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Revised Predictions of Impingement Effects at Hinkley Point C – 2018

Edition 2

Revised Predictions of Impingement Effects at Hinkley Point C – 2018

Edition 2

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Table of contents

List of Tables and Figures

Tables

Figures

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:

- 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 reduce the risk of impingement for fish swimming with the tidal stream. However, no quantitative assessment of their expected effect on impingement rates at HPC was provided in TR148.
- 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 a variable proportion of pelagic and some demersal species to swim away from the intakes and thereby avoid impingement.

The predictions of impingement by HPC were compared with relevant fish stock sizes (expressed as spawning stock biomass, SSB), commercial fish catches or with population trend data dependent upon the availability of data for each assessed species. 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 (2012), the TR148 predictions were updated with more robust evidence for cod and shad impingement in BEEMS Scientific Position Papers SPP065 and SPP071/S Edition2, respectively. These predictions formed the final impingement evidence base that supported the Hinkley Point C DCO application.

The Environment Agency (EA) 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 C.

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. Specifically, 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 the Hinkley Point C intakes 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 undertaken in this report

This report provides revised impingement assessments for:

a. The existing HPB (which has no impingement mitigation measures);

b. HPC with LVSE intakes but no FRR systems; and

c. HPC fitted with LVSE intake heads and FRR systems.

Given the six 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, this report:

i. explains the impingement process more fully and provides more 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 scientific justification for continued use of the 1% negligible effect thresholds adopted for the DCO assessment;
    c. the selection of the Equivalent Adult Values (EAVs) used to convert the number of juvenile fish impinged at Hinkley Point into equivalent adults;
    d. the selection of impingement effects indicators;
    e. a comprehensive assessment of the uncertainty of the impingement predictions by Monte Carlo analysis;
    f. an extensive analysis of the effect of interannual variability in fish numbers on the reliability of the impingement assessments;
    g. an assessment of the impact of climate change upon the predicted impingement effects.
iv. provides updated impingement predictions that include an assessment of the impact of the HPC intake head design upon impingement numbers
v. provides impingement effect predictions for species that could not be assessed in TR148 (salmon and sea trout) or for which the assessment was unrealistically precautionary (marine lamprey)

In considering the effects of not fitting an AFD, this report collates 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 HPC Environmental Statement (ES), WFD and shadow HRA, 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 6 (shown underlined below) to 21 species that include:

- Socio-economically important species – 4 taxa: sole, cod, bass and thornback ray
- Conservation species - 13 taxa: allis and twaite shad, eel, herring, cod, whiting, blue whiting, plaice, sole, salmon, sea trout, river and marine lamprey

- Ecologically important species– the 7 taxa that comprised 95% of the fish abundance at HPB: sprat, whiting, sole, cod, thin lipped grey mullet, flounder, five-bearded rockling plus sand goby and the crustacean brown shrimp.

These species are representative of the fish assemblage at Hinkley Point because:

a. they represent 98.3% of the total fish impingement numbers during the CIMP programme;

b. they contain all the conservation species listed as HRA interest features;

c. they contain examples from all functional guilds with the exception of freshwater species which, as would be expected, are rarely found at Hinkley Point;

d. they contain examples from all feeding guilds and habitat groups;

e. they contain all the indicator species found at Hinkley Point that are assessed in the WFD *fish* biological quality element in transitional waters (See section 5.1); and

f. they contain the key prey species that supports the fish food web at Hinkley Point.

Assessments are provided for salmon and sea trout which were not detected during the 2009/10 comprehensive impingement monitoring programme (CIMP) at HPB but which have been detected rarely in the routine impingement monitoring programme (RIMP) which has been ongoing for 37 years at HPB.

1.4 Assessment of the significance of impingement effects

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 HPC 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.

The HPC shadow HRA assessment (EDF Energy 2011b) evaluated the effects on the integrity of the following designated 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 assessment is whether the HPC impingement impact will produce a likely significant effect (LSE) on site integrity, assessed against the conservation objectives for the sites. The conservation objectives seek, subject to natural change:

- For the fish assemblage – to at least maintain the overall diversity of species and individual populations against an established baseline (that baseline has yet to be established).
- For the individual designated fish species – to ensure that populations are at least maintained and are at a level that is sustainable in the long term.

For both the assemblage and individual designated species the conservation objectives also seek to maintain associated prey populations.

For the harbour porpoise the draft conservation objectives seek to maintain fish prey populations. There is geographical and seasonal variation in porpoise diets that reflects the local availability of fish species. The conservation objectives would therefore be achieved by maintaining the fish assemblage.

The fish assemblage is diverse and contains the characteristic species from all the functional guilds, habitat groups and feeding guilds that would be expected of a European Atlantic seaboard estuary at this latitude. The site integrity test is, therefore, one of determining whether there is an LSE on the sustainability of fish populations.

1.4.1 Determination of an impingement screening threshold for negligible effects on the sustainability of individual fish populations

Fishing is the selective removal (or harvesting) of fish. Impingement is therefore a form of fishing but of lower selectivity and a much lower impact magnitude.

At the time of the HPC 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 SSB or >1% of the fishery landings for herring where an SSB had not been established.

This report considers the evidence for the continued use of a screening threshold of 1% SSB:

- by comparison with international best practice for the sustainable management of fish stocks;
- in the context of the natural variability of fish populations at Hinkley Point; and
- by comparison with a screening threshold that has been previously applied and accepted for the Thames Tideway tunnel, another Nationally Significant Infrastructure Project.

This report concludes that to have a negligible impact on a fish stock the predicted total anthropogenic harvest rate must be less than the value whereby the stock can replace itself on a year to year basis. For data-limited species a precautionary level of 10% -20% SSB is considered sustainable in international fisheries management practice. Marine fisheries assessments are undertaken within the North-east Atlantic by the International Council for Exploration of the Sea (ICES). ICES advises in the context of current management policy which is to manage all species within sustainable limits by 2020; and policy measures have been recommended to the European Commission, which is responsible for managing marine fisheries in Europe, and are now being implemented in order to meet this objective as soon as possible in relation to the 2020 target.

For species which are heavily exploited by fishing a lower effect threshold for impingement is considered appropriate and 1% negligible effect screening threshold for annual impingement for all species is considered to provide a precautionary level which is negligible compared with fishing mortality on exploited stocks and would have negligible effect on their sustainability. For stocks that are not commercially exploited such a level is highly precautionary on the basis of fish population dynamics and any observed decline in stock numbers would be due to other factors well beyond the influence of HPC impingement.

A precautionary level of 1% of SSB is much less than the natural variability of any species at Hinkley Point which 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, the predicted impingement effects for HPC fitted with the planned LVSE intake heads and FRR systems are much less than 1% of SSB for all species as a mean or as an upper 95th percentile.

1.5 Impingement effect 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 landings (or catch when discards are significant) of a fish stock in the assessment year (ICES); and

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 RIMP programme).

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.

1.6 Uncertainty in the Equivalent Adult Value (EAV) factors

The processes and data used to calculate the EAVs used in this assessment have been comprehensively reviewed in order to ensure that the EAVs are based on the most up-to-date, peer reviewed science and are as reliable and accurate as possible. Evidence is provided for expected and worst-case values for EAVs based upon the latest scientific evidence. On a precautionary basis the worst case EAVs have been used for the HPC impingement assessment.

1.7 Changes to the impingement assessments – unmitigated HPC and HPC 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

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 have increased,

		others have decreased. (Sections 5.2.2 and 8.1.6)
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 (Sections 5.3, 8.1.3)
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 (Appendix A).
d.	Added assessments for six additional species not included at the time of DCO (bass, thornback ray, flounder, thin lipped grey mullet, five-bearded rockling and sand goby).	Provides confidence that the assessment is fully representative of the effects of HPC impingement on the fish assemblage (Sections 4.3, 7.3.1)
e.	Quantitative analysis of the expected impact of the HPC LVSE intake heads on impingement. This was not addressed in TR148.	By not taking account of the design of the HPC intake heads the previous impingement estimates were unrealistically conservative. The revised estimates are considered more reliable but still conservative as they do not take into account the full impact of the HPC intake design and location.
f.	Revised impingement numbers from the CIMP programme and use of a statistically more robust bootstrapping procedure to calculate the mean and confidence limits on the impingement estimates. A comprehensive uncertainty analysis using Monte Carlo simulation process has been undertaken. A significantly expanded analysis on the effects of interannual variability in impingement numbers has been included. A more robust statistical analysis of trends has been undertaken on the RIMP data. The CIMP data have been subject to enhanced quality assurance which has resulted in increased numbers for 16 fish species in the raw CIMP impingement dataset.	Provides substantially more confidence in the reliability of the impingement predictions Appendix D Section 8 Section 9 Appendix E

g.	Revised mean weights used to convert the number of equivalent adult fish into impingement weight.	More reliable impingement predictions. Results in increases in predicted impingement impacts for some species (Section 8.1.4).
h.	Provision of assessments for species that were not detected during the CIMP survey (Salmon and sea trout) using the RIMP dataset.	Substantially increased confidence in the DCO assessment that the impingement effect on these designated species is negligible Section 7.3.2)

1.8 The impingement assessment process adopted in this report

The predicted effects of HPC impingement with and without FRR systems were calculated in Section 7 of this report from the 1-year CIMP dataset with the exception of sprat, salmon and sea trout which were assessed from the RIMP dataset. The predicted impingement effects in all cases were less than the 1% SSB/fishery catch negligible effects threshold.

