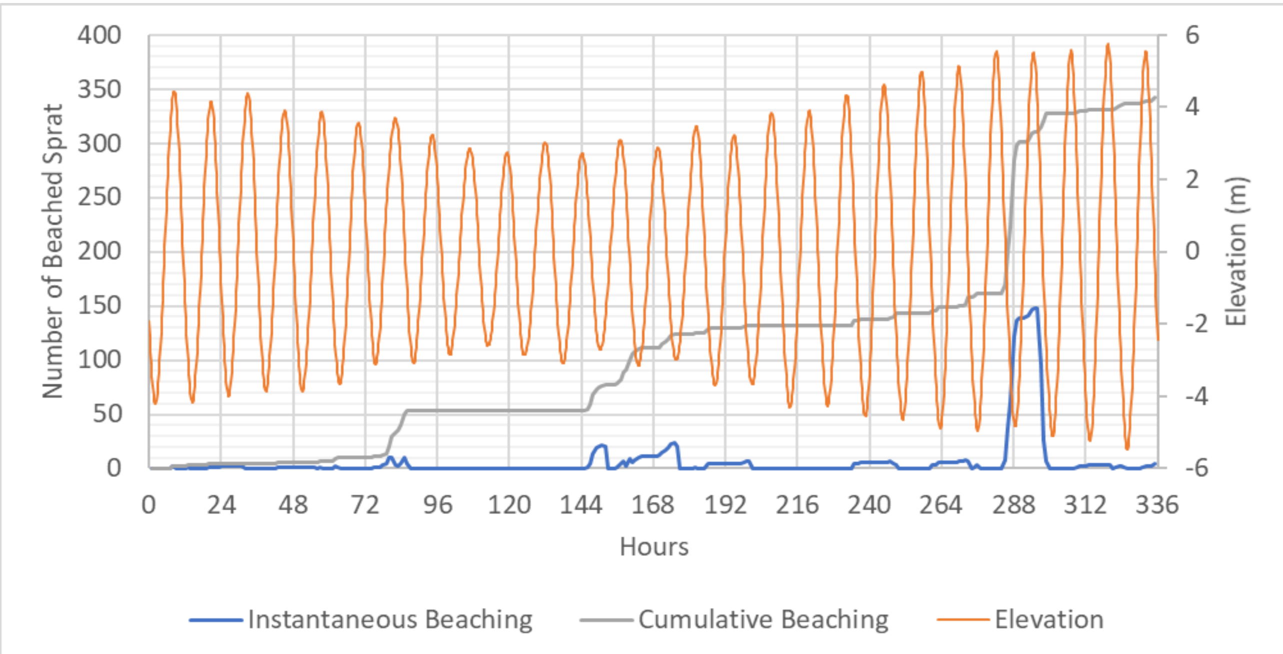

Figure 7: Instantaneous (blue) and cumulative number of beached particles (grey) over the 14-day simulation, with the free surface elevations at Hinkley Point (orange).

Table 6: Total number of the beached particles per day.

Day	Total number of beached particles per day
1	4
2	2
3	4
4	44
5	0
6	0
7	57
8	19
9	2
10	6
11	11
12	74
13	107
14	12
Total	**342**
Average	**24.43**

Over the 14-day simulation, a total of 342 sprat beached, representing 0.12% of the total number of particles modelled. At the end of the simulation, only 5 particles were on the beach, or 0.002% of the total number of particles. Beaching predominantly occurred during night time hours, as during the day time hours the number of birds present meant particles were eaten within 1-2 hours of daybreak. Figure 8 shows the instantaneous number of beached and eaten particles, with daylight hours represented by a binary value of 0 or 1, for the hours of 7 am to 5 pm.

