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Revised Predictions of Impingement Effects at Hinkley Point C - 2018

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1 Executive Summary

BEEMS Technical Report TR148 (2011) presented an assessment of predicted losses due to impingement of fish and crustaceans at Hinkley Point C (HPC). Impingement predictions were provided for HPC both with and without the planned mitigation measures of:

- A Fish Recovery and Return (FRR) system designed to return robust species (particularly flatfish, eels, lampreys and crustacea) that are impinged onto the station drum screens safely back to sea.
- An Acoustic Fish Deterrent (AFD) system designed to cause pelagic and some demersal species to swim away from the intakes and thereby avoid impingement.
- Low velocity side entry (LVSE) intake heads. TR148 assumed the provision of LVSE intakes that are designed to limit the exposure of the intake surfaces to the tidal stream and in so doing reducing the risk of impingement for fish swimming with the tidal stream. However, it was not possible to make any quantitative assessments of their effect on expected impingement rates at HPC.

The predictions of impingement by HPC were compared with local commercial landings and local fish populations (expressed as spawning-stock biomass, SSB), where such data existed. These predictions were used in the HPC Environmental Statement (EDF Energy 2011a), Water Framework Directive Assessment (EDF Energy 2011a) and the Report to Inform the Habitats Regulations Assessment (EDF Energy 2011b) submitted as part of the Development Consent Order (DCO) application for HPC.

Subsequently, during the DCO examination phase, the TR148 predictions were updated with more robust evidence for cod and shad impingement in BEEMS Scientific Position Papers SPP065 and SPP071/S, respectively. These predictions formed the final impingement evidence base that supported the Hinkley Point C DCO application.

The Environment Agency concluded in its Appropriate Assessment for operational discharge permitting purposes (EA 2013) that impingement from HPC fitted with an AFD and an FRR system would not have an adverse effect on the integrity of the European marine sites in the vicinity of Hinkley Point.

1.1 HPC design developments since grant of DCO

The impingement predictions presented during the DCO examination (2012) were based upon the best available evidence at that time. Where ecological uncertainties were present, worst-case assumptions were used for the assessment. In the time since the DCO was granted the impingement estimates have been refined as further information became available. In particular, improved information is now available on the fish community in Bridgwater Bay and on the detailed design of the HPC cooling water (CW) system.

The planned LVSE intakes and FRR systems, both for the drum screens and the band screens associated with the essential and auxiliary cooling water systems have been successfully incorporated into the final design (EDF Energy 2017). However, the proposed AFD system has caused significant technical, operational and health and safety concerns. The AFD system would require up to 288 underwater sound projectors located at the CW intakes approximately 3.3 km offshore. The harsh marine environment at Hinkley Point would require that each of the projectors be recovered for maintenance by divers every 12 months for the 60 year lifetime of the station. The system would be extremely complex to construct and to maintain with offshore operations restricted to narrow tidal windows and subject to lengthy periods of weather downtime. An assessment of the risks involved with such an operational system has concluded that the risks to maintenance staff would be unacceptable.

Given the safety and technical challenges associated with installation and maintenance of an AFD system in this location, EDF Energy has concluded that there is a need to consider what the effects of not fitting an AFD system would be on impingement predictions.

1.2 Revised impingement assessments

This report provides revised impingement assessments for:

a. HPC with no impingement mitigation; and

b. HPC fitted with the planned LVSE intake heads and FRR systems.

Given the 6 years that have passed since the HPC DCO examination and the advancement of science and knowledge about the Bristol Channel fish community that have occurred in this time, this report provides more context and a more in-depth coverage of HPC impingement than the original BEEMS Technical Report TR148. In particular, the report:

i. explains the impingement process more fully and provides contextual information on the Bristol Channel fish community
ii. reproduces the predicted effects of HPC impingement that were provided for the DCO examination
iii. details all stages of the revised assessment process including
    a. the selection of species included in the assessment
    b. the justification for continued use of the 1% negligible effect thresholds adopted for the DCO assessment
    c. the uncertainty in the calculated Equivalent Adult Values (EAV) used to convert the number of juvenile fish impinged at Hinkley Point into equivalent adults
    d. the selection of impingement effects indicators
    e. the effect of interannual variability in fish numbers on the assessment
    f. an assessment of uncertainty especially for species where predicted impingement is near to the 1% negligible effects threshold
    g. An assessment of the impact of climate change upon the predicted impingement effects
    h. Documenting where precautionary assumptions have been made.

In considering the effects of not fitting an AFD, this report draws together and presents all of the changes that are relevant to the impingement predictions in order to enable both a like for like comparison with the original assessment and a full re-assessment based on all of the latest available information.

1.3 Selection of species included in the assessment

In the DCO assessment, 15 species were assessed (14 fish species plus the brown shrimp *Crangon crangon*). The number of species assessed in this report has been increased by 5 (shown underlined below) to 20 species that include:

- Socio economically important species – 4 taxa: sole, cod, <u>bass</u> and <u>thornback ray</u>
- Conservation species - 13 taxa: allis and twaite shad, eel, herring, cod, whiting, blue whiting, plaice, sole, salmon, sea trout, river and sea lamprey
- Ecologically important species– the 7 taxa that comprised 95% of the fish abundance at HPB: sprat, whiting, sole, cod, <u>thin lipped grey mullet</u>, <u>flounder</u>, <u>5 bearded rockling</u> plus the crustacean brown shrimp.

Together the fish species account for 97.3% of the total fish impingement numbers at HPB and are considered representative of the assemblage at Hinkley Point and contain all of the species listed as HRA interest features. In terms of suitability for the WFD assessment, the 19 fish species contain examples from all functional guilds with the exception of freshwater species (which are rarely found at Hinkley Point) , all the feeding guilds and all of the indicator species found at Hinkley Point that are assessed in the WFD “fish” biological quality element (See section 5.3).

Commentary is also provided on conservation species and associated life stages which were not detected during the 2009/10 comprehensive impingement monitoring programme (CIMP) at HPB.

1.4 Uncertainty in the Equivalent Adult Value (EAV) factors

The EAVs used in this assessment have been comprehensively investigated to determine their reliability and accuracy. Corrections have been made to the EAVs for cod and herring based upon the best available evidence. The EAVs used in this report are considered precautionary.

1.5 Selection of impingement effects thresholds

The justification for the continued use of 1% of Spawning Stock Biomass (SSB) of a particular fish stock as the screening threshold for negligible effects is provided. This threshold has been selected such that predicted impingement below this value would have no effect on the biodiversity or abundance of the fish community at Hinkley Point, no adverse effect on site integrity and no effect on the water body status under WFD,

Where estimates of SSB are not available, the use of international landings in the stock area as a worst case estimate of the SSB is justified. The latter replaces the UK landings data used as an indicator in the DCO assessment. The reason why this statistic is not considered a useful impingement effects indicator are provided.

A higher threshold of 10% of SSB is appropriate for a potentially significant effects threshold for non-exploited species which are not in decline. However, the 1% negligible effects threshold has been used for all species in this report and is considered precautionary.

1.6 Impingement effects indicators

Three impingement effects indicators are used in this report. In order of preference these are:

i. Comparison with the adult SSB in the assessment year as published by the International Council for Exploration of the Sea (ICES)

ii. Comparison with the international catch of a fish stock in the assessment year (ICES)

iii. Analysis of the 37 year impingement trend data to draw conclusions about the local population and the impact of the station (from the HPB Routine Impingement Monitoring Programme, RIMP).

The stock units that have been used in this assessment are the ICES 2017 definitions which are the outcome of the best available international science. (ICES provides unbiased scientific advice to the governments of 20 member nations and to international regulatory commissions in support of the management and conservation of coastal and ocean resources and ecosystems. Advice on the management of 135 separate finfish and shellfish stocks is provided to the North-East Atlantic Fisheries Commission, North Atlantic Salmon Conservation Organization and the European Commission).

1.7 Revised impingement assessments – unmitigated HPC and with a Fish Recovery and Return (FRR) system fitted

The impingement predictions provided as evidence for the HPC DCO submission have been revised in this report to reflect the changes in the assessment described below:

Changes to the HPC impingement assessment since the DCO submission

	Description of change	Impact on assessment compared with the DCO assessment
a.	Revised impingement indicators based upon the latest scientific advice (Adult population sizes, international catch, HPB impingement time series extended to 2017)	Uses the most up to date scientific evidence. For some species the adult population sizes has increased, others have decreased.
b.	Use of site specific EAVs derived from measurements made at Hinkley Point during the CIMP survey programme in 2009/10.	Uses the most biologically relevant data rather than non-site specific data from different years of uncertain accuracy. Causes the predicted impingement impact to increase for some species, decrease for others.
c.	Incorporates the detailed design for the HPC cooling water system. HPC CW flow rate is now assumed to be 131.86 cumecs (at Mean Sea Level) with a worst case of 9% water flow through the band screens. Band screens to be fitted with an FRR system and HPC forebay to be fitted with trash racks of 50mm vertical bar spacing fitted with fish friendly buckets for fish recovery.	More accurate impingement assessment. Results in increases in predicted impingement impact.
d.	Added assessments for 5 additional species not included at the time of DCO (bass, thornback ray, flounder, thin lipped grey mullet, 5 bearded rockling)	Provides more confidence in the effects of impingement on the fish assemblage assessment.
e.	Revised impingement numbers from the CIMP programme. The programme data have been subject to enhanced quality assurance and a more robust procedure has been used to calculate the confidence limits on the impingement estimates.	The QA programme has led to more reliable impingement predictions and has resulted in increased impingement numbers for 16 fish species.

1.8 Conclusions of the revised HPC impingement assessment

The predicted HPC impingement with an FRR but no AFD fitted is described in the table below.

Predicted HPC Impingement effects (FRR fitted)

Common Name	*Species*	Mean HPC impingement effect	Impingement indicator	Effect on the species population
Sprat	*Sprattus sprattus*	0.016% - 0.11%	SSB 2013- 2015	Negligible
Whiting	*Merlangius merlangus*	0.05%	SSB 2009	Negligible
Sole, Dover	*Solea solea*	0.09%	SSB 2009	Negligible
Cod	*Gadus morhua*	0.40%	SSB 2009	Negligible
Mullet, thin lipped grey	*Liza ramada*	Population trend increasing. Total impingement pressure with HPC lower than in first 14 y of the trend analysis.	RIMP trend analysis	Negligible
Flounder	*Platichthys flesus*	Population trend stable. Total impingement pressure with	RIMP trend analysis	Negligible

		HPC lower than in first 14 y of the trend analysis.		
5 bearded rockling	*Ciliata mustela*	Population trend increasing. Total impingement pressure with HPC lower than in first 14 y of the trend analysis.	RIMP trend analysis	Negligible
Herring	*Clupea harengus*	0.23%	International catch 2009	Negligible
Bass	*Dicentrarchus labrax*	0.02%	SSB 2009	Negligible
Plaice	*Pleuronectes platessa*	0.00%	SSB 2009	Negligible
Ray, Thornback	*Raja clavata*	0.13%	International catch 2009	Negligible
Whiting, Blue	*Micromesistius poutassou*	0.00%	SSB 2009	Negligible
Eel	*Anguilla anguilla*	0.06%	Independent stock estimate[1]	Negligible
Shad, Twaite	*Alosa fallax*	0.04%	Independent stock estimate[1]	Negligible
Shad, Allis	*Alosa alosa*	Negligible numbers expected at HPC	N/A	**Screened out**. Negligible.
Lamprey, Marine	*Petromyzon marinus*	0.24%	Independent stock estimate[1]	Negligible
Lamprey, River	*Lampetra fluviatalis*	Negligible numbers expected at HPC	Independent stock estimate[1]	**Screened out.** Negligible.
Salmon	*Salmo salar*	Not expected at HPC		**Screened out**
Sea trout	*Salmo trutta*	Not expected at HPC		**Screened out**
Brown shrimp	*Crangon crangon*	Population trend increasing. Total impingement pressure with HPC lower than in first 14 y of the trend analysis.	RIMP trend analysis	Negligible

Note:

1. See Appendix G

It is concluded that HPC with FRR systems fitted would have negligible effect on the species assessed in this report which are considered representative of both the fish assemblage and all of the HRA designated conservation species.

1.8.1 Conclusions from interannual variability and assessment uncertainty analyses

A study of the effect of interannual variations in fish populations for three representative species did not change the HPC impingement assessment conclusion of negligible effects.

The uncertainty analyses did not identify any species where the negligible effects threshold of 1% of the SSB or the relevant international landings was exceeded.

1.8.2 Effect of removing juvenile fish from the Hinkley Point fish community

Juvenile fish form an important part of the diet of piscivorous fish and many seabirds and marine mammals and as well as considering the effect of impingement on each individual fish species, it is important to consider potential effects on predators. Sprat is a small pelagic species that is the most abundant species at Hinkley Point (at nearly 50% of the impingement numbers), and it is predated on by many species in the estuary including harbour porpoise. Assessment of the predicted effects of HPC on juvenile sprat demonstrate that impingement is negligible compared to the very large number of juvenile sprat in the local population (0.0047%) and negligible compared to existing natural mortality (0.0055%). It is concluded that impingement losses of juvenile fish will have a negligible effect on the local ecosystem.

1.8.3 Effect of climate change on HPC impingement

An assessment of the effects of climate change concluded that the fish assemblage at Hinkley Point has changed in the past 37 years and is likely to continue to change as water temperatures increase. However, HPC will efficiently sample the fish population at Hinkley Point. If a population abundance increases, impingement will increase and vice versa. However, the ratio of impingement to adult population size will not change and it is concluded that climate change would have no effect on the predicted negligible effect of HPC impingement on the fish assemblage.

1.8.4 Overall conclusion

It is concluded that the effects of HPC with FRR systems fitted on impingement of each of the 20 species assessed would be negligible. These species are considered representative of the assemblage and there would, therefore, be no adverse effect on site integrity or deterioration of status of Water Framework Directive water bodies if an AFD system is not fitted to HPC.

2 Introduction

BEEMS Technical Report TR148 (2012) presented an assessment of predicted losses due to impingement of fish and crustaceans at Hinkley Point C (HPC) in relation to adjacent fish populations and fisheries. Impingement predictions were provided for HPC both with and without the planned impingement mitigation measures of:

- An Acoustic Fish Deterrent (AFD) system designed to cause pelagic and some demersal species to swim away from the intakes and thereby avoid impingement.
- A Fish Recovery and Return (FRR) system designed to return robust species (particularly flatfish, eels, lampreys and crustacea) that are impinged onto the station drum screens safely back to sea.
- Low velocity side entry (LVSE) intake heads. TR148 assumed the provision of LVSE intakes that are designed to limit the exposure of the intake surfaces to the tidal stream and in so doing reducing the risk of impingement for fish swimming with the tidal stream. However, it was not possible to make any quantitative assessments of their effect on expected impingement rates at HPC.

The predictions of future impingement by HPC were compared with local commercial landings and local fish populations (expressed as spawning-stock biomass, SSB), where such data existed. Impingement predictions were also provided for the existing Hinkley Point B (HPB). These predictions were used in the HPC Environmental Statement (EDF Energy 2011a), Water Framework Directive Assessment (EDF Energy 2011a) and the Report to Inform the Habitats Regulation Assessment (EDF Energy 2011b) submitted as part of the Development Consent Order (DCO) application for HPC.

Subsequently, during the DCO examination phase (2012), the TR148 predictions were updated with more robust evidence for cod and shad impingement in BEEMS Scientific Position Papers SPP065 and SPP071/S respectively. These predictions formed the final impingement evidence base that supported the Hinkley Point C DCO application.

Based upon the proposed design for HPC that incorporated preventative (mitigation) measures of a low velocity intake design, an AFD system and an FRR system, the Environment Agency concluded in its Appropriate Assessment conducted for the HPC Water Discharge Activity (WDA) permit (EA 2013):

> *"Based on the information provided in EDF's report to support the HRA and supporting technical documents, and on the conclusions from our assessments, we conclude that the predicted rates of fish impingement and entrainment at HPC alone appear to be at a level that would not adversely affect either the protected species or estuarine assemblage (other fish species), in view of their conservation objectives, and there will be no adverse effect on the integrity of the site. "*

The Secretary of State concluded in Section 6.155 of the HPC Habitats Regulation Assessment (DECC 2013):

> *"Based on the applicant's HRA and supporting technical documents, and the EA's assessments, the Secretary of State is satisfied that, with the appropriate EA permit measures in place, along with the relevant DCO requirements, the predicted rates of fish impingement and entrainment at HPC alone and in combination would not adversely affect the migratory fish species nor estuarine fish assemblage of the Severn Estuary SAC and Ramsar."*

2.1 Events post grant of HPC DCO

2.1.1 Updates to the HPC impingement assessment

The impingement predictions at the time of the DCO examination in 2012 were based upon the best available evidence at that time. Where ecological uncertainties were present, worst-case assumptions were used for the assessment. In the time since the DCO was granted the HPC impingement predictions have been refined as further information became available. In particular, better information is now available on the fish community in Bridgwater Bay and on the detailed design of the HPC cooling water (CW) system:

1. The mortality of fish caused by power station cooling water intakes chiefly involves the juvenile part of a population because it is that part that is particularly vulnerable to impingement as a result of their presence in inshore nursery areas and their poorer swimming capability compared with adult fish. The majority of the fish impinged at Hinkley are juveniles (Section 4.6). Although commercial fishers may regard these mortalities as a threat to stocks, juvenile fish suffer substantial natural mortality before recruitment to a fishery or an adult fish population. Consequently, the additional mortality attributable to power station intakes may have relatively little extra impact (numerically and in terms of biomass) on a population. To determine population impacts the numbers of fish impinged must be converted via a species-specific factor (the Equivalent Adult Value or EAV) into the numbers of equivalent adults that would be expected to reach adulthood based upon natural mortality estimates. The EAVs in TR148 were derived from an expert system which calculated EAVs from historic multi-year average values for fish size and age for specific sea regions. These EAVs were only available for a few species and were not derived from biological measurements made at Hinkley Point in the 2009 baseline assessment year. In practice EAVs vary by site and by year and these variations can be considerable. Site specific EAVs have now been calculated for all of the most abundant species using biological data collected during the HPB CIMP programme (BEEMS Technical Report TR426).

2. At the time of the original TR148 predictions the design of the HPC CW system was not complete and so the impingement predictions were based upon a simplified, schematic design with an assumed 125 cumec cooling water flow through the drum screens. The detailed design is now available (Appendix A) and has been used to refine the impingement predictions in this report.

2.1.2 Detailed design of impingement mitigation measures

Since the HPC DCO was granted, detailed design of the impingement mitigation systems has been undertaken by EDF Energy and its engineering contractors. The planned low velocity intakes and FRR systems, both for the drum screens and the band screens associated with the essential and auxiliary cooling water systems have been successfully incorporated into the final design (EDF Energy 2017). However, the proposed AFD system has caused significant technical, operational and health and safety concerns.

The proposed AFD system for HPC consists up to 72 underwater sound projectors (dependent upon the required system redundancy for component failures and the available space for installations on either side of the intake heads) at each of the four offshore intake heads. These projector arrays are designed to create a pulsed, swept frequency sound field that will cause some fish to move away from trajectories that would intersect with the cooling water intakes and thereby avoid impingement. The underwater projectors have to operate in a hostile environment and must be recovered for annual maintenance in addition to aperiodic replacement if damaged by underwater debris or sediment.

AFD systems have been installed at other coastal power stations (e.g. Pembroke combined cycle gas turbine (CCGT) plant) and whilst the principles of such systems are well understood, the design challenge at HPC is to devise a system that can be safely installed and maintained for its 60+ year lifetime in very difficult physical conditions. The challenges at the other sites where AFD systems have been successfully installed are very different to those encountered at HPC and whilst the acoustical design of an HPC system was well developed at the time of the HPC DCO application, the installation was, necessarily, only at concept design stage (BEEMS Technical Report TR194).

Typical existing AFD installations have a single projector array on shore-mounted or close to shore structures with frames or rails that are used to raise the projectors to the surface. Maintenance is, therefore, performed on a fixed platform with minimal use of divers or boats (for example, the 72 projectors mounted on 18 columns at Pembroke CCGT).

The proposed HPC AFD system has a very different set of requirements:

- The 4 seabed mounted low velocity side entry (LVSE) intakes are approximately 3.3 km offshore with no above sea surface structures.
- The intake heads each have 2 intake surfaces
- Up to 288 projectors would be required in total for the 4 intake heads.
- Provision of the required reliable electrical power at 3.3 km offshore is problematical.

The environment at Hinkley Point is also very challenging:

- Very high tidal range (mean spring tidal range of 10.7 m)
- Slack water periods of only approximately 30 minutes per tide.
- Tidal currents of approximately 1.5 m s^{-1}
- Very high suspended sediment levels (up to and sometimes greater than 1g l^{-1}) and zero underwater visibility
- Exposed location subject to high wave heights and frequent winter storms.
- Floating and submerged debris, particularly marine weed after storms.
- At 3.3 km offshore any surface structures would have a collision risk with shipping

After extensive engineering studies it has been concluded that permanent structures with rails or other lifting frames to raise the projectors out of the water are impractical. The AFD sound projectors would need to be fixed to seabed-mounted piled structures and installed and recovered in clusters by divers operating from vessels in the narrow tidal windows when diving would be safe. In practice such operations would only be possible in summer and the large number of projectors that would need to be recovered annually means that servicing would require a near continuous operation for up to 3 months every year (assuming that the reliability of current projectors could be improved to permit 18 month servicing intervals). Servicing could not be timed to coincide with reactor outages and would, therefore, require diving operations to be conducted with operational cooling water intakes which is not current safe working practice. AFD systems would provide most benefit to species which occur at Hinkley Point during the winter months when the prevailing weather conditions are frequently most hazardous and could prevent system repairs. This is also the time when the projectors would be most susceptible to damage and extended periods of AFD system downtime would therefore be likely. The conclusion of the engineering studies was that an AFD system for Hinkley Point C would be extremely complex to construct and to maintain. An assessment of the risks involved with such an operational system has concluded that the risks to maintenance staff and to safety critical plant would be unacceptable.

Given the safety and technical challenges associated with installation and maintenance of an AFD system in this location, EDF Energy have concluded that there is a need to consider what the effects of not fitting the AFD system would be on impingement predictions.

In considering the effects of not fitting the AFD system, this report draws together and presents all of the changes that are relevant to the impingement predictions in order to enable both a like for like comparison with the original assessment and a full re-assessment based on all of the latest available information.

3 Background to impingement at Hinkley Point

Like other coastal power stations with ‘once-through’ cooling systems, Hinkley Point B power station abstracts large volumes 33.7 $m^3 s^{-1}$ (33.7 cumecs) of seawater to condense the turbine steam and to provide essential and auxiliary cooling water flows. Hinkley Point C will also comprise a once-through cooling system design, though the total volume of cooling water abstracted will be larger (~132 cumecs at Mean Sea Level) than at Hinkley Point B. Although the cooling water intakes will be protected by widely spaced bars to prevent the intake of cetaceans, seals and large items of debris, a significant number of small organisms (small fish and crustaceans, and plankton) will inevitably enter the cooling water intake. The larger organisms must be removed before the water enters the power station cooling system to prevent them blocking the condenser tubes. These organisms (fish and crustaceans >25 mm in length) are removed through impingement on fine-mesh (10 mm at Hinkley Point B, 5 mm for Hinkley Point C) drum screens which protect the main cooling water supply to the station condensers and band screens that protect the essential and auxiliary cooling water systems. The smaller organisms (mostly fish eggs and larvae and other plankton) that pass through the drum screens are entrained and pass through the power station cooling system without causing significant blockages.

3.1 Relevant site features

The Severn estuary is Britain's second largest estuary, with an area of 557 km^2 including an intertidal area of 100 km^2. When its seaward extension, the Bristol Channel, is included, the intertidal habitat is 200 km^2. It is ecologically appropriate to consider the Severn and the Bristol Channel as one unit. It has an exceptional tidal range of up to 13.2 m, resulting in strong currents of up to 1.5 m s^{-1} at mid tide which suspend large quantities of silt through which little light can pass. This great tidal range is also responsible for the large intertidal areas. Periods of slack water are short; typically of 30 minutes duration at high and low water.

The predicted tidal levels from the UKHO Admiralty Tide Tables used in the design of the HPC cooling water systems are shown in Table 1.

Table 1 Tidal Parameters at Hinkley Point

Tide Condition	Level in metres relative to Ordnance Datum Newlyn
Highest Astronomical Tide HAT	+7.12 mOD
Mean High Water Springs MHWS	+5.64 mOD
Mean High Water Neaps MHWN	+2.50 mOD
Mean Sea Level MSL	+0.10 mOD
Mean Low Water Neaps MLWN	-2.30 mOD
Mean Low Water Springs MLWS	-5.10 mOD
Lowest Astronomical Tide LAT	-6.10 mOD

Hinkley Point is at the western end of Bridgwater Bay, on the southern shore of the estuary, near the mouth of the River Parrett. Hinkley Point B power station intakes are at the western end of the 48 km^2 Stert and Berrow intertidal flats.

Hinkley Point is an area of intercalated shale, slate and limestone. The sublittoral substrate is highly mobile, nearly liquid mud with some areas of sand waves and reefs of agglomerated *Sabellaria* worm tubes. The intertidal area is firmer sandy mud. The measured salinity at Hinkley Point typically ranges from 22 to a near fully marine value of 33‰, depending on the freshwater flow from the rivers, and the sea temperature ranges from 2 to 21°C.

Primary production in the Severn Estuary/ Inner Channel is largely from dissolved organic matter from riverine sources or from microphytobenthos on the mudflats. There is negligible phytoplankton production due to the very low underwater light levels. Phytoplankton levels are much higher in the deeper waters of the Outer Channel where underwater light levels are higher. The common shrimp (*Crangon crangon*) dominates the bottom of the food web for fish and is available all year round. Sand gobies fulfil a similar trophic role but are much less abundant.

3.1.1 Hinkley Point intake structures

Hinkley Point hosts 3 power station sites; Hinkley Point A (HPA), Hinkley Point B (HPB) and Hinkley Point C (HPC) which is under construction. HPA was closed in 2000 and is being decommissioned. HPA was a twin Magnox reactor which operated from 1965 to 1999 producing an electrical output of approximately 470MWe. HPA abstracted 44 cumecs of cooling water from the Bristol Channel. HPB has a twin AGR reactor generating approximately 960MWe. HPB has been operational since 1976 and was life extended in 2016 to 2023. HPB abstracts 33.7 cumecs of cooling water. (AGRs operate with considerably less cooling water per MW than the older Magnox design). HPC will use a twin EPR reactor generating 3.2GWe and requiring a total cooling water flow of 132 cumecs at Mean Sea Level.

The cooling water intakes planned for HPC are very different to those installed for HPA and HPB. These differences are expected to materially affect the relative impingement impacts of the stations and therefore merit some description.

HPB intake

Power station intakes need to be sited where there is a minimum of 2-3 m of water overlying the intake apertures at extreme low water to prevent vortex formation and the risk of air entrainment. The location of the HPB intake caisson in relation to the bathymetric profile of the Bristol Channel is shown in Figure 1. The intake was located as close as possible to the coast whilst still achieving the minimum water depth requirement. At mean low water springs the HPB intakes are in about 3 m of water. It can also be seen that the HPB intake is approximately 15 km from the deep water channel in the estuary.

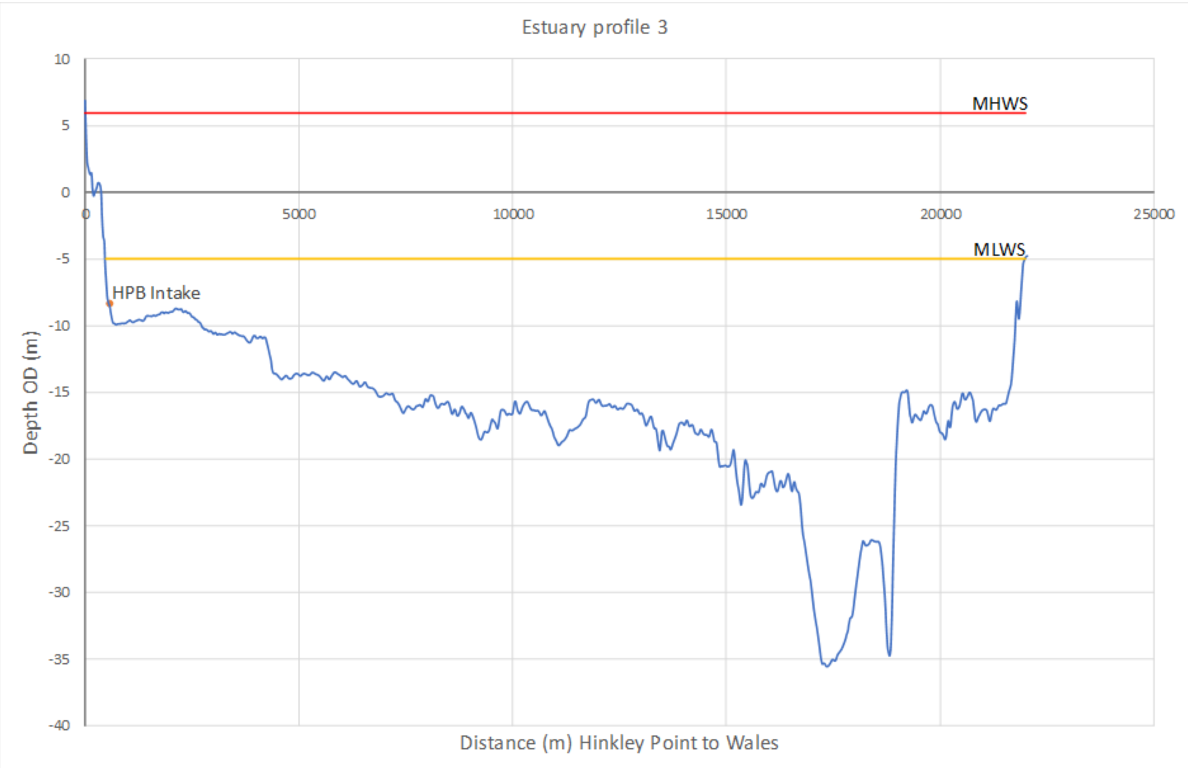


Figure 1 Location of HPB intakes. The figure shows from left to right a northerly transect from HPB through the HPB intake caisson to close to the Welsh coast. The depths of mean low water springs (MLWS) and mean high water springs (MHWS) are also shown.