The impingement predictions were then subject to a comprehensive and precautionary uncertainty analysis in Section 8 that considered uncertainties in:

a. the measurement of impingement at HPB via the CIMP programme;
b. scaling HPB impingement to HPC using the ratio of cooling water flows at the 2 stations and the ratio of intake cross sectional intercept areas;
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 FRR mortality; and
f. the SSB or international catch estimates used as impingement indicators.

These analyses did not identify any species where the negligible effects threshold of 1% of the SSB or international catch was exceeded for either mean or 95th percentile HPC impingement predictions (Table *32*).

Impingement numbers fluctuate annually in line with the natural variabilities of the local fish populations. The largest changes in impingement occur when a significant annual recruitment event occurs and an atypically large number of 0 group fish are impinged at Hinkley Point. In order to determine whether interannual fluctuations in fish impingement numbers could have any material effect on the predicted HPC impingement effects from the uncertainty analyses, the five species with the highest predicted impingement effects as a percentage of SSB/fishery catch in 2009 (sole, cod, thornback ray, whiting, marine lamprey) plus the pelagic species of herring, sprat and twaite shad were selected for multiyear impingement analysis using the RIMP dataset.

The aims of this analysis were to identify:

- the magnitude of the potential worst-case impingement underestimation error caused by use of the CIMP 1-year dataset; and
- whether any correction should to be applied to the impingement predictions derived from the uncertainty analyses.

The conclusions from the interannual variability analyses were:

I. For all of the eight species and all of the years analysed the variation in annual impingement numbers did not change the overall conclusion that predicted impingement effects remained much less than the 1% negligible effect threshold.

II. The worst case potential underestimate of impingement effects that could have resulted from the use of the 1-year CIMP programme was a factor of six for herring. i.e. if the CIMP had been undertaken in that year the predicted mean impingement effect would have been expected to be a factor of approximately six below the multiyear mean from the RIMP. The predicted impingement effects from HPC from the CIMP are so low that the application of that factor to any of the species that were not analysed for interannual variability, could not change the overall conclusion of negligible impingement effect from HPC.

The CIMP derived predictions of impingement effect for sole, cod and whiting were overestimated by factors of 3.5, 3.0 and 2.65 respectively. The herring prediction was underestimated by a factor of 1.63. These factors were applied to predictions from the uncertainty analyses to produce the finalised HPC impingement effect predictions in

III. Table 43 and reproduced below.

1.9 Revised HPC impingement assessment

The predicted HPC impingement effects with LVSE intake heads and FRR systems fitted but no AFD fitted are listed below as a mean effect and an upper 95th percentile effect.

Predicted HPC Impingement effects (LVSE intakes and FRR fitted)

Common Name	*Species*	Mean effect	Upper 95%ile effect	Impingement indicator
Sprat	*Sprattus sprattus*	0.016% (from RIMP data)	0.043%	PELTIC SSB for 2013- 2016
Whiting[4]	*Merlangius merlangus*	0.038%	0.072%	SSB for 2009
Sole, Dover[4]	*Solea solea*	0.069%	0.140%	SSB for 2009
Cod[4]	*Gadus morhua*	0.054%	0.119%	SSB for 2009
Mullet, thin lipped grey	*Liza ramada*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis
Flounder	*Platichthys flesus*	Population trend increasing. Negligible effect predicted		RIMP trend analysis
Five-bearded rockling	*Ciliata mustela*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis

Herring[4]	*Clupea harengus*	0.050%	0.081%	International catch for 2009
Sand Goby	*Pomatoschistus minutus*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis
Bass	*Dicentrarchus labrax*	0.011%	0.013%	SSB for 2009
Plaice	*Pleuronectes platessa*	0.002%	0.005%	SSB for 2009
Ray, Thornback	*Raja clavata*	0.118%	0.194%	International catch for 2009 + Cefas discard estimate.
Whiting, Blue	*Micromesistius poutassou*	0.000%	0.000%	SSB for 2009
Eel	*Anguilla anguilla*	0.043%	0.084%	Independent stock estimate[1]
Shad, Twaite	*Alosa fallax*	0.0026% (from RIMP data)[3]	0.0043%	Independent stock estimate[1]
Shad, Allis	*Alosa alosa*	0.017%	0.053%	Independent stock estimate[2]
Lamprey, Marine	*Petromyzon marinus*	0.078%	0.166%	Independent stock estimate[1]
Lamprey, River	*Lampetra fluviatalis*	0.008%	0.021%	Independent stock estimate[1,5]
Salmon	*Salmo salar*	Less than 0.0086%. From RIMP data.	Less than 0.020%	EA/NRW estimates
Sea trout	*Salmo trutta*	Less than 0.0054%. From RIMP data.	Less than 0.04%	Extrapolated from rod catch for 2012-2016
Brown shrimp	*Crangon crangon*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis

Notes:

1. Appendix G.
2. BEEMS SPP071 edition 3.
3. 50th percentile impingement effect from SPP071 edition 3.
4. Corrected by results of interannual variability analyses
5. Marine lamprey effect is number of impinged adults assessed against adult population of the Wye/Usk (see note 6 to Table 23)

These results are considered conservative. It is concluded that HPC with LVSE intake heads and FRR systems fitted would have negligible effect on the species assessed in this report which are considered representative of the fish assemblage and include all the HRA designated fish species.

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

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 sprat.

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. The impingement numbers in 2014 were the highest in the 18-year period between 2000 and 2017.

In October 2014 the biomass of the sprat population in the Bristol Channel Approaches (that migrates in and out of the Bristol Channel in November – January) was 57,236 t (from the Cefas PELTIC survey described in BEEMS SPP089). The 50th percentile weight of those fish was approximately 2.3g per fish (from Cefas PELTIC survey biological data); i.e. the local population comprised approximately 24.9 billion fish. Impingement at HPC would have taken an estimated 0.744 million fish (Table 37) i.e. 0.003% of the number of fish in the population in the Bristol Channel Approaches.

The ecological effect of such impingement levels would be completely negligible given, for example, the natural variability in sprat numbers of 560% between 2013 and 2015 (BEEMS SPP089) to which predators are already adapted. Due to their abundance sprat are major source of prey for local piscivorous fish and for harbour porpoise. To put the annual HPC sprat catch into context it is equivalent to the annual dietary requirement of between 1.4 and 6.3 harbour porpoise based upon the measured dietary requirements of 750 – 3250g fish per day from Kastelein *et al* 1997.

The same principle applies to other potential prey fish at Hinkley Point. If the impingement effect on the adult population is negligible then the corresponding effect on the number of juveniles will be also negligible because of the reciprocal manner in which the EAV calculation works; i.e. the number of juveniles in the population is vastly greater than the number of adults.

1.11 Effect of climate change on HPC impingement

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

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-year 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.
d. There have been relative changes in abundance for some species but disentangling the causes, which include 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, five-bearded rockling, grey mullet and the important prey species *Crangon crangon*, accompanied by declines in the number of eel, dab, poor cod and pout. Over the 37-year period of the RIMP survey 29 out of the 87 fish species show a statistically significant population trend (19 increasing, 10 declining).

The RIMP dataset shows that the fish assemblage in the Bristol Channel/ Severn Estuary is changing. This is 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 effects of assessment uncertainties and interannual variability as described in Sections 8 and 9 of this report respectively. In such circumstances climate change will have no effect on the predicted negligible effect of HPC impingement on the fish assemblage.

1.12 Conclusions

1.12.1 Commercially exploited species

For all of the commercial species assessed in this report (sprat, whiting, sole, cod, herring, bass, plaice, thornback ray and blue whiting) the predicted worst-case impingement from HPC is much less than the 1% negligible effects threshold with the largest predicted effect being for thornback ray at 0.118% fishery catch (and based upon analysis of the RIMP data this prediction may have been overestimated by a factor of more than three – see Section 9.6). HPC will therefore, have a negligible effect on the long-term sustainability of these fish stocks.

Using the results from Section 7, the total impingement weight for the assessed fish species at HPC in 2009 was predicted to be 56.4 tonnes (adult equivalent weight) whereas the equivalent impingement weight for HPB was 51.0 tonnes. HPB impingement losses are in the baseline for Hinkley Point. As HPB is expected to cease operation before HPC becomes fully operational, the net increase in impingement weight from HPC will only be 10.6% above the baseline. To put this figure into context when HPA was operational with HPB the impingement level was 131% above the baseline but this additional mortality had no measured effect on the fish populations at Hinkley Point as gauged by the statistical trend analysis of RIMP data.

In an impingement study prepared for the Public Inquiry into the Sizewell B new nuclear power station the annual catch of Sizewell A was estimated to be 66 tonnes which was noted at the time to be ‘less than that of a single small, inefficient trawler’ and therefore of minor significance (Turnpenny and Taylor 2000).

For the commercial species assessed in this report the total catch in the assessment year of 2009 was 653,797 tonnes compared with the predicted HPC impingement total of 56.4 tonnes (Table 23). Excluding the very large commercial catch of blue whiting which distorts the figures and the sprat catch for which an accurate commercial catch figure is not available, for the other seven assessed species the commercial catch was 18,797 tonnes whereas a precautionary estimate of the HPC impingement is 48.4 tonnes or a negligible 0.26% of the commercial catch.