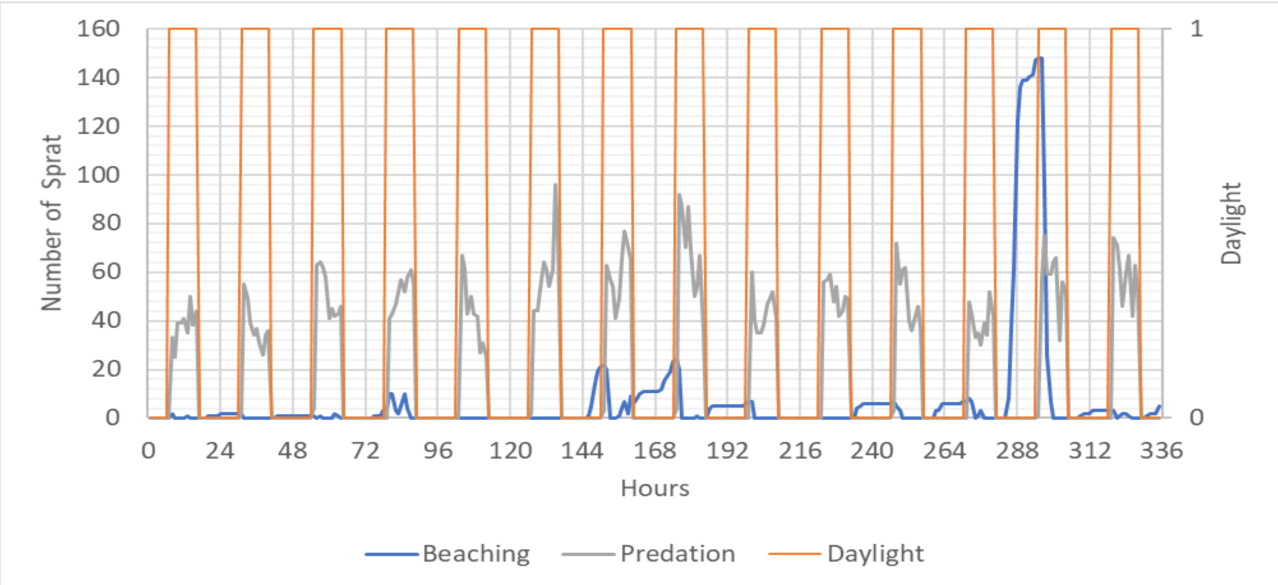

Figure 8: Instantaneous number of beached (blue) and eaten (grey) particles, overlaying daylight hours (orange).

The mean instantaneous number of beached particles over the 14 day simulation was 1.02. The maximum instantaneous number of particles on the beach over the 14-day simulation was 148, at daybreak on 13th

December, however, within 5 hours of daybreak, all those beached particles had been eaten by birds. The 148 particles covered a maximum total length of 10.1 km, with an average linear distribution of one sprat every 68 m. The average daily rate of beaching was 24.43 sprat per 24 hours. The mean instantaneous number of beached particles over the 14 day simulation during daylight hours was 4.17 fish.

5 Discussion

The HPC FRR is designed to return as many impinged fish as possible to safely to sea. The system is expected to work well for robust species such as eel, lamprey, flatfish and crustacea with survival rates greater than 80%. However, the system is not effective for more delicate pelagic species such as sprat and herring where the expected survival rate for impinged fish is zero. Some dead fish will, therefore, be discharged from the HPC FRR outfall throughout the year and there is a concern that if these fish come ashore in large numbers they could represent a nuisance on public beaches. To assess the potential for such an impact, a worst-case modelling study has been undertaken.

Most fish impingement at Hinkley Point takes place in winter from November – January corresponding to the period when 99% of sprat impingement occurs. This is therefore the period when the maximum number of dead fish would be discharged from the HPC FRR system. In the HPB impingement data record the peak period for impingement was from 19 November 2009 to 14 January 2010. During this peak period sprat accounted for 76% of total fish impingement at HPB, the remainder being predominantly whiting (16%), with some mullet (3%) and small numbers of other species. The calculated discharge of dead fish from HPC in this period consists of approximately 70% dead sprat and that species is, therefore, the focus of this report. The sprat discharge rate was overestimated in this study by a factor of approximately 1.6 which more than compensated for the other 30% of the discharge that are not sprat. The worst-case impingement month of December was also selected for the modelling in order to be conservative.

Most dead fish will sink rapidly and be consumed by benthic organisms. The remaining fish will initially float and be dispersed by the local hydrodynamics. These fish will gradually sink; with the majority sunk within 24 hours. Floating fish will be predated by local marine birds during daylight hours but some fish will beach. Marine birds will also predate on beached fish. The purpose of this study was to determine where dead fish would come ashore and the expected number of such fish in order to assess whether this would represent a nuisance on public beaches.

A particle tracking study was conducted using the validated 3D GETM hydrodynamic model of Hinkley Point to investigate the dispersion of impinged sprat released from the Hinkley Point C Fish Recovery and Return outfall. Particle sinking behaviour and bird predation was included in the particle tracking model.