The HPA and HPB intakes both share a single, shared massive concrete headworks that consists of a cylindrical caisson structure of approximately 39 m diameter and 24 m height. Apart from at the base of the structure, the caisson is open to seawater flow from all directions. The caisson is located approximately 640 m offshore and has provision for 6 intake tunnels (3.45 m diameter) which could be connected to onshore pump houses and screening plant. A dry tunnel is also provided which allows pedestrian access to the interior of the caisson. Onshore, at HPB and previously at HPA, the intake tunnels rise into open forebays from which water to cool the condensers flows via four large drum screens. Each drum screen has a square mesh of 10 mm aperture.

At the intake caisson, the power station water intake tunnels rise through the base of the structure which is divided into 6 equal sectors with no interconnections between the sectors; 2 sectors were used previously for HPA, 3 were reserved for a future HPC (this option was discounted in the mid 1990s due to the age of the structure) and one is used for HPB.

The HPB sector faces approximately south east (Figure 2). Each sector has 2 intake surfaces; a vertical face that rises from just above the seabed to a height of approximately 4 m and a horizontal surface extending approximately 4m towards the centre of the caisson. Water entering the intakes is screened through 250 mm pitch bar screens. The vertical screen could originally be lifted but the bars screening the horizontal surface are fixed.

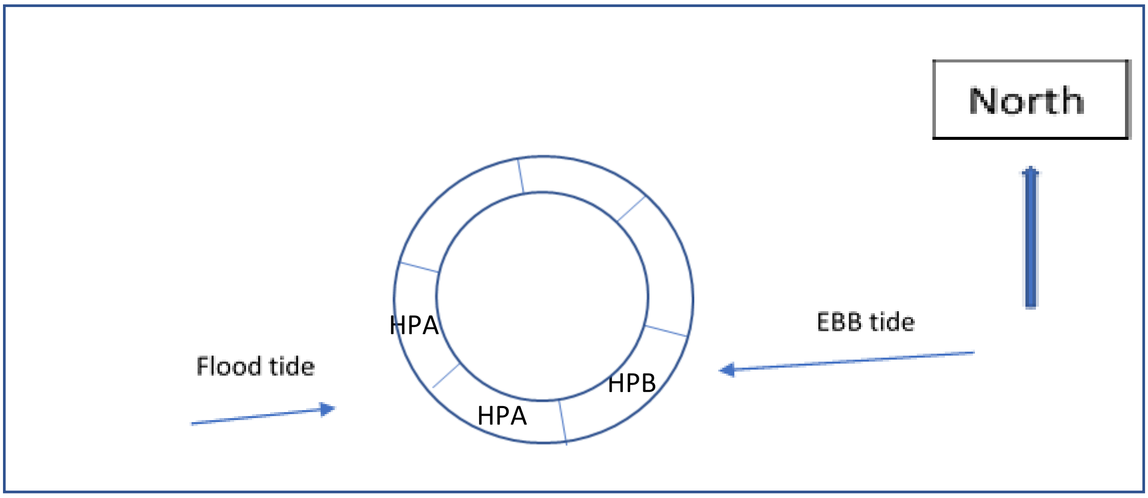


Figure 2 Plan view of HP intake caisson, showing HPB intake sector; the HPA intakes were in the South and South West sectors.

At low water neaps both the vertical and horizontal intake surfaces are submerged and the cooling water flow is abstracted through a surface area of approximately 88 m^2 (after allowing for the area of the structure's concrete walls), at low water springs the water level is below the level of horizontal screen bars and the intake surface is reduced to approximately 36 m^2. This means that the intake velocities vary at low water from those at other states of the tide. At most tidal levels the mean HPB intake water velocity is calculated to be 0.4 m s^{-1} (no measurements exist) and the intake abstracts vertically as well as horizontally. However, at water levels below low water neaps, the intake only abstracts on part of the vertical face and mean intake velocity is calculated to increase to approximately 0.9 m s^{-1} with the intake acting more like a capped structure with little vertical velocity component. Such intake velocities would only apply around low water slack.

Peak tidal velocities at mid-flood and mid-ebb are about 1.5 m s^{-1} On the ebb tide the tidal velocity is additive to that due to water abstraction and water velocities at the vertical face of the HPB intake will be up to approximately 2 m s^{-1}.

Planned HPC intakes

HPC will have 4 low-velocity side-entry (LVSE) intake heads sited approximately 3.3 km offshore. Each head has 2 intake surfaces of 2m height. Figure 3 shows a transect from HPC through one pair of intake heads to the Welsh coast. It can be seen that as well as being further offshore, the HPC intakes are sited in deeper water than at HPB. The intakes are approximately 13 km from the deep water channel in the estuary.

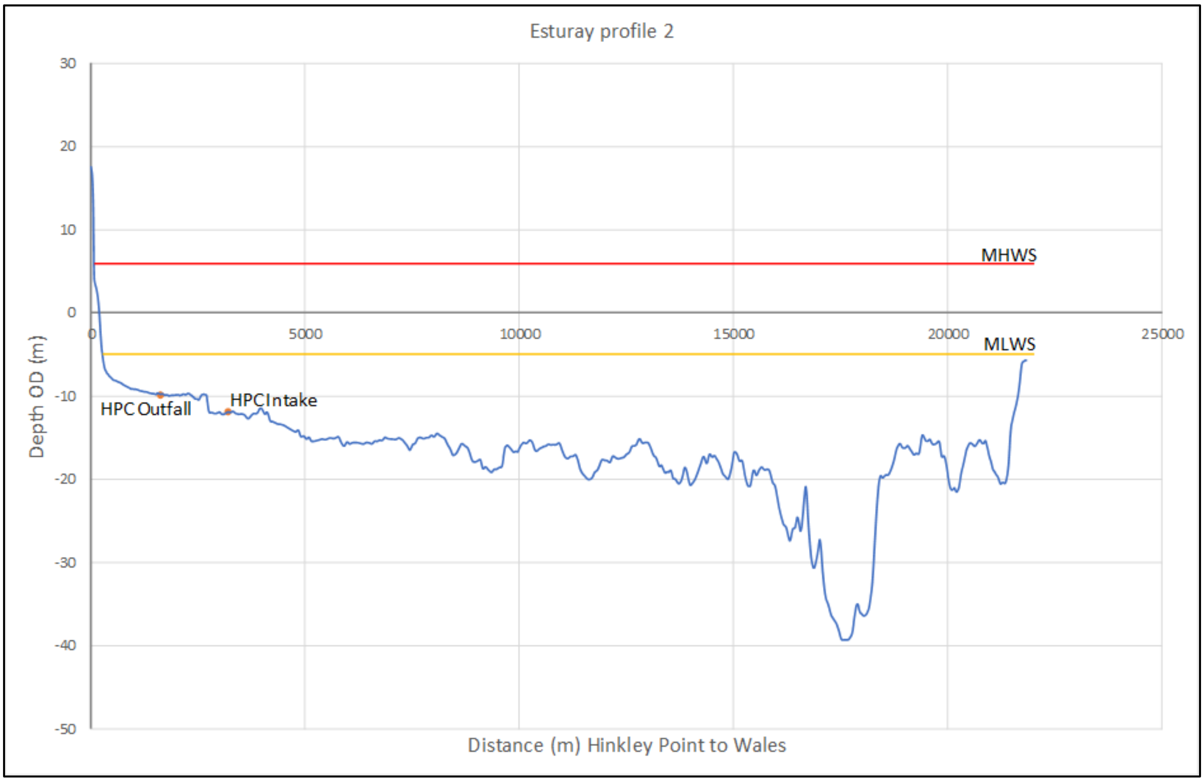


Figure 3 Location of HPC intakes and outfalls. The figure shows from left to right a northerly transect from HPC through one pair of the HPC intake heads to close to the Welsh coast

The HPC intakes are capped structures with the intake surfaces orthogonal to the approximately E-W direction of the tidal flows. In theory such a design presents a zero cross sectional area to any fish being transported by the tidal currents and an intake current with a minimal vertical velocity component. Such a design should lower the numbers of fish abstracted per cumec of cooling water flow compared to the HPB design. A practical example of how the design of the intake heads is expected to affect impingement is the comparison between impingement at SZB and SZA.

a. Sizewell B has a capped head inlet design that substantially reduces the magnitude of vertical currents at the head. Studies in the USA have shown that such a design can reduce impingement of pelagic fish by up to 90 %. (Fleming *et al* 1994);

b. The Sizewell A inlets were 300 m offshore whereas the Sizewelll B inlets are 600 m offshore. The Sizewell B inlets are therefore further from the shallow inshore flatfish nursey areas and would be expected to produce reduced impingement for such species.

A 30-day impingement intercomparison between Sizewell A and B stations during the Sizewell B commissioning trials in 1994 (Fleming *et al* 1994) showed the significant differences in impingement shown in Table 2.

Table 2 Comparison of measured Sizewell B and Sizewell A impingement rates

Species	Reduction in impingement per unit of cooling water flow at Sizewell B compared with Sizewell A
Sole	37%
Dab	54%
Plaice	46%
Sprat	62%
Bass	9%
Average of other fish species	**51%**

Even without an AFD, the design and location of the HPC intake head is expected to provide the same type of advantage as that provided by the SZB intake design compared with that of SZA i.e. reduced impingement of pelagics (e.g. sprat, herring and shad) due the capped head design and a generalised impingement reduction due to the greater water depths at low water at HPC than at HPB resulting in lower fish densities at the intakes.

The low velocity head is also expected to provide benefits compared with HPB by providing a minimal cross section to intercept fish being transported in the tidal flows. In practice, fish swimming close to the intake face could be abstracted but the risk of this occurring has been mitigated by reducing the intake velocity at the intake surface to a design target of as close to 0.3 m s^{-1} as could be achieved. (Modelling of the current flow at the HPC intakes over the tidal cycle showed that the flow patterns revert to an undisturbed pattern within 2 m of the intake surfaces, HRW 2011. This is the horizontal zone of influence of the intakes). For the majority of the tidal cycle fish would be transported past the intakes in tidal currents of approximately 1.0 to 1.5 m s^{-1} and, therefore, unless they actively turn into the intake structure the risk of impingement would be expected to be substantially reduced compared with the HPB intake which faces into the ebb tidal flow. The LVSE intake heads are therefore expected to provide benefit at HPC regardless of whether an AFD is fitted or not as described in Table 3.

3.2 Factors influencing impingement

Impingement rates at Hinkley Point B are determined by the local fish density and the cross-sectional area that the intake surface presents to the tidal stream. During the ebb tide the effective intake velocity is up to 2 m s^{-1} which is far in excess of the swimming speed of most of the fish present at Hinkley Point. In the suspended sediment regime at HP, fish being transported in the tidal stream cannot see the intakes and if their path intersects with the intake they will most probably be impinged. However, except at slack water the size of the tidal stream from which the intake abstracts its cooling water approximates to the intake surface's cross-sectional area which is negligible compared to the cross-sectional area of the estuary and therefore from physical principles impingement would not be expected to take a substantial part of the local fish population. If the fish are present all round the year the cumulative impingement risk could increase by up to 365-fold if the fish redistribute themselves spatially and if the fish are not density limited. However, impingement records demonstrate that the majority of the species at HP only spend a limited time in the zone where they would be at risk from impingement and migrate in and out of the estuary, thereby substantially reducing impingement risk. In addition, the intakes do not efficiently sample benthic species and, except at low water, pelagic species.

Table 3 compares the designs of the HPB and HPC intakes. In terms of reducing impingement, the HPC intakes are much better designed than the HPB intake. However, there is no evidence to quantify this design benefit and for the purposes of this assessment no benefit has been factored into the HPC impingement predictions. This is a precautionary assumption and it is reasonable to expect that in practice impingement rates will be lower per cumec of cooling water abstracted than at HPB.

Table 3 Comparison of the HPB and HPC intake designs.

Ideal intake characteristics to minimise impingement	HPB	HPC
Intakes should not be sited near the low water mark where intertidal fish may congregate	Intake near to the low water mark on springs. Water depth is only about 3 m at MLWS.	Minimum water depth at MLWS is much deeper than at HPB at approximately 7-8 m. Fish densities will, therefore, be lower and impingement is expected to be lower.
Intakes should be capped to reduce vertical velocities which fish are poorly adapted to resist. Studies undertaken in March/April 1994 at Sizewell concluded that the B station impinged significantly fewer fish than the A station, which was not fitted with a velocity cap (Fleming *et al* 1994).	Intake has a vertical velocity component for most of the tidal cycle with the exception of near low water on Springs	Capped intakes with low vertical velocities at all states of the tide.
Intakes should be raised off the seabed to reduce impingement of benthic species	Intake surfaces start close to the seabed	Intakes are 1 m off the seabed
Intakes should be orthogonal to the tidal stream to avoid tidal velocities adding to the intake velocity	Not orthogonal to ebb tide when fish are retreating off the mudflats	Intake surfaces orthogonal to tidal flow on ebb and flood.
Intakes should have minimal superstructure which can act as an artificial reef.	Massive superstructure that occupies whole water column at high water. Ability to act as a reef is uncertain in the prevailing strong tidal currents.	Low profile structure with minimal areas of shelter.
Intakes should not be in the estuary deep water channel where tidal velocities are greatest and which is the favoured route for migratory species using selective tidal stream transport.	Not in main channel which is >10 km away (Figure 2)	Not in main channel which is > 10 km away (Figure 3).
Intake velocities should be as low as practical to give some fish the chance to swim away from the intakes' zone of influence.	Intake velocity is approximately 0.4 m s^{-1} over the majority of the tidal cycle but the tidal velocity is additive on the ebb. At low water intake velocities increase to approximately 0.9 m s^{-1} (plus the tidal component)	Uses low velocity side entry (LVSE) intake heads. Over most of the surface the intake velocity is less than 0.4 m s^{-1}.

3.3 Other power station cooling water abstractions in the Bristol Channel/Severn

During the 37 year period of the RIMP survey HPB has not been the only power station to be abstracting cooling water from the estuary. Table 4 and Figure *4* show how the cooling water abstraction has changed since 1980 and what the projected abstraction rate is forecast to be in 2025 when HPC is planned to be online.

Table 4 Power stations abstracting cooling water from the Bristol Channel/Severn estuary (Estimated CW flow rates where no published figures available)

Station	Open	Closed	Electrical Power output	Estimated CW flow (cumecs)	Station type
Berkeley	1962	1988/89	276 MW	25.8	Magnox
Aberthaw A	1960	1995	384 MW	13.5	Coal
Aberthaw B	1971	2025 (UK policy for all coal stations to close by 2025)	1560 MW (winter only operations since 2017 – assumed 6 months per annum).	54.8 CW annual equivalent flow assumed = 27.4 cumecs from 2017)	Coal
Uskmouth A	1950s	1981	228 MW	8	Coal
Uskmouth B	1959	1995	363 MW	12.7	Coal
Uskmouth B	2001 reopened	2014 and partial to 2017	393 MW	12.7	Coal
HP A (2 units)		1999	470 MW	44	Magnox
Oldbury (2 units)		2011/12	424 MW	39.6	Magnox
Pembroke	Sept. 2012		2000 MW	40	CCGT
HP B (2 units)		2023 (forecast)	960 MW	33.7	AGR
HP C reactor 1	2024 planned		1600 MW	66	EPR
HP C reactor 2	2025 planned		1600 MW	66	EPR

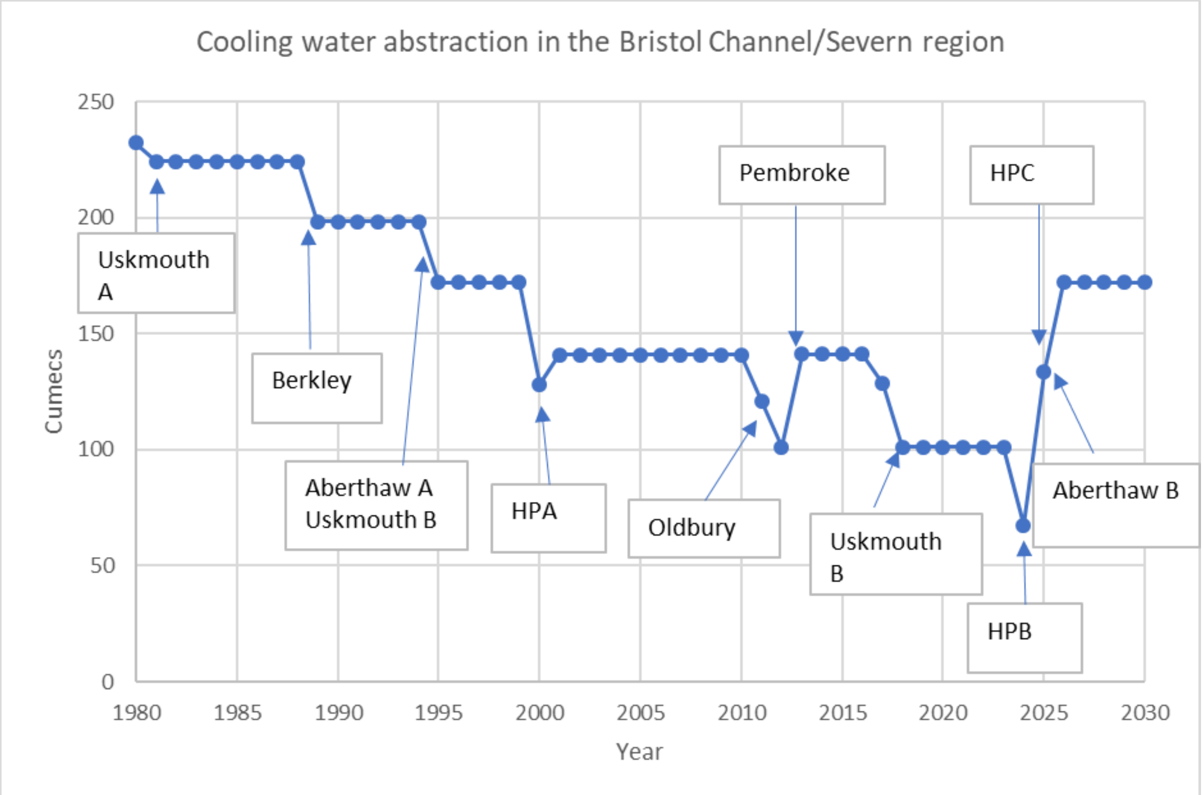


Figure 4 Changes in power station seawater abstraction from the Bristol Channel region 1980 – 2030 showing actual or projected power station closures and new stations opening.

If the fish community is the same at different locations, to a first approximation impingement rates are proportional to the volume of cooling water abstracted. At different locations in the Bristol Channel most of the fish species will largely be the same but their relative densities will differ from location to location. Previous studies have shown that many species impinged at Hinkley Point are migrating in and out of the estuary and the same species have been detected in impingement sampling at Oldbury but with a time lag relative to Hinkley Point. It is, therefore, a reasonable first approximation to consider that the total impingement pressure on the fish community in the Bristol Channel/Severn is proportional to the cooling water volumes abstracted by all of the power stations in the region.

However, the modern stations (Pembroke and HPC) have or will have embedded impingement mitigation measures fitted and therefore the impingement effect from abstraction of 1 cumec from HPC with its embedded FRR systems and LVSE heads will be lower than 1 cumec from HPA and HPB which had no impingement mitigation technology. The performance of these mitigation measures is species specific and therefore it is not straight forward to compare the impingement performance of modern stations with those of previous generations except on the basis of the effects on individual species.

Figure *4* shows the change in abstraction from the main power stations operating in the region since 1980 projected forward to 2030. By the time that both units of HPC are operational the cooling water abstraction in the estuary and therefore the total impingement pressure is projected to be approximately the same as in the period 1995-1999. However, such a comparison assumes that HPC has no embedded impingement mitigation measures fitted. In practice the equivalent HPC impingement per cumec will be substantially lower for most species at Hinkley Point due to the presence of FRR systems, LVSE intakes and the offshore location of the HPC intakes in deeper water than those at HPB.

4 Background to the Bridgwater Bay fisheries community

This section is intended to provide an overview of the Bridgwater Bay fisheries community in order to put the HPC impingement predictions into context.

The two primary datasets for assessing the fisheries community at Bridgwater Bay are the routine impingement monitoring programme (RIMP) that has been conducted at HPB since 1981 (Henderson and Holmes 1989) and the BEEMS comprehensive impingement monitoring programme (CIMP) conducted at HPB in 2009/10 (BEEMS Technical report TR129). There are other short duration impingement records from the Oldbury nuclear power station and there are a few trawl survey datasets but the impingement datasets have by far the greatest sampling intensity, the least sampling bias and provide a unique insight into the local fisheries ecology. Compared with trawl surveys, the HPB impingement is considered to have much lower species selectivity, surveys can be done day or night, continuously in any weather and at any state of the tide and at a much lower cost per hour sampled. Impingement does not provide a perfect sample of the fish community and species that use the top half of the water column and live on the bottom will be undersampled in impingement monitoring programmes. However, such bias is exactly what is required to estimate the performance of real HPC intake heads

4.1 Results from impingement monitoring programmes

The RIMP sampling method has not changed during its entire 37 year period and consists of 6 hours of sampling (in one day) off 2 of HPB's 4 drum screens every month i.e. 72 hours sampling per annum. Sampling is conducted during daylight, midway between springs and neaps, from high water on the ebb tide. Note that the RIMP was designed to assess long term changes in fish populations at Hinkley Point not to provide an unbiased estimate of HPB impingement. By sampling on the ebb tide, any HPB impingement estimates derived from the RIMP samples will be worst case as the tidal velocity will be additive to the intake velocity at that time (Section 3.1.1). The sampling frequency at 6 hours per month means that this survey can undersample changes that happen over short periods of time e.g. the waves of sprat migration into and out of the Bristol Channel in November - January. The programme has detected 87 fish species at HPB in 37 years, with typically about 38 species sampled in each year.

The 1 year CIMP survey consisted of 40 * 24 hour samples conducted on pseudo randomly selected sampling dates stratified into 10 samples per quarter i.e. 960 hours sampling per annum. The survey detected 62 species (due to its 13 times greater sampling intensity than the RIMP) and of these, 5 species have not been detected in the 37 year RIMP survey.

The total number of species detected by both surveys is, therefore, 92. However, 68 species were rare and contributed less than an average of 2 fish per year to the dataset.

The RIMP survey provides a unique record of the status and changes in the fish and crustacean community in Bridgwater Bay both seasonally and interannually. Its relatively low sampling intensity does lack resolution for studying high frequency events e.g. recruitment events and produces high variances on the impingement estimates for rare species. Over the 37 year period the fish community is characterised by:

- Exponential rise in total fish abundance – 54% increase in fish numbers (excluding sprat) over the period or more than 100% if sprat is included
- With a few exceptions, the same group of 13 species has dominated the fish community (top 95% by numbers) for the entire period, but the relative rankings of each species has changed between 2008-2012 and 1981- 1985 (Table *5* and Table *6*) due to a combination of climate change, changes in fishing pressure and management action to conserve ecosystems (Section 11). The analysis in Appendix E shows that a number of species display a

statistically significant trend in abundance over the period. Of these there has been an exponential increase in numbers of herring, sole, sprat, 5 bearded rockling and mullet with declines in the number of eel, sea snail, dab and pout. The numbers of whiting, sand goby and flounder have shown no significant trend. These relative changes are sufficient to explain the changes in the species ranking for those species that make up the top 95% of abundance in the 37 year survey period (Table *5* and Table *6*).

- Considerable year to year variability in species abundance e.g. for species that made up the top 95% of the RIMP numbers, Coefficients of Variation varied from 49% for whiting to 180% for herring. For many species this variation was driven by highly variable year to year recruitment (as evidenced by the numbers of 0 group fish per annum in the RIMP impingement record)
- In terms of the designated migratory species, the well documented international decline in eel numbers is clearly shown in the RIMP impingement record. The numbers of twaite shad have also reduced since the large recruitments that occurred the early 1980s.More recently twaite shad recruitment events have been less frequent and of lower magnitude than at the start of the time series due to climate change and particularly the construction of barriers to shad migration in spawning rivers (Aprahamian *et al* 2003)
- River and marine lampreys, allis shad, salmon and sea trout were rare and in many years not present in the RIMP impingement record. No trend analysis is possible for these species because of the low numbers impinged, indeed meaningful impingement assessment from the RIMP data is not possible for these species. The 37 year dataset for these 5 species consists of:
    - 9 salmon impinged with the last record being 2 fish in 2004
    - 9 river lampreys, last 1 being in 2010
    - 2 sea lampreys, last 1 being in 2008
    - 1 sea trout in 2017
    - No allis shad.

- Length data show that the community is dominated by immature juvenile fish, with only a few mature adults present (Section 4.6).

Table 5 Most abundant species from the HPB RIMP surveys 2008 - 2012

Rank	2008	2009	2010	2011	2012
1	Whiting	Whiting	Sprat	Sprat	Sprat
2	Sprat	Sprat	Herring	Whiting	Whiting
3	Goby, sand	Cod	Sole	Sole	Goby, sand
4	Sole	Sole	Whiting	5 bearded rockling	Sole
5	Snake Pipefish	5 bearded rockling	Flounder	Goby, sand	Herring
6	Poor cod	Flounder	Goby, sand	Mullet, grey	Sea snail
7	Herring	Goby, sand	Cod	Sea snail	Poor cod
8	5 bearded rockling	Herring	5 bearded rockling	Flounder	Pout
9	Flounder	Snake pipefish	Mullet, grey	Dab	Flounder
10	Pout	Mullet, grey	Sea snail	Herring	5 bearded rockling
11	Sea snail	Bass	Shad, twaite	Goby, common	Dab
12	Bass	Sea snail	Snake pipefish	Hooknose	Mullet, grey
13	Dab	Poor cod	Bass	Pout	Bass

Total number of fish	5612	5300	5559	3120	5990

Notes:

1. Species shaded orange make up the top 95% by annual abundance
2. Total number of fish is total annual RIMP impingement for all species

Table 6 Most abundant species from the HPB RIMP surveys 1981- 1985

Rank	1981	1982	1983	1984	1985
1	Sprat	Poor cod	Whiting	Sprat	Whiting
2	Whiting	Sprat	Poor cod	Whiting	Sea snail
3	Poor cod	Whiting	Sprat	Goby, sand	Sprat
4	Goby, sand	Goby, transparent	Goby, sand	Poor cod	Sole
5	Sea snail	Pout	Sea snail	Sea snail	Flounder
6	Sole	Sea snail	Dab	Dab	Goby, sand
7	Pout	Sole	Pout	Sole	Poor cod
8	Dab	Goby, transparent	Flounder	Lumpsucker	Dab
9	Flounder	Dab	Hake	Flounder	Shad, twaite
10	Eel	Eel	Sole	Goby, transparent	Goby, transparent
11	Bass	Bass	Bass	Norway Pout	Bass
12	Mullet, grey	5 bearded rockling	Goby, transparent	Shad, twaite	Eel
13	Conger eel	Norway Pout	Shad, twaite	Eel	Pout
Total number of fish	2457	4561	2493	3497	1940

Notes:

1. Species shaded orange make up the top 95% by annual abundance
2. Total number of fish is total annual RIMP impingement for all species

4.2 Species numbers and abundance

Whilst the RIMP programme has provided a useful dataset for interannual trend analysis, the CIMP survey was designed to provide an unbiased, high resolution dataset which would enable the seasonal fish community to be analysed in detail even for the rare species.

In the CIMP 2009/10 survey, 64 fish species were detected in the 40 * 24 hour samples. From these data the bootstrapped annual mean impingement for HPB and HPC together 95% confidence limits were calculated (Appendix D). A total of more than 217,000 fish were counted with numbers ranging from 106,000 for sprat to 5 species with only 1 individual. The high number of sampling hours means that much more realistic estimates of the density of protected species could be made than with the RIMP survey. One fish caught in the RIMP could scale up to 952 fish at HPC, whereas 1 fish in the CIMP survey could scale up to 35 fish at HPC. Of the protected migratory species sufficient numbers of twaite shad and eel were impinged to allow a meaningful assessment of impingement effects. The numbers of marine lamprey were very small (5 in the year) but sufficient to make an indicative assessment of effect. However, the numbers of allis shad and river lamprey (both at only 2 fish in the whole year) were so low that they can be discounted as being part of the fish community vulnerable to impingement at Hinkley Point and the 2 species have been screened out of the impingement assessment.

The fish community was dominated by sprat with 48.8% of the measured fish numbers; the pelagic species sprat and herring provided 50.2% of the total abundance. A total of 7 fish species represented 95% of the impingement numbers and 12 species made up 99% of the abundance. Four species sprat, whiting, sole and cod represented 88% of the total numbers with mullet, flounder and 5 bearded rockling providing the next 7%. 50 species occurred rarely or in very low numbers, contributing a total of 0.56% of the annual impingement and individually constituting 0.1% to 0.0004% of the annual impingement numbers.

4.3 Selection of key taxa for HPC impingement assessment

In order to undertake an impingement assessment for HPC the CIMP dataset was used as the primary evidence base. For interannual comparisons the RIMP dataset has been used as a secondary evidence source which is useful for fish species caught in high numbers but much less so for protected rare species.

It is necessary to assess the effects of HPC on the fish assemblage. 92 species have been detected at Hinkley Point, however most of these species occur infrequently in very low numbers and are not present in sufficient numbers to play an important role in the functioning of the ecosystem. Taking a functional approach considering energy flows in the ecosystem only species that represented more than 1% of the assemblage numbers would be a selected. However, this would exclude assessment of the important protected species which are present in much lower numbers.