Considering the sustainability of the commercial species found at Hinkley Point, it is clear that fishing overwhelmingly represents the greatest effect. Marine fisheries are managed in Europe under the EU Common Fisheries Policy (CFP) that has the objectives to ensure that fishing and aquaculture are environmentally, economically and socially sustainable and that they provide a source of healthy food for EU citizens. Its goal is to foster a dynamic fishing industry and ensure a fair standard of living for fishing communities. The CFP recognises that whilst maximising catch is important that there must be limits, and the policy seeks to ensure that fishing practices do not harm the ability of fish populations to reproduce. The current policy stipulates that between 2015 and 2020 catch limits should be set that are sustainable and maintain fish stocks in the long term. For some stocks that have been overfished in the recent past and where the adult stock is highly dependent on annual recruitment, it is likely that the CFP policy will not be fully met by 2020. However, ICES is advising the EU commission on fishing limits that will bring each stock within sustainable limits as quickly as possible and appropriate actions are being taken; e.g. the recent temporary moratorium on most fishing for bass.

If a stock is fished unsustainably it is clear that it is the fisheries management policy that will determine the sustainability of the stock not the impact of HPC; e.g. for cod the commercial landings in 2009 were 3292 tonnes whereas a precautionary estimate of the effect of HPC fitted with FRR systems would have been 7.4 tonnes or 0.22% of the cod landings. To put the predicted HPC effect into an alternative context, the discard rate (unwanted fish which are not included in the landings figure or the 2017 cod SSB assessment) has typically been in the range 10-15% of landings in recent years (ICES WGCSE 2017) equivalent to greater than 300 tonnes per annum based upon the 2009 landings figure. i.e. the cod discards were 41 times the predicted impingement from HPC. For cod HPC impingement would have a negligible effect on the sustainability of the stock.

1.12.2 HRA designated species

The predicted HPC effects on the 7 HRA designated fish species are summarised below and range from 0.078% SSB for marine lamprey to less than 0.0026% SSB for twaite shad.

International best practice in fisheries management is that a harvesting rate of 1% would have a negligible effect on the sustainability of a fish stock. The worst-case predicted impingement effect for the HRA designated species is for marine lamprey at 0.078% SSB i.e. approximately 13 times lower than the 1% threshold. At this level there is high confidence that HPC impingement will not affect the sustainability of the population.

Predicted effects of HPC with FRR systems fitted on HRA designated species

Species	% SSB (mean)	% SSB (upper 95th percentile)
Eel	0.043%	0.084%
Shad, twaite	0.0026%	0.0043%
Shad, allis	0.017%	0.053%
Lamprey, marine	0.078%	0.166%
Lamprey, river	0.008%	0.020%
Salmon	<0.0086%	<0.021%
Sea trout[1]	<0.0054%	<0.040%

The table below compares the predictions of HPC annual impingement numbers for each of seven HRA designated species with the numbers predicted during the DCO examination (Table 18). In all cases, with the exception of allis shad, the predicted impingement numbers at HPC are lower than those predicted during the Appropriate Assessment of HPC. The allis shad impingement prediction differs by a negligible 2.6 fish per year between the two assessments, with the revised assessment being a negligible 0.017% SSB.

Comparisons of updated predicted equivalent adult mortality with those provided for the HPC DCO/HRA

Species	Predicted annual mean adult losses (number of fish) per annum at HPC	
	This report	Shadow HRA at DCO
Eel	156	261
Shad, twaite	4.3	8
Shad, allis	4.6	2
Lamprey, marine	11.7	41
Lamprey, river	9	16
Salmon	<1.36	Not assessed
Sea trout	<0.45	Not assessed

1.12.3 Species assessed by trend analysis

Five species were assessed by trend analysis:

- Thin lipped grey mullet
- Flounder
- Five-bearded rockling
- Sand goby
- The brown shrimp, *Crangon crangon*

These 5 species are not conservation species and are widely distributed geographically. From the trend evidence the following conclusions can be drawn:

a. The abundance of all 5 species at Hinkley Point has a statistically significant positive trend. From well-established principles for the sustainable management of fish populations, if the impingement numbers are constant or rising under constant impingement pressure, using the precautionary approach for data poor stocks described in Section 5.1.1, the harvest rate (i.e. impingement mortality) is sustainable. i.e. if the mortality due to HPB (at approximately 33.7 cumecs) was unsustainable the population would show a decline.

b. When HPA closed down an abstraction of 44 cumecs was removed from the Hinkley Point intakes. This impingement reduction cannot be detected in the RIMP impingement record (Appendix E). The populations of the five species are, therefore, not sensitive to at least a 44 cumec change in abstraction. The equivalent abstraction for HPC will be less than 44 cumecs for 4 of the 5 species with only mullet experiencing a slightly higher equivalent abstraction at 46 cumecs. Given the statistically strong trend in mullet numbers, the 46 cumecs from HPC is not expected to have any effect on the mullet population level.

c. The equivalent unmitigated abstraction in all five cases is less than 97 cumecs of abstraction that has ceased operation in the Bristol Channel/Severn Estuary since 1989 and it can, therefore, be expected that the operation of HPC would have no effect on the population trend for all five species.

d. Finally, the impingement impact on 3 of the species at HPC will be less than the current HPB at 33.7 cumecs. When HPC becomes operational, impingement effects on these species will drop compared with the DCO baseline. For mullet and flounder the net increase in impingement will be 12.3 and 3.3 cumecs respectively, both are of which are far less than the 44 cumecs impingement pressure that was exerted by HPA and which had no effect on population numbers.

1.12.4 The Severn Estuary SAC fish assemblage

For each of the individual HRA designated species (shads, lampreys, eel, salmon and sea trout) the principles of what is a sustainable fish population are well understood. Section 5.1.4 discussed the context surrounding the sustainability of the SAC estuarine assemblage:

- The assemblage is changing with time in terms of relative species abundance and species composition in response to climate change.
- There are very large diel, seasonal and interannual fluctuations in the population density of individual species at Hinkley Point. Estuaries are amongst the most fluctuating aquatic environments on earth, with the boundaries of natural variability, even for individual systems, seldom defined or recorded. The Severn is no exception and given its exceptionally dynamic nature, it is not surprising that no population baseline has been established for the assemblage.
- Individual species migrate into and out of the estuary in succession and the overwhelming majority spend most of their lifecycles outside of the SAC; there are very few truly estuarine resident species and these are not common at Hinkley Point (black goby, common goby, sand smelt, 3 spined stickleback) and all of these show either a statistically significant positive trend in abundance or no trend at the site, Appendix E).

- For most species only the juvenile life stage is exposed to impacts in the estuary and for most species the exposure to impingement risk at Hinkley Point is measured in weeks or a few months. Even within the estuary, species are mobile moving into and out of the regions of inner estuary whilst following prey or retreating from predators, seeking overwintering areas etc.
- The main influences on fish populations are outside the estuary either in reproductive success or survival against predation and fishing in coastal or oceanic waters in the case of marine species whose juveniles use the estuary.

In such circumstances, the concept of estuarine populations of the assemblage species has no biological meaning and the community reflects the state of each stock on a much broader spatial scale which is predominantly outside of the SAC. In just the same manner that the much larger effects of fishing are assessed against the spawning stock biomass of recognised fish stocks (Section 5.2), there is no scientific rationale for assessing the species at Hinkley Point in any other manner where such information exists.

The fish assemblage at Hinkley Point is diverse and contains all of the characteristic species from all the functional guilds, habitat groups and feeding guilds that would be expected of a European Atlantic seaboard estuary at this latitude. The 21 species assessed in this report are representative of the fish assemblage at Hinkley Point. In all cases the predicted HPC impingement was much less than the 1% negligible effect threshold and the populations of each of the species shows either a positive rising trend or no trend. It is therefore concluded that impingement at HPC with LVSE intakes and FRR systems fitted will have no effect on the sustainability of the populations that make up the assemblage. In particular there will be no significant effect on:

i. the conservation species listed as HRA interest features;

ii. the number of functional guilds, feeding guilds and habitat groups present at Hinkley Point;

iii. the abundance of the species present in these guilds and groups; and

iv. the key prey species that supports the fish food web at Hinkley Point.

It is therefore concluded that HPC impingement will have no significant effect on the assemblage nor on the integrity of the SAC.

1.12.5 Summary

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

The test for the HRA assessment is whether the HPC impingement impact will produce a likely significant effect (LSE) on site integrity, assessed against the conservation objectives for the sites. The conservation objectives seek, subject to natural change:

- For the fish assemblage – to at least maintain the overall diversity of species and individual populations against an established baseline (that baseline has not been established).
- For the individual designated fish species – to ensure that populations are at least maintained and are at a level that is sustainable in the long term.

For both the assemblage and individual designated species the conservation objectives also seek to maintain associated prey populations.

For the harbour porpoise the draft conservation objectives seek to maintain fish prey populations. There is geographical and seasonal variation in porpoise diets that reflects the local availability of fish species. The conservation objectives would therefore be achieved by maintaining the fish assemblage.

The evidence presented in this report which is both precautionary and which has been subjected to exhaustive uncertainty analyses shows that HPC without an AFD fitted would have no adverse effect on site integrity for any of the designated sites.

Acknowledgements

This report is based upon the most up to date fisheries science and represents contributions from a large number of internationally recognized marine fisheries scientists. The authors are especially grateful for the independent review and helpful suggestions provided by Dr. C. O’Brien, Chief fisheries science advisor to Defra and vice President of ICES.