A total of 281,219 particles were released in the model, with each particle representing one sprat. Based on the observed buoyancy data of sprat impinged at Sizewell (which is not expected to be materially different from that at Hinkley Point), particle sinking behaviour has been included whereby 88.3% of particles sink immediately. An exponential decay curve with a half-life of 12 hours was then applied to the remaining particles and after 24 hours, any remaining particles were classified as sunk. The sinking rate parameterized into the model is based on observed sinking behavior of impinged sprat held in buckets of still seawater. In reality, the dead fish at HPC would be exposed to further external forces during their return to sea via the FRR tunnel and also via vertical turbulence once out at sea. This agitation is considered likely to release any pockets of air trapped in the sprat causing them to sink faster. It is therefore considered that the sinking rates used in this model are precautionary.

The model was run with predation individually parameterised for all five bird species identified in the WeBS data in the immediate vicinity of Hinkley Point (black headed gull, common gull, great black backed gull, herring gull and lesser black backed gull). Once a particle beached, it could no longer move, but was still able to be eaten.

Results show that despite the large number of sprat released, the model was not saturated with sprat and predation by sea birds only accounted for a small percentage of their dietary needs. The sinking behaviour was the largest controlling factor in the total number of beached fish. The study showed that only a very small total number of sprat (0.12%) reached the beach along the surrounding coastline, with an average daily beaching rate of 24.4 sprat per 24 hours, or 0.009% of the total number of sprat modelled. To put this in context, this just exceeds the minimum daily energy consumption of a single Black Head Gull or just under half the daily energy consumption of a single Herring Gull.

The cumulative distribution of beached sprat over the 14-day simulation reached 6.4 km west of the FRR outfall and 5.7 km east, a total of 12.1 km from west of Lilstock to east of Stolford. The number of fish on the beaches was maximum during night time hours, as during the day time hours the number of birds present meant any beached fish were typically eaten within 1-2 hours of daybreak. The mean instantaneous number of beached fish over the 14-day simulation was 1.02 and the maximum instantaneous number was 148 (at daybreak) and these were all eaten with 5 hours i.e. by noon. These 148 fish were spread over a total length of 10.1 km of coastline, with an average linear distribution of one sprat every 68 m.

6 Conclusions

During the peak impingement period of November to January a small number of dead fish are expected to beach on the shoreline over a 12.1 km stretch of coast from west of Lilstock to east of Stolford. Over the 14-day simulation, a total of 342 sprat beached, representing 0.12% of the total number of fish modelled. At the end of the simulation, only 5 fish were on the beach, or 0.002% of the total number of released fish. The number of beached fish was maximum during night time hours due to the absence of bird predation but during day time hours the number of birds present meant fish were eaten within 1-2 hours of daybreak.

The predicted mean instantaneous number of fish on the beaches is expected to be 1.02 fish. The maximum instantaneous number of fish on the beach over the 14-day simulation was 148, at daybreak on 13th December, however, within 5 hours of daybreak, all those beached fish had been eaten by birds. The 148 fish were distributed over a total length of coastline of 10.1 km, with an average linear density of one sprat every 68 m. The average daily rate of beaching was 24.43 sprat per 24 hours. The mean instantaneous number of beached particles over the 14-day simulation during daylight hours was 4.17 fish spread over a length of coastline of up to 12.1km or 1 fish every 2.9km.

Even during the peak impingement event (148 beached sprat in one night) the average density along the shoreline was only one sprat per 68 m, rapidly falling to zero within 5 hours once bird predation started. The mean instantaneous density was much lower. Such dead fish densities are not considered to represent a nuisance and would be unlikely to be discernable on the shoreline.

References

BEEMS Technical Report TR129. 2011. Comprehensive Impingement Monitoring Programme at Hinkley Point B power station, Final Report 2009-2010. Cefas, Lowestoft.

BEEMS Technical Report TR177. 2011. Hinkley Point Thermal Plume Modelling: GETM Stage 3a results with the final cooling water configuration. Cefas, Lowestoft.

BEEMS Technical Report TR197. 2011. Modelling of the optimal position of a fish recovery and return system for Hinkley Point C. Cefas, Lowestoft.

BEEMS Technical Report TR267 (ed. 2). 2017. Hinkley Point: GETM Plume Model - Version 2 Model Setup and Validation. Cefas, Lowestoft.

BEEMS Technical Report TR409 (ed. 5). 2017. Hinkley Point C: Updated impingement predictions based upon the detailed design of the cooling water system.