For the purposes of the HPC impingement assessment, taxa were therefore considered to be important if they met at least one of the following criteria:

- Socio-economic value: Species that contribute to the first 95 % of the first sale value of commercially landed finfish in the area off Hinkley Point and contribute to the first 95 % of total impingement abundance. Socio-economic value was calculated using data supplied by the Marine Management Organisation (MMO) and presented in BEEMS Technical Report TR071. **4 taxa (sole, cod + bass and thornback ray). Note: Bass and Thornback ray were added post grant of DCO due to the locally important recreational fisheries for both species and the international decline in the bass population.**

- Conservation importance: The "S41 Priority Species" spreadsheet provided by Natural England (http://publications.naturalengland.org.uk/publication/4958719460769792) was used to assess the conservation status of the fishes recorded in Bridgwater Bay. This spreadsheet was based on the legislation in Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006. It is worth noting that measures in place to provide protection for the named species apply to the adult stock rather than the eggs or larvae, and focus on halting the decline of the spawning stock biomass mainly *via* restriction on exploiting recruited species. **13 taxa (allis shad, twaite shad, European eel, herring, Atlantic cod, whiting, blue whiting, plaice, sole, salmon, sea trout, river lamprey, sea lamprey).**

  Note that this list of 13 conservation species contains two taxa which were not detected in the CIMP impingement sampling and only rarely during the RIMP programme (Section 4.1): sea trout (1 fish in 37 years) and Atlantic salmon (9 fish in 37 years). Due to their migratory behaviour, neither of these species would be expected to be impinged in any significant numbers at HPB and even less likely at HPC (Section 4.7). The predicted impingement numbers in this assessment are therefore zero for both species and the species are screened out of the assessment. Similarly, the numbers of allis shad and river lamprey caught at Hinkley Point (2 individuals of each species in the 1 y CIMP programme and 0 allis shad and 9 river lampreys in 37 y in the RIMP programme) were so low that they can be discounted as being part of the fish community vulnerable to impingement at Hinkley Point and the 2 species have also been screened out of the impingement assessment.

- Ecological importance: Abundant species that play a key trophic role within the ecosystem. From the HPB CIMP impingement data the four most abundant fish species at HPB were sprat (*Sprattus sprattus*), whiting (*Merlangius merlangus*), Dover sole (*Solea solea*) and cod (*Gadus morhua*) These four species accounted for 88% of the measured annual fish impingement numbers. Three additional species were included to ensure that the assessment included those species which constituted 95% of the measured impingement. In addition, the brown shrimp *Crangon crangon* was added to the list due to its importance in the Bridgwater Bay foodweb.**8 taxa (sprat, whiting, sole, cod, thin lipped grey mullet, flounder, 5 bearded rockling and the brown shrimp).**

These criteria produced the list of 19 fish species plus brown shrimp shown in Table 7. Of these, the 17 fish species that were detected during the CIMP programme represent 97.3% of the total fish impingement numbers. These species are considered representative of the assemblage at Hinkley Point and contain all of the conservation species listed as HRA interest features. In terms of suitability for the WFD assessment, the 19 fish species contain examples from all functional guilds with the exception of freshwater species (which are rarely found at Hinkley Point), all the feeding guilds and all of the indicator species found at Hinkley Point that are assessed in the WFD “fish” biological quality element (See section 5.3).

The list contains 5 additional species that were not assessed in the HPC Environmental Statement (ES), WFD and shadow HRA (bass, thornback ray, mullet, flounder and 5 bearded rockling).

4.4 Annual Impingement Seasonality

Most fish species at HP are not present for the entire year in significant numbers and the community changes throughout the year as different species migrate in and out of Bridgwater Bay. Of the 64 fish species in the CIMP dataset only whiting, 5 bearded rockling and conger eel were recorded all year round at broadly similar densities but even these species have periods of higher density e.g. August - December for 5 bearded rockling. A number of species such as sprat, sole, cod and flounder are present for all or nearly all of the year but they display very distinct seasonality with their peak numbers concentrated in a few months and very low numbers in other months e.g. 50% of cod were associated with the arrival of new recruits in June, 99% of sprat are present from November - January as they migrate into and then out of the Bristol Channel. This means that HPC impingement will not exert a constant mortality pressure for 365 days a year on each species. In fact, the majority of the effect on many species is often only for weeks to a few months per annum (Table 7).

Table 7 Measured seasonality for the fish species assessed in this report showing percentage of annual impingement numbers for each species

Species	HPB annual impingement	% of annual total	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sprat	999,252	48.5%	26%										32%	41%
Whiting	577,707	28.1%	8%	10%	5%	4%	3%	14%	4%	8%	7%	4%	13%	18%
Sole, Dover	138,579	6.7%				3%	12%	7%	27%	37%	9%	3%	2%	
Cod	97,419	4.7%	7%				4%	48%	7%	8%	7%	5%	8%	6%
Mullet, Thin-lipped grey	55,200	2.7%	45%	3%	2%						3%	1%	3%	42%
Flounder	54,201	2.6%		3%	2%	16%	19%	27%	16%	8%	6%	2%		
Rockling, 5-Bearded	35,861	1.7%	4%	3%	3%	5%	7%	5%	3%	11%	12%	11%	14%	23%
Herring	31,842	1.5%	19%	50%	7%			3%	2%	2%	2%	3%	6%	5%
Bass	8,672	0.42%	9%	14%	9%	12%	3%	12%	6%	4%	8%	11%	6%	7%
Plaice	1,282	0.06%	3%	2%			12%	50%	6%	12%	2%	4%	5%	2%
Ray, Thornback (Roker)	712	0.03%			1%	9%	23%	11%	26%	6%	6%	3%	13%	1%
Whiting, Blue	266	0.01%	68%											32%
Shad, Twaite	525	0.03%		11%	1%	3%	18%				17%	27%	10%	14%
Eel	306	0.015%	15%	14%	8%	5%	3%	7%	15%	9%	10%	13%		3%
Lamprey, Marine	51	0.002%	27%	28%		30%	16%							
Shad, Allis	22	0.001%		64%	36%									
Lamprey, River	16	0.001%	100%											
Salmon	0	0.0%												
Sea Trout	0	0.0%												

Key:

% of annual impingement	Colour
>20%	Pink
5% to 20%	Yellow
1% to <5%	Green
Not present or< 1%	White

Notes:

1. The impingement numbers are calculated from raw impingement data, not the bootstrapped mean.
2. Orange cells in first column = fish species that made up the first 95% of total impingement.
3. Salmon and sea trout were not detected during the CIMP programme.

4.5 Tidal variation in HPB impingement

Previous studies at HPB have shown that 80% of the impingement occurs on the ebb tide (Turnpenny *et al* 1994). There are two possible reasons why this occurs:

1. On the ebb tide fish feeding on the shallow mudflats in Bridgwater Bay are forced to retreat with the tide and to congregate in the shallow water near to the HPB intakes
2. Peak current velocities of up to 1.5 m s^{-1} occur except for short periods around slack water. On the ebb the tidal current would be additive to the HPB intake velocity and prevent any realistic chance of escape for most species that were aligned on a tidal stream with the intake surface (Section 3.2). On the flood the substantially increased depth of water would mean that only fish swimming within approximately 3 m of the seabed would be at risk of impingement.

4.6 Fish age and maturity distribution

The majority of the fish at Hinkley Point are immature juveniles (Figure 5 and Figure 6).

Figure 5 Fish age and maturity distributions from CIMP programme at HPB in 2009/10

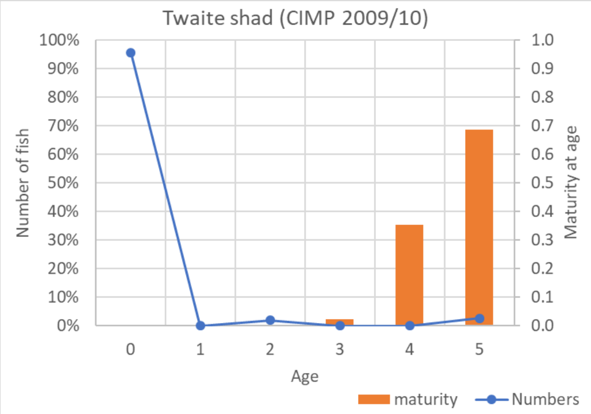


Figure 6 Fish age and maturity distributions from CIMP programme at HPB in 2009/10

4.7 Species not detected in HPB CIMP impingement programme - migrating adult salmon, sea trout and twaite shad, migrating salmon and sea trout smolts and glass eels

4.7.1 Adult salmon, sea trout and twaite shad

Adult salmon and sea trout migrate up the estuary using selective tidal stream transport on the flood tide, close to the sea surface and in mid channel following an olfactory trail to their natal rivers (Defra 2004). Adult twaite shad migrating up estuary to freshwater are expected to use the same energy efficient migratory pattern as other diadromous species i.e. migration on the flood tide, near to the surface and in mid channel where current speeds are highest (Dr A Moore, Fisheries Ecologist. Cefas, Pers. Comm.).

The deep water channel is more than 10 km to the north of either HPB or the planned HPC intakes. On the flood tide the HPB and HPC intakes will abstract from a tidal stream that approximates to the size of the intake surface i.e. they will only abstract from a layer near to the seabed. (Turnpenny *et al* 1994)

The distance from the main channel and the surface migratory pattern means that none of these species would be expected to be impinged in any significant numbers at either station.

4.7.2 Salmon and sea trout smolts

Tagging studies in estuaries have shown that seaward migrating salmon and sea trout smolts migrate on the ebb tide using selective tidal stream transport at or near to the surface and in the main channel where the current speed is highest. (Thorstad *et al* 2012, Moore *et al* 1998). The HPB and the future HPC intakes are more than 10 km from the deep-water channel and when combined with their near surface migratory behaviour, neither salmon nor sea trout smolts would be expected to be impinged in any significant numbers at either station.

4.7.3 Glass eels

All European eels belong to a single panmictic stock that is widely distributed in marine, coastal and freshwater habitats of Europe and occurs from the Atlantic coast of north Africa, through Europe, the Baltic Sea and in the Mediterranean waters of Europe and northern Africa (OSPAR 2010). Eels spawn in the Sargasso Sea. Their larvae (leptocephali) drift with the Gulf Stream across the Atlantic Ocean for one to three years until they reach the coasts of Europe by which time they have metamorphosed into glass eels (juvenile translucent eels). Once glass eels locate an estuary they migrate up the estuary to freshwater using selective tidal stream transport on the flood tide. Glass eels of approximately 70-80 mm total length enter the Bristol Channel in the approximate period

February to April. Virtually all of any glass eels abstracted by HPC would be entrained as they will be small enough to pass through the 5 mm drum screen mesh. (BEEMS Scientific Position Paper SPP063)

In 2012 and 2013 targeted fishing surveys were undertaken to determine the spatial distribution of glass eels across the Bristol Channel at three depths – the surface (0 m), at 4 m and at 7 m. The results of the surveys (BEEMS Technical Report TR274) confirmed that:

a. glass eels migrated up estuary on the flood tide by day and night; they were not found in the water column on the ebb tide;
b. glass eels used the full width of the Severn Estuary to migrate up estuary to freshwater;
c. glass eel densities were consistently highest in shallow, inshore zones close to the Welsh and English coasts;
d. there was evidence that eel densities are greater at the surface than at deeper depths; particularly than at depths of 7m
e. The density of eels at the location of the proposed HPC intakes was significantly less than at further inshore sites.

.As the maximum glass eel densities occur near the sea surface on the flood tide, they are largely invulnerable to abstraction at HPB which only abstracts from the bottom 3-4 m of the water column on the flood tide. They would be even less at risk at HPC due to the deeper water at the intake locations. Any glass eels that may be abstracted at HPC would pass through the drum screen mesh and be entrained. As would be expected there are no records of glass eel impingement at HPB although a few glass eels have been found in zooplankton samples taken from the HPB forebay in February and March (BEEMS SPP063). Entrainment simulation experiments have shown that glass eels will have a high rate of entrainment survival in HPC in the range 72% to 92% (BEEMS Technical Report TR273). The predicted effect of HPC entrainment on the eel population was reported in the HPC DCO submission to be negligible (BEEMS SPP063).

5 The Impingement Assessment Process

To estimate the unmitigated impingement at HPC the assessment approach adopted in this report is to scale the measured impingement at HPB by the ratio of the cooling water volumes extracted by the two stations. The accuracy of the assessment depends upon whether:

- the fish community is the same at the location of the HPC intakes (3.3 km offshore) as at the HPB intakes (640 m offshore); and
- the HPC intakes will abstract the same amount of fish per cumec as HPB.

The results of subtidal fishing surveys in the wider Bridgwater Bay area are described in BEEMS Technical Report TR083. The surveys, over 3 years and consisting of 104 fishing stations, found a very low density of predominantly juvenile fish. Only 21 taxa were sampled with individuals from all but 2 taxa (2 thornback ray and 1 conger eel) being less than 30 cm total length. The fishing surveys were unable to distinguish significant spatial differences in the fish community between the locations of the HPC and HPB intakes.

As described in Section 3.2 the design of the HPC intakes combined with the greater water depth at the HPC intakes is expected to reduce fish abstraction per cumec of cooling water flow compared with HPB. Section 3.1.1 provided the results of an impingement intercomparison between the Sizewell A and B stations where the combination of capped intakes at Sizewell B and further offshore intakes (600m as opposed to 300m at Sizewell A) significantly reduced catches for pelagic and some demersal fish). It is, therefore, reasonable to expect that impingement rates at HPC will be lower than at HPB but there this insufficient evidence to quantify the expected benefit. On a precautionary basis the two stations of been assumed to have the same catch rates per cumec.

The impingement assessment process is illustrated in Figure 7.

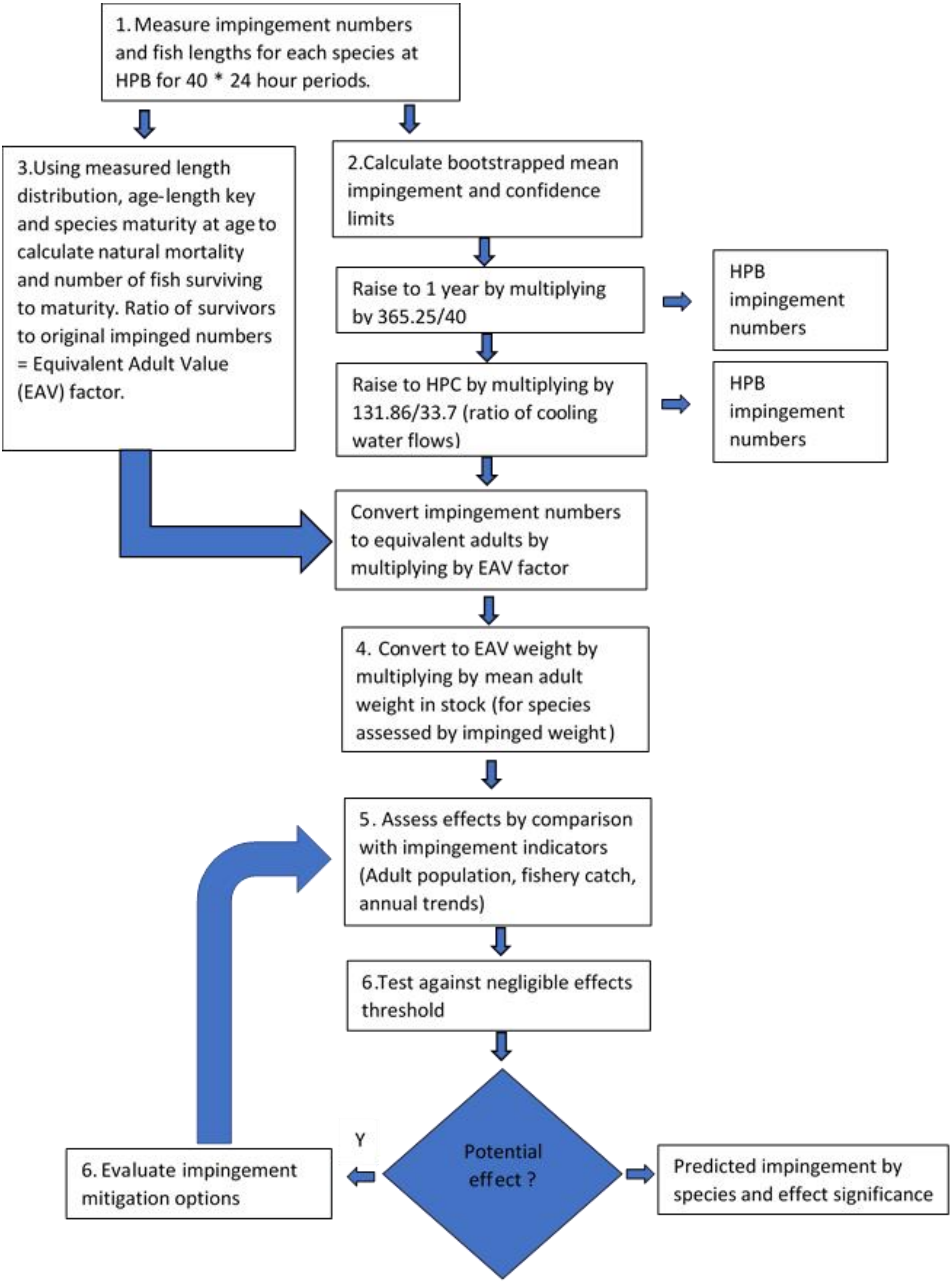


Figure 7 The CIMP impingement assessment process

5.1 Calculation of Equivalent Adult Value (EAV) factors

The fish community at Hinkley point is predominantly made up of immature juveniles (Section 4.6). To undertake an effects assessment it is necessary to convert the number of juveniles into the number of adults that would survive to maturity ('equivalent adults').

To perform this calculation it is necessary to have:

a. The species annual length distribution
b. Length at age estimates
c. Maturity at age estimates
d. Natural mortality (M) at length estimates

Items a-c are routine biological measurements which are relatively easy to perform but it is very difficult to directly measure M which involves following the different year classes of a species and determining the number of survivors in each year over several years until maturity. The analysis of the survey results must factor in the effects of migration and ideally the population must not be commercially exploited otherwise it becomes difficult to disentangle natural and fisheries mortality. For many species such measurements are not practical. To overcome these difficulties various researchers have derived species independent empirical formulae to relate M and fish length or weight using measured mortality data from a wide variety of fish species from different latitudes. The question then becomes which formula is the most reliable for a specific assessment.

For the calculation of EAVs (BEEMS Technical Report TR426) the peer reviewed Gislason formula was selected (Gislason *et al* 2010) that predicts M for marine and brackish water stocks as a function of the von Bertalanffy growth parameters (http://www.fao.org/docrep/W5449e/w5449e05.htm):

- L_∞ asymptotic length of the stock (cm),
- K is a rate function which determines how fast the fish approaches L_∞ (year^{-1}); and
- L length (cm).

This formula was selected because:

- it is in accordance with theoretical considerations;
- It was derived after carefully screening M estimates for quality from a very large dataset (367 publications) which included geographically relevant species;
- It is length based (individual lengths can readily be measured quickly and efficiently at an exposed field site, weights cannot). It should be noted that it is possible to convert lengths to weights but that requires the use of yet another empirical relationship if site based measurements are not available which could introduce further uncertainty to the assessment;
- It was derived by leading ICES fish stock assessment scientists.

Gislason provided a best fit, or mean, relationship between the variables:

$Ln(M) = 0.55 - 1.61\ Ln(L) + 1.44\ Ln(L_\infty) + Ln(K)$

Exploring this equation indicates that for a given fish length natural mortality increases with the rate function K but also with the amount of growth required to reach the fish maximum length. As the fish length increases the required growth decreases and the natural mortality decreases.

e.g. comparing an 8 cm long sprat and cod. Both species have similar rate functions (K) but their maximum lengths are very different (maximum length of sprat is 15 cm but that of Celtic Sea cod is nearly 1 m) It therefore takes much longer to reach the cod maximum length and the natural mortality for an 8 cm cod is therefore much greater than that for an 8 cm sprat which will reach its maximum length in a fraction of the time.

Gislason also provides 95% confidence limits for the formula coefficients. Use of these confidence limits produces very wide ranges for calculated M and subsequently EAVs (Figure 8). This variability is most likely due to a combination of experimental scatter in the measured M estimates and the wide range of different species, from benthic to pelagic and from geographically widespread locations used to produce the empirical relationship.

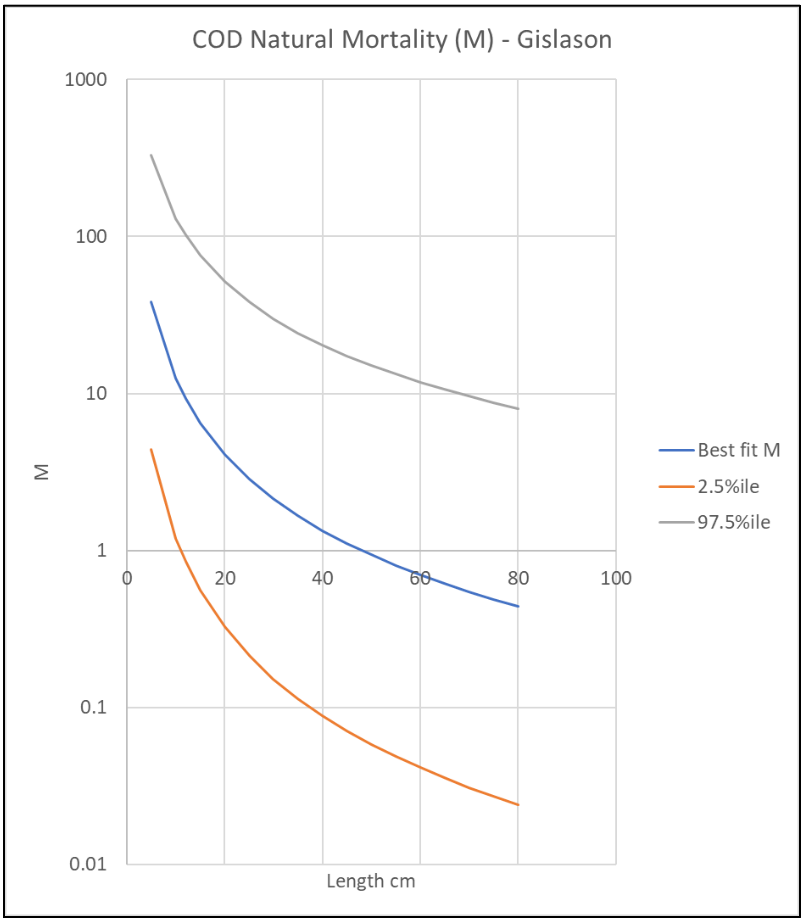


Figure 8 Gislason natural mortality values for cod at Hinkley Point showing the calculated 95% confidence range

For impingement assessment purposes the greatest concern is that M should not be overestimated; the higher the value of M, the lower the number of adult survivors and the lower the predicted effect of impingement. The question that then arises is how much confidence can be placed in the Gislason mean results.

Estimation of uncertainty was approached in 2 ways:

Test 1: Comparing Gislason best fit mean predictions with data from geographically relevant species contained within the supplementary dataset accompanying the scientific paper (i.e testing whether the relationship was valid only for selected relevant species)

Test 2: Comparison of the Gislason derived values of EAV with those produced using another widely used natural mortality equation – the Lorenzen weight based relationship (Lorenzen 1996)

The Lorenzen best fit equation is:

$M=3 * (\text{fish weight})^{-0.288}$ where fish weight is given by the species specific length-weight relationship.

The results of Test 1 are described in Appendix F. The initial test species was cod which in the CIMP dataset consisted of very large numbers of new recruits in their first year of life. Natural mortality is highly dependent on the size of individual fish and therefore this species created a challenging test case. Validation on North Sea cod data showed that the Gislason formula using 2.5%ile coefficients produced unrealistically low values of M which were much lower than the measured M values. The Gislason mean M estimates were higher by a factor of 1.3-1.9 compared with the M values assumed in the ICES stock estimates for cod and by a factor of 2.45 compared with measured values of M for the smallest fish in the Gislason dataset. Field measurement of M is difficult, particularly for young fish which suffer high natural mortality rates. It is considered likely that the reported field data are underestimates of M for small fish and their use will bias the Gislason correction factor, leading to overestimates of adult impingement. However, to be precautionary a correction factor of 2.45 has been used for cod assessment purposes in this report. When this process was repeated for whiting the Gislason results essentially agreed with the estimates of M used in the ICES stock assessments.

Table 8 Effect of applying different correction factors to the Gislason derived natural mortality formula on the calculated cod EAV

Correction factor (CF) applied to the Gislason calculated values of natural mortality (M)	Resultant Hinkley Point cod EAV after applying correction factor
Original Gislason i.e. CF=1	0.0022
CF = 2	0.0135
CF = 2.45	0.0216

Table 9 shows the results of Test 2.

Table 9 Calculated EAV for different Hinkley Point fish species based upon the 2009/10 CIMP data

Species	EAVs derived from the Gislason equation	EAVs derived from the Lorenzen equation	Ratio Lorenzen:Gislason
Sprat	0.412	0.315	0.76
Cod	0.0022	0.115	**52.3**
Whiting	0.099	0.195	1.97
Herring	0.027	0.122	4.52
Sole	0.076	0.061	0.8
Bass	0.121	0.11	0.91
Plaice	0.132	0.131	0.99
Thornback ray	0.185	0.196	1.06

The conclusion that has been drawn from this analysis is that for species where there are not a large number of very young fish in the impingement dataset and the time to 50% maturity is short, the differences in the calculated value of M between the two formulae do not produce large differences in calculated EAVs. For populations that are dominated by newly recruited juveniles that take a long time to reach maturity, the differences between the 2 formulae produce wide differences in calculated EAVs. In Table 9 this is most vividly demonstrated for cod which had the largest recruitment peak of 0 group fish in the CIMP dataset with 50% of annual cod impingement occurring in a 4 week period in May/June 2009. In such circumstances Lorenzen’s underprediction of M results in too high an EAV whilst Gislason’s overestimate of M results in too low an EAV. However, Gislason produced the closest estimates to measured M values for North Sea cod.

However, there are no measured M values for whiting and very few for herring. The few herring results that are available suggest that Gislason M values need to be reduced by approximately a factor of 2 producing a revised herring EAV of about 0.113. However, the dataset is too sparse to have confidence in this result. For whiting the Lorenzen results are lower than the values used by

ICES in its stock assessment whereas the Gislason numbers essentially agree with the ICES estimates and are therefore internally consistent with the stock assessment. To be conservative in this assessment, the Lorenzen values have been used for herring and the revised EAV for cod of 0.022 from Table 8 has been used (i.e. an increase in EAV of 8.3 times the original uncorrected value). The Gislason values have been used for the other species in Table 9. The revised EAV compared with the values used in TR148 are shown in Table 10.

Table 10 Comparison between the EAVs used in this assessment with those used in TR148

Species	Original EAVs used for DCO assessment. With the exception the 2 shad species these were not site specific.	EAVs based upon CIMP measurements at Hinkley Point, (EAV Source)
Sprat	1 (no data to compute at DCO)	0.412 (TR426 Ed 2)
Whiting	0.137	0.099 (TR426 Ed 2)
Sole	0.0538	0.076 (TR426 Ed 2)
Cod	0.0864	0.022 (corrected Gislason from TR426 Ed 2)
Herring	0.4948	0.122 (Lorenzen)
Bass	N/A	0.121 (TR426 Ed 2)
Plaice	0.0916	0.132 (TR426 Ed 2)
Blue Whiting (Whiting value used)	0.137	0.099 (TR426 Ed 2)
Thornback Ray	N/A	0.185 (TR426 Ed 2)
Eel, lamprey marine, lamprey river	1 (worst case – no data to compute true value which is <1)	1 (worst case – no data to compute true value which is <1)
Twaite shad	0.02768 (SPP071 Ed 2)	0.035 (SPP071 Ed 3)
Allis shad	0.2618 (SPP071 Ed 2)	0.2618 (SPP071 Ed 3)

5.2 Indicators for the assessment of impingement effects

To assess the effect of impingement it is necessary to compare the predictions against an objective measure of the status of each population. In theory, if the data existed, a model could be created of the relevant ecosystem complete with interspecies relationships and the effects of impingement judged by abstracting the predicted number of fish over an extended period of time. In practice such a model does not exist and is well beyond the scientific state of the art. EcoPath with EcoSim are widely used ecosystem modelling tools and have been used to simulate several UK and European marine areas (Mackinson and Daskalov (2007) and Christensen and Walters (2004)). The constructed models typically have the following characteristics:

- Very large geographic coverage e.g. North Sea, Celtic Sea. The areas have to be selected such that organisms do not migrate out of the model domain. Model parameters need to be selected to be representative of the entire area
- Collapsed time steps e.g. 1 step per annum (thereby requiring seasonality to be averaged)
- Grouped species and life stages (e.g. small demersal, filter feeding pelagics, juvenile, adult) because the required model parameters do not exist for most species

- Used for exploring the effects of large scale change e.g. ±50% changes in specific parameters.

Mackinson and Daskalov,G (2007) and Christensen and Walters (2004) provide examples of how these fisheries ecosystem modelling tools have been used and their strengths and limitations.

Even if the data existed to parameterise a model that could simulate the number of species and their seasonality in the Bristol Channel (which they do not) the model would still have no possibility of detecting sub 1% changes caused by HPC impingement against the much larger natural variability in fish numbers and predator prey relationships to which the ecosystem is adapted. Such changes would be invisible within the model 'noise'.

Ecosystem modelling to assess the effect of the predicted HPC impingement is impractical and instead a variety of indicators have been used:

a. Comparison with the adult spawning stock biomass (SSB) in the assessment year as published by the International Council for Exploration of the Sea (ICES)
b. Comparison with the international catch on a fish stock in the assessment year (ICES*)*
c. Analysis of the 37 year impingement trend data to draw conclusions about the stock status and the impact of the station (from the HPB RIMP programme).