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). Impingement predictions were provided for HPC both with and without the planned impingement mitigation measures of:

- 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, due to a lack of information at the time, no quantitative assessments were made of their effect on expected impingement rates at HPC.
- 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 a variable proportion of pelagic and some demersal species to swim away from the intakes and thereby avoid impingement.

The predictions of future impingement by HPC were compared with relevant fish stock sizes (expressed as spawning-stock biomass, SSB), commercial fish catches or with population trend data dependent upon the availability of information for each assessed species. 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 (Edition 2) respectively. These predictions formed the final impingement evidence base that supported the Hinkley Point C DCO application.

2.1 Assessment of the significance of the predicted environmental impacts of impingement for the HPC DCO application

There are no formal UK regulatory guidelines for assessing the significance of fish mortality levels caused by impingement in coastal power stations (nor where there any such guidelines at the time of the HPC DCO submission and examination) and therefore any assessment must be based on expert judgment.

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

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

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.

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.

River Usk SAC, River Wye SAC, River Tywi SAC

- Interest features: sea lamprey; river lamprey & brook lamprey; allis & twaite shad; and Atlantic salmon

c. **The Water Framework Directive (WFD) assessment** (EDF Energy 2011a, Appendix 18B). evaluated the effects of HPC impingement on the ecological status of the Parrett Estuary transitional water body water body. In particular, the assessment considered the effect of impingement on the “fish” biological quality element.

2.1.1 Significance test applied at the time of the HPC DCO

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 SSB or fishery landings for the stock.

2.1.2 Appropriate Assessment Conclusions in 2013

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.”*

2.2 Events post grant of HPC DCO

2.2.1 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, improved 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 4.5). 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.

2.2.2 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 evidence.

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 twin Advanced Gas-cooled Reactors (AGRs) generating a total of 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.

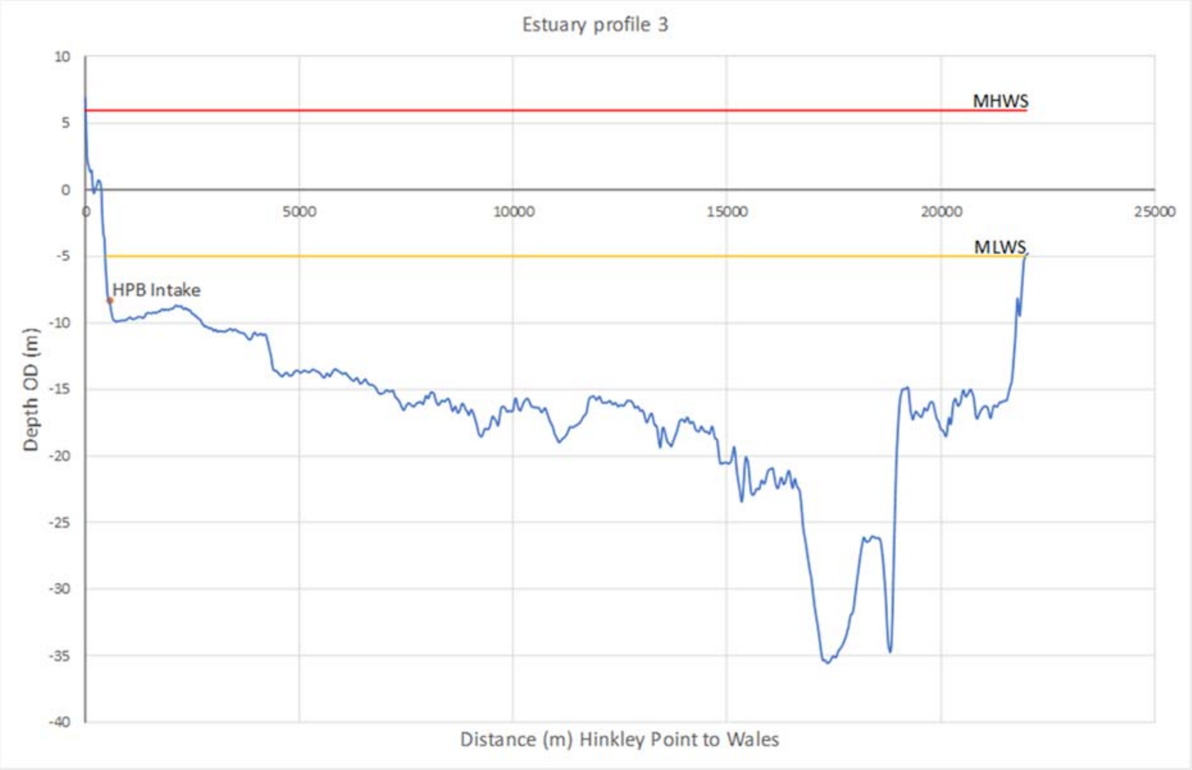


Figure 1 Location of HPB intakes. The figure shows from left to right a northerly transect from HPB through the HPB intake caisson to close to the Welsh coast. The depths of mean low water springs (MLWS) and mean high water springs (MHWS) are also shown.

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 5.8 m with a surface area 118.4 m^2 and a horizontal surface extending approximately 5.3 m towards the centre of the caisson with a surface area of 93.5 m^2 (Source EDF Energy). 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.

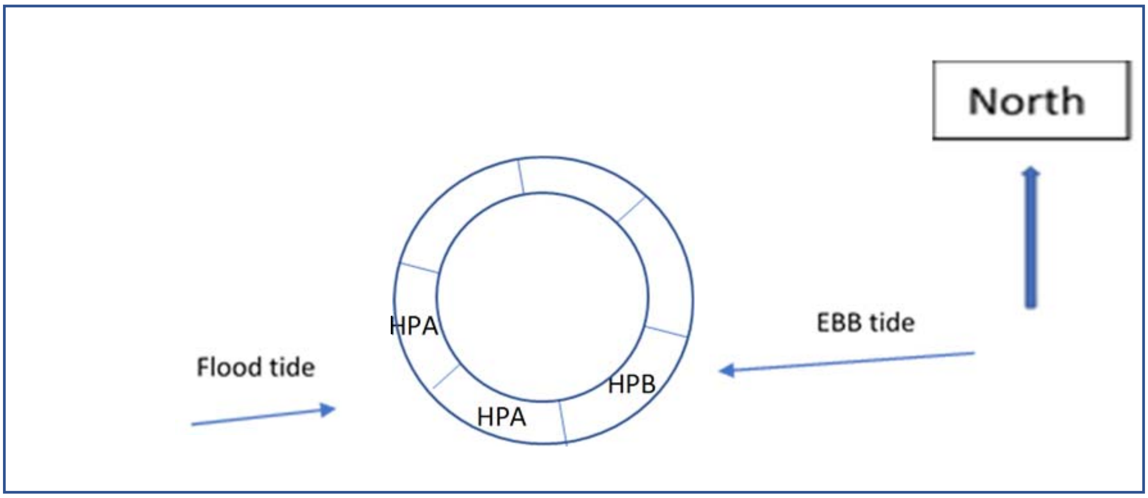


Figure 2 Plan view of HP intake caisson, showing HPB intake sector; the HPA intakes were in the South and South West sectors.

At and above low water neaps both the HPB vertical and horizontal intake surfaces are submerged and the cooling water flow is abstracted through a surface area of approximately 212 m^2. At low water on springs the seawater level drops below the horizontal screen (at which point the intake surface area is 118.4 m^2) and the intake surface area then falls to a minimum of approximately 77 m^2 at low water slack.

The theoretical intake velocity (excluding the tidal component) under such conditions is 0.16 $m\,s^{-1}$ at and above low water neaps to a maximum of 0.44 $m\,s^{-1}$ at slack water on low water springs; i.e. the intake velocity varies at low water springs from those at other states of the tide.

At most tidal levels the HPB 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.

Peak tidal velocities at mid-flood and mid-ebb are up to approximately 1.5 $m\,s^{-1}$. At such velocities few fish at Hinkley Point would be able to do other than swim with the tide and on the ebb tide the tidal velocity is additive to that due to water abstraction and water velocity at the vertical face of the HPB intake will be up to approximately 1.8 $m\,s^{-1}$.

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 with the bottom of each surface located 1 m above the seabed. 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.