Garthe. S., Camphuysen K. and Furness R.W. (1996) Amounts of discards by commercial fisheries and their significance as food for seabirds in the North Sea. Marine Ecology Progress Series, Vol 136, 1-11.

Hudson, A.V., 1989. Interspecific and age-related differences in the handling time of discarded fish by scavenging seabirds. Seabird, Vol 12, 40-44.

Pianka, E.R. Evolutionary Ecology 5th Edition 1994, Harper Collins p 309.

Appendix A Impingement data

A.1 24h HPB impingement data from the CIMP programme during the peak impingement period.

Table 7 Raw CIMP sprat impingement data HPB (peak impingement period data are shaded green)

Date	Hour1	Hour2	Hour3	Hour4	Hour5	Hour6	Total of hourly samples	18h bulk	bulk+ sum 6 hours	4*sum 6 hours
13-Nov	168	70	79	83	100	130	630	2196	2826	2520
19-Nov	667	654	1513	1177	1006	371	5388	14498	19886	21552
20-Nov	969	803	1295	1268	680	232	5247	3966	9213	20988
01-Dec	933	853	281	208	236	223	2734	1862	4596	10936
17-Dec	900	1688	1475	1045	445	351	5904	No bulk	N/A	N/A
30-Dec	4050	1638	1098	864	549	806	9005	2376	11381	36020
06-Jan	519	315	169	143	698	531	2375	9189	11564	9500
14-Jan	1542	1339	642	336	475	339	4673	No bulk	N/A	N/A
28-Jan	282	69	35	20	24	29	459	1147	1606	1836
Total 13/11 - 28/1							**36415**	**35234**	**61072**	**103352**
Total 19/11 - 14/1							**35326**			
Ratio of sprat impingement in 2 periods							1.03			
Ratio of (4*sum hourly samples)/(bulk+sum hourly samples)										1.69

Table 7 shows the 24h HPB impingement data for the period 13/11/2009 to 28/01/2010 consisting of 6 one hour samples and an 18h bulk sample for each 24h sampling occasion. Bulk samples were not collected for logistical reasons on 17 December 2009 and 14th January 2010.

The peak sprat impingement period was 19/11 to 14/01. Widening the period to 13/11 to 28/01 only increased total sprat impingement by 3%.

If the impingement rate was constant throughout the 24 hours, the (sum of the 6 hourly samples * 4) should have equaled the (sum of the bulk + sum of the hourly samples). Table 7 shows that between these two measures for those dates when all of the required data were collected (i.e. excluding 17/12 and 14/1), was not unity but 1.69 demonstrating that the measured impingement rate was greater during the 6 hourly samples than during the bulk sample.

A.2 CIMP impingement record for the species that dominated during the peak impingement period (shaded green)

Total fish in Table 8 is the total number of fish impinged in the 24h period and is therefore greater than the sum of the 7 species shown. In the peak impingement period the seven species accounted for 99% of the impingement at HPB.

Table 8 Number of fish impinged at HPB per 24 hour for the period Feb 2009 to Feb 2010. The data in green were sampled in the peak impingement period between 19 Nov 2009 and 14 Jan 2010.

Sample No.	whiting	sprat	mullet	cod	herring	rockling	sand goby	Total fish
1	1930	88	58	23	464	30	40	2962
2	2395	58	69	10	672	36	35	3630
3	1271	24	25	2	159	20	42	1879
4	2214	15	98	11	85	65	26	3109
5	296	27			31	25	11	583
6	174	20	1	2	11	9		373
7	717	5	2		17	66	36	1372
8	1002	21	3		1	57	45	1920
9	1299	6	3			129	1	2804
10	400	37				117	43	1467
11	268	16				52	12	1125
12	326	61	1	187		60	6	1820
13	307	51		365		20	3	1324
14	6400	16		3640	64	96	16	11240
15	1566	16		782	6	38	2	3716
16	384	4		232	10	54		1078
17	531	2	2	44		46		1223
18	544		4	168	44	12		2041
19	634	10		268	48	32	2	1842
20	1589	122	8	452		36		5667
21	118	26	2	42		34	2	508
22	2821	48		536	48	216	572	8401
23	1385	44	43	215	1	119	67	2950
24	2277	59	41	418	65	140	72	3929
25	1150	40	80	127	1	148	43	2140
26	804	19	31	97	10	149	118	1532
27	536	12	24	84	12	140	45	1145
28	1176	9	23	134	7	131	123	1841
29	1224	32	8	272	44	152	127	2091
30	271	71	6	77	73	105	24	753
31	1377	2826	51	214	88	107	104	4926
32	4288	19885	97	419	77	259	257	25729
33	1819	9212	21	158	17	135	24	11566
34	3720	4596	176	230	110	210	108	9316
35	4389	23616	1157	240	21	512	5	30160
36	1941	11381	931	86	24	84	20	14524
37	2255	11565	1075	242	161	105	7	15570
38	2908	18692	804	496	596	16	4	23745
39	255	1606	513	79	21	23	2	2564
40	391	1943	797	88	20	30	4	3338
Total in peak impingement period	**21,319**	**98,945**	**4,261**	**1,870**	**1,006**	**1,322**	**425**	**130,610**
% of total fish in peak period	16%	76%	3.3%	1.4%	0.8%	1.0%	0.3%	98.9%