The preferred measure is comparison with ICES estimates of SSB as this is how the much larger environmental impact of fishing is internationally managed. It must be emphasised that comparison with the SSB in the assessment year is not a full fisheries population assessment and in stocks where the population biomass is heavily dependent upon new recruits which suffer a high rate of natural mortality (e.g. cod at Hinkley Point) this simple measure can provide a misleading overestimate of impingement effects. However, a full population assessment is disproportionately difficult to undertake when impingement effects are negligible. If predicted effects of impingement were above the precautionary 1% negligible effects threshold a full population assessment is one of the steps that could be undertaken to reduce uncertainties and to determine, if there was in fact any risk to site integrity.

For some species estimates of SSB are not available and the total international landings can be used as a surrogate indicator. In TR148 local UK landings was used as a simplistic assessment indicator but it was recognised that it had limitations as UK landings can have little relation with fish biomass size (e.g. for some species a large part of the catch in UK waters is not landed into the UK due to quota ownership or marketing reasons). For this reason, this indicator has been replaced by the total international landings for a stock which provides a much more realistic indication of the fishing pressure on the stock. Clearly if the total catch approaches the adult stock size the population is going to rapidly collapse and fisheries are managed with the objective of preventing such an outcome. For a heavily exploited stock the total international fish catch can be used as a worst case estimate of the fish population size. In most cases where the population is not rapidly collapsing, this estimate will be an underestimate of the population size.

For species that are not commercially exploited there are frequently no SSB estimates nor landings data. For conservation species such as shad, eel and lampreys independent estimates are available for the adult population size (Appendix G; TR148 and SPP071/S), however for many other common species no such data exist. The HPB impingement trend data can then be used to provide an indication of the state of the stock. If the stock size is rising, it is reasonable to conclude that the power station impingement is having negligible effect. Prior to being taken offline in 2000, HPA abstracted more cooling water than HPB (44 as opposed to 33.7 cumecs) from essentially the same intake location. If HPA was having any effect on local fish populations then the closure should have been visible in the impingement record. In practice no such effect can be found. Some species are reducing in abundance at Hinkley Point but these are changes mirrored elsewhere far beyond the impact zone of HPB e.g. the international decline in the eel population and the reduction in the abundance of species that are at the southern limit of their natural range which are moving either northwards or into deeper water to mitigate rising sea temperatures due to climate change.

Spawning Stock Biomass (SSB) is the adult population of a fish stock. The key parameter is the definition of the relevant stock unit and its geographical area. The following definitions are used:

- A stock unit is where the effects of exploitation by a particular fishery or fisheries are recognisable.
- A biological stock is where there is sufficient spatial and temporal integrity for the stock to be considered as a self-perpetuating unit.

For many fish species, stock areas are very large with widescale temporal and seasonal migrations and often considerable inter mixing between stocks. A Bridgwater Bay fish stock has no biological meaning for most species, nor does a Severn Estuary fish stock.

The stock units that have been used in this assessment are the ICES 2017 definitions which are the outcome of the best available international science. In TR148 for the HPC DCO the 2010 ICES stock units were used but two SSB estimates were transformed by Cefas into tentative and highly precautionary estimates of ‘local SSBs’ to reflect the possibility that the stock identity for some species might have been smaller than the 2010 ICES stock identities. In the subsequent 7 year period no further evidence to substantiate the existence of these sub stocks has materialised and they have they been adopted by ICES. The continued use of these sub stocks is, therefore, not evidence based and for this report the latest (2017) agreed ICES stock identities have been used as these are the basis for all management decisions in Europe on fishing impacts which are much greater than those expected from HPC (Table 11).

SSBs are assessed internationally by ICES using virtual population analysis (VPA). VPA is a cohort modelling technique commonly used in fisheries science for reconstructing historical fish numbers at age using information on the death of individuals each year. This death is usually partitioned into catch by fisheries (F) and natural mortality (M). VPA is virtual in that the population size is not measured directly but is back-calculated to have been a certain size in the past in order to support the observed fish catches and an assumed natural mortality (Definition adapted from Wikipedia). As such estimates of SSB in any year are refined with the passage of time and tend to converge on a stable estimate some years after the assessment year. Most ICES estimates of SSBs do not have accompanying confidence limits.

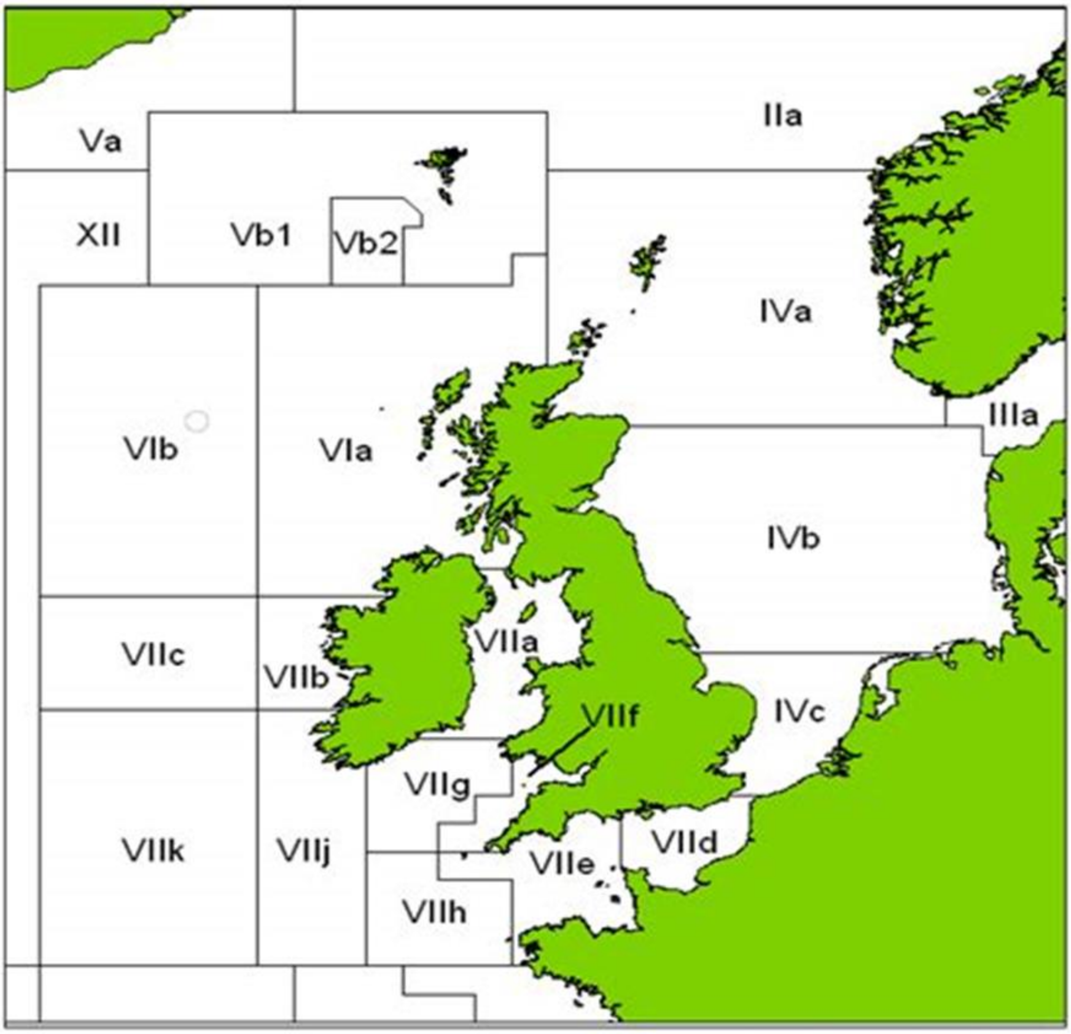


Figure 9 Map of ICES Divisions

Table 11 ICES fish stock assessment units relevant to Hinkley Point (ICES 2017)

Species	Stock Units	ICES Working Group report
Whiting	VIIbc, e-k	WGCSE, Celtic Sea Ecoregion
Sole	VIIfg	WGCSE, Celtic Sea Ecoregion
Cod	VIIe-k	WGCSE, Celtic Sea Ecoregion
Herring	VIIef (no SSB estimate)	HAWG, Herring Assessment for area to south of 62N. stocks with limited data
Plaice	VIIfg	WGCSE, Celtic Sea Ecoregion
Bass	IVbc, VIIa, VIId-h	Celtic Sea and Greater North Sea Ecoregions
Thornback ray	VIIafg (no SSB estimate)	WGCSE, Celtic Sea Ecoregion
Blue Whiting	1-9,12 and 14	North East Atlantic

For Area VII sprat there is no SSB estimate and as part of a coordinated ICES programme Cefas has constructed an acoustically derived biomass estimate (ground-truthed by trawl samples). Biological measurements indicate that the populations north and south of Cornwall are separate (BEEMS SPP089). The selected assessment indicator is the biomass of the population that congregates in the Bristol Channel approaches in October of each year (BEEMS SPP089).

ICES does not undertake stock assessments for twaite shad nor river and sea lampreys.

5.3 Selection of the significant effect threshold

There are no formal UK regulatory guidelines for assessing the significance of fish mortality levels caused by impingement in coastal power stations and therefore any assessment must be based on expert judgment.

The HPC Environmental Statement (EDF Energy 2011a) evaluated the effects of impingement on commercial fish species and on biodiversity.

The shadow HRA assessment (EDF Energy 2011b) evaluated the effects on integrity of the following sites and interest features:

1. **Severn Estuary SAC**
    - Estuaries Feature: the fish assemblage is a sub-feature of the overarching 'estuaries' feature. Additionally, the river and sea lamprey and twaite shad are also identified as Annex II species and a primary reason for site selection.
2. **Severn Estuary Ramsar**
    - Criterion 4: qualifies as it is important for the run of migratory fish between sea and river via the estuary. Species include salmon, sea trout, sea lamprey, river lamprey, allis & twaite shad, and eel
    - Criterion 8: qualifies as the fish assemblage of the whole estuarine and river system is one of the most diverse in Britain, with over 110 species recorded.
3. **River Usk SAC, River Wye SAC, River Tywi SAC**
    - Interest features: sea lamprey; river lamprey & brook lamprey; allis & twaite shad; and Atlantic salmon.

Since the award of the HPC DCO a new SAC has been proposed which must now be included in an updated HPC impingement assessment:

4. **Bristol Channel Approaches pSAC**
    - Qualifying feature harbour porpoise, *Phocoena phocoena*

The test for the HRA is whether the impingement impact produces a likely significant effect (LSE) on site integrity, assessed using the conservation objectives for the sites. In terms of the fish assemblage and designated conservation species, the conservation objectives seek to maintain, subject to natural variability, populations at sustainable levels and to maintain associated prey populations. For the harbour porpoise the draft conservation objectives seek to maintain fish prey populations which would be achieved by maintaining the fish assemblage.

The Water Framework Directive (WFD) assessment (EDF Energy 2011a, Appendix 18B). evaluated the effects of HPC impingement on the ecological status of water bodies in the vicinity of the development. In particular, the assessment considered the effect of impingement on the "fish" biological quality element. Two water bodies were identified as part of this assessment;

1. Bridgwater Bay (coastal water body)
2. Parrett Estuary (transitional water body)

The test for WFD compliance assessment is whether HPC has the potential to cause deterioration in the status of the surface water bodies (both within and between status classes) by adversely affecting biological, hydromorphological and/or physico-chemical quality elements. In principle, impingement could affect the fish biological quality element.

The United Kingdom Technical Advisory Group for WFD (WFD-UKTAG) has produced an assessment method for fish in transitional water bodies - the Transitional Fish Classification Index (TFCI). (UKTAG 2014). The method is not applicable to coastal water bodies.

The TFCI is a multimetric index composed of 10 individual components known as metrics and listed in Table 12.

Table 12 WFD Transitional Fish Classification Index metrics

Number	Metric	Community characteristic
1	Species composition	Species diversity and composition
2	Presence of indicator species	
3	Species relative abundance	Species abundance
4	Number of taxa that make up 90% of the abundance	
5	Number of estuarine resident taxa (ER)	Nursery function
6	Number of estuarine-dependent marine taxa (MS & MJ)	
7	Functional guild composition	
8	Number of benthic invertebrate feeding taxa	Trophic integrity
9	Number of piscivorous taxa	
10	Feeding guild composition.	

Each metric is assessed by comparing the observed metric values with those expected metric values under reference conditions. A set of reference conditions have been developed for different water body types and sampling gears (the latter does not include power station impingement which provides a much greater sampling efficiency than the alternative net based sampling methods).

UKTAG advise that the index must be applied at the whole transitional water level (estuary), rather that sub-divisions into WFD water bodies.

With exception of metric 3 in Table 12, all the other metrics are counts of the number of species in functional, feeding or indicator species groups found in the population samples. As described in Section 4, the fish community at Hinkley Point is subject to considerable in year and between year variability and to long term trends due predominantly to climate change and changes in fishing pressure. Measurements of the TFCI will therefore be subject to considerable variability and only developments that have a widescale, very large impact on the community would be expected to make any significant changes to the index.

At the time of the DCO the screening test that was applied and accepted for potentially significant environmental effects in the HPC Environmental Statement, shadow HRA and WFD was whether the predicted impingement of any of the assessed species was >1% of the local SSB or fishery landings.

The 1% level was established as the threshold for negligible effects as this level is much lower than the measured natural variability of the Hinkley Point fish populations. Effects above this threshold would require further investigations to determine whether significant effects were, in fact, present.

5.3.1 Re-examination of the evidence for a 1% Screening threshold for negligible effects

This section re-examines the evidence for the 1% threshold for negligible effects to determine whether this threshold level remains appropriate for this 2018 assessment.

5.3.1.1 Natural variability of fish stocks

Fish stocks are subject to considerable natural variability due to highly variable levels of recruitment, food availability and predation pressure. Individual populations and ecosystems are resilient to such high levels of variability. Impingement at HPB mirrors the variability of local fish populations as the power station is an efficient sampler with low interspecies bias unlike trawl or other net sampling techniques. The coefficient of variation of impingement numbers from the RIMP survey over the period 1981 - 2017 was in the range 69% to 180% for each of the top 13 species that constituted 95% of the local abundance, and greater for rarer species. The populations of many marine species are highly dependent upon annual recruitment levels which results in very high year to year variation in local populations. Some examples of measured year to year variability in local fish populations since 2000 from the RIMP programme are shown in Table 13.

Table 13 Measured variations that have occurred in Hinkley Point fish population numbers since 2000.

Species	Measured year to year change in annual numbers from the RIMP dataset
Bass	1,000%
Cod	1,500%
Herring	1,000%
Sprat	600%
Sole	300%
Whiting	400%
Twaite shad	1,800%

Given the magnitude of such changes, a <1% change due to impingement is negligible. In particular, it is negligible to any predator prey relationships which are adapted to cope with much greater natural variability.

5.3.1.2 Comparison with sustainable levels of fishing mortality

It is accepted practice in fisheries management that a level of fishing mortality of 18% per annum (Fishing mortality F=0.2) will have negligible effects on the sustainability of unexploited populations (Pers. Comm. Dr J Ellis fisheries ecologist, Cefas). A loss of 1% is, therefore, far below the level predicted to have negligible effect.

The natural mortality of adult (mature) fish is typically within the range 10 - 40% per annum, higher for short lived species. In this assessment a highly conservative assumption has been made that <u>adult</u> natural mortality is <u>zero</u>.

ICES produces estimates of the sustainable levels of fishing mortality (Fpa) (i.e. mortality in addition to natural mortality) that will ensure that fish stocks will remain within safe biological limits for many of the dominant species found at Bridgwater Bay. Examples from ICES 2017 stock assessments are shown in Table 14. Set against such numbers, an impingement mortality of less than 1% is negligible.

Table 14 Sustainable fishing mortality values based upon a precautionary management approach for species relevant to Hinkley Point

Species	Sustainable fishing mortality using precautionary approach (Fpa)	ICES Working Group Report	Coefficient of variation of the SSB 1999-2017
Whiting	55%	WGCSE, Celtic Sea Ecoregion	38%
Plaice	30%	WGCSE, Celtic Sea Ecoregion	70%
Sole	29%	WGCSE, Celtic Sea Ecoregion	19%
Cod	43%	WGCSE, Celtic Sea Ecoregion	42%

5.3.1.3 Conclusions

To have a negligible impact on all non-exploited species that are not in decline the predicted impingement effect must be less than natural variability of the species and less than the 20% SSB considered sustainable in fisheries management. In such circumstances a threshold of 10% SSB is a reasonable threshold for potentially significant effects. However, for species which are in decline a lower effect threshold is appropriate. A 1% negligible effect threshold for all species provides a precautionary level which is much less than the natural variability of any species at Hinkley Point, negligible compared with fishing mortality on exploited stocks and would have no effect on the sustainability of fish stocks.

A level of 1% could not be discerned against the natural variability of the SSB and the number of recruits that the ecosystem is adapted to and hence would have no significant effects on predator prey relationships.

The use of a negligible effect threshold of 1% of SSB is, therefore, considered to be precautionary. In practice, as demonstrated in the DCO assessments reproduced in Section 7, the impingement effect for many species is much less than 1% SSB.

6 Impingement predictions presented for the HPC DCO

The test that was applied for potentially significant environmental effects in the HPC Environmental Statement, WFD and shadow HRA was whether the predicted impingement of any species was >1% of the local SSB.

6.1 Original DCO impingement predictions

The impingement predictions provided in BEEMS Technical Report TR148, assuming the use of an acoustic fish deterrent and a fish recovery and return system, are reproduced below in Table 15. These are the values that were assessed in the HPC ES, shadow HRA and WFD assessments.

Table 15 Predicted total annual impingement at HPC for key species assuming an abstraction rate of 125 cumecs and the use of AFD and FRR systems compared with local fishery and estimated local population size. ("NA" indicates no assessment made). Adapted from BEEMS Technical Report TR148 Appendix B4.

Species	Number	EAV	Entrapment risk AFD	FRR mortality	EAV number (AFD+FRR)	EAV wt (t)	local fishery (t)	local SSB (t or number)	% of local fishery	% local SSB
Sprat	3,380,850	3,380,850	0.12	100%	405,702	3.16	0.19	NA	1665.5%	-
Whiting	2,102,759	288,078	0.45	50%	64,818	11.54	33.50	1613	34.4%	0.72%
Sole	602,776	32,429	0.84	20%	5,448	1.25	263.00	3240	0.5%	0.04%
Cod	371,097	32,063	0.45	50%	7,214	31.60	65.20	975	48.5%	3.24%
Herring	90,526	44,792	0.05	100%	2,240	0.28	119.40	NA	0.2%	-
Plaice	5,383	493	0.84	20%	83	0.04	84.00	952	0.0%	0.00%
Blue whiting	1,166	160	0.45	50%	36	0.00	37,900	5,360,000	0.0%	0.00%
Eel	1,304	1,304	1	20%	261	0.08	-	133.40	-	0.06%
Twaite shad	2,276	2,276	0.12	100%	273		-	184,000	-	0.15%
Allis shad	68	68	0.12	100%	8		-	-	-	-
Sea lamprey	207	207	1	20%	41		-	15,269	-	0.27%
River lamprey	82	82	1	20%	16		-	116,109	-	0.01%
Salmon	0	0	1	50%	0		-	NA	-	-
Sea trout	0	0	1	50%	0		-	NA	-	-
Crangon crangon	19,135,756	19,135,756	1	20%	3,827,151	5.70	-	NA	-	-

Notes

1. Due to a lack of data an EAV of 1 was assumed for sprat, eel, twaite and allis shad, sea and river lamprey and the common shrimp (*Crangon crangon*).
2. Note that the HPC CW abstraction rate used in TR148 was assumed to be 125 cumecs. The abstraction rate has been updated in this report to reflect the final design of the HPC CW system.

6.2 Updated impingement predictions produced during the DCO examination

Table 16 reflects the revisions to the cod and shad impingement predictions detailed in BEEMS Scientific Position Papers SPP065 and SPP071/S, respectively. These updated predictions were produced during the DCO examination period.

Table 16 Updated predictions total annual impingement (numbers of fish) at HPC for key species assuming an abstraction rate of 125 cumecs and the use of AFD and FRR systems compared with local fishery and estimated local population size. ("NA" indicates no assessment made).

Species	Number	EAV	Entrapment risk AFD	FRR mortality	EAV number (AFD+FRR)	EAV wt (t)	local fishery (t)	local SSB (t or number)	% of local fishery	% local SSB
Sprat	3,380,850	3,380,850	0.12	100%	405,702	3.16	0.19	NA	1663%	-
Whiting	2,102,759	288,078	0.45	50%	64,818	11.54	33.50	1613	34.4%	0.72%
Sole	602,776	32,429	0.84	20%	5,448	1.25	263.00	3240	0.5%	0.04%
Cod	27,090	2,341	0.45	50%	527	2.31	65.20	975	3.5%	0.24%
Herring	90,526	44,792	0.05	100%	2,240	0.28	119.40	NA	0.2%	-
Plaice	5,383	493	0.84	20%	83	0.04	84.00	952	0.0%	0.00%
Thornback ray	3,325	652	1	20%	130	0.35	168.17	NA	0.2%	-
Blue whiting	1,166	160	0.45	50%	36	0.00	37,900	5,360,000	0%	0.00%
Eel	1,304	1,304	1	20%	261	0.08	-	133.40	-	0.06%
Twaite shad	2,276	63	0.12	100%	8		-	184,000	-	0.00%
Allis shad	68	18	0.12	100%	2		-	700,000	-	0.00%
Sea lamprey	207	207	1	20%	41		-	15,269	-	0.27%
River lamprey	82	82	1	20%	16		-	116,109	-	0.01%
Salmon	0	0	1	50%	0		-	NA	-	-
Sea trout	0	0	1	50%	0		-	NA	-	-
crangon crangon	19,135,756	19,135,756	1	20%	3,827,151	5.70	-	NA	-	-

Notes

1. Due to a lack of data an EAV of 1 was assumed for sprat, eel, sea and river lamprey and the common shrimp (*Crangon crangon*).

2. Table 16 includes a prediction for the impingement losses for thornback ray which was not included at the time of the DCO examination. This species was the only ray recorded in the HPB CIMP impingement dataset. The impingement prediction for this species has been included subsequently to reflect its commercial importance in the Bristol Channel and was derived using the method described in BEEMS TR148.

3. In Table 16 the predicted cod impingement numbers were derived using the method described in BEEMS SPP065 and the shad EAV numbers were derived from BEEMS SPP071/S.

4. Local fishery was defined as reported UK landings data in specified ICES rectangles – see TR148.

In all cases where estimates of the local SSB were available, the impingement levels, at less than 1% of the local SSB, were considered ecologically negligible when considered against the natural variability in SSB. For species where an estimate of the SSB was not available, the comparison with the local fishery landings demonstrated that the predicted impingement levels were also negligible except for sprat which was impinged in much larger numbers than the local fishery. However, this species is ubiquitous in coastal waters of the UK and the percentage of the local catch estimate in this instance simply reflected the very small size of the sprat fishery in the Bristol Channel area at 190 kg (MMO reported landings data for UK vessels fishing in the Bristol Channel in ICES statistical rectangles 32 E5–E7, 31 E5–E7 and 30 E5). Catch comparators are only useful as impact comparators when the species is fished in reasonably significant numbers. Moreover, the sprat impingement losses were overestimated, as the use of an EAV value of 1 implied that all of the sprat impingement was of adult fish whereas, in fact, the majority were immature fish, a percentage of which would suffer natural mortality before entering the adult population.

The ES, WFD and shadow HRA concluded that the predicted HPC impingement losses presented in Table 16 would have no adverse effect on local populations, waterbody status or to site integrity, respectively.

7 Revised HPC Impingement predictions (2018)

The HPC impingement predictions provided as evidence for the DCO submission have been updated in this report to reflect the changes in the assessment described in Table 17 and to evaluate the environmental effects of not fitting an AFD system.

Table 17 Changes to the HPC impingement assessment since the DCO submission

Item	Description of change	Impact on assessment compared with the DCO assessment
a.	Revised impingement indicators based upon the latest scientific advice (Adult population sizes, international catch, HPB impingement time series extended to 2017)	Uses the most up to date scientific evidence. For some species the adult population sizes has increased, others have decreased.
b.	Use of site specific EAVs derived from measurements made at Hinkley Point during the CIMP survey programme in 2009/10.	Uses the most biologically relevant data rather than non-site specific data from different years of uncertain accuracy. Causes the predicted impingement impact to increase for some species, decrease for others.
c.	Incorporates the detailed design for the HPC cooling water system. HPC CW flow rate is now confirmed to be 131.86 cumecs (at Mean Sea Level) with a worst case of 9% water flow through the band screens. Band screens to be fitted with an FRR system and HPC forebay to be fitted with trash racks of 50mm vertical bar spacing fitted with fish friendly buckets for fish recovery.	More accurate impingement assessment. Results in increases in predicted impingement impact.
d.	Added assessments for 5 additional species not included at the time of DCO (bass, thornback ray, flounder, thin lipped grey mullet, 5 bearded rockling)	Provides more confidence in the effects of impingement on the fish assemblage assessment.
e.	Revised impingement numbers from the CIMP programme. The programme data have been subject to enhanced quality assurance and a more robust procedure has been used to calculate the confidence limits on the impingement estimates.	The QA programme has led to more reliable impingement predictions and has resulted in increased impingement numbers for 16 fish species.

7.1 Revised HPC unmitigated impingement predictions

Table 18 Revised HPC impingement assessment assuming no embeddded impingement mitigation fitted.

Species	Number	EAV	EAV Number	EAV wt (t)	Fishery (t)	SSB (t or number)	% of fishery	% of SSB
Sprat	3,797,169	0.412	1,564,434	17.8	-	4,000	-	**0.45%**
Whiting	2,120,487	0.099	209,928	32.3	6554	34,918	0.49%	**0.09%**
Sole, Dover	563,431	0.076	42,821	9.3	807	2,857	1.16%	**0.33%**
Cod	372,924	0.022	8,055	28.0	3263	5,092	0.86%	**0.55%**
Herring	107,516	0.122	13,117	1.4	627	-	**0.23%**	-
Bass	32,049	0.121	3,878	3.8	5667	18,317	0.07%	**0.02%**
Plaice	5,056	0.132	667	0.1	1089	4,707	0.01%	**0.00%**
Ray, Thornback	3,054	0.185	565	1.6	617	-	**0.26%**	-
Whiting, Blue	1,127	0.099	112	0.0	635000	2,781,230	0.00%	**0.00%**
Eel	1,210	1	1,210	0.4	-	133	-	**0.30%**
Shad, Twaite	2,152	0.035	76		-	184,000	-	**0.04%**
Shad, Allis	71	0.262	19		-	-	-	**screened out**
Lamprey, Marine	181	1	181		-	15,269	-	**1.18%**
Lamprey, River	71	1	71		-	116,109	-	**screened out**
Salmon	0							**screened out**
Sea trout	0							**screened out**
Crangon Crangon	17,705,453	1	17,705,453	26.38				

Notes

1. Predictions based upon HPC CW flow of 131.86 cumecs
2. EAVs in red are corrected as described in Section 5.1.
3. There is no survey estimate of sprat SSB for 2009. The SSB of 4000t shown is a worst case extrapolation of data from later years. The evidenced assessments provided in Section 8 indicate that HPC impingement was in the range 0.016% to 0.11% of SSB in the 3 year period 2013-2015 inclusive. This is considered a more reliable estimate of the effects of HPC impingement.

As described in section 4.3, allis shad, river lamprey, salmon and sea trout have been screened out of the assessment due to the predicted negligible impingement numbers at HPC

For all species in Table 18 the predicted unmitigated HPC impingement as a % of SSB or the fishery landings is less than 1% with the exception of marine lamprey which at 1.18% SSB is slightly above the negligible effects threshold.

7.2 Revised HPC Impingement predictions with Fish Recovery and Return systems fitted.

Table 19 shows the predicted impingement levels with HPC fitted with Fish Recovery and Return (FRR) systems to recover fish from the band and drum screens and return them to sea via a dedicated FRR discharge tunnel. The derivation of the FRR mortality is described in Appendix A.

Table 19 Revised HPC impingement assessment assuming that FRR systems fitted to HPC

Species	Number	EAV	EAV Number	FRR mortality	EAV number after mitigation	EAV wt (t)	Fishery (t)	SSB (t or number)	% of fishery	% of SSB
Sprat	3,797,169	0.412	1,564,434	100%	1564434	17.8	-	4,000	-	**0.45%**
Whiting	2,120,487	0.099	209,928	55%	114411	17.6	6554	34,918	0.27%	**0.05%**
Sole, Dover	563,431	0.076	42,821	26%	11176	2.4	807	2,857	0.30%	**0.09%**
Cod	372,924	0.022	8,055	73%	5864	20.4	3263	5,092	0.63%	**0.40%**
Herring	107,516	0.122	13,117	100%	13117	1.4	627	-	**0.23%**	-
Bass	32,049	0.121	3,878	77%	3002	3.0	5667	18,317	0.05%	**0.02%**
Plaice	5,056	0.132	667	64%	425	0.075	1089	4,707	0.01%	**0.00%**
Ray, Thornback	3,054	0.185	565	54%	305	0.9	671	-	**0.13%**	-
Whiting, Blue	1,127	0.195	112	55%	61	0.0	635000	2,781,230	0.00%	**0.00%**
Eel	1,210	1	1,210	20%	242	0.1	-	133	-	**0.06%**
Shad, Twaite	2,152	0.035	76	100%	76	-	-	184,000	-	**0.04%**
Shad, Allis	71	0.262	19	100%	19	-	-	-	-	**screened out**
Lamprey, Marine	181	1	181	20%	36	-	-	15,269	-	**0.24%**
Lamprey, River	71	1	71	20%	14	-	-	116,109	-	**screened out**
Salmon	-	0	-	100%	0	-	-	0	-	**screened out**
Sea trout	-	0	-	100%	0	-	-	0	-	**screened out**
Crangon Crangon	17,705,453	1	17,705,453	20%	3,541,091	5.28	-	0	-	-

Notes

1. Predictions based upon HPC CW flow of 131.86 cumecs
2. EAVs in red are corrected as described in Section 5.1.
3. There is no survey estimate of sprat SSB for 2009. The SSB of 4000t shown is a worst case extrapolation of data from later years. The evidenced assessments provided in Section 8 indicate that HPC impingement was in the range 0.016% to 0.11% of SSB in the 3 year period 2013-2015 inclusive

With the FRR systems installed the predicted impingement for all fish species shown in Table 19 is less than 1% SSB or 1% of landings in the commercial fishery for herring and thornback ray. At such levels HPC would have negligible effect on fish populations, would not have any adverse effect on the integrity of the designated fish assemblage or migratory species and would have no effects on waterbody status.