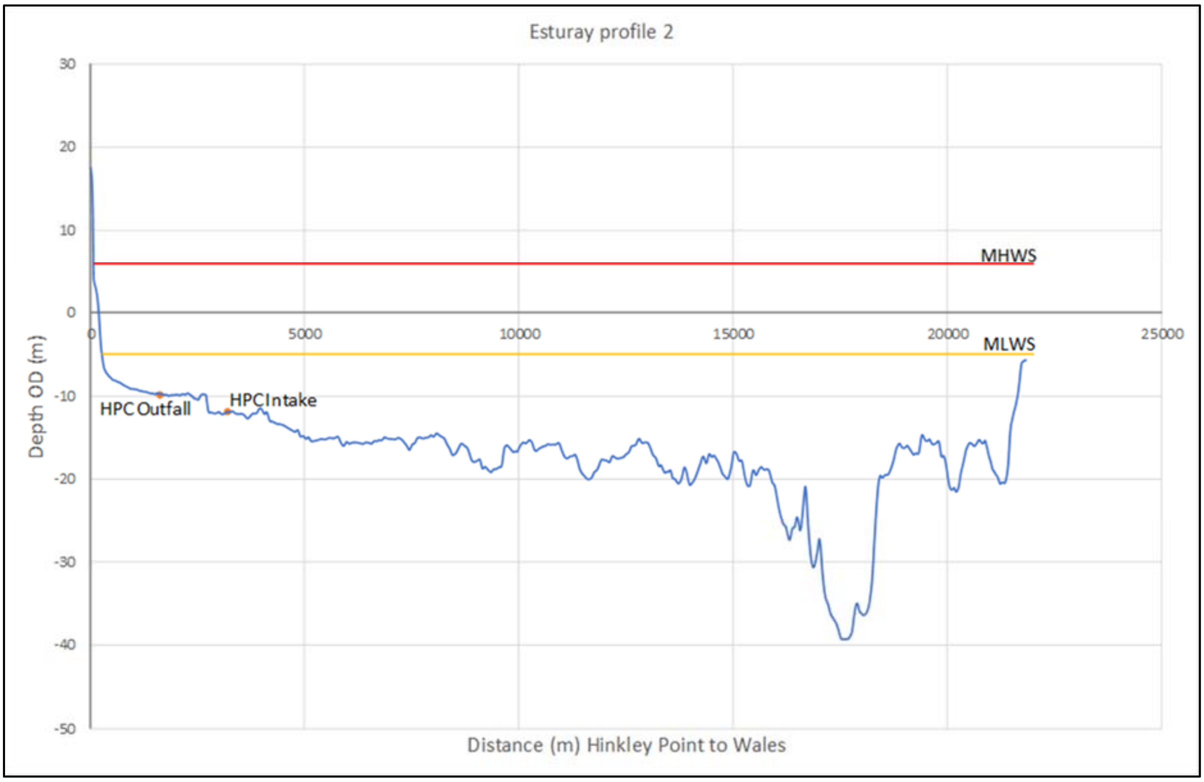


Figure 3 Location of HPC intakes and outfalls. The figure shows from left to right a northerly transect from HPC through one pair of the HPC intake heads to close to the Welsh coast

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 the intake current has a minimal vertical velocity component. Such a design is expected to 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 Sizewell B and Sizewell A.

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 %. (cited in 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 36-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	**Impingement per unit of cooling water flow at Sizewell B as a percentage of impingement at Sizewell A**
Sole	63%
Dab	46%
Plaice	54%
Sprat	38%
Bass	91%
Average of other fish species	**49%**

The design and location of the HPC intake head is expected to provide similar advantages to that provided by the SZB intake design over that of SZA; i.e. reduced impingement of pelagics (sprat, herring and the two shad species in this assessment) 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 previously achieved 38% reduction in impingement rates for pelagic fish compared with HPB due to the use of capped intakes at HPC has been built into the current assessment (Table 2) but no allowance has been made for the expected reduction in impingement due to the deeper water at the HPC intakes and the assessment is, therefore, conservative.

The HPC intake heads will also provide a key benefit compared with the existing HPB intake by providing a minimal cross-sectional area to intercept fish being transported in the tidal flows. In practice, the intercept area of the HPC heads will not be zero as 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 a tidal cycle showed that the flow patterns revert to an undisturbed pattern within 2 m of the intake surfaces (HRW 2013). A worst-case assumption has therefore been made that any fish swimming within 2m of the intake surface would be abstracted. This is the assumed horizontal zone of influence of the intakes; in practice the zone will be smaller as there is no influence from the intake velocity at 2m range. The intake surface areas presented to fish in the tidal stream has been computed for the 4 HPC intake and the single HPB head over a full tidal cycle with the results shown in Table 3 (From Appendix J).

Table 3 Comparison of calculated intake intercept cross sectional areas presented to fish being transported in the tidal streams at HPC and HPB.

Tidal state	HPC intakes (4) total cross-sectional intercept area m^2	HPB intake mean cross sectional intercept area m^2	HPC/HPB intercept area ratio
Neaps	32	52	0.615
Springs	32	47	0.681
Over a spring/neap cycle			0.646

Based upon the ratio of calculated intake intercept areas over a spring-neap cycle, assuming that the fish density at each location is equal at the two locations, HPC is expected to abstract:

- 64.6% of the HPB fish per cumec for all species; and in addition
- 38% of the HPB fish per cumec for sprat, herring and the two shad species (allis and twaite shad) due to the use of capped intakes at HPC.

The LVSE intake heads are therefore, expected to provide substantial reductions in impingement at HPC regardless of whether an AFD is fitted or not.

In addition, as discussed above, impingement per cumec is expected to be lower than this for some species due to:

- An expected lower density of fish at the HPC intakes which are 3km offshore. Fish in the vicinity of the HPC intakes will be in much deeper water at low tide than at HPB and therefore less vulnerable to impingement.
- the height of the HPC intakes at 1m off the seabed is expected to reduce impingement of benthic fish.

These two additional factors have not been built into the current assessment.

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 1.8 m s^{-1} which is in excess of the swimming speed of most of the fish present at Hinkley Point. In the suspended sediment regime at Hinkley Point, 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 a fish species was present all round the year at a constant density the cumulative impingement risk could theoretically increase by up to 365-fold. 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 at HPC will not efficiently sample benthic species and, except at low water, pelagic species.

Table 4 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 and impingement rates are expected to be lower per cumec of cooling water abstracted than at HPB. As described in section 3.1.1, a reduced impingement rate due the smaller intercept area of the HPC intakes compared with the HPB intakes (a ratio of 0.646) and the use of capped intakes at HPC (a ratio of 0.38 for pelagic species) has been built into this assessment report. The expected additional reduction in impingement rates due the lower fish density at low water at the HPC intake heads has not been included in this assessment.

Table 4 Comparison of the HPB and HPC intake designs.

Ideal intake characteristics to minimise impingement (based upon Environment Agency 2010)	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 when the intake surface fills the entire water column.	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 unlikely 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.	Calculated mean intake velocity is approximately 0.16 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 0.4 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 5 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 5 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

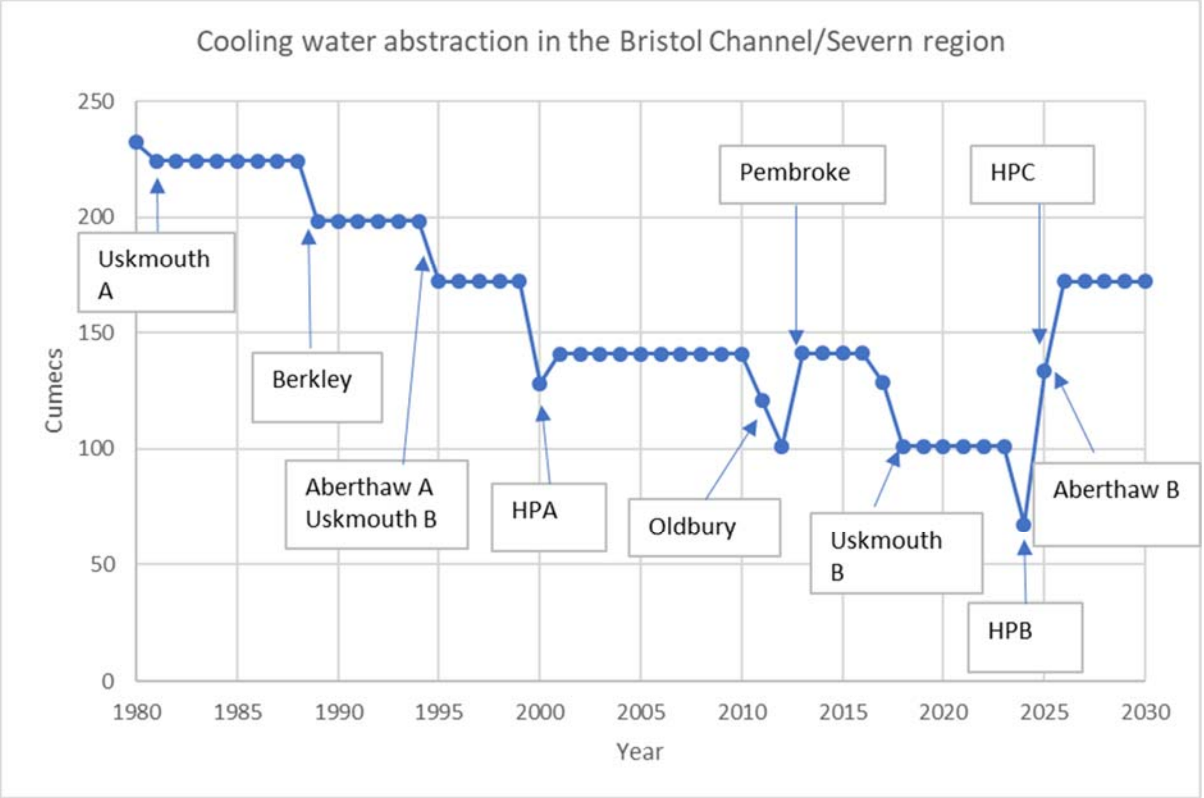


Figure 4 Changes in power station seawater abstraction from the Bristol Channel region 1980 – 2030 showing actual or projected power station closures and new stations opening. Graph does not show the effect of the impingement mitigation measures fitted at Pembroke and HPC

When comparing impingement rates at different stations the key parameters are the similarity of fish communities at the sites, the hydrodynamic performance and location in the water column of the intake heads and the cooling water flow rate. For sites in biologically similar locations with functionally similar intake heads the impingement rate is proportional to the cooling water flow rate. An extreme example of this was at HPA and HPB which shared the same physical intake structure and therefore sampled one fish community. The intake surfaces had slightly different alignment and the flow velocity at the intake surfaces differed but the differences were negligible compared with the tidal flow velocity.