Table 9 Derivation of scaling factor to convert HPB mortality to that at HPC

	whiting	sprat	mullet	cod	herring	rockling	sand goby
HPC flow rate	3.913	3.913	3.913	3.913	3.913	3.913	3.913
intake head	0.646	0.245	0.646	0.646	0.245	0.646	0.646
FRR mortality	0.545	1.000	0.545	0.553	1.000	0.200	0.200
Scaling factor to HPC	**1.378**	**0.961**	**1.378**	**1.398**	**0.961**	**0.506**	**0.506**

Notes – All factors from TR456

i. Ratio of Cooling water flows HPC/HPC = 131.86/33.7 = 3.913

ii. HPC intake head reduces impingement at HPC by a factor of 0.646 for non pelagic fish and 0.2455 for pelagic species.

iii. FRR Mortality factors are calculated for each species in the range: minimum 0.2 for benthic species to a maximum of 1.0 for pelagic species.

A.3 Calculation of fish mortality at HPC

The data in Table 8 have been multiplied by the conversion factors in Table 9 to produce the HPC mortalities in Table 10. The results show that the percentage of sprat in the dead fish discharge in the peak impingement period fall from approx. 76% to approx. 70% at HPC

Table 10 Calculated fish mortality at HPC for the same period as Table 8.

Sample No.	whiting	sprat	mullet	cod	herring	rockling	sand goby	Total of 7 species
1	2659	85	80	32	446	15	20	3337
2	3299	56	95	14	645	18	18	4145
3	1751	23	35	3	152	10	21	1996
4	3050	14	135	15	82	33	13	3342
5	408	26	0	0	30	13	6	482
6	240	19	1	3	11	5	0	278
7	988	5	3	0	16	33	18	1063
8	1380	20	4	0	1	29	23	1456
9	1790	6	4	0	0	65	1	1865
10	551	36	0	0	0	59	22	668
11	369	15	0	0	0	27	6	417
12	450	58	2	262	0	30	3	805
13	423	49	0	510	0	10	1	993
14	8816	15	0	5088	61	49	8	14038
15	2157	15	0	1093	6	19	1	3291
16	529	4	0	324	10	27	0	894
17	731	2	3	61	0	23	0	820
18	749	0	6	235	42	6	0	1038
19	873	10	0	375	46	16	1	1320
20	2189	117	11	632	0	18	0	2967
21	163	25	3	59	0	17	1	267
22	3886	46	0	749	46	109	289	5126
23	1908	42	59	300	1	60	34	2405
24	3136	57	56	584	63	71	36	4003
25	1584	38	111	178	1	75	22	2009
26	1108	18	43	136	10	75	60	1449
27	738	12	33	117	12	71	23	1006
28	1619	9	32	188	7	66	62	1983
29	1686	31	11	380	42	77	64	2291
30	373	68	8	108	70	53	12	693
31	1897	2715	70	299	85	54	52	5173
32	5907	19099	133	585	74	131	130	26059
33	2506	8848	29	221	17	68	12	11701
34	5124	4414	243	321	105	106	54	10368
35	6047	22683	1594	335	20	259	3	30942
36	2674	10931	1282	120	23	43	10	15083
37	3106	11108	1481	338	155	53	4	16244
38	4006	17954	1108	693	572	8	2	24343
39	351	1542	707	110	20	12	1	2744
40	538	1866	1097	123	19	15	2	3660
Total in peak impingement period	**29,369**	**95,037**	**5,870**	**2,613**	**967**	**668**	**215**	**134,739**
% of total 7 species in peak period	22%	71%	4.4%	1.9%	0.7%	0.5%	0.2%	100%