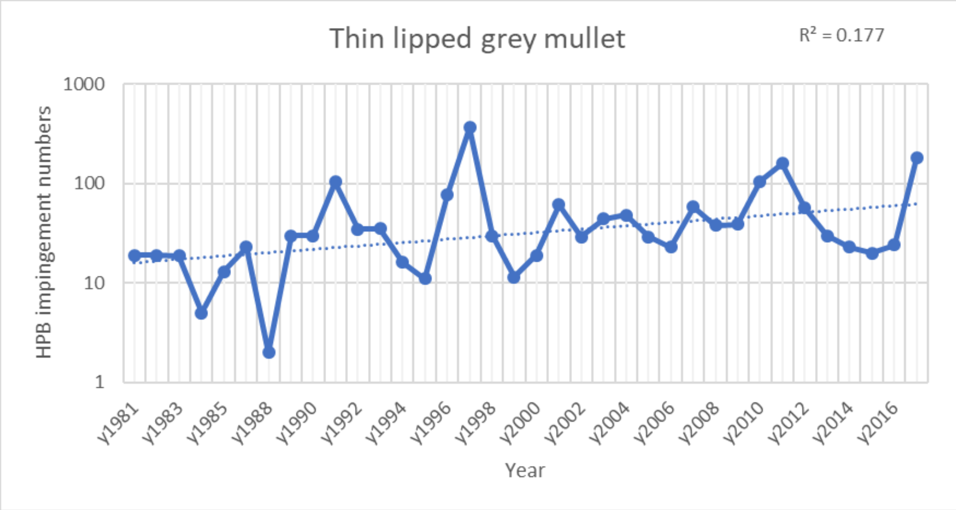
This table provides an assessment of 2 species not included in the DCO submission; bass and thornback ray. It also presents an assessment of sprat impingement which was not possible at the time of DCO submission due to lack of evidence.

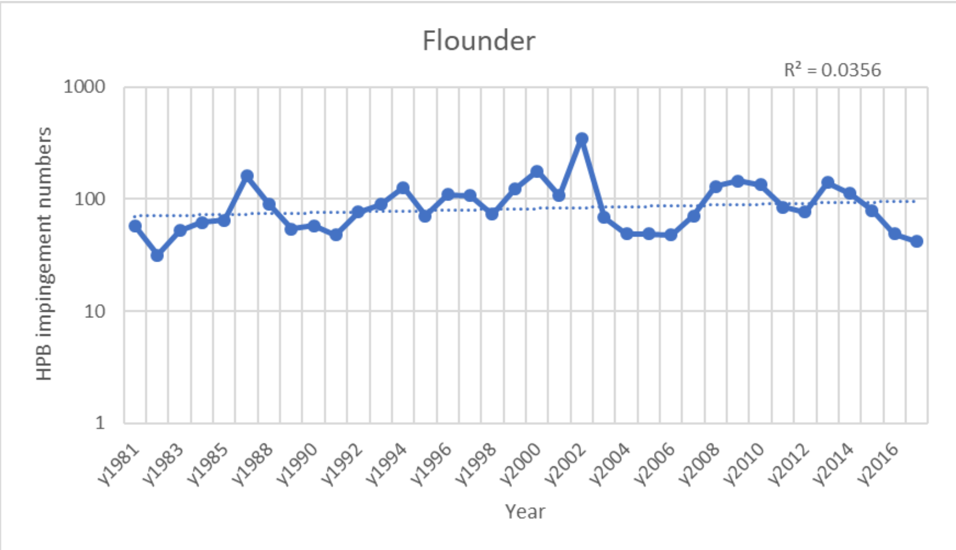
In section 4.3 it was stated that 4 other species would be assessed:

- Thin lipped grey mullet
- Flounder
- 5 bearded rockling
- The brown shrimp, *Crangon crangon*

These 4 species are not conservation species and are widely distributed geographically. The grey mullet is a warmer water species that is expected to shift northwards due to climate change (Lassalle and Rochard 2009) and this change is shown clearly in the RIMP data which indicates that the local population is increasing exponentially. None of the four species are subject to stock assessment, they do not have defined stock units and international catch data are sparse. None are important for commercial fisheries locally although mullet is becoming important for recreational angling.

No EAV estimates are available for these species. Mullet are present throughout the Bristol Channel/Severn as 0 and 1 group juveniles in winter and will have a low EAV with substantial natural mortality until maturity. The analytical approach for assessing impingement used for the species in Table 19 is therefore not possible for these 4 species and instead trend analysis of HPB impingement data has been used. Figure 10 and Figure 11 show the 37 year trend for the 4 species. Mullet, 5 bearded rockling and *Crangon crangon* abundances have grown exponentially over the period, whereas the flounder shows a slightly positive but statistically insignificant trend.





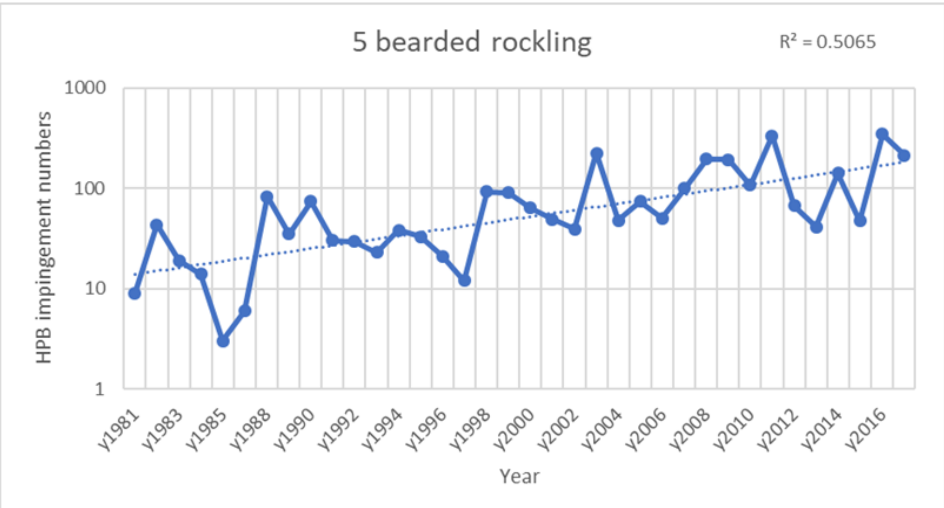


Figure 10 Trend analysis for grey mullet, flounder and 5 bearded rockling

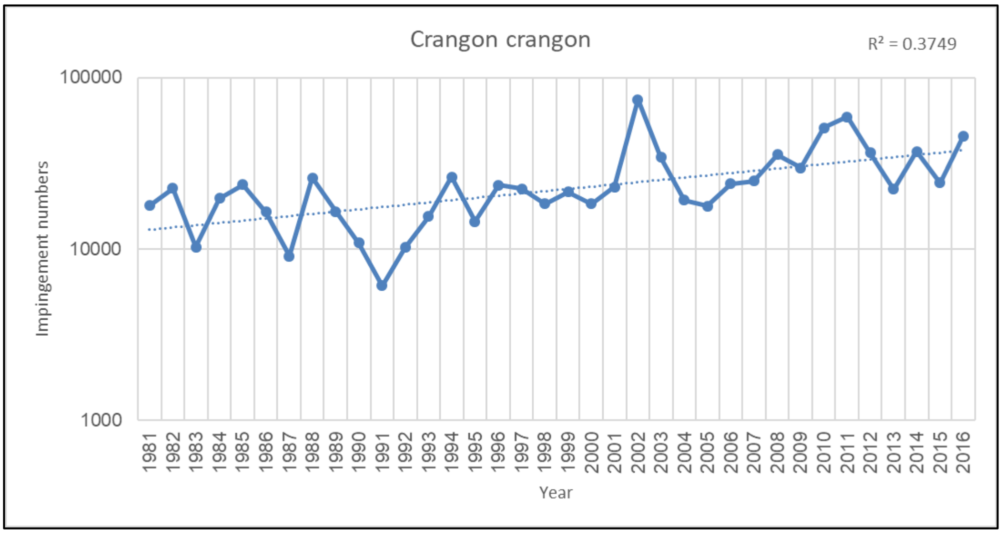


Figure 11 Trend analysis for Brown shrimp (*Crangon crangon*)

Appendix E confirms these trends for the fish species with mullet and 5 bearded rockling showing a statistically significant positive trend, and no trend for flounder.

These 4 species are found throughout the estuary and would have been impacted by all of the coastal power stations abstracting from the estuary. Between 1989 and 2017 the total power station cooling water abstraction decreased from 198 cumecs to 101 cumecs due to the closure of 4 stations including HPA in 1999 and Oldbury in 2011/12 (see section 3.3). This reduction in impingement pressure is not visible in the RIMP trend data and a future reciprocal increase in abstraction of 97 cumecs would, therefore, be expected to have no effect on the populations at Hinkley Point. HPC with both reactors operational will abstract 132 cumecs but with FRR mitigation the equivalent impacts will reduce as shown in Table 20.

Table 20 Effect of fitting an FRR to HPC on each of the 3 species listed.

Species	Estimated HPC FRR mortality (based upon size of largest individuals impinged at HPB	Equivalent unmitigated abstraction (cumecs) = FRR mortality *HPC CW abstraction (132 cumecs)
Flounder	25%	33
Mullet	55%	72.6
5 bearded rockling	20%	26.4
Crangon crangon	20%	26.4

The equivalent unmitigated abstraction in all 4 cases is less than 97 cumecs and it can, therefore, be expected that the operation of HPC would have no effect on the population trend for all four species.

It is concluded that HPC with FRR systems fitted would have negligible effect on the species assessed in this report which are considered representative of both the fish assemblage and all of the HRA designated conservation species.

In terms of WFD water body status in the transitional waters of the estuary, HPC impingement at < 1% of SSB is much smaller than natural variability in the size of fish populations and would, therefore, have no effect on the calculated WFD fish biological quality element (Section 5.3). Similarly, there are no predicted changes due to impingement in the number of functional and feeding guilds at Hinkley

Point nor to the number of indicator species. There would, therefore, be no predicted change in the WFD status of local water bodies due to HPC impingement.

It is concluded that the predicted HPC impingement losses from HPC with FRR systems fitted but no AFD system would have no adverse effect on local populations, waterbody status or to site integrity, respectively.

8 Assessment of the effects of interannual variability in the fish community

The quantitative impingement assessments presented in this report are based upon the results of the one year CIMP programme at HPB. This section provides evidence on the effects of interannual variations in fish numbers in order to provide greater confidence in the reliability of the impingement effect assessments.

The multiyear RIMP programme provides information on impingement trends in the period 1981 – 2017. This programme produces monthly fish numbers and fish length distributions which, in principle, can be used to determine interannual variations in HPC impingement effects. However, as described in Section 4, the sampling frequency is much lower than that for the CIMP programme with the attendant likelihood of missing transitory events, the variances on the impingement numbers are much higher than those from the CIMP survey and the number of samples are only sufficient to construct valid length distributions for a small number of common species.

Examples of the effect of inter annual variations are provided below for the abundant species of whiting, cod and sprat. The RIMP impingement numbers have been processed in exactly the same manner as the CIMP data, the only difference being the cooling water scaling factor used to convert the RIMP numbers into HPC predicted impingement numbers and the EAVs which have been recalculated using the length distributions obtained from the RIMP survey.

8.1 Whiting

Whiting is an example of a species that has modest year to year population variability. The Coefficient of Variation (CV) in the impingement numbers is 48% over the 37 year RIMP programme and the local population is not dominated by annual recruitment. As would be expected the length distributions from year to year are similar leading to little variation in EAVs. Impingement as a percentage of SSB is therefore driven by the size of the local population which in the representative 4 years shown in Table 21 ranged from a calculated 0.01% to 0.07% SSB. The calculated effect from the CIMP data in 2009 was 0.05% of SSB (Table 19).

Table 21 Predicted HPC impingement effect for whiting in the period 2007- 2010 (FRR fitted)

Year	RIMP annual numbers	Predicted HPC annual numbers	Calculated EAV	EAV number	FRR mortality	EAV number after mitigation	EAV wt (t)	SSB (t)	% of SSB
2007	2,173	2,070,341	0.087	180,120	55%	98,165	15.12	29709	0.05%
2008	2,445	2,329,491	0.098	228,290	55%	124,418	19.16	25724	0.07%
2009	2,941	2,802,058	0.090	252,185	55%	137,441	21.17	34918	0.06%
2010	680	647,875	0.093	60,252	55%	32,838	5.06	49971	0.01%

8.2 Cod

Table 22 shows the predicted impingement effects of HPC in 2007-2010 on cod. The EAVs were corrected as described in section 5.1 such that the assessment methodology is consistent with the CIMP assessment. The recruitment peak in 2009 stands out from the low numbers impinged in other years and 2009 had the highest cod recruitment in the 37 year history of the RIMP programme. Extreme recruitment events, when the numbers of fish impinged rise rapidly to much greater than normal levels, are the most likely to cause concern over HPC impingement effects. The number of recruits causes the length distribution to skew to smaller sizes. Smaller size fish have greater natural mortality which causes the EAV to reduce (Table 22).

Table 22 Predicted HPC impingement effect for cod in the period 2007- 2010 (FRR fitted)

Year	RIMP annual numbers	Predicted HPC annual numbers	Calculated EAV	EAV number	FRR mortality	EAV number after mitigation	EAV wt (t)	SSB (t)	% of SSB
2007	64	60,976	0.084	5,122	68%	3,468	12.06	5,121	0.24%
2008	33	31,441	0.037	1,154	68%	781	2.72	5,455	0.05%
2009	661	629,772	0.028	17,634	68%	11,938	41.52	5,092	0.82%
2010	32	30,488	0.110	3,357	68%	2,273	7.90	4,956	0.16%

Note: EAVs have been calculated using the Gislason method with a correction factor of 2.45 applied (Section 5.1).

The estimated HPC impingement effect in 2009 derived from the RIMP data is 0.82% of SSB i.e. approximately twice that estimated from the CIMP data at 0.4% of SSB (Table 19). Examination of the respective datasets explains the reason for this difference and highlights the potential pitfalls with the low sampling frequency of the RIMP when assessing fish populations subject to rapid seasonal change.

The RIMP only collected one 6 hour sample per month which was then scaled up to the expected impingement for a month by multiplying by 4 (to arrive at a daily total) and then by the number of days in the month. For transitory events such a low sampling rate is likely to lead to considerable errors in the monthly estimates (positive or negative) For example the single RIMP sample in June was scaled up to the month by multiplying by 120, whereas in the CIMP three 24 h samples were taken in June which were scaled were scaled up to the month by multiplying the total by 10. By chance the single RIMP sample corresponded with a local peak in recruit numbers and the estimate for the whole month was based upon this one high value. The CIMP shows that the cod impingement in June was more variable and that the RIMP monthly total was an overestimate. Examination of the CIMP dataset for cod for the entire 12 months shows that the higher RIMP estimates in June, July, November and January are artefacts likely to be the result of undersampling (Figure *12*). This had the effect of increasing the RIMP annual impingement estimate.

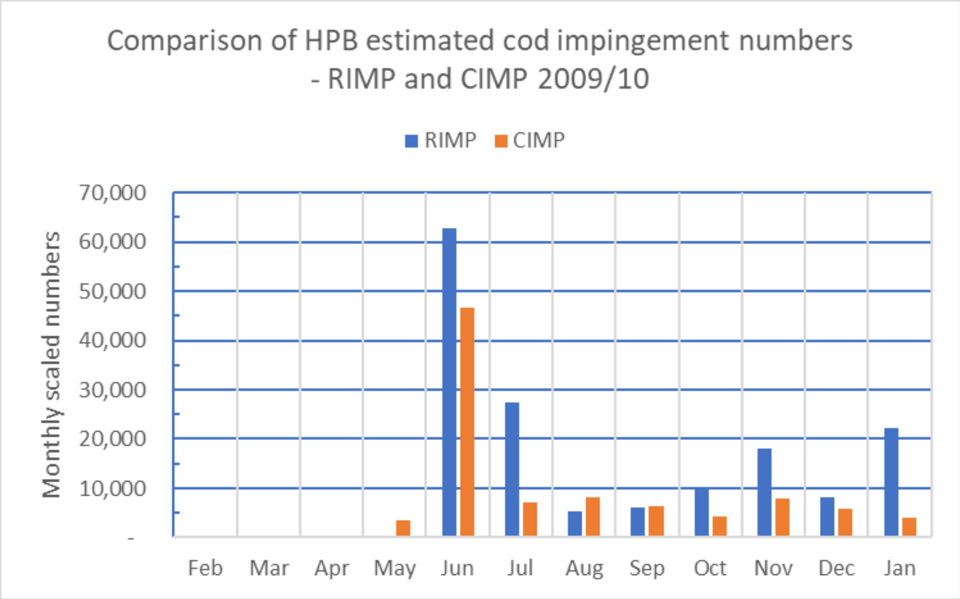


Figure 12 Relative differences between the scaled up estimates of monthly impingement numbers for cod using the RIMP and CIMP datasets.

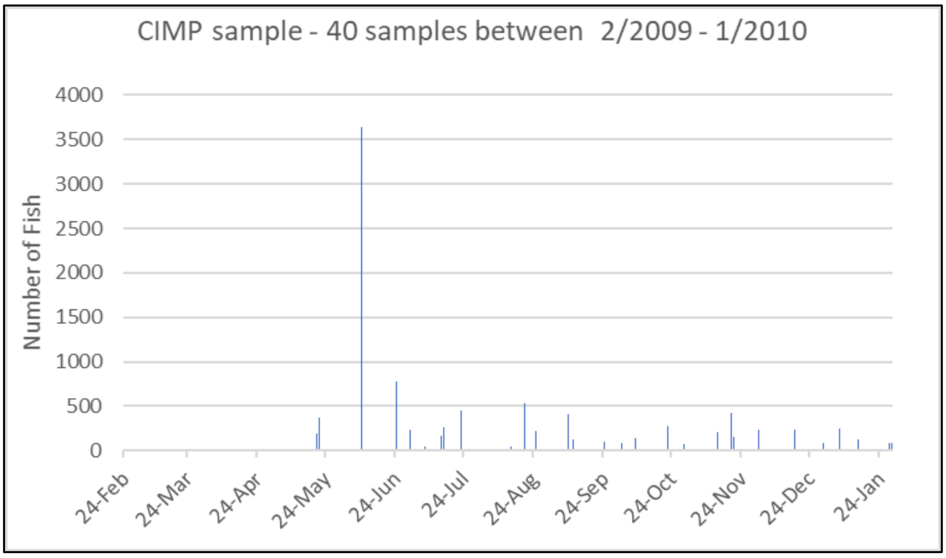


Figure 13 Variation in cod impingement numbers from the CIMP programme

Nevertheless, despite the largest cod recruitment event in the 37 years of the RIMP programme and the biased assessment result due to limitations in the RIMP sampling frequency, the conclusion on HPC impingement effect remains the same as that from the CIMP survey i.e. less than 1% of SSB or negligible effect. In practice the RIMP estimate for cod impingement in 2009 is overestimated and the CIMP estimate is more reliable.

8.3 Sprat

The HPC impingement effect on sprat has been calculated in Table 19 based upon an extrapolated SSB of 4000 t as there was no measured stock biomass measurement in 2009. The 4000 t figure is considered a worst case estimate and the indication is that the population was nearer to 10,000 t in that year (BEEMS SPP089). From 2013 Cefas has been conducting an annual survey that covers the Bristol Channel approaches and it is this population which is considered to migrate into and out of the

Bristol Channel during November to January of each year. Table 23 shows the calculated HPC impingement effect based upon the use of the measured population biomass. The effect range over the period 2013 to 2015 is 0.11% to 0.016% SSB compared with the estimate for 2009 of 0.45% based upon a worst case SSB estimate.

Table 23 Predicted HPC impingement effect for sprat in the period 2013- 2015 (FRR fitted)

Year	RIMP annual numbers	Predicted HPC annual numbers	Calculated EAV	EAV number	FRR mortality	EAV number after mitigation	EAV wt (t)	SSB (t)	% of SSB
2013	2050	1,953,152	0.211	412,115	100%	412,115	4.7	4200	0.112%
2014	5093	4,852,391	0.050	242,620	100%	242,620	2.8	12534	0.022%
2015	3157	3,007,854	0.139	418,092	100%	418,092	4.8	29510	0.016%

8.4 Summary

The study of the effect of interannual variations in fish populations for three representative species does not change the HPC impingement assessment conclusion of negligible effects.

For populations at Hinkley Point that are not dominated by in year recruitment (such as whiting), the length distributions stay reasonably constant from year to year and therefore so does the EAV. The fish impingement effect then tracks the size of the local population as measured by the impingement numbers.

For species with a large recruitment spike in numbers (e.g. cod), the number of small fish changes the annual length distribution and reduces the EAV. The lower EAV reduces the apparent substantial impingement effect on the adult population. This is illustrated in 2009 when the largest cod recruitment in 37 years did not change the negligible effect conclusion the species (Table 22).

9 Uncertainty Analysis

9.1 The principle sources of uncertainty

The HPC impingement estimates presented in this report are subject to uncertainty which is a function of:

a. The measurement of impingement at HPB
b. Scaling HPB impingement to HPC using the ratio of cooling water flows at the 2 stations
c. The predicted EAVs for each species
d. The estimated mean weight of adult fish used to convert impingement EAV numbers in to EAV weights
e. The SSB estimates used as impingement indicators

9.1.1 Estimates of HPB impingement numbers used to compute HPC impingement

The predicted mean impingement levels at HPC and the associated 95 percentile confidence limits have been computed by bootstrapping and are listed in Appendix D. This appendix also outlines the bootstrapping procedure. The upper 95%ile confidence limits vary between a factor of 1.27 greater than the mean for bass to 2.99 times for blue whiting (Table 24).

Table 24 Predicted unmitigated impingement numbers at HPC, ratio between the upper 95 percentile and the mean impingement values

Species	Ratio between upper 95%ile and mean impingement numbers (CIMP dataset)
Sprat	1.75
Whiting	1.34
Sole	1.68
Cod	2.27
Herring	1.62
Bass	1.27
Plaice	1.81
Thornback ray	1.65
Whiting, Blue	2.99
Eel	1.48
Shad, Twaite	1.68
Shad,allis	2.01
Lamprey, marine	2.15
Lampey, river	2.01
Crangon crangon	1.53

9.1.2 Derivation of HPC impingement rates by scaling HPB rates by relative cooling water flows

Section 3.2 explained why the HPC intakes are expected to abstract less fish per cumec than HPB. However, there are no data to quantify this and so the precautionary approach has been adopted that scaling by the ratio of HPC:HPB cooling water flows will produce a worst case estimate of HPC unmitigated impingement rates.

9.1.3 Confidence in calculated Equivalent Adult Value (EAV) factors

The derivation of EAVs is discussed in Section 5.1 where it was shown that EAVs are dependent upon the assumptions made for the natural mortality (M) of the different sized fish. It is not possible to produce probability distributions for EAVs by species. Instead, in an effort to assess variability, EAVs were computed via 2 different empirical formulae for natural mortality produced by 2 different authors (Gislason and Lorenzen). Both formula are peer reviewed and based upon field measurements of M. The 2 formulae gave comparable results for Hinkley Point species with the exception of cod, herring and whiting.

For cod comparison with data used in the relevant ICES stock assessment and with historic field estimates indicated that the Gislason formula produced M estimates that were in the range of 2 to 2.45 times too high. Therefore, a precautionary correction factor of 2.45 was adopted for the Gislason formula in the present assessment which is expected to produce overestimates of impingement at HPC. For herring there are insufficient field measurements of M to determine whether a correction factor is required and so the more lower M values from the Lorenzen formula were adopted which is expected to result in overestimates of impingement. For whiting the M values produced by the Gislason formula are consistent with the M estimates used in the ICES stock assessment, whereas the Lorenzen M values were too low to be credible and hence unmodified Gislason M values were used for whiting.

For the other commercial species, the two formulae produced similar estimates of M with the Gislasson formula producing higher EAVs for most species (Table 9 Section 5.1). Since these were more precautionary the Gislason derived EAVS were used in the impingement assessment

For twaite shad, the scarce dataset led to the use of a simpler calculation (BEEMS SPP071) but one which produced good agreement with published M estimates for adult shad.

For lampreys and eel due to the lack of data for species with such complex life cycles, an EAV of 1 was used which will produce overestimates of impingement as most of the fish impinged were not mature.

It is therefore considered that a precautionary approach has been adopted for the calculation of the EAVs used for all species in this assessment.

9.1.4 Mean weight of adult fish in the fish stock

Based upon expert judgement the mean weight of adult fish used to convert EAV numbers in to EAV weights was selected as the weight when the 75% of the stock achieves maturity. For each stock the the mean maturity and hence mean weight will differ. To determine how reliable the selection of the weight at 75% maturity was in practice, the ICES landings data were examined. Table 25 shows the ratio of the weight at 75% maturity to the mean landed weight for stocks where such data are available in ICES working group reports. It can be seen that the use of weight at 75% maturity would underestimate impingement for whiting, sole and plaice by a factor of 1.68, 1.39 and 1.82 respectively but overestimate cod and bass impingement by a factor of 1.67 and 1.96 respectively.

Table 25 Ratio of mean landed weight of cod to mean weight at 75% maturity

Species	L75 values kg	mean weights from landings kg	landings to L75 ratio
Whiting	0.154	0.259	168%
Sole	0.218	0.304	139%
Cod	3.478	2.074	60%
Plaice	0.177	0.323	182%
Bass	0.985	0.507	51%

However, for stocks where a significant part of the catch is discarded the mean landed weight is an overestimate of the mean weight of adults in the stock because the undersized portion of the catch (i.e. the smaller, lighter fish) has not been landed.

Considering the predicted HPC impingement levels shown in Table 19, the correction factors indicated by Table 25 are immaterial as they would not increase the predicted HPC impingement such that the 1% negligible effect threshold was exceeded. It is notable that the cod impingement has most likely been overestimated by a factor of 1.67 i.e. the mean impingement estimate should be 0.24% SSB not the 0.4% SSB shown in Table 19.

9.1.5 SSB estimates used as impingement indicators

For the commercial fish species assessed in this report ICES stock estimates have been used where possible. Of these, confidence limits on the SSB size are only provided in the ICES stock assessment reports for plaice and bass. Confidence limits are available for the Cefas sprat survey estimates.

Confidence limits are available for the twaite shad, river and sea lamprey adult populations (expressed as numbers of fish) as documented in BEEMS Technical Report TR148 and reproduced in Appendix G of this report.

9.2 Uncertainty assessments – SSB and impingement numbers

The uncertainty in the effect of HPC impingement on a particular stock can be computed by a joint probability assessment of the probability density function of the impingement estimate divided by the population estimate via Monte Carlo simulation. However, given the small size of the predicted HPC impingement in Table 19, a rough, highly precautionary estimate of the worst case effect can be computed by dividing the upper 95 percentile impingement estimate by the lower 95 percentile SSB estimate (Table *26* and Table 27).

Table 26 Uncertainty on the impingement assessments where the data to perform the calculation are available

Species	Mean SSB (t or number)	Lower 95 %ile SSB (t or number)	Mean impingement (t or number)	Upper 95%ile impingement (t or number)	Mean % SSB	Worst case % SSB
Bass	18,317	15,813	3.0	3.81	0.016%	0.024%
Plaice	4,707	2,141	0.075	0.136	0.002%	0.006%
Twaite shad	184,000	112,000	76	128	0.041%	0.114%
River lamprey	116,109	97,087	14	28	0.012%	0.029%
Sea Lamprey	15,269	12,978	36	77	0.236%	0.593%

Note: as described above, the worst case is an overestimate, not the upper 95%ile confidence limit.

Table 27 Uncertainty on the sprat impingement assessments for 2013-2015

Year	Mean SSB (t)	SSB CV	Lower 95%ile SSB (t)	EAV wt (t)	Upper 95%ile EAV wt (t)	mean % SSB	worst case % SSB
2013	4200	24.4%	2,150	4.7	8.2	0.11%	0.38%
2014	12534	17.6%	8,122	2.8	4.8	0.02%	0.06%
2015	29510	14.7%	20,834	4.8	8.3	0.02%	0.04%

Notes:

1. as described above, the worst case is an overestimate, not the upper 95%ile confidence limit.
2. 2013 was the first year of the sprat survey and as the survey design has improved, the Coefficient of Variation has dropped.

9.3 Uncertainty assessments – impingement numbers only

Using the results in Table 24 the upper 95 percentile impingement effects of HPC can be computed (Table 28).

Table 28 Upper 95%ile HPC impingement effect (taking variation in impingement numbers into account)

Species	Upper 95%ile impingement as a % of fishery	Upper 95%ile impingement as a % of SSB	Comment
Sprat		0.78%	2009 SSB is not extrapolated not measured. Impingement is over estaimated
Whiting		0.07%	
Sole, Dover		0.14%	
Cod		0.91%	Exceptional recruitment in 2009
Herring	0.37%		
Bass		0.02%	
Plaice		0.00%	
Ray, Thornback	0.21%		
Whiting, Blue		0.00%	
Eel		0.09%	
Shad, Twaite		0.07%	
Shad, Allis	Screened out – negligible impingement expected		
Lamprey, Marine		0.51%	
Lamprey, River	Screened out – negligible impingement expected		

9.4 Summary

The uncertainty analyses did not identify any species where the negligible effects threshold of 1% of the SSB or fishery was exceeded. The conclusion of the HPC impingement effects analysis remains one of negligible effect.