At different locations in the Bristol Channel the fish species will be similar 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. With the exception of Pembroke and the future HPC, the power stations were designed without impingement mitigation measures and had similar but not identical hydrodynamic characteristics. With few exceptions all of the stations operated within the strong tidal flow regime in the estuary. 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 the future 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 theoretically 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 losses 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 some 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. Due to the sampling efficiency of the intakes and their lack of species selectivity the HPB impingement records are considered to mirror the changes in local fish community at Hinkley Point. Impingement sampling does not provide a perfect sample of fish in the water column in that the top half of the water column is not sampled until near to low tide but for the majority of fish species at Hinkley Point it provides the best possible sampling tool. As the HPC intake heads are also seabed mounted, such a vertical sampling profile is also well suited to providing the raw data for HPC impingement estimation.

4.1 Results from impingement monitoring programmes

The RIMP sampling method has not changed during its entire 37-year period and consists of six hours of sampling (in one day) off 2 of HPB’s 4 drum screens every month; i.e. 72 hours sampling per annum off two pumps. 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. The design of the HPB intake described in Section 3 means that HPB will impinge more fish on the ebb tide than on the flood. Previous studies at HPB have shown that 80% of the impingement occurs on the ebb tide (Turnpenny *et al* 1994). By sampling only on the ebb tide, 24 h impingement estimates scaled up from the RIMP samples have an ebb tidal bias of a factor of 1.6. To scale up the RIMP numbers to calculate HPB or HPC impingement it is therefore necessary to reduce the RIMP numbers by this factor of 1.6. (The CIMP programme took 24 h samples and did not suffer from tidal bias and CIMP data do not need to be corrected in this manner). The sampling frequency at 6 hours per month means that the RIMP survey undersamples 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 on three to four cooling water pumps not just two pumps) and of these, five 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 an average of two or fewer fish per year to the dataset.

The RIMP survey provides a unique record of trends 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 following conclusions can be drawn:

- There is a wealth of evidence that fish assemblages are changing significantly at all latitudes in response to fishing and climatic change (Section 11). The assemblage at Hinkley Point is no exception and over the past 37 years it has changed with time. As would be expected, as the population of some species has declined, the populations of other species have grown in number to fill vacated ecological niches; i.e. the assemblage is a dynamic system in which predator-prey relationships adjust on a seasonal and annual basis to maintain energy balances.
- There has been a significant rise in total fish abundance over the 37-year period with a 54% increase in fish numbers (excluding sprat) or more than 100% increase 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 have changed due to a combination of climate change, changes in fishing pressure and management action to conserve ecosystems (Section 11). These pressures have been exerted over a much larger spatial area than the Severn Estuary and the changes seen at Hinkley Point reflect these broad scale changes, Table 7 and Table 8 show the changes in dominant fish species at Hinkley Point between 2008-2012 and 1981- 1985. Table 9 shows the most recent data 2013- 2017.
- 29 species display a statistically significant trend in abundance over the period (Appendix E) with 19 showing an increasing and 10 a decreasing trend. Of these there has been an exponential increase in numbers of herring, sole, sprat, five-bearded rockling and grey mullet with declines in the number of eel, dab, poor cod and pout. 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 7 and Table 8).
- 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 variable year to year recruitment (as evidenced by the numbers of 0 group fish per annum in the RIMP impingement record).
- Length data show that the community is dominated by immature juvenile fish, with only a few mature adults present (Section 4.5).

- 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 recruitment events that occurred in 1989 and 1990. The 37-year record shows a decline in impingement numbers compared with those 2 high recruitment years but there is no trend from 2000 onwards (and probably earlier from visual inspection of the dataset). The reduction in twaite shad numbers has been ascribed particularly to the construction of barriers to shad migration in spawning rivers (Aprahamian *et al* 2003). More recently the twaite shad 2010 recruitment was the third largest in the 37-year data series.
- River and marine lampreys, allis shad, salmon and sea trout were rare and for many years not present in the RIMP impingement record. No trend analysis is possible for these species because of the low numbers impinged. The 37-year impingement dataset for these five species consists of:
    - 9 salmon - 2 fish in 2004, 1 in 2002, 1 in 2000, 1 in 1998, 1 in 1989, 1 in 1987, 1 in 1983 and 1 in 1981
    - 9 river lampreys - 1 in 2010, 1 in 2005, 1 in 1999, 2 in 1998, 1 in 1997, 1 in 1995, 1 in 1992 and 1 in 1981
    - 2 marine lampreys - 1 in 2008 and 1 in 1999. Both fish were parasitic juveniles.
    - 1 sea trout in 2017.
    - No allis shad.

- Table 6 shows that the impinged salmon included examples of parr, smolts, returning adults and kelts (post spawning adults).

Table 6 RIMP impingement records for salmon at HPB

Date	Number	Weight (g)	Length(s). (Not recorded in the 1980s)	Likely development stage
1981	1	-	N/A	Recorded as salmon parr but more likely to have been a smolt
1983	1	-	N/A	Salmon parr or smolt
1987	1	-	N/A	Kelt. Many fish die after spawning but a proportion return to the sea and survive to spawn for a second time. Kelts dropping downstream are in poor condition.
1989	1	-	N/A	Kelt (post-spawning adult salmon).
1998	1	-	97 mm SL (standard length)	Smolt
2000	1	6	35 mm SL	Salmon parr. Fish was very small, so possibly a fish that was in poor condition / subject to wash-out after flooding
2002	1	3400	605 mm SL	Returning adult fish
2004	2	162	117 mm and 165 mm SL	Salmon parr or smolts

An EAV factor for salmon has not been computed because of its complex lifecycle but only the adults (returning adults or kelts) would have had an EAV of 1 and the EAV factor for smolts and parr would have been much less than 1. In terms of impact on the adult stock, the peak impingement during the 37-year impingement record is, therefore, of one salmon in a year with no fish detected in most years.

Marine lamprey spend the majority of their lifecycle in rivers. Metamorphosis into the parasitic sea going form occurs at 3 to 5 years sometimes at up to 8 years. Juveniles migrate to sea through estuaries in the period late autumn to the end of winter. They are poor swimmers and on energy efficiency grounds juveniles will use selective tidal stream transport on the ebb tide with peak densities in the estuary deep water channel near to the sea surface. The marine phase lasts 1-2 years and, because of their feeding strategy, they become regionally widely dispersed at sea and have been found at depths ranging from the surface to 4000m on the continental shelf. Adults do not home to natal rivers and search out suitable rivers based upon the detection of bile acid pheromones from lampreys living in freshwater (Waldman *et al* 2008). On energy efficiency grounds adult lampreys will migrate up estuary on the flood near to the surface in the main channel. Once a suitable river has been located, they migrate upstream to river stretches where they build nests, spawn, and then die. In Europe, adults begin to migrate into streams in December–January, with the peak of migration in February–April, and spawning in April–May (Hansen *et al* 2016, Silva *et a*l 2013, Beamish 1980).

Due to their migration strategy both adult and juvenile marine lampreys are not expected to be impinged at HPB and even less so at HPC due to the deep water at the HPC intakes. Only two marine lampreys were sampled in the entire RIMP programme. They were both caught in February and were parasitic juveniles that would not spawn for another 1-2 years. In the 1-year CIMP programme four marine lamprey were sampled: two adults migrating up estuary and two parasitic juveniles migrating to sea. For adults an EAV of 1 has been used in the impingement assessment. An EAV for juveniles has not been calculated as the loss of juveniles has been assessed against the juvenile population estimate (See Section 8.1.6).

For river lamprey EAVs have not been calculated and a precautionary EAV of 1 has been assumed in this report. From the RIMP dataset the peak impingement impact was from two fish in one year (1998) with no fish detected in most years. Two fish were sampled in the 1-year CIMP programme.

Table 7 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	Five-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	Five-bearded rockling	Herring	Five-bearded rockling	Flounder	Pout
9	Flounder	Snake pipefish	Mullet, grey	Dab	Flounder
10	Pout	Mullet, grey	Sea snail	Herring	Five-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 in the RIMP surveys.
2. Total number of fish is total annual RIMP impingement for all species.
3. Rank ordering is from the calendar year RIMP dataset and is approximate due to the low sampling frequency of the RIMP (see Section 4.1).

Table 8 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	Five-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.
3. Rank ordering is from the calendar year RIMP dataset and is approximate due to the low sampling frequency of the RIMP (see Section 4.1).

Table 9 Most abundant species from the HPB RIMP surveys 2013 - 2017

Rank	2013	2014	2015	2016	2017
1	Whiting	Sprat	Sprat	Sprat	Whiting
2	Sprat	Whiting	Whiting	Whiting	Sole
3	Herring	Goby,sand	Herring	Sole	Sprat
4	Poor cod	Bass	Goby, sand	Five-bearded rockling	Goby, sand
5	Sole	Poor cod	Sole	Goby, sand	Five-bearded rockling
6	Cod	Sole	Bass	Herring	Mullet, grey
7	Goby,sand	Five-bearded rockling	Flounder	Poor cod	Bass
8	Flounder	Flounder	Five-bearded rockling	Gurnard, grey	Gurnard, grey
9	Sea snail	Herring	Poor cod	Sea snail	Sea snail
10	Gurnard, grey	Cod	Sea snail	Bass	Flounder
11	Five-bearded rockling	Mullet, grey	Cod	Flounder	Goby, transparent
12	Pout, Norway	Gurnard, grey	Gurnard, grey	Dab	Cod
13	Mullet, grey	Pollack	Mullet, grey	Cod	Herring
Total number of fish	5959	8310	6793	7005	3625

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.
3. Rank ordering is from the calendar year RIMP dataset and is approximate due to the low sampling frequency of the RIMP (see Section 4.1).