Nevertheless, it is worthwhile making a few comments about the results in Table 28. As stated in Section 8.3 the sprat SSB is extrapolated from values in later years. An extrapolated rather than measured SSB value of 4000 t has been used for 2009 (Table 19) which has resulted in the impingement effect being overstated probably by at least a factor of 2. The sprat results in Section 8.3 for 2013-2015 are considered more reliable because they are based upon measurements rather than extrapolation and as such provide an evidence based assessment of sprat impingement. These indicate worst case impingement as a percentage of (mean) SSB in the range 0.02% to 0.11% (compared with 0.45% reported in Table 19).

The estimated upper 95%ile cod impingement is 0.91% SSB but, as described in Section 9.1.4, the mean adult weight used to convert the EAV number of fish into the EAV weight is overestimated by a factor of 1.67. After correcting the mean adult weight, the predicted upper 95%ile impingement reverts to 0.54% SSB.

10 Ecological impact of removing juvenile fish

The impingement assessment described in this report is based upon comparison of the weight or number of equivalent adults with the adult population of each species. However, the juveniles that are removed represent a portion of the prey for many species either locally or at other times of the year in different locations. It is therefore necessary to consider the impact of extracting juvenile fish that form the prey for other species. The impact is best illustrated by an example.

Sprat is a small pelagic species that is the most abundant species at Hinkley Point (at nearly 50% of the impingement numbers, Section 4.2) and it is predated on by many species in the estuary including harbour porpoise. In October 2015 the biomass of the sprat population in the Bristol Channel approaches (that migrates in and out of the Bristol Channel in November – January) was 147,551 t (from the Cefas PELTIC survey described in BEEMS SPP089). The 50%ile weight of those fish was approximately 2.3g per fish i.e. the population comprised approximately 64,000 million fish (64 billion). Impingement at HPC would have taken an estimated 3 million fish i.e. 0.0047% of the population.

Alternatively, based upon the calculated EAV of 0.139 (Section 5.1), 55,000 million fish would have died of natural mortality by the time 50% reached maturity in 1-2 years (mostly consumed by predators). i.e. HPC impingement would increase mortality by 0.0055% compared with expected natural mortality in the absence of HPC.

In either case, the ecological effect of such impingement levels would be completely negligible given, for example, the fluctuation in sprat numbers of 260% between 2014 and 2015 or 670% between 2015 and 2016.

11 Potential effects of climate change on HPC impingement predictions

Sea temperatures around the UK and Ireland have been warming at between 0.2 and 0.6 °C decade^{-1} over the past 30 years. Projected future changes in the temperature and chemistry of marine waters around the UK and Ireland are having, and will have, effects on the phenology (timing of lifecycle events), productivity and distribution of marine fish and shellfish (Heath *et al* 2012). In a detailed study of terrestrial birds, butterflies and alpine herbs it was found that these species were undergoing northerly latitudinal change of 6.1 ± 2.4 km decade^{-1} and that there was an advancement of spring events of 2.3 d decade^{-1}. (Parmesan and Yohe 2003). Perry *et al* 2005 described that distributions of both exploited and nonexploited North Sea fishes have responded to recent increases in sea temperature, with nearly two-thirds of species shifting in mean latitude or depth or both over 25 years. They found that species with shifting distributions have faster life cycles and smaller body sizes than nonshifting species and that the differential change between species could have consequences for predator-prey relationships. For species that shifted, the mean shift was 99 km northwards in 25y.

Dulvy *et al* 2008 found that North Sea winter bottom temperature had increased by 1·6 °C over 25 years and that during this period, the whole demersal fish assemblage deepened by ~3·6 m decade^{-1}.

Simpson *et al* 2011 found that the majority of common northeast Atlantic fishes are responding significantly to warming with:

- Three times more species increasing in abundance with warming than declining
- Local communities are being reorganized despite decadal stability in species composition
- Species range shifts are the tip of iceberg compared to modification of local communities

However, the effects of climate change on fish communities are hard to predict with accuracy because behaviour, genetic adaptation, habitat dependency and the impacts of fishing on species, result in complex species' responses (Heath *et al* 2012)

Petitgas *et al* 2013 considered that the key issue for the significance of climate change impact on fishes is habitat availability and connectivity between lifecycle stages with climate driven changes in larval dispersion being a major unknown. Pettigas *et al* 2013 considered that there was a significant risk for species with strict connectivity between spawning and nursery grounds.

11.1 Changes in the Bristol Channel fish community

From the RIMP survey at HPB it is possible to observe changes in the Bristol Channel fish community (that are predominantly immature juveniles) in the 37 y period 1981-2017:

a. There has been an increase in overall fish abundance (comparing 5 y means of 1981-1985 with 2013-2017, there was a 204% increase in fish numbers for all species, or 154% increase excluding sprat)
b. In terms of absence – presence, the fish community has been relatively stable. A number of warm water species have started to appear in small numbers, but species that are near their southern latitudinal boundary have generally not disappeared. Over the period there has been no trend in the number of species sampled per year i.e. fish biodiversity in terms of number of species has remained stable but some of the species in the annual list have changed.
c. The 13 most abundant species have remained largely unchanged over the period (with the notable exception of eel) but their relative abundance has changed (see below).
d. There have been relative changes in abundance for some species but disentangling the effects of climate change, changes in fishing pressure and the outcomes of management actions to conserve specific species and ecosystems is complex, especially for commercial species. There have been exponential increases in the numbers of herring, sole, sprat, 5 bearded rockling, mullet and the important prey species *Crangon crangon*, accompanied by declines in the number of eel, sea snail, dab and pout. Appendix E shows that over the 37 y period of the RIMP survey 24 out of the 87 fish species show a statistically significant population trend (14 increasing, 10 declining) but several of those species have only been found in very low numbers and the calculated trends for those species need to be considered with caution. Some common species have shown no trend at all e.g. whiting, sand goby and flounder.

11.2 Potential future changes

Some of the key observed trends in the estuary are likely to continue:

- Potential further increases in productivity driven by increasing riverine sources of organic carbon caused by increased rainfall events and microphytobenthos production on the mudflats.
- Relative changes in species abundance with growing numbers for species that favour warmer water (in winter, in summer or both) and reducing abundance of species near to their southern latitudinal boundary.
- Effects on the phenology of some species (e.g. timing of the arrival of new recruits) and changes in migration patterns as some areas of the estuary become more or less suitable habitat for each species and/or their prey.
- The presence of large numbers of juvenile species in the estuary is dependent upon the connectivity between spawning locations further offshore and to the west of Hinkley Point and their nursey grounds on the mudflats e.g. of Bridgwater Bay. Some species have a lower tolerance to changes in winter temperatures than to summer temperatures (Perry *et al* 2005, Dulvy *et al* 2008) and it is possible that winter temperatures will reach a level such that some species may have to abandon fidelity to long established spawning locations which could produce a rapid reduction in the numbers of those species at Hinkley Point but not necessarily in the wider population biomass.

11.3 Effect on HPC impingement predictions

The RIMP dataset shows that the fish assemblage in the Bristol Channel/ Severn Estuary is changing probably due to a combination of climate change, changes in fishing pressure and other anthropogenic causes (e.g. changes in accessibility of freshwater spawning sites for diadromous species). HPC will efficiently sample the fish community at Hinkley Point. If a local population increases in abundance then impingement numbers will increase, if a local population declines in abundance then impingement numbers will reduce. In either case the impingement effect of HPC as a percentage of the adult population will be unchanged subject to the variability described in sections 8 and 9 on the effects of interannual variability and assessment uncertainties respectively. In such circumstances climate change will have no effect on the predicted negligible effect of HPC impingement on the fish assemblage.

In addition to changes in the sizes of fish populations, climate change is also likely to cause some fish to change their behaviour e.g. the timing of migrations in and out of the estuary is expected to change. Such timing changes would have no effect on the significance of HPC impingement which would remain negligible

12 Conclusions

The predicted HPC impingement with an FRR fitted but no AFD is described in Table 29.

Table 29 Predicted HPC Impingement effects (FRR fitted)

Common Name	*Species*	Mean HPC impingement effect	Impingement indicator	Effect on the species population
Sprat	*Sprattus sprattus*	0.016% - 0.11%	SSB 2013- 2015	Negligible
Whiting	*Merlangius merlangus*	0.05%	SSB 2009	Negligible
Sole, Dover	*Solea solea*	0.09%	SSB 2009	Negligible
Cod	*Gadus morhua*	0.40%	SSB 2009	Negligible
Mullet, thin lipped grey	*Liza ramada*	Population trend increasing. Total impingement pressure with HPC lower than in first 14 y of the trend analysis.	RIMP trend analysis	Negligible
Flounder	*Platichthys flesus*	Population trend stable. Total impingement pressure with HPC lower than in first 14 y of the trend analysis.	RIMP trend analysis	Negligible
5 bearded rockling	*Ciliata mustela*	Population trend increasing. Total impingement pressure with HPC lower than in first 14 y of the trend analysis.	RIMP trend analysis	Negligible
Herring	*Clupea harengus*	0.23%	International catch 2009	Negligible
Bass	*Dicentrarchus labrax*	0.02%	SSB 2009	Negligible
Plaice	*Pleuronectes platessa*	0.00%	SSB 2009	Negligible
Ray, Thornback	*Raja clavata*	0.13%	International catch 2009	Negligible
Whiting, Blue	*Micromesistius poutassou*	0.00%	SSB 2009	Negligible
Eel	*Anguilla anguilla*	0.06%	Independent stock estimate[1]	Negligible
Shad, Twaite	*Alosa fallax*	0.04%	Independent stock estimate[1]	Negligible
Shad, Allis	*Alosa alosa*	Negligible numbers expected at HPC	N/A	**Screened out**. Negligible.

Lamprey, Marine	*Petromyzon marinus*	0.24%	Independent stock estimate[1]	Negligible
Lamprey, River	*Lampetra fluviatalis*	Negligible numbers expected at HPC	Independent stock estimate[1]	**Screened out.** Negligible.
Salmon	*Salmo salar*	Not expected at HPC		**Screened out**
Sea trout	*Salmo trutta*	Not expected at HPC		**Screened out**
Brown shrimp	*Crangon crangon*	Population trend increasing. Total impingement pressure with HPC lower than in first 14 y of the trend analysis.	RIMP trend analysis	Negligible

Note

1. See Appendix G.

It is concluded that HPC with FRR systems fitted would have negligible effect on the species assessed in this report which are considered representative of the fish assemblage, the local WFD water bodies and all of the HRA designated conservation species.

The study of the effect of interannual variations in fish populations for three representative species did not change the HPC impingement assessment conclusion of negligible effects.

Wherever possible, throughout the assessment precautionary or worst case assumptions have been made. Uncertainty analyses did not identify any species where the negligible effects threshold of 1% of the SSB or fishery was exceeded. The conclusion of the HPC impingement effects analysis remains one of negligible effect.

It is concluded that not fitting an AFD system at HPC would have no adverse effect on local populations, waterbody status or to site integrity, respectively

13 References

Aprahamian M. W., Baglinière J-L., Sabatie M. R., Alexandrino P., Thiel R., Aprahamian C. D. (2003) Biology, status and conservation of the anadromous Atlantic twaite shad Alosa fallax fallax. In Biodiversity, Status, and Conservation of the World's Shads. American Fisheries Society Symposium, 35: 103–124.

BEEMS Scientific Position Paper SPP063 Edition 2/S. Entrainment impact on organisms at Hinkley Point – supplementary note

BEEMS Scientific Position Paper SPP065. Reassessment of juvenile cod impingement predictions at HP C. Cefas, Lowestoft.

BEEMS Scientific Position Paper SPP071/S. Shad (Alosa fallax and Alosa alosa) impingement predictions for HP C, Edition 2. Cefas, Lowestoft

BEEMS Scientific Position Paper SPP089. Hinkley Point - Estimates of the abundance and distribution of sprat in the Bristol Channel 2013-2016. Cefas, Lowestoft.

BEEMS Technical Report TR071 Edition 4. Review of commercial fisheries activity in the vicinity of Hinkley Point Power Station. Cefas, Lowestoft.

BEEMS Technical Report TR083 Hinkley Point Nearshore Communities: Results of the 2 m Beam Trawl and Plankton Surveys Edition 3; 2008–2010

BEEMS Technical report TR129. Comprehensive Impingement Monitoring Programme 2009/2010: Final Report, Pisces Conservation Ltd

BEEMS Technical Report TR148 Edition 2. A synthesis of impingement and entrainment predictions for NNB at Hinkley Point. Cefas, Lowestoft.

BEEMS Technical Report TR194. Modelling Acoustic Fish Deterrents at Hinkley Point C. Cefas, Lowestoft.

BEEMS Technical Report TR273. Entrainment Mimic Unit (EMU) Experimental Programme Report: European glass eel (*Anguilla anguilla*), June 2013. Cefas, Lowestoft.

BEEMS Technical Report TR274. Dynamics of glass eels in the Bristol Channel 2012 - 2013 Cefas, Lowestoft.

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

Christensen,V. and Walters,C.J (2004). Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172, 109–139.

Coates, S.A., Waugh, A., Anwar, A. and Robson, M. (2007) Efficacy of a multi-metric fish index as an analysis tool for the transitional fish component of the Water Framework Directive. Marine Pollution Bulletin 55, 225–40.

DECC (2013). Record of the Habitats Regulations Assessment undertaken under Regulation 61(1) of the Conservation of Habitats and Species Regulations 2010 (As Amended) for an application under the Planning Act 2008 (as amended). Project Title: Hinkley Point C Nuclear Generating Station and Associated Development. Dept. Energy and Climate Change, 18 March 2013.

Defra (2004) Salmon migration and climate change, Cefas contract report SF0230.

Dulvy, N.K., Rogers, S.I., Jennings, S., Stelzenmüller, V,, Dye, S.R., Skjoldal, H.R. 2008

Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas. J. App. Ecol. 45, 1029–1039.

EA 2013. Hinkley Point C Appropriate Assessment for related Environment Agency permissions. Environment Agency.

EDF Energy 2011a. Hinkley Point C Project Environmental Statement.

EDF Energy 2011b. Hinkley Point C Project Report to inform Habitats Regulations Assessment. Doc Ref 3.16.

EDF Energy 2017. Hinkley Point C Cooling Water Infrastructure Fish Protection Measures: Report to Discharge DCO Requirement CW1 (paragraph 1) and Marine Licence Condition 5.2.31.

Fleming, J.M., Seaby, R.M.H., Turnpenny, A.W.H., Fleming, 1994. A comparison of fish impingement rates at Sizewell A & B power stations. Fawley.

Gislason, H., Daan, N., Rice, J.C., Pope, J.G., 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries. 11, 149–158.

Heath, M.R., Neat, F.C., Pinnegar, J.K., Read, D.G., Sims D.W., Wright.P.J. 2012. Review of climate change impacts on marine fish and shellfish around the UK and Ireland. Aquatic Conservation, V22, Issue 3, p337-367.

Henderson, P.A. and Holmes, R.H.A. 1989. Whiting migration in the Bristol Channel: a predator-prey relationship. J. Fish Biol. 34,409-416

HRW 2013. Numerical & Physical Modelling of the Hinkley Point C Intake & Outfall Structures. Task 1 – Physical modelling of Flows at the Intake Heads (TN-10). HR Wallingford Ltd, EBR4878

Lassalle, G. and Rochard, E. (2009) Impact of twenty-first century climate change on diadromous fish spread over Europe, North Africa and the Middle East. Global Change Biology (2009) 15, 1072–1089

Lorenzen, K. (1996) The relationship between body weight and natural mortality in juvenile and adult fish: a comparison of natural ecosystems and aquaculture. Journal of Fish Biology 49, 627–647.

Mackinson, S. and Daskalov,G., 2007. An ecosystem model of the North Sea to support an ecosystem approach to fisheries management: description and parameterisation. Sci. Ser. Tech Rep., Cefas Lowestoft, 142: 196pp

Moore, A., Ives, M., Scott, M. Bamber, S. (1998). The migratory behaviour of wild sea trout (*Salmo trutta* L.) smolts in the estuary of the River Conwy, North Wales. Aquaculture V168,issues 1-4. p57-68

OSPAR. 2010. Background document for European eel *Anguilla anguilla*. *Biodiversity Series Report*, 479/2010: 28 pp.

Parmesan, C. and Yohe, G. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature V421, 37–42

Perry, A.L., Low, P.J., Ellis, J.R., Reynolds, J.D. 2005. Climate Change and Distribution Shifts in Marine Fishes. Science, V308, Issue 5730, 1912-1915.

Petitgas, P., Rijnsdorp, A.D, Dickey-Collas, M. Engelhard, G.H., Peck, M.A., Pinnegar, J.K., Drinkwater, K., Huret, M., Nash, R.D.M. 2013. Impacts of climate change on the complex life cycles of fish. Fisheries Oceanography V22, Issue 2, 121-139.

Reis E.G. and M.G. Pawson, 1992. M.G. Determination of gill-net selectivity for bass (Dicentrarchus labrax L.) using commercial catch data. Fisheries Research, 13(2). 173-187

Simpson S D., Jennings, S., Johnson, M.P., Blanchard, J.L., Schon, P-J., Sims, D.W., Genner, M.J. (2011). Continental Shelf-Wide Response of a Fish Assemblage to Rapid Warming of the Sea. Current Biology, V21, Issue 18.1565-1570.

Thorstad, E.B., Whoriskey, F., Uglem, I., Moore, A., Rikardsen, A.H. and Finstad, B. 2012. A critical life stage of the Atlantic salmon Salmo salar: behaviour and survival during the smolt and initial post-smolt migration. J. Fish Biol. **81**, 500–542

Turnpenny, A. W. H., Wood, R. and Thatcher, K. P. (1994). Fish deterrent field trials at Hinkley Point Power Station. Fawley Aquatic Research Laboratories Ltd. Report to Energy Technology Support Unit, DTI. Report ETSU T/04/00198/REP.

Turnpenny, A. W. H., Fleming, J.M., Thatcher, K. P. & Wood, R. (1995). Trials of an acoustic fish deterrent system at Hartlepool Power Station. Fawley Aquatic Research Laboratories Ltd. Client Research Report to Nuclear Electric plc, No. FCR 163/95.

Turnpenny, A. W. H. & O'Keeffe, N. (2005). Screening for intake and outfalls: a best practice guide. Environment Agency Science Report, SC030231. Environment Agency, Bristol.

Turnpenny, A.W.H., Taylor, C.J.L., 2000. An assessment of the effect of the Sizewell power stations on fish populations. Hydroe´cologie Applique´ 12, 87–134.

UKTAG (2014). Practitioners Guide to the Transitional Fish Classification Index (TFCI), Water Framework Directive: Transitional Waters. UKTAG Version 07 301112

Appendix A Detailed design of the HPC cooling water system

Since BEEMs Technical Report TR148 was produced detailed design details of the HPC cooling water system have become available to Cefas and are considered further in this report. EDF Energy has confirmed that:

a. the total cooling water abstraction at HPC will be approximately 132 cumecs with a maximum of 9% of the total cooling water flow supplying the essential and auxiliary cooling water systems via band screens and the remaining 91% (120 cumecs) supplying the main cooling water systems (CRF) via the station drum screens.

b. the HPC band screens will be fitted with their own FRR systems

c. for operational and constructability reasons, the trash rack bar spacing for HPC will be 50mm and not the 75mm spacing used at the existing HPB. The HPC trash rack will have a rake which returns impinged materials (including fish) to the FRR system.

d. the HPC system will not be chlorinated unless there is a major change in the future water quality conditions of the Bristol Channel that would facilitate the rapid growth of biofouling organisms but this is considered unlikely.

In BEEMS Technical Report TR148 the simplifying assumptions were made that all of the HPC cooling water flow would pass through the station drum screens and that the mean seawater abstraction would be 125 cumecs. This section describes the corrections that must be applied to the HPC impingement predictions in order to accurately model the seawater abstraction and filtration in HPC.

1. Main cooling water systems in each pumping station

HPC will consist of two EPR units. Each unit has its own forebay, pumping station, debris recovery building (HCB) and discharge pond. Each pumping station is divided into four distinct sectors: two central sectors (four channels (or 'trains') each) with high flow volume drum screens (ds2 and ds3) and two lateral sectors (one channel (or 'train') each) with lower flow volume band screens (bs1 and bs4).

Each pumping station supplies seawater to a number of systems; the main ones of which are:

CRF: Cooling Water System used to extract waste heat from the turbine steam condensers.

SEC: Essential Cooling Water system (Nuclear Island)

SEN: Auxiliary Cooling Water system (Conventional Island)

SRU: Ultimate cooling water system (Emergency use only)

CFI: Circulating Water Filtration system: supplies wash water for the drum and band screens.

The schematic layout of each pump station is shown in Figure 14.

At Mean Sea Level (MSL) the system flow rates per unit are as follows:

CRF 2*30 cumecs per unit (supplied from the 2 drum screens in each pump station)

SEC 2*1.2 cumecs per unit (can be supplied from the drum screens or band screens in any combination)

SEN 2*1.61 cumecs per unit (normally supplied from the 2 band screens in each pump station)

SRU Negligible flow (only used when testing the system or in emergency)

CFI additional to SEC flow consisting of 2*0.117 cumecs for the 2 drum screens and a worst case of 2*0.039 cumecs for the 2 band screens.

As the SEC/CFI seawater sources can be from the drum screens or band screens there is a range of different water flows through the different filtration systems at HPC.

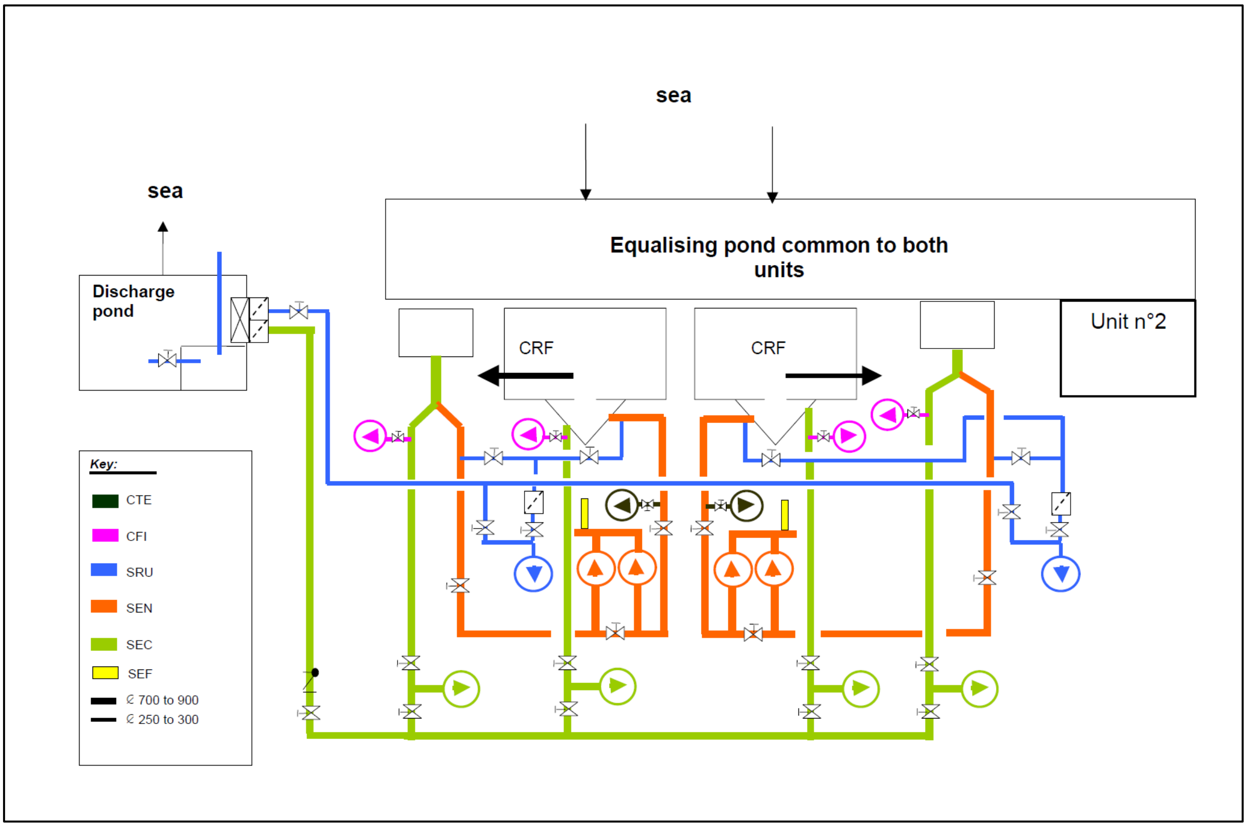


Figure 14 Illustrative schematic of EPR cooling water circuits for each unit (Source EDF CNEPE E.T.DOMA/09 0119 A1 Approved). The equalising pond shown in the figure is the station forebay and HPC has 1 forebay for each unit.

Note that the SRU system (Ultimate Cooling Water System, UCWS) shown in Figure 14 is normally only run during certain maintenance operations when it has a total flow of 0.43 m^3s^{-1} per unit. It is, therefore, not considered in the following analysis.

Table 30 details the minimum flow at MSL (mean sea level) through the drum screens and Table 31 shows the maximum flow through the drum screens at MSL. Dependent upon the system configuration the seawater flow through the band screens can, therefore, vary between 4.9% and 9% of the total seawater abstraction of 131.86 cumecs.

Table 30 Cooling water flow volumes when SEC/CFI systems are supplied from the band screens

	Channel	flow (cumecs)	Flow through	cumecs		cumecs
	bs1	2.966	drum screens	60		
	ds2	30	band screens	5.932		
	ds3	30	Total CW flow	65.932	of which CRF	60
	bs4	2.966				
Total flow/EPR		65.932				
	2 EPRs	131.86	Flow through drum screens			120
			Total CW flow			131.86
			Band screen flow as % of total flow			**9.0%**

Table 31 Cooling water flow volumes when SEC/CFI systems are supplied from the drum screens

	Channel	flow (cumecs)	Flow through	cumecs		cumecs
	bs1	1.61	drum screens	62.712		
	ds2	31.356	band screens	3.22		
	ds3	31.356	total CW flow	65.932	of which CRF	60
	bs4	1.61				
Total flow/EPR		65.932				
	2 EPRs	131.86	Flow through drum screens			125.42
			Total CW flow			**131.86**
			Band screen flow as % of total flow			**4.9%**

2. Filtration systems

At the existing HPB station the drum screens are protected by trash racks in the forebay with 75mm vertical bar spacing that can be raised for cleaning. For operational and constructability reasons the proposed HPC trash rack bar spacing will be 50mm but the rack will also be fitted with trash rakes that will send debris plus any fish that do not pass through the trash rack bars to the debris recovery building (HCB building). The HCB building has another trash rack with 200mm bar spacing and fish that pass through the HCB trash rack will be sent to the FRR system, with any remainder going to waste (see Appendix A section 2.2).

Table 32 Comparison of HPB and HPC seawater filtration systems

Station	Pre filtration trash rack pitch (bar spacing)	Drum / band screen mesh size	Fate of fish washed off drum screens
HPB existing	75mm	10mm	Trash basket
HPC design	50mm	5mm	FRR system

Well-designed FRR systems have been reported to achieve 80−100% survival rates for robust epibenthic species such as plaice and flounder, and moderate rates (~50−60%) for demersal species such as the robust gadoids (e.g. cod). However, survival rates for delicate pelagic species such as herring, sprat and shad are usually low (<10%, Turnpenny & O'Keeffe, 2005). The planned FRR system for HPC has been designed to achieve high rates of survival for eels and lamprey in particular, but it is expected that survival rates for other epibenthic (flatfish including rays) and demersal species will also be higher than achieved in older designs. However, for the purpose of this study we have assumed the conservative FRR recovery rates in Table 33 for HPC that are taken from the EA science report (Turnpenny & O'Keeffe, 2005).

The HPC band screens will be protected by 50mm trash racks and have a 5mm mesh size. Due to their safety role, the band screens must be seismically qualified and capable of surviving an aircraft impact. The normal operating mode of band screens is to be stationary and to only rotate intermittently at 6 hourly intervals unless significant clogging occurs. It is possible to fit an FRR system to the band screens but this would have little to no purpose if the screens only rotated every 6 hours. It would, however, serve a purpose if the screens rotated continuously. The band screen manufacturer considers that the screens could be operated continuously at a 'creep' rotation speed of 0.5 metres per minute; any faster would have unacceptable implications for the operational life and maintenance of the safety-classified band screen motor and chains. The size of the band screens required to cope with the extreme tidal range at Hinkley Point means that, at a rotation speed of 0.5 m min^{-1}, the fish retention time in the band screen fish buckets would be approximately 33 minutes at MSL and 50 minutes at LAT. It is considered that demersal fish would not survive this time in the fish buckets. However, with a fish-friendly design ensuring they cannot fall out of the buckets during the predicted retention time, robust epibenthic species such as flatfish, eels and lamprey are expected to survive.

In this report we have, therefore, assumed that the fish survival percentages for epibenthic species will be the same for drum screen and band screen FRR systems (Table 33).

Table 33 Survival rates for the different HPC filtration systems

Group	Survival rate: drum screens with integrated FRR system	Survival rate: band screens with no integrated FRR system	Survival rate: band screens with integrated FRR system
Pelagic (e.g. herring, sprat, shad),	0%	0%	0%
Demersal (e.g. cod, whiting, gurnard)	50%	0%	0%
Epibenthic (e.g. flatfish, eels, gobies, rocklings and crustaceans)	80%	0%	80%

2.1 Consideration of the effect of the trash racks on impingement predictions

Trash racks are required in front of the drum and band screens to protect those screens from large debris and HPC will have a narrower vertical bar spacing (50mm) than HPB (75mm). The question then arises about the potential impact on fish impingement of the narrower HPC bar spacing because the racks will act as a barrier to fish above a certain size that would prevent those fish from leaving the forebay and passing through to the station drum and band screens where they would be recovered by the FRR system.

Most fish at Hinkley Point are juveniles with only small numbers of fish expected to be more than 2-3 years old. The main exceptions would be for migratory species such as adult eels which would be expected to pass by the site on their migration route to the Atlantic Ocean and potentially for species that use inshore waters to spawn e.g. thornback rays.

The width of fish of a given total length can be calculated from morphometric formulae. Table 34 shows the largest fish sampled during the HPB comprehensive impingement monitoring programme and their calculated widths. The fish species are those species from Table 18 which the HPC FRR is intended to benefit.

Table 34 Calculated width of the largest fish sampled during the HPB impingement monitoring programme (obtained with 75mm trash rack bar spacing)

Species	Maximum Total Length measured mm	Calculated maximum width mm
River lamprey	254	15.9
Whiting	389	35
Blue whiting	220	34
Eel	770	48.1
Sea lamprey	807	45.6
Bass	657	93.2
Cod	709	96.5
Sole	449	126.7
Plaice	382	161
Thornback Ray	952	626

From Table 34 it is evident that all the sea lamprey, river lamprey, whiting, blue whiting and eel that were sampled at HPB would pass through the proposed HPC trash racks with 50mm vertical bar spacing. For the flatfish in Table 34, individuals that were much wider than the HPB bar spacing were routinely sampled and it is considered likely that these fish are changing their orientation in the water column to get through the bars. This is most marked for thornback rays where the smallest measured ray at 132mm total length had a disc width of 88mm and therefore might have been expected not to pass through the rack if the fish had presented against the bars in a horizontal swimming attitude, whereas the CIMP shows that fish of up to 625mm width were able to pass through (i.e. they must have approached the bars at a roll angle from the horizontal). The effect of adopting a narrower bar spacing at HPC would be to prevent a proportion of these species from progressing from the forebays to the subsequent drum or band screens. When these fish become exhausted some might then pass through the bars or be recovered via the trash rake but in both cases we have assumed that such individuals would suffer 100% mortality.

For cod only 0.1% of the measured fish at HPB had a width greater than 50mm and at first sight the effect of the narrower bars would appear negligible. However, the fish that pass through the bars would predominantly be 0 and 1 group fish of which a negligible number would survive to become adults. By increasing the mortality of 2 and 3 group fish the narrower bars would have a disproportionate effect on the fish impingement expressed as equivalent adults. Using the calculation method described in Appendix B it was demonstrated that the 50mm bars reduce the number of cod equivalent adults that are predicted to survive impingement by approximately 40%. The predicted effects on the other species from Table 34 is shown in Table 35.

Table 35 Calculated percentage of the selected Hinkley Point fish impingement that are expected to pass through the 50mm trash rack bars at HPC (expressed as equivalent adults)

Species	Maximum Total Length measured at HPB (mm)	Calculated maximum width (mm) at HPB	Predicted % of HP impingement (as equivalent adults) that will pass through the 50mm bars at HPC	Max fish width (mm) at HPC
Cod	709	96.5	59.7%	64
Sole	449	127	92.4%	84
Bass	657	93.2	49.6%	62
Plaice	382	161	45.4%	107
Thornback Ray	952	626	57.5%	418

2.1.2 Calculation of FRR mortality (Using cod as an example)

FRR mortality with no trash rack fitted

FRR mortality for cod impinged via drum screens = 50% (drum screen mortality) (Table 33).
FRR mortality for cod impinged via band screens =100% (band screen mortality)
Percentage of CW flow through band screens =9% (Table 30).

Total FRR mortality, no trash rack (FRR-NTR) = (1-9%)*drum screen mortality+9%* band screen mortality =54.5%

FRR mortality with trash rack

Percentage pass through trash rack = 59.7% (Table 35)
Combined FRR mortality with trash rack = (1-59.7%)+ 59.7%* FRR-NTR
= (1-59.7%)+ 59.7%* 54.5% =72.9%

2.2 Assessment of the likelihood of fish being sent to waste rather than to the HPC FRR system.

Section 9.2 above describes how fish and debris that are recovered from the trash racks that protect the cooling water drum and band screens (with 50mm vertical bar spacing) will be sent to the HCB building where the stream will be passed through another trash rack with 200mm vertical bar spacing. Only fish that fail to pass through this trash rack will be sent to waste.

Table 36 summarises the maximum dimensions of fish impinged at HPB during the 2009/10 CIMP programme. (HPB has a 75mm trash rack bar spacing with no trash rake).

Table 36 Maximum expected fish sizes in the Celtic Sea area

Species	Adult Maximum Total Length (TL) cm	Maximum Width mm	Data source	Age that the species is expected to leave nursery areas
Cod	109 - 113	174 - 183	Fishbase 2000-2001 unsexed trawl data Celtic Sea, ICES Division VII e - k	2 to 3 years old
Sole	51.5	145	Fishbase: 2000-2001 unsexed trawl data Celtic Sea, ICES Division VII f & g E&W	2 to 3 years old
Plaice	50.5 - 58.5	213 - 246	Fishbase 2000-2001 unsexed trawl data Celtic Sea, ICES Division VII f & g	-
Thornback Ray	102.5	675	Fishbase (1986-) E&W	2 years. However, adults move into shallow water (<10m) in spring – late summer to mate

From Table 36 it can be seen that the largest expected cod and sole at Hinkley Point would all pass through the 200mm HCB trash rack but, in principle, some plaice and thornback ray may not.

The largest plaice measured at HPB was 38.2cm total length (TL) with a width of 161mm which was likely to be a 4 - 5 year old fish. Hinkley Point is a nursery area for immature plaice with the majority being less than 3 years old. If fish larger than 161mm wide were present in the area it would be expected that some would have been detected in the impingement record given, for example, that 46% of the measured thornback rays (another flatfish species) in the CIMP dataset were >161mm wide. It is therefore considered that the HPB CIMP programme adequately sampled the plaice population at Hinkley Point. At HPC plaice in the range 107 to 161mm wide that fail to pass through the 50mm trash rack would all pass through the 200mm HCB trash rack (which is expected to pass all fish up to at least 47cm TL)

The largest thornback ray measured at HPB was 95.2cm TL with a width of 626mm. Only 3% of the expected thornback ray length distribution in the Celtic Sea in 1986 was longer than the 95cm TL fish measured at HPB (Fishbase) i.e. very few thornback rays larger than those found in the HPB CIMP survey are expected to be abstracted by HPC. All of the measured rays at HPB were greater than 75mm wide (range 133 – 626mm) and the length distribution clearly showed a bimodal distribution of juveniles (age 0-4) up to 53cm TL and of adults (age 5-6+) with juveniles representing 91% of the measured population. The numbers of adult rays sampled in the CIMP dataset were too small to draw statistically robust conclusions about the effect of the HPB 75mm trash rack bar spacing on the measured length distribution. Qualitatively the largest number of adults were at 74.75cm TL in the impingement dataset and 72.5cm in the Fishbase length distribution. It is not evident from comparing the two length distributions that the HPB trash rack bars acted as a barrier to the passage of thornback rays but the data are too sparse to be confident in this conclusion. It is possible that some adults in the range 75cm to the largest expected 103cm TL could have been underrepresented in the CIMP dataset. It is not possible to quantify this effect but the impact of different scenarios on impingement mortality can be estimated. Assuming that the real number of adults greater than 75cm TL present at Hinkley Point was 100% larger than estimated from the CIMP dataset, this would cause the predicted HPC impingement losses for thornback rays in Table 19 of this report to increase from 0.6% of the local fishery to 0.89% of the local fishery. On the basis that rays of 75cm TL (width 493mm) pass through the 75mm bar spacing at HPB, it is expected that the largest rays expected at HPC (width 675mm) would pass through the 200mm spaced HCB trash rack bars

In conclusion, it is expected that all fish that failed to pass through the 50mm trash rack bar spacing at HPC would be able to pass through the 200mm trash rack bars in the HCB building unless debris blocked their passage.

Appendix B Calculation of the effect of 50 mm trash rack bar spacing at HPC

In summary, the method used to determine the effect of narrower trash rack bars for each species was as follows:

1. Calculate the maximum total length of fish that can pass through the 50 mm bars at HPC
    a. From the HPB impinged fish length measurements determine the longest individual for each species. Calculate the maximum width at this total length using published morphometric relationships (Appendix C). This is the maximum width that can pass through the HPB 75 mm trash rack bar spacing
    b. Recalculate the *pro rata* maximum fish width assuming a 50 mm bar spacing
    c. Determine the maximum total length (TLmax50) at this maximum width
2. Using the EAV calculation method described in BEEMS Technical Report TR426, determine what percentage of the adult equivalent fish can pass through the 50mm bar spacing.
    a. Using TLmax50 recalculate the number of impinged fish at each age group until maturity
    b. Recalculate the number of fish that are mature at impingement
    c. At each age calculate the number of fish that will survive to maturity
    d. Sum to obtain the total number of survivors with 50 mm bars
    e. Calculate the percentage of equivalent adults that can pass through the 50 mm bar spacing (%EAVpass) by the ratio of total number of survivors at 50 mm/total numbers of survivors at 75 mm bar spacing
3. Apply the %EAVpass ratio to the impingement predictions for HPC

Appendix C Morphometric calculations

Table 37 The relationship between standard length (SL) and total length (TL) and calculation of width parameters.

Species	SL (mm) to TL	Source	TL (mm) to width	TL to depth	Source
Cod	1.0839SL+1.9659	BEEMS TR129	$0.012*TL^{1.37}$		Sistiaga[1] CS3
Whiting	1.0966SL+0.4569	BEEMS TR129	0.09TL+0.27		Tosunoğlu
Blue whiting	SL/0.835	Cohen		0.153 TL	Cohen
Dover sole	1.1331SL-0.494	BEEMS TR129	TL *0.281		Desoutter
Bass	1.1939SL+3.6	BEEMS TR129	Girth = 14.09+ 0.5127*TL Depth = 19.6% TL Width calculated assuming elliptical body shape		Reis & Pawson 1992. Fishbase.
Plaice	1.264*SL	Fishbase	TL *0.421		Cooper
Eel	Measured as TL			TL/16	Turnpenny & O'Keefe (2005)[2]
River lamprey	Measured as TL			TL/16	Turnpenny & O'Keefe (2005)[2]
Sea lamprey	Measured as TL		0.0334*TL^1.078		Pers.comm. Dr. Sergio Silva, University of Santiago de Compostela.
Thornback Ray			Disc width mm = (TL/10*0.6572 + 0.09095)*10		Dr S Walmsley, Cefas. Pers.comm

[1] Calculated as CS3 – the width at the maximum height and girth
[2] F = fineness ratio i.e. length/maximum depth. Calculated assuming a round body shape (i.e. depth equals width)

Appendix D Bootstrapped estimates of the predicted variability of the number of fish that would be impinged at based upon the 2009/10 CIMP programme.

Method

Estimates of variability were calculated using bootstrapping. The CIMP measurements of fish impingement at HPB were resampled with replacement within each quarter of the year to match the data collection procedure (10 visits per quarter). Then, for each of 10,000 bootstrap iterations, the sum of the 40 sampled values was calculated. Standard errors and 95% confidence intervals were derived from the resulting bootstrap distribution using the bias-corrected and accelerated (BCa) method for the confidence intervals (Efron, 1987; this method is a refinement of directly taking the percentiles).

Next, the sum from the 40 samples, its standard error and confidence limits were multiplied by 365.25/40 to give an annual estimate for HPB. This was further multiplied by 131.86/33.5 to scale to the pumping capacities of HPC, respectively, assuming a linear increase in the number of fish impinged with increased pumping capacity. (Scaling the bootstrap intervals is valid as the method used is "transformation respecting" (Hall, 1992, page 137)).

Bootstrapping was carried out in the software R v3.4.3 (R Core Team, 2017) using package 'boot' (Canty and Ripley, 2017).

References

Canty, A. and Ripley, B. (2017) boot: Bootstrap R (S-Plus) Functions. R package version 1.3-20.

Efron, B. (1987) Better bootstrap confidence intervals. J. American Statistical Association, 82: 171-185.

Hall, P. (1992) The Bootstrap and Edgeworth Expansion. Springer-Verlag, New York, pp 354.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Table 38 Predicted unmitigated impingement numbers at HPB and HPC

Scientific Name	Common Name	Annual mean HPB (33.7 cumecs)	Lower.95	Upper.95		Annual mean HPC (131.86 cumecs)	Lower.95	Upper.95
Sprattus sprattus	Sprat	970,458	477,629	1,694,355		3,797,169	1,868,846	6,629,605
Merlangius merlangus	Whiting	541,942	419,946	724,197		2,120,487	1,643,147	2,833,610
Solea solea	Sole, Dover	143,998	90,840	241,280		563,431	355,434	944,071
Gadus morhua	Cod	95,310	56,650	216,493		372,924	221,659	847,084
Liza ramada	Mullet, Thin-lipped grey	56,189	29,752	94,740		219,854	116,412	370,696
Platichthys flesus	Flounder	54,971	44,167	67,890		215,090	172,813	265,639
Ciliata mustela	Rockling, 5-Bearded	34,846	28,571	45,428		136,343	111,790	177,748
Clupea harengus	Herring	27,478	15,697	44,439		107,516	61,420	173,881
Pomatoschistus minutus	Goby, Sand	18,706	11,615	35,633		73,193	45,447	139,424

Entelurus aequoreus	Pipefish, Snake	11,819	6,893	18,862		46,246	26,970	73,801
Dicentrarchus labrax	Bass	8,191	6,346	10,360		32,049	24,831	40,536
Liparis liparis	Sea snail, Common	7,678	5,056	13,823		30,044	19,782	54,086
Trisopterus minutus	Poor cod	2,655	1,776	3,918		10,389	6,951	15,329
Trisopterus luscus	Pout	2,016	1,290	3,110		7,889	5,046	12,168
Scyliorhinus canicula	Dogfish, Lesser spotted	1,332	717	2,993		5,213	2,806	11,710
Conger conger	Conger	1,317	909	1,941		5,155	3,556	7,595
Pleuronectes platessa	Plaice	1,292	735	2,333		5,056	2,877	9,129
Limanda limanda	Dab	882	518	1,481		3,452	2,025	5,796
Maurolicus muelleri	Pearlsides	819	442	1,436		3,204	1,730	5,619
Raja clavata	Ray, Thornback	780	466	1,284		3,054	1,825	5,025
Agonus cataphractus	Hooknose (Pogge)	758	456	1,176		2,966	1,784	4,600
Alosa fallax	Shad, Twaite	550	304	925		2,152	1,191	3,619
Ciliata septentrionalis	Rockling, Northern	548	247	950		2,144	965	3,716
Gasterosteus aculeatus	Stickleback, 3-Spined	336	162	635		1,314	635	2,486
Anguilla anguilla	Eel	309	197	458		1,210	771	1,794
Micromesistius poutassou	Whiting, Blue	288	76	860		1,127	298	3,366
Cyclopterus lumpus	Lumpsucker	286	55	948		1,119	214	3,708
Pomatoschistus pictus	Goby, Painted	282	101	664		1,102	394	2,597
Hyperoplus lanceolatus	Sand eel, Greater	238	36	751		929	141	2,937
Psetta maxima	Turbot	237	79	671		929	309	2,627
Mullus surmuletus	Mullet, Red	237	66	724		926	258	2,834
Syngnathus rostellatus Nillson	Pipefish, Nillson's	220	37	517		862	143	2,023
Trisopterus esmarkii	Pout, Norway	197	100	441		772	391	1,726
Atherina boyeri	Smelt, Sand	178	82	296		695	322	1,159
Callionymus lyra	Dragonet	177	71	364		694	278	1,423
Trigla lucerna	Gurnard, Tub	164	60	335		643	235	1,311
Eutrigla gurnardus	Gurnard, Grey	150	73	286		587	286	1,118
Pollachius pollachius	Pollack	134	61	249		524	238	976
Merluccius merluccius	Hake	127	46	279		496	179	1,092
Aphia minuta	Goby, Transparent	100	33	205		389	131	802
Lophius piscatorius	Angler fish	86	34	158		335	132	617
Spinachia spinachia	Stickleback, 15-spined	71	0	177		279	0	693

Syngnathus acus	Pipefish, Greater	70	9	177		274	36	691
Labrus bergylta Ascanius	Wrasse, Ballan	67	9	213		262	36	833
Trachinus vipera Cuvier	Weever, Lesser	55	9	130		217	36	510
Blennius gattorugine	Blenny, Tompot	49	12	110		191	48	429
Petromyzon marinus	Lamprey, Marine	46	12	99		181	47	389
Balistes carolinenis	Trigger Fish	46	0	155		179	0	607
Gaidropsaurus vulgaris	Rockling, 3-Bearded	37	0	121		145	0	474
Sardina pilchardus	Pilchard	28	0	84		110	0	329
Capros aper	Boar fish	21	0	54		81	0	210
Perca fluviatilis	Perch	19	0	56		73	0	218
Engraulis encrasicolus	Anchovy	18	0	55		71	0	214
Zeus faber	Dory (John dory)	18	0	37		71	0	143
Lampetra fluviatalis	Lamprey, River	18	0	37		71	0	143
Alosa alosa	Shad, Allis	18	0	37		71	0	143
Gaidropsarus mediterraneus	Rockling, Shore	18	0	55		71	0	213
Scophthalmus rhombus	Brill	17	0	51		66	0	199
Gobius niger	Goby, Black	17	0	51		66	0	199
Ammodytes tobianus	Sand eel, Common	12	0	36		48	0	143
Sander lucioperca	Zander	12	0	36		48	0	143
Hippoglossoides platessoides	Dab, Long rough	9	0	27		36	0	107
Sparus aurata	Gilthead bream	9	0	27		36	0	107
Leuciscus cephalus	Chub	9	0	27		36	0	107
Crangon crangon	Shrimp, Grey	4,525,055	3,500,760	6,935,857		17,705,453	13,697,634	27,138,340
Pasiphaea sivado	Shrimp, Ghost	2,777,929	1,877,840	4,319,999		10,869,369	7,347,538	16,903,118
Pandalus montagui	Shrimp, Pink	796,979	531,799	1,074,402		3,118,389	2,080,802	4,203,876
Palaemon serratus	Prawn, Atlantic	306,706	240,808	391,614		1,200,065	942,223	1,532,293
Liocarcinus holsatus	Crab, Swimming	11,507	7,923	16,629		45,026	31,001	65,066
Cancer pagurus	Crab, Edible	10,863	8,504	13,492		42,505	33,274	52,790
Carcinus maenas	Crab, Shore	4,681	3,401	6,597		18,316	13,307	25,811
NA	Jellyfish	2,674	183	8,802		10,462	715	34,439
Eupagurus bernhardus	Crab, Hermit	2,345	1,535	3,698		9,177	6,008	14,470
Necora puber	Crab, Velvet swimming	383	187	662		1,499	730	2,589
Sepiola atlantica	Cuttlefish, Little	219	49	761		857	190	2,976

Sepia officinalis	Cuttlefish, European common	73	0	195		287	0	764
Pilumnus hirtellus	Crab, Hairy	71	9	173		277	36	679
Macropodia rostrata	Crab, Long-legged spider	67	18	134		262	71	524
Polybius henslowii	Crab, Sardine	37	0	110		143	0	429
Homarus gammarus	Lobster	18	0	55		71	0	213
NA	Krill	9	0	27		36	0	107

Appendix E Trends in Fish Numbers at Hinkley Point from the HPB RIMP data

Trends in fish numbers may be assessed using the Mann-Kendall statistic (Mann, 1945; Kendall, 1975). For a particular species, this looks at all pairs of counts (Cj,Ck) such that j>k. If Ck>Cj then the pair scores a 1, if Ck<Cj then the pair scores a -1, if they are the same then the score is 0. The statistic MK is the sum of all these scores. Thus, an increasing series would have a positive score; a decreasing series would have a negative score. To make comparisons easier, the statistic have been standardised by dividing by the number of paired comparisons. Thus, if there was a perfect increasing series then the statistic would have value +1; if there was a perfect decreasing series then the statistic would have value -1.

This statistic only measures trend in some average sense over the whole range of years. Thus, it could detect generally increasing positive or negative trends. The statistic will not be able to tease out more subtle situations where, for example, the trend increases and then decreases. Thus, it is important to consider this statistic in conjunction with plots of the data.

For a more formal definition of the MK statistic, you might consider the following. Denote the set of n (n=27 for our series) observations by Y_j (j=1,…,n) and the set of m observations which occur in a later year than Y_j by Y_k (k=1,…,m). We then calculate the statistic

$$MK = \sum_{j=1}^{n}\sum_{k=1}^{m}\frac{I(Y_j, Y_k)}{n(n-1)/2}$$

where I is an indicator variable defined by the sign of D =Y_j-Y_k. If D is positive then I = 1, if D is negative then I = -1, if D = 0 then I = 0.

Under the alternative hypothesis of some form of trend (not specifying positive or negative trend) we can calculate p-values for our observed value of the absolute value of MK using Monte-Carlo simulation. We do this by simulating the MK statistic 10,000 times (each time with the n data points randomly re-ordered) and then calculating the absolute value of MK. We use this null distribution to calculate p-values for the observed value of the absolute value of MK by calculating the proportion of the null distribution that is greater than our observed value.

Where a statistically significant trend is observed, we have plotted the data for each species with a LOESS smoothing curve to illustrate trends. This local polynomial method combines robustness ideas from linear regression and local fitting ideas from kernel methods. Polynomials are fit to the data in selected window and the predicted response at the middle of the window is the fitted value. We then slide the window over the range of the data, repeating the fitting process as the window moves. All computations were carried out in R (R Development Core team, 2017) using the emon package to generate p-values (Barry & Maxwell, 2017).

Results

The MK statistic and its associated p-value have been calculated for each of the 87 species. The results are shown below. All values for which the p-value was less than 0.05 have been highlighted; this is commonly taken as the level to define statistical significance. There are a number of species with statistically significant trends as shown in Table 39 and the direction of the trend can be determined from the sign of the MK statistic and subsequent plots (Figure 15).

Table 39 Calculated MK statistic and associated probability value for each species in the RIMP dataset from 1981 to 2017.

Species	**Common name**	**MK**	**P value**	**Interpretation**	**Number of fish**
Agonus cataphractus	Hooknose (Pogge)	0.26	0.024	Significant	248
Alosa fallax	Shad,Twaite	-0.25	0.033	Significant	555
Ammodytes marinus	Raitt's sandeel	0	1		1
Ammodytes tobianus	Sand eel, Common	0.03	0.826		28
Anguilla anguilla	Eel	-0.7	0	Significant	330
Aphia minuta	Goby, Transparent	-0.09	0.44		534
Atherina boyeri	Sand smelt	0.12	0.259		34
Balistes capriscus	Trigger Fish	0.01	0.815		2
Belone belone	Garfish	0	0.944		1
Buglossidium luteum	Solenette	0.03	0.6		3
Callionymus lyra	Dragonet	-0.05	0.645		95
Callionymus reticulatus	Reticulated dragonet	0.15	0.001	Significant	15
Capros aper	Boarfish	0.15	0.001	Significant	18
Centrolabrus exoletus	Rock cook	-0.02	0.692		3
Chelidonichthys lucerna	Gurnard,Tub	-0.02	0.888		67
Chelon labrosus	Mullet, thick lipped grey	-0.05	0.494		75
Ciliata mustela	Rockling,5-Bearded	0.52	0	Significant	2987
Ciliata septentrionalis	Rockling, Northern	0.25	0.029	Significant	115
Clupea harengus	Herring	0.57	0	Significant	4257
Conger conger	Conger	-0.1	0.377		336
Crystallogobius linearis	Goby,Crystal	-0.13	0.045	Significant	8
Ctenolabrus rupestris	Wrasse, Goldsinny	-0.13	0.054		6
Cyclopterus lumpus	Lumpsucker	-0.25	0.022	Significant	113
Dicentrarchus labrax	Bass	0.1	0.416		3272
Echiichthys vipera	Weaver, Lesser	0.11	0.073		4
Engraulis encrasicolus	Anchovy	-0.05	0.434		7
Entelurus aequoreus	Pipefish,Snake	0.08	0.474		748
Eutrigla gurnardus	Gurnard,Grey	0.37	0.001	Significant	768
Gadus morhua	Cod	0.26	0.03	Significant	2159
Gaidropsaurus vulgaris	Rockling,3-Bearded	0.08	0.324		13
Gasterosteus aculeatus	Stickleback,3-Spined	0.2	0.074		69

Glyptocephalus cynoglossus	Witch	-0.03	0.495		1
Gobius niger	Goby,Black	-0.07	0.449		27
Gobius paganellus	Goby, Rock	0.23	0.001	Significant	10
Hyperoplus lanceolatus	Sandeel, Greater	0	1		8
Labrus bergylta	Wrasse, Ballan	-0.08	0.327		16
Labrus mixtus	Wrasse, Cuckoo	-0.06	0.345		3
Lampetra fluviatalis	Lamprey,River	-0.06	0.52		9
Limanda limanda	Dab	-0.46	0	Significant	1717
Liparis liparis	Sea snail, Common	-0.25	0.036	Significant	3393
Liza aurita	Mullet, Golden	0	1		24
Liza ramada	Mullet, Thinlipped grey	0.3	0.009	Significant	1835
Lophius piscatorius	Angler fish	-0.05	0.569		21
Maurolicus muelleri	Pearlsides	0.1	0.359		58
Merlangius merlangus	Whiting	0.17	0.148		54938
Merluccius merluccius	Hake	-0.49	0	Significant	198
Micromesistius poutassou	Blue Whiting	0.09	0.33		68
Microstomus kitt	Sole,Lemon	-0.02	0.703		3
Molva molva	Ling	-0.03	0.678		4
Mullus surmuletus	Mullet,Red	0.09	0.426		121
Mustelus asterias	Starry smoothhound	0.06	0.052		1
Nerophis lumbriciformis	Worm pipefish	0.04	0.382		2
Parablennius gattorugine	Blenny, Tompot	-0.05	0.521		6
Petromyzon marinus	Lamprey, marine	0.03	0.619		2
Platichthys flesus	Flounder	0.15	0.214		3372
Pleuronectes platessa	Plaice	0.18	0.119		207
Pollachius pollachius	Pollack	-0.16	0.179		146
Pollachius virens	Saithe	-0.04	0.384		1
Pomatoschistus microps	Goby, Common	0.25	0.023	Significant	157
Pomatoschistus minutus	Goby,Sand	0.18	0.126		12530
Pomatoschistus pictus	Goby,Painted	0.08	0.416		61
Psetta maxima	Turbot	0.09	0.396		31
Raja brachyura	Ray,Blonde	-0.01	0.912		2
Raja clavata	Ray, Thornback (Roker)	0	1		92

Raja microocellata	Ray,Small eyed	-0.04	0.389		2
Raniceps raninus	Tadpolefish	-0.11	0.127		5
Salmo salar	Salmon	-0.15	0.079		9
Salmo trutta	Sea trout	0.06	0.06		1
Sardina pilchardus	Pilchard	-0.04	0.402		5
Scophthalmus rhombus	Brill	-0.14	0.103		21
Scyliorhinus canicula	Dogfish, Lesser spotted	0.54	0	Significant	114
Solea solea	Sole (Dover sole)	0.62	0	Significant	9595
Sparus aurata	Gilthead	0.06	0.052		1
Spinachia spinachia	Stickleback,15-spined	-0.03	0.683		8
Spondyliosoma cantharus	Sea bream,Black	-0.19	0.019	Significant	7
Sprattus sprattus	Sprat	0.24	0.039	Significant	66056
Symphodus melops	Wrasse, Corkwing	-0.03	0.623		2
Syngnathus acus	Pipefish, Greater	0.02	0.839		45
Syngnathus rostellatus	Pipefish, Nillson's	0.02	0.87		86
Trachurus trachurus	Scad (Horse mackeral)	-0.05	0.616		19
Trigla lyra	Piper	-0.01	0.891		3
Triglopourus lastoviza	Streaked gurnard	0.05	0.119		1
Trisopterus esmarkii	Pout,Norway	-0.25	0.033	Significant	308
Trisopterus luscus	Pout	-0.34	0.003	Significant	4150
Trisopterus minutus	Poor cod	-0.22	0.063		7281
Zeugopterus punctatus	Topknot	-0.01	0.779		1
Zeus faber	Dory (John dory)	-0.02	0.803		4

References

Barry, J and Maxwell, D (2017). emon: Tools for Environmental and Ecological Survey Design. R package version 1.3.2. https://CRAN.R-project.org/package=emon

Kendall, M. G. (1975) *Rank correlation methods,* 4th ed.; Charles Griffith: London.

Mann, H. B. (1945) Non-parametric tests against trend. *Econometrica*, *13*, 245-259.