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 40 * 24-hour samples. From these data the bootstrapped annual mean impingement for HPB and HPC together 95% confidence limits were calculated (Appendix D). The raw data for the CIMP assessment consists of 24-hour daily totals of fish impinged with all 4 cooling water pumps operational. These data comprise a total of more 217,000 fish with numbers ranging from 106,000 for sprat to three species with only one individual. The high number of sampling hours means that much more realistic estimates of the density of protected species can be made than from the RIMP survey data. For example, a total of one fish caught in one 6-hour sample in one month of the RIMP would scale up to an HPC maximum impingement prediction of 385 fish (non pelagic species) or 146 fish (pelagic species) after making the unlikely assumption that the same fish density would occur for each 6-hour period of every day of the month. This is not to say that an impingement of one fish in a year in the RIMP would equate to an HPC impingement of 385 (or 146) fish in reality, rather that the prediction is a high variance artefact of the low sampling frequency in the RIMP and the consequential large scaling factor required to arrive at HPC predictions. In contrast one fish caught during one 24-hour sample in the CIMP annual survey would scale up to a predicted maximum HPC impingement of 23 fish (or 9 fish for pelagic species). In the absence of evidence to the contrary, an impingement record of one fish in 1 month of an annual RIMP data record, is more likely to represent a likelihood of much less than 385 fish and possibly only one stray fish at HPC; i.e. impingement predictions of rare species from the RIMP dataset need to be treated with caution.

Of the protected migratory species sufficient numbers of twaite shad and eel were impinged in the CIMP programme to allow a reasonable assessment of impingement effects. The numbers of marine lamprey were very small (four in the year) but sufficient to make a precautionary assessment of effect. However, the numbers of allis shad and river lamprey (both at only two fish in the whole year) were so low that they are both considered to be species that are not vulnerable to impingement effects at Hinkley Point (See predicted effects in Table 23). No salmon or sea trout were detected.

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 seven 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 five-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.

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. **Four 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 recent 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 (one fish in 37 years) and Atlantic salmon (nine 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 4.6). The predicted impingement numbers in the assessment from the CIMP dataset are therefore zero for both species. Similarly, the numbers of allis shad and river lamprey caught at Hinkley Point (two individuals of each species in the 1-year CIMP programme and zero allis shad and nine river lampreys in the 37-year RIMP programme) were so low that they can be discounted as being part of the fish community vulnerable to impingement at Hinkley Point. However, as these species are all HRA designated species a precautionary assessment is provided in Section 7.3.2 to put these rare impingement events into a population context using the available data from the CIMP or RIMP datasets.

- 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 (thin lipped grey mullet, flounder, five-bearded rockling). Sand Goby was also added to the list due to its importance as a prey species for many piscivorous fish and its high abundance in many years (Table 7 -Table 9). Finally, the brown shrimp *Crangon crangon* was added to the list due to its importance in the Bridgwater Bay foodweb. **Nine taxa (sprat, whiting, sole, cod, thin lipped grey mullet, flounder, five-bearded rockling, sand goby and the brown shrimp).**

These criteria produced the list of 20 fish species plus brown shrimp shown in Table 10. These species are representative of the fish assemblage at Hinkley Point because:

a. these species represent 98.3% of the total fish impingement numbers during the CIMP programme;

b. they contain all of the conservation species listed as HRA interest features;

c. they contain examples from all functional guilds with the exception of freshwater species which, as would be expected, are rarely found at Hinkley Point;

d. they contain examples from all feeding guilds and habitat groups; and

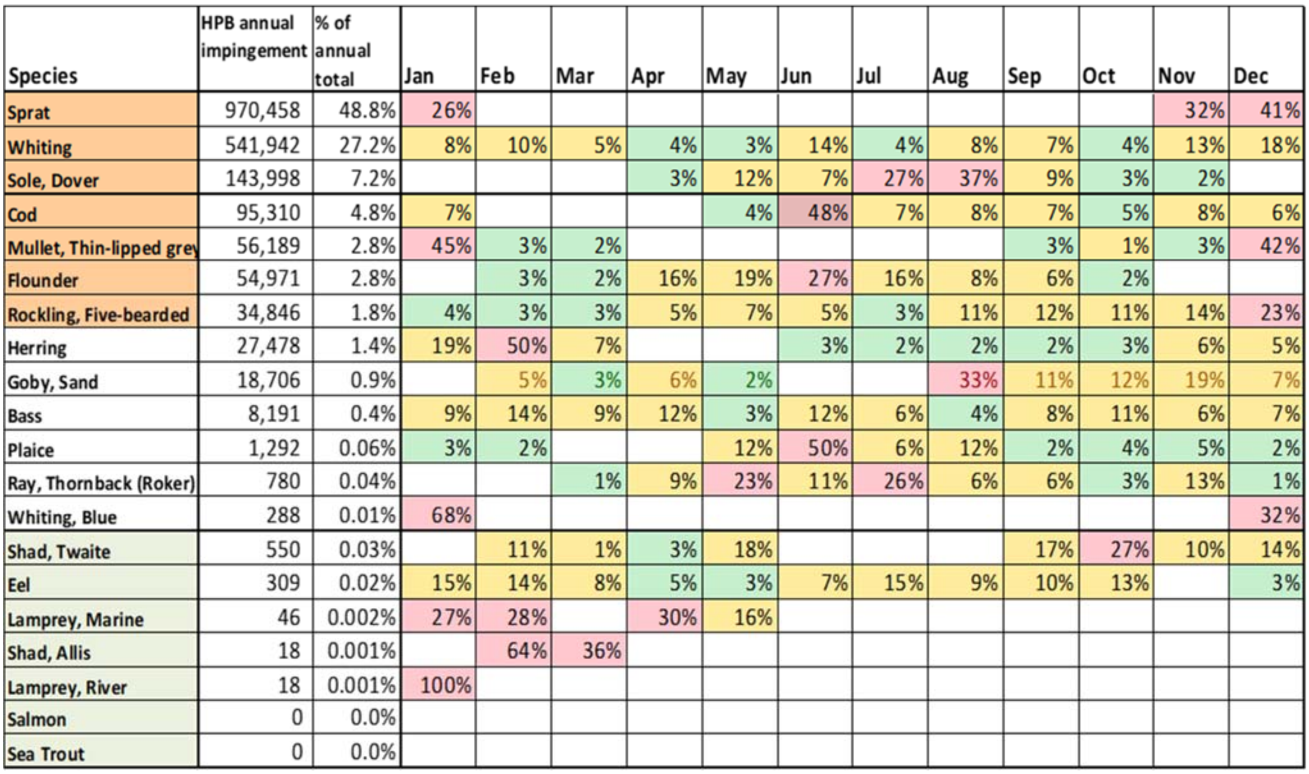
e. they contain all of the indicator species found at Hinkley Point that are assessed in the WFD “fish” biological quality element in transitional waters (See section 5.1).

The list contains 6 additional species that were not assessed in the HPC Environmental Statement (ES), WFD and shadow HRA (bass, thornback ray, mullet, flounder, five-bearded rockling and sand goby).

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, five-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 five-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. 48% 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 frequently only for weeks to a few months per annum (Table 10).

Table 10 Measured seasonality for the fish species assessed in this report showing percentage of the 12-month HPB CIMP 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	970,458	48.8%	26%										32%	41%
Whiting	541,942	27.2%	8%	10%	5%	4%	3%	14%	4%	8%	7%	4%	13%	18%
Sole, Dover	143,998	7.2%				3%	12%	7%	27%	37%	9%	3%	2%	
Cod	95,310	4.8%	7%				4%	48%	7%	8%	7%	5%	8%	6%
Mullet, Thin-lipped grey	56,189	2.8%	45%	3%	2%						3%	1%	3%	42%
Flounder	54,971	2.8%		3%	2%	16%	19%	27%	16%	8%	6%	2%		
Rockling, Five-bearded	34,846	1.8%	4%	3%	3%	5%	7%	5%	3%	11%	12%	11%	14%	23%
Herring	27,478	1.4%	19%	50%	7%			3%	2%	2%	2%	3%	6%	5%
Goby, Sand	18,706	0.9%		5%	3%	6%	2%			33%	11%	12%	19%	7%
Bass	8,191	0.4%	9%	14%	9%	12%	3%	12%	6%	4%	8%	11%	6%	7%
Plaice	1,292	0.06%	3%	2%			12%	50%	6%	12%	2%	4%	5%	2%
Ray, Thornback (Roker)	780	0.04%			1%	9%	23%	11%	26%	6%	6%	3%	13%	1%
Whiting, Blue	288	0.01%	68%											32%
Shad, Twaite	550	0.03%		11%	1%	3%	18%				17%	27%	10%	14%
Eel	309	0.02%	15%	14%	8%	5%	3%	7%	15%	9%	10%	13%		3%
Lamprey, Marine	46	0.002%	27%	28%		30%	16%							
Shad, Allis	18	0.001%		64%	36%									
Lamprey, River	18	0.001%	100%											
Salmon	0	0.0%												
Sea Trout	0	0.0%												

Key:

% of annual impingement	Colour
>20%	🟥
5% to 20%	🟨
1% to <5%	🟩
Not present or< 1%	

Notes:

1. Orange cells in first column = fish species that made up the first 95% of total impingement.
2. Salmon and sea trout were not detected during the CIMP programme.
3. Annual impingement number is based upon bootstrapped means.