R Core Team (2017). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

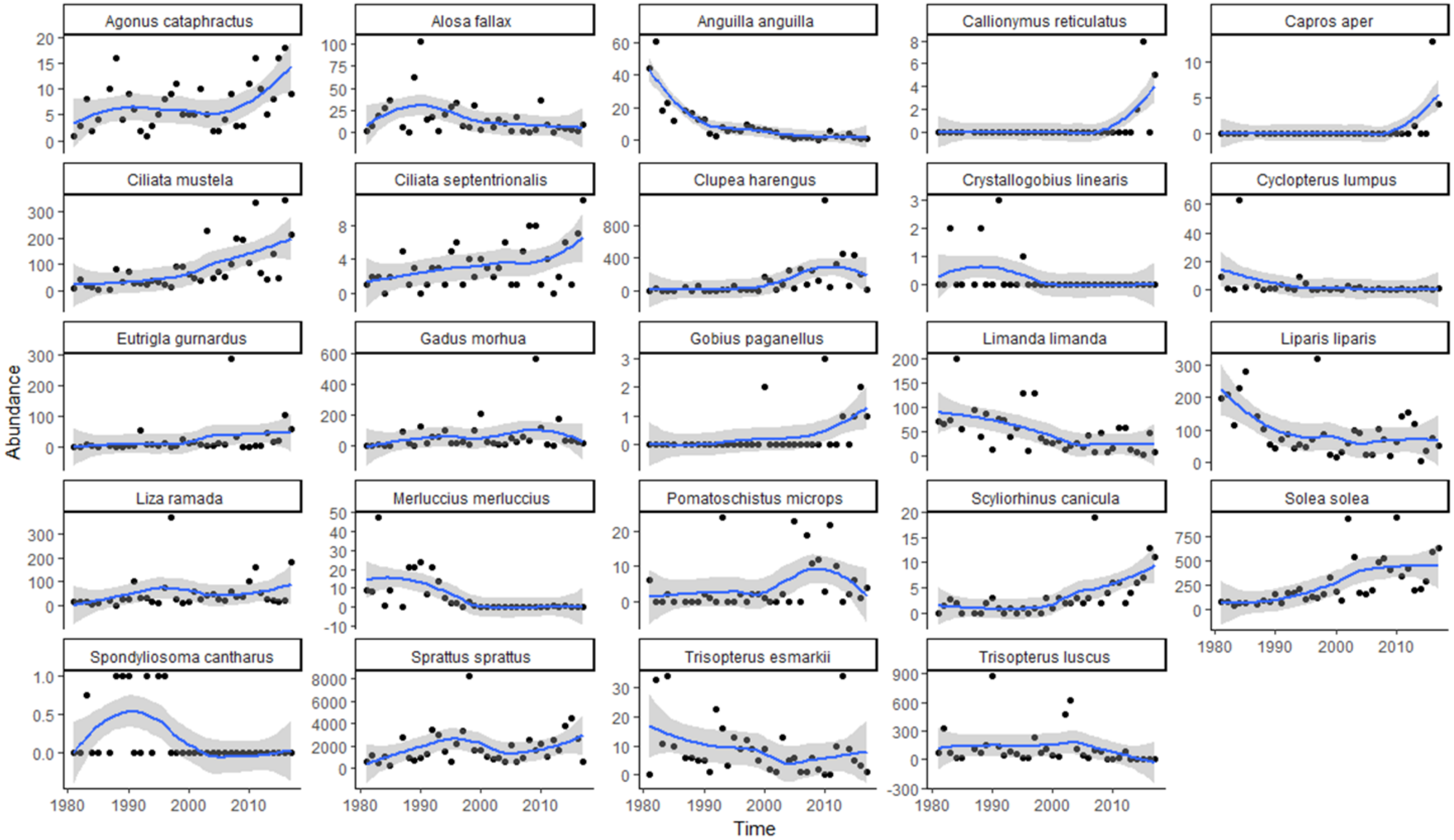


Figure 15 Species with significant annual trends in the RIMP dataset

Appendix F Tests to determine the reliability of the Gislason formula to estimate fish natural mortality

In Section 5.1 it was shown that the greatest uncertainty in the EAV calculations was over cod at Hinkley Point. This section therefore focusses on that species. Figure 16 shows how the calculated natural mortality for cod varies with the size of the fish. Cod at Hinkley point in 2009/10 were virtually all 0 group.

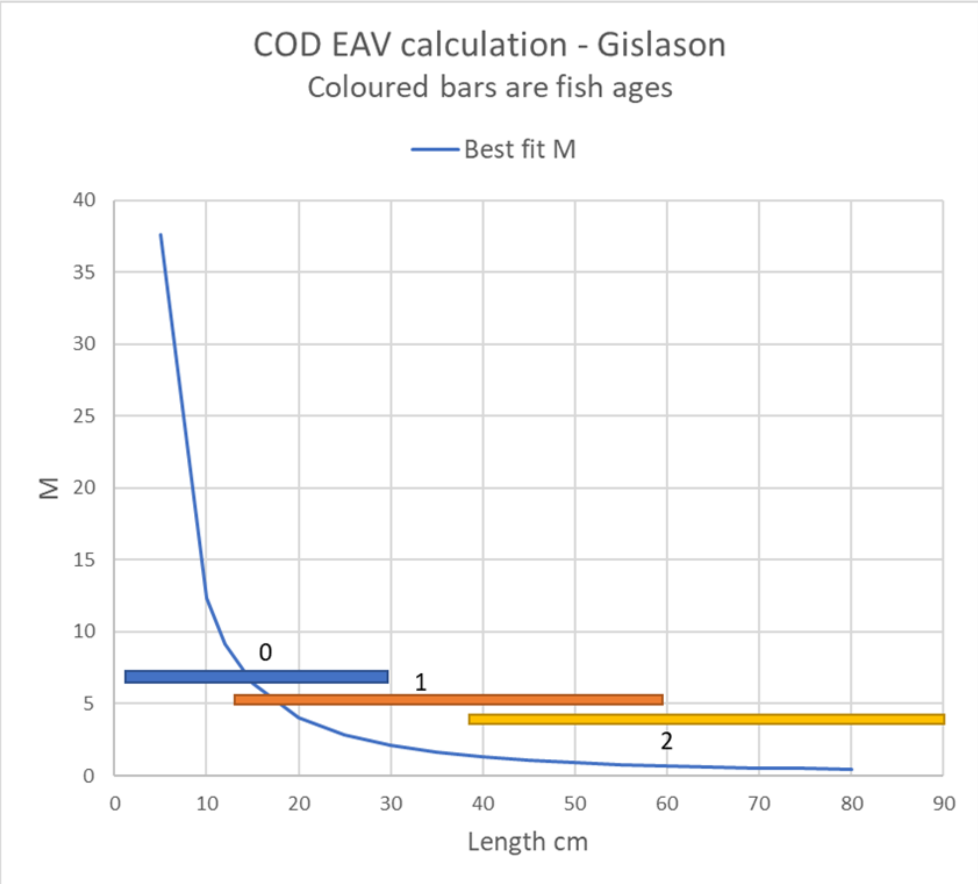


Figure 16 Variation in calculated natural mortality from the best fit Gislason equation with cod age. Coloured bars show fish size at age.

Figure 17 shows how the calculated value of M varies using with the 95 percentile formula coefficients that Gislason calculated.

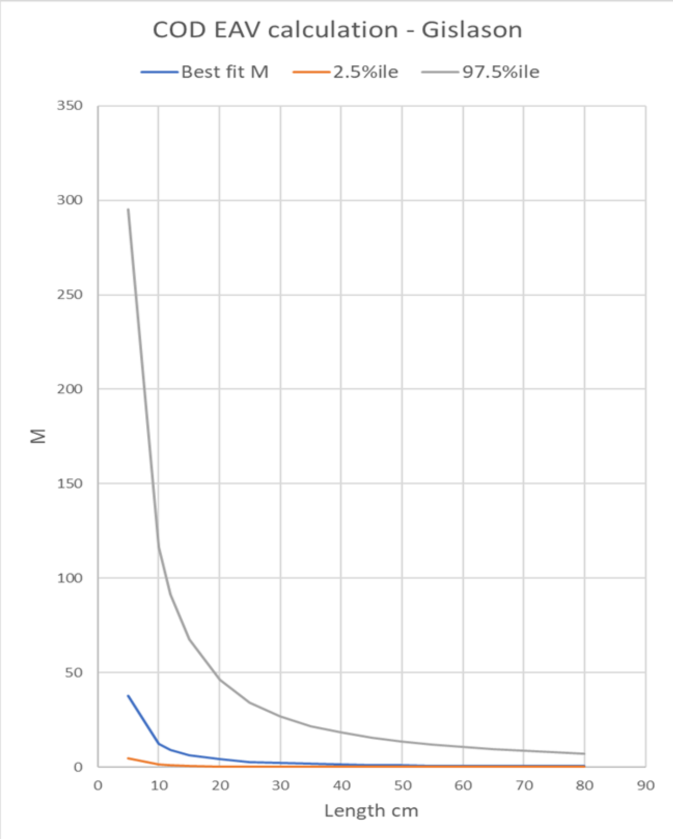


Figure 17 Variation in calculated natural mortality for cod with the different Gislason formula coefficients

There are 2 sources of cod natural mortality data to compare with these predictions:

- The values that ICES used in its cod stock assessment (selected by ICES to be conservative)
- Data provided by Gislason for measured values of M for North Sea cod

Table 40 shows that the Gislason values are in a range of 1.3 to 1.9 times greater than the values used by ICES.

Table 40 Comparison of the ICES values of cod M with those calculated by the Gislason formula

l cm	ICES M	Best fit Gislason M	Ratio
58.6	0.37	0.71	1.94
78.9	0.30	0.44	1.46
89.9	0.27	0.36	1.33

Comparing the measured values of M for North Sea cod with the Gislason formula produces the results shown in Figure 18.

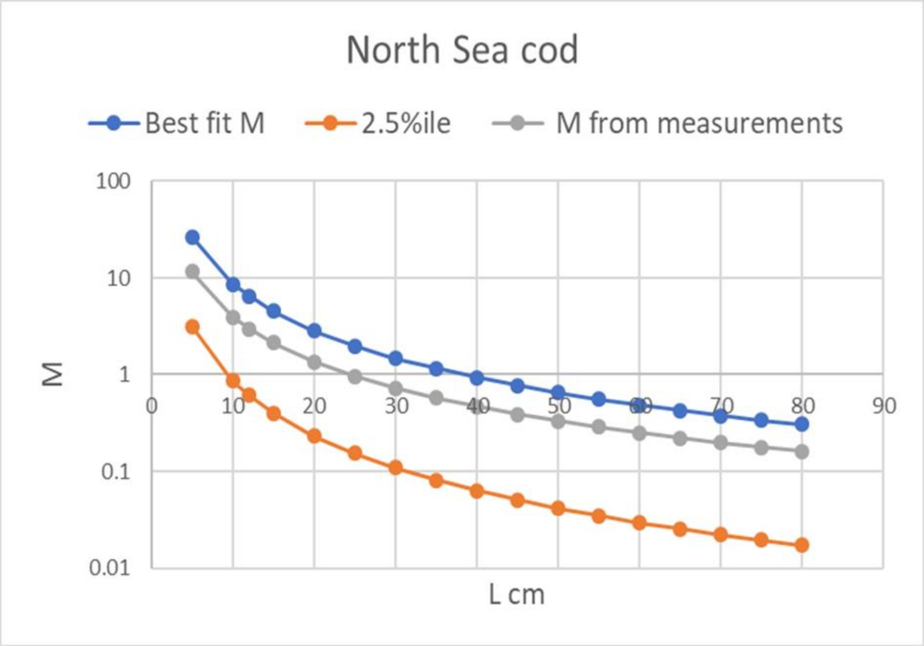


Figure 18 Measured values of M for North Sea Cod plotted against the best fit Gislasson equation and the 2.5 percentile Gislason equation

Conclusions

1. Gislason formula produces estimates approximately 2 - 2.5 times the measured values.
2. The 2.5%ile estimates are approximately 7 -10 times too low .

Appendix G Impingement Effect – Fish Stock Indicators (Conservation species – adapted from BEEMS Technical Report TR148 and BEEMS SPP071/S)

Designated conservation species

1. Eel (Eel management plan)

The EA monitors fish populations extensively within the Severn River Basin District (RBD), although the (mostly) multispecies electric fishing surveys used may underestimate the true density of eel (Knights *et al*., 2001). The data suggest that eels are currently well distributed throughout the lower and middle parts of the catchments, and the EA has concluded that the eel population in the Severn downstream from Worcester has shown little change since the early 1980s, over the period when average recruitment to Europe has declined substantially (by 95% or more; Walker *et al*., 2009). The density and the biomass of eel in the middle reaches of the Severn and Warwickshire Avon catchments were low during the 1980s, but have not been surveyed in recent years. Similar survey data for the Bristol Avon catchment and Somerset rivers within the Severn RBD indicate a general decline in densities and biomasses between 1991 and 1993, and 1994 and 2006, by 37% and 48%, respectively.

A modelling approach to estimate the proportional impact of estuarine glass eel fisheries on the population is available (see Briand *et al*., 2003; Beaulaton and Briand, 2007) and, though it could be used here, it requires extensive sampling of glass eels during spring, when they enter the estuary.

In the absence of data on historical production of eel in England and Wales, a standard production rate of 16.9 kg per hectare has been applied by the Environment Agency in estimating historic production and hence setting the 40% escapement biomass target (6.76 kg per hectare) required under the European Eel Regulation 110/2007. This production rate was selected with reference to estimated production rates for the Bann (Northern Ireland) and Loire (France) catchments, reported by ICES (2008). Using the Environment Agency's Probability Model (see: http://www.defra.gov.uk/foodfarm/fisheries/freshwater/eelmp.htm), silver eel output from the Severn RBD is estimated to be about 8.4 kg per hectare, which equates to about 133.4 t of silver eel per year (Severn Eel Management Plan, March 2010). As such, the Severn RBD is tentatively assessed as exceeding its management target for silver eel production at this time. Note, however, that this model estimate is based on estimates of local yellow eel densities for 109 sites in the Severn catchment, extrapolated to the entire wetted area and converted to silver eel equivalents using a "silvering index", and therefore has a high degree of uncertainty.

The declared annual catches of yellow eels in the years 2005–2008 were 4088, 2785, 892 and 27 kg, respectively, and 419, 968, 134 and 17 kg of silver eels. These annual decreases do not necessarily reflect just changes in eel abundance, but are likely to be attributable too to fluctuations in the fishing effort. Given the small size of the yellow and silver eel fisheries in the Severn RBD, it is not particularly useful to compare these statistics with Her Majesty's Revenue & Customs (HMRC) net export data for eels from the UK as a whole (the best estimate of the UK fishery's catches), and the perceived impact of the Hinkley Point power station can only be evaluated in comparison with the catches declared by the local fisheries.

Currently, eel fishing is banned in the Severn Estuary. However, given that the assumed wetted area is 15881 ha (i.e. 133 400 kg / 8.4 kg ha^{-1}), the 40% escapement biomass target equates to 15 881 x 6.76 = 107.36 t. This leaves a fishery potential of 26 t (i.e. 133.4 – 107.36) if fishing is allowed to resume.

Conclusions

Given Hinkley Point power station's location on the south coast of the Severn Estuary seawards of the River Parrett, the potentially susceptible population consists of glass eels/elvers migrating upstream to freshwater, silver eels migrating downstream from freshwater, and any yellow eels living in the marine environment of the local area. Comparisons of glass eel and yellow/silver eel mortalities through impingement with population estimates are theoretically possible, but the models to permit this are still being developed and it is uncertain anyway which are the relevant ‘populations’. The European eel is currently considered to comprise a single reproductive stock throughout its distribution range (and spawns in the Sargasso Sea off the Gulf of Mexico), and individual river and adjacent coastal marine populations appear to mix considerably.

We consider that the most useful indicator of impact is a comparison between impingement data for eels (although these are not differentiated by life stage) at Hinkley Point power station and estimates of the reported catch of each life stage 2005–2008 in the Severn Estuary RBD. A total of 774 kg of glass eels was declared as caught in the Severn RBD in 2005, 684 kg in 2006 and 1254 kg in 2007. The declared annual catches of yellow eels in the years 2005–2007 were 4088, 2785 and 892 kg respectively, and 419, 968 and
133 kg of silver eels.

Eels are highly unlikely to benefit from lower-velocity cooling water intakes. However, they are considered to be a robust fish and an appropriate FRR system could reduce impingement mortality by up to 100% (Travade and Bordet, 1982), but we have assumed the more conservative estimate of 80% (Turnpenny & O’Keeffe , 2005).

2. Twaite shad (SAC designated)

Spawning populations of twaite shad are confined to four rivers in the UK, namely the Rivers Tywi, Usk, Wye and Severn (including its tributary the River Teme). The twaite shad is a protected species, but there is only sparse population data for them in the Severn Estuary, so the potential for the estimation of shad stock sizes from current sampling techniques is limited and, as such, few estimates have been made. However, as part of the Severn Tidal Power Feasibility Study Strategic Environmental Assessment, APEM Ltd have recently attempted to estimate shad population size and age distribution using a simplified age-structured matrix model (APEM, 2010). The model applies a matrix incorporating life-history parameters (adult survival rates; sex ratio; fecundity at weight/age; spawning propensity and density-dependence) to predict the number of adult female shad within the River Severn RBD. The model incorporates a density-dependent egg deposition function based on a stock–recruitment relationship derived by M. Aprahamian (pers. comm., cited in APEM, 2010) for adult females aged 6 years and applies forecasting and hindcasting methods using documented life history parameters to predict adult population size in a given year. For the purposes of this study, adults are considered to be aged between 3 and 9 years old.

The model estimate indicates an average population size of approximately 92 000 female shad. Given a sex ratio of 1:1, the total mean population of twaite shad aged between 3 and 9 years in the Severn RBD is therefore estimated to be 184 000, although variation in year-class strength may result in estimates ranging between 112 000 and 596 000.

Twaite shad are a delicate-bodied species, similar to herring and sprat, so we anticipate that a FRR system is unlikely to reduce impingement mortality markedly (Turnpenny & O’Keeffe , 2005).

3. Allis shad (SAC designated)

Alosa alosa was originally distributed along the eastern Atlantic seaboard from Norway to North Africa and also in the western Mediterranean. It has declined significantly throughout its range and is now extinct in several former areas. Currently known populations of *Alosa alosa* exist along the northeastern Atlantic coasts in some rivers of France (Loire, Gironde-Garonne-Dordogne and Adour and Portugal (Minho and Lima) (Rougier *et* al 2012, Maitland & Hatton-Ellis, 2003).

Alosa alosa was once abundant in the River Severn and supported a commercial fishery (Day, 1890, cited by Henderson, 2003). It was recorded as breeding in the River Wye in 1935 and is considered to have spawned in the River Severn and some other British rivers, but in recent years has been caught only rarely in UK waters, and no spawning has been recorded. There are, therefore, currently no known spawning sites for this species in the United Kingdom, and only two locations in the UK where individuals in breeding condition have been recorded: the river Tamar in SW England and the Solway Firth on the border between England and Scotland (Jolly *et al*., 2012). Immature adults are occasionally found in the Bristol Channel, the English Channel and the east coast. It is considered possible that British-caught specimens are part of the Loire–Gironde population (Henderson, 2003).

In Ireland there are also no known spawning locations, but the species has a recorded presence in the rivers Slaney and Suir in breeding condition and there are some indications that spawning may be taking place. There is also evidence of hybridisation with *A. fallax* in those rivers (King & Roche, 2008).

Alosa alosa mature at between 3 and 8 years old, with most females maturing at 5 and 6 years (mean length 481 mm) and males at 4 and 5 years (mean length 421 mm) (Maitland & Lyle, 2005). Mature fish that have spent most of their lives in the marine environment cease feeding and move up the estuaries of large rivers at the end of February, migrating into freshwater during late spring (April–June), thus giving them the colloquial name 'May Fish'. Males migrate upstream first, followed by females 1 or 2 weeks later. In some of the larger European rivers, *A. alosa* have been known to ascend upstream for several hundred kilometres – for example, more than 500 km in the River Loire (Boisneau *et al*., 1985).They used to migrate upstream as far as Shrewsbury and Welshpool in the River Severn (Salmon Fisheries Commission, 1861). Spent *A. alosa* (fish that have spawned) migrate back to the sea, though most die after reproduction (i.e. they are semelparous). Most juveniles migrate rapidly through the estuarine environment to reach the marine environment by December of their first year and then remain at sea until they mature. Studies on population genetic structure for both *A. alosa* and *A. fallax* have demonstrated strong fidelity to breeding grounds, compatible with homing to natal spawning sites (Jolly *et al*., 2012)

The spawning migration into estuaries begins between February (southern populations, e.g. in France) and May (northern populations), lasts for three months, and is temperature-dependent. Spawning occurs in freshwater at night over substrata ranging from mud to sandy gravel at depths of 0.15–9.5 m. Eggs (1.7–4.5 mm) develop optimally at temperatures of 15–25°C. Incubation takes 72–120 h depending on temperature. Larvae measure 4.25–9.2 mm at hatching. Age-0 fish migrate seawards in the surface layers of the water column during autumn and winter (Aprahamian *et al*., 2003)

After hatching, the young remain in the slow-flowing reaches of the lower parts of rivers, and then move into the estuary and eventually into coastal waters and the open sea, occasionally having been recorded in water up to 300 m deep. The larvae grow rapidly to between 80 and 140 mm at age 1. Lochet (2008) determined by otolith microchemistry that *A. alosa* in the Gironde basin spend about 54–124 days in the freshwater environment after hatching, and then migrate through the estuarine environment in about 13 days. Thereafter they spend the rest of their lives in the marine environment until they return to the natal estuary once they become sexually mature.

There is no international stock assessment for *A. alosa*. However, the Gironde–Garonne–Dordogne basin, which may be the source of individuals caught in the Severn, is well sampled scientifically. Given the rarity of the species, population models have not been developed for this species in the UK.

Allis shad are considered to be a delicate bodied species, similar to herring and sprat, and it is anticipated that an FRR system is unlikely to reduce impingement mortality markedly.

Lamprey (SAC designated)

More than half the UK SAC designations for the presence of either one or both of river and sea lamprey are situated on the Welsh coast, including the Rivers Wye and Usk. The most recent condition assessment round in 2007 classified all but the River Usk as unfavourable for river lamprey and all but the River Wye as unfavourable for sea lamprey. Stock status information is restricted to

SAC rivers and is primarily in the form of ammocoete densities and distribution. The River Usk has the greatest *Lampetra* spp. ammocoete population across all British SAC rivers, and the River Wye has the greatest sea lamprey ammocoete population (APEM, 2010). Although river and sea lamprey are believed to spawn and reside within the River Severn, no assessment has been undertaken of their stock. However, as part of the Severn Tidal Power Feasibility Study Strategic Environmental Assessment, APEM Ltd recently attempted to estimate lamprey population size and age distributions (APEM 2010) using measurements of life-history traits collated from the literature to construct a generic life table for sea lamprey and river lamprey. Lampreys were assumed to represent one discrete population, given the species' capacity to disperse as evidenced by their lack of homing and wide juvenile movement within several rivers throughout the UK. The life cycle of lamprey was represented by a stage-structured model and constructed with vital rate data and information on: average age at metamorphosis (ammocoete and parasitic juvenile); average ammocoete density per m^2 of optimal and suboptimal habitat; metmorphosis success (ammocoete to parasitic juvenile); ammocoete survival; and sex ratio.

Markov Chain Monte Carlo (MCMC) simulations were used to estimate the mean population size from the model output and provide a likely average population size of adult lamprey in the Rivers Usk and Wye. These estimates have been based on best guesses of available habitat of 1% per metre length of river for both optimal and suboptimal habitat. The population estimates are (mean ± s.d.) (APEM, 2010):

River lamprey		**Sea lamprey**	
Usk:	27 667 ± 4696	Usk:	3069 ± 455
Wye:	88 442 ± 14 326	Wye:	12 200 ± 1836
Total:	**116 109**	**Total:**	**15 269**

As it is not currently possible to derive an EAV for lamprey because of their complex life history, we have not rescaled the impingement estimates derived from the CIMP data. Like other similar weakly swimming species, lampreys are unlikely to benefit from AFD/low-velocity cooling water intakes. However, lampreys are considered to be a robust fish and an appropriate FRR system could reduce impingement mortality by up to 100% (Travade and Bordet, 1982), though we have assumed the more conservative estimate of 80% (Turnpenny & O'Keeffe , 2005).

4. Salmon (SAC designated)

Although estimates of the upstream run of adult salmon are obtained using electronic fish counters or upstream traps on a number of catchments in England and Wales, there are no such data available for rivers entering the Severn Estuary. However, estimates of spawning escapement (numbers of spawning adult fish) are obtained from catch data and exploitation rates, and these are used to assess individual river stock status against conservation limits (CLs: the minimum spawning stock level below which further reductions in spawning numbers are likely to result in significant reductions in the number of juvenile fish produced in the next generation). The CL for each river is defined in terms of eggs deposited.

The River Severn CL is 12.85 million eggs, and the egg deposition estimated for 2008 was 16.56 million, 120% of the CL (mean 131%, 2004–2008). The River Wye CL is 35.66 million eggs, and the egg deposition estimated for 2008 was 22.58 million, 63% of the CL (mean 61%, 2004–2008). The River Usk CL is 10.11 million eggs, and the egg deposition estimated for 2008 was 21.36 million, 211% of the CL (mean 189%, 2004–2008). From these values we can estimate the number of smolts produced, using average egg-to-smolt survival data.

The mean annual catch (2004–2008) of salmon from the Severn Estuary net fishery was 837 fish (the long-term average is ~3000 fish), with rods taking an average of 336, 682 and 987 fish from the Rivers Severn, Wye and Usk, respectively.

Conclusion

For the purposes of evaluating the impact of impingement of salmon smolts or adult fish on the intakes at Hinkley Point power station, data on catches or estimates of abundance for the Severn

Estuary and its major rivers, the Severn, Wye and Usk, cover the overwhelming majority of salmon that might be vulnerable. Over the five-year period 2004–2008, the mean annual catch of salmon from the commercial net fishery in the Severn Estuary was 837 fish, and recreational anglers caught an average of 2005 salmon from the Rivers Severn, Wye and Usk combined. Although some 55% of salmon reported caught by anglers on these rivers were released alive, any impact of power station mortalities should be compared with the total catch (not fish killed), because recreational fisheries are valued per salmon caught.

No salmon were recorded in the RIMP long-term impingement monitoring programme at Hinkley Point between 2005 and 2009 and none were recorded in the CIMP programme.

References

APEM Ltd, (2010) Severn Tidal Power Feasibility Study Strategic Environmental Assessment, Final Reports – Sea Topic Paper, Migratory and Estuarine Fish, Annex 4 – Migratory Fish Life Cycle, Models. 120pp.

Aprahamian M. W., Baglinière J-L., Sabatie M. R., Alexandrino P., Thiel R., Aprahamian C. D. (2003) Biology, status and conservation of the anadromous Atlantic twaite shad *Alosa fallax fallax*. *In* Biodiversity, Status, and Conservation of the World's Shads. American Fisheries Society Symposium, 35: 103–124.

Beaulaton, L. & Briand, C. (2007). Effect of management measures on glass eel escapement. ICES Journal of Marine Science 64, 1402-1413.

Boisneau P, Mennesson C, Baglinière J-L (1985) Observations sur l'activité de migration de la grande alose *Alosa alosa* en Loire (France). Hydrobiologia, 128: 277–284.

Briand, C., Fatin, D., Fontenelle, G. & Feunteun, E. (2003). Estuarine and fluvial recruitment of the European glass eel, *Anguilla anguilla*, in an exploited Atlantic estuary. Fisheries Management and Ecology 10, 377-384.

Chanseau M., Castelnaud G., Carry L., Martin-Vandembulcke D., Belaud A. (2005) Essai d'evaluation du stock de geniteurs d'alose Alosa alosa du bassin versant Gironde–Garonne–Dordogne sur la periode 1987–2001 et comparaison de differents indicateurs d'abondance. Bulletin Français de la Pêche et de la Pisciculture, 374: 1–19.

Henderson P. A. (2003) Background information on species of shad and lamprey. Countryside Commission for Wales, Bangor.

ICES. (2008). Report of the Working Group on the Assessment of Southern Shelf Demersal Stocks, 30 April–6 May 2008. ICES CM 2008/ACOM:12.

Jolly M. T., Aprahamian M. W., Hawkins S. J., Henderson P. A., Hillman R., O Maoileidigh N., Maitland P. S., Piper R., Genner M.J. (2012) Population genetic structure of protected Allis shad (*Alosa alosa*) and twaite shad (*Alosa fallax*). Marine Biology, 159: 675–687.

King J.J. Roche W.K. (2008) Aspects of anadromous Allis shad (*Alosa alosa* Linnaeus) and twaite shad (*Alosa fallax* Lacépède) biology in four Irish Special Areas of Conservation (SACs): status, spawning indications and implications for conservation designation. *In* Fish and Diadromy in Europe (Ecology, Management and Conservation). Developments in Hydrobiology, 602: 145–154.

Knights B., Bark A., Ball M., Williams F, Winter E. and Dunn, S. 2001. Eel and Elver Stocks in England and Wales – Status and Management Options. Environment Agency R&D Technical Report W248.

Lambert P., Martin Vandembulcke, D., Rochard E., Bellariva, J. L., Castelnaud, G. (2001) Àge à la migration de reproduction des géniteurs de trois cohortes de grandes aloses (*Alosa alosa*) dans le basin versant de la Garonne (France). Bulletin Français de la Pêche et de la Pisciculture, 362/363: 973–987.

Lochet A. (2008). Devalaison des juveniles et tactiques gagnantes chez la grande alose *Alosa alosa* et l'alose feinte *Alosa fallax*: *apports de la microchimie et de la microstructure des otolithes.* PhD thesis, University of Bordeaux I.

Maitland P.S, Lyle A.A (2005). Ecology of Allis shad *Alosa alosa* and twaite shad *Alosa fallax* in the Solway Firth, Scotland. Hydrobiologia, 534: 205–221.

Maitland P. S., Hatton-Ellis T. W. (2003). Ecology of the Allis and Twaite Shad. Natural England, Peterborough.

Turnpenny, A. W. H. and O'Keeffe, N. and (2005). Screening for intake and outfalls: a best practice guide. Environment Agency . Science Report. SC030231.

Rougier. T., Lambert, P. Drouineau, H., Girardin, M., Castelnaud,G. Carry, L., Aprahamian,M., Rivot, E, and Rochard, E. (2012) Collapse of allis shad, *Alosa alosa*, in the Gironde system (southwest France): environmental change, fishing mortality,or Allee effect? ICES Journal of Mar. Sci. 69(10), 1802–1811

Travade, F. and Bordet, F. (1982). Etudes expérimentales relatives aux entrainments d'organismes dans les prises d'eau de la Centrale du Blayais. Resultats de 1981 – Perspectives. Electricité de France, Report No. HE/31 – 82.07, 17pp.

Walker, A. M., Aprahamian, M., Godfrey, J., Rosell, R. & Evans, D. (2009). Report on the eel stock and fishery in the UK 2008/2009. In Report of the 2009 Session of the Joint EIFAC/ICES Working Group on Eels (WGEEL), ICES CM 2009/ACOM:15, pp. 504-540: EIFAC/ICES.