4.5 Fish age and maturity distribution

The majority of the fish at Hinkley Point are immature juveniles (Figure 5 and Figure 6). (Data are from BEEMS Technical Report TR426).

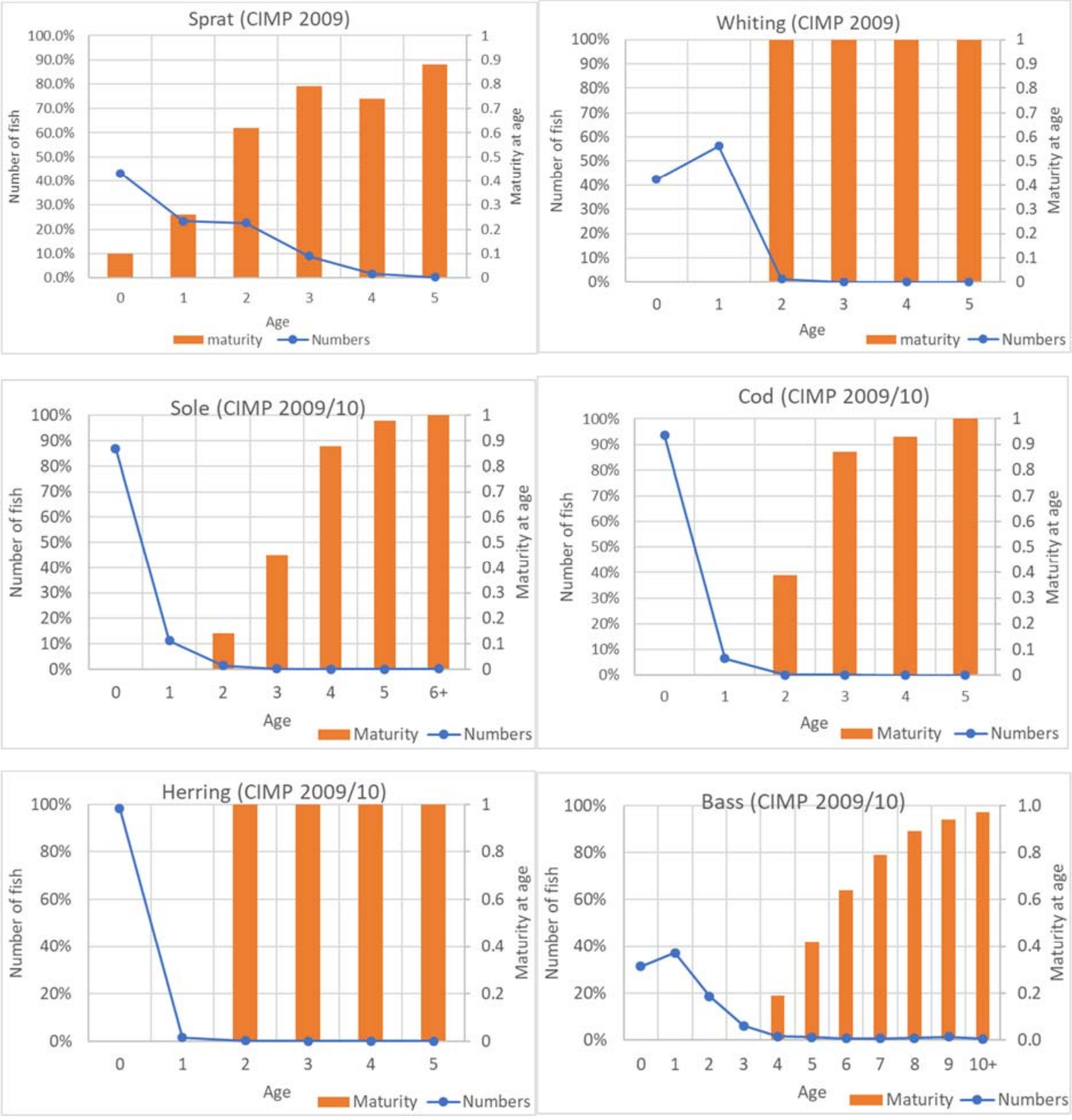
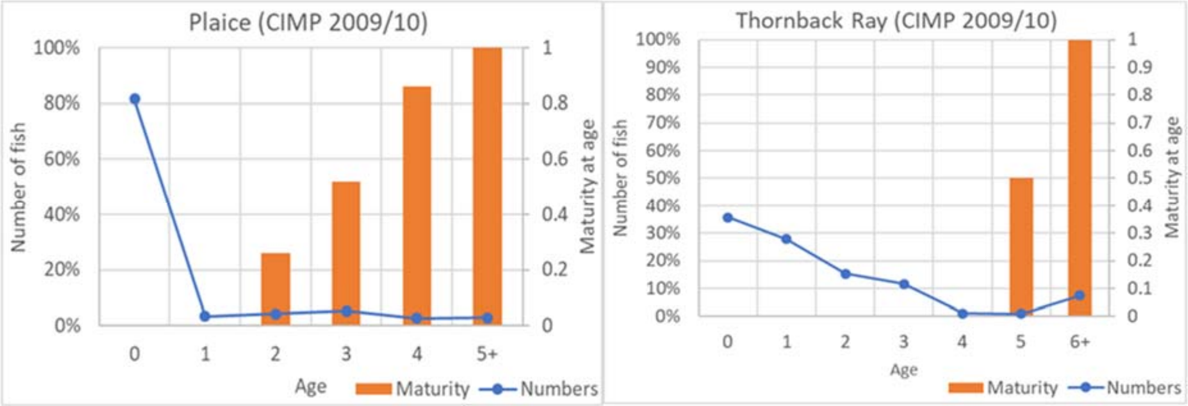


Figure 5 Fish age and maturity distributions from CIMP programme at HPB in 2009/10



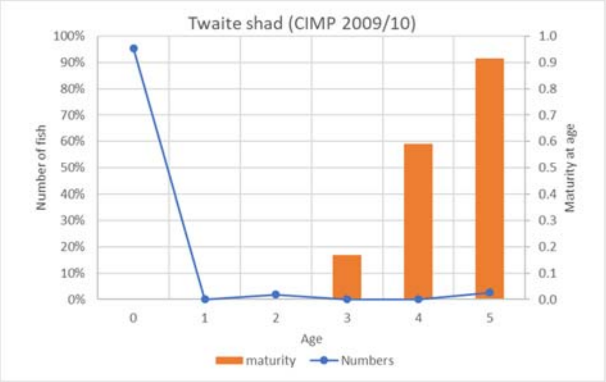


Figure 6 Fish age and maturity distributions from CIMP programme at HPB in 2009/10

4.6 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

4.6.1 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 considered 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.,* Aprahamian *et al* 2003).

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.

4.6.2 Salmon and sea trout smolts and kelts

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). Kelts (post spawning adults) of both species also migrate seawards in the same manner (Dr A Moore, Cefas, *pers.comm.*). 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 or kelts would be expected to be impinged in any significant numbers at either station.

The HPB RIMP programme has sampled a total of three seaward migrating salmon kelts in 37 years (1987,1989 and 2002). These adult fish had already spawned and made their contribution to the next year's recruitment. After spawning the majority of salmon do not survive but a few kelts in poor condition do return seawards. Typically, only approximately 2-5% of salmon kelts return to freshwater to spawn again (Cefas 2017) and of those their contribution to the proceeding year's recruitment success is unknown. The probability is that the salmon kelts impinged at HPB were strays from rivers joining the Bristol Channel but it also possible that these are stray fish from other catchments that are on their way to feeding grounds. If stray kelts were in the vicinity of the HPB intakes at low water, the combination of the high intake velocity of the HPB intakes and the uncapped designs would mean that fish that were in poor condition could be vulnerable to impingement. The design of the HPC intakes means that impingement risks for these stray fish would be much reduced (Section 3). An assessment of the predicted HPC impingement of salmon kelts is in Section 7.3.2.

4.6.3 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 abstracts from the bottom 6m 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 and the reduced height of the intake surfaces (from 1m to 3m off the seabed). 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 three 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 two taxa (two thornback ray and one conger eel) being less than 30 cm total length. The fishing surveys found no significant spatial differences in the fish community nor the fish length distributions between the locations of the HPC and HPB intakes.

An assumption that HPC will abstract the same amount of fish per cumec as HPB is unreasonably conservative and as described in Section 3.2 the design of the HPC intakes is expected to result in a ratio of fish impingement per cumec at HPC compared with HPB of:

- 64.6% for all species due to the reduced intercept cross sectional area of the HPC intakes; and
- An additional 38% for pelagic species (sprat, herring, twaite and allis shad) due to the use of capped intakes at HPC

The CIMP impingement assessment process is illustrated in Figure 7. The equivalent RIMP assessment process is illustrated in Appendix G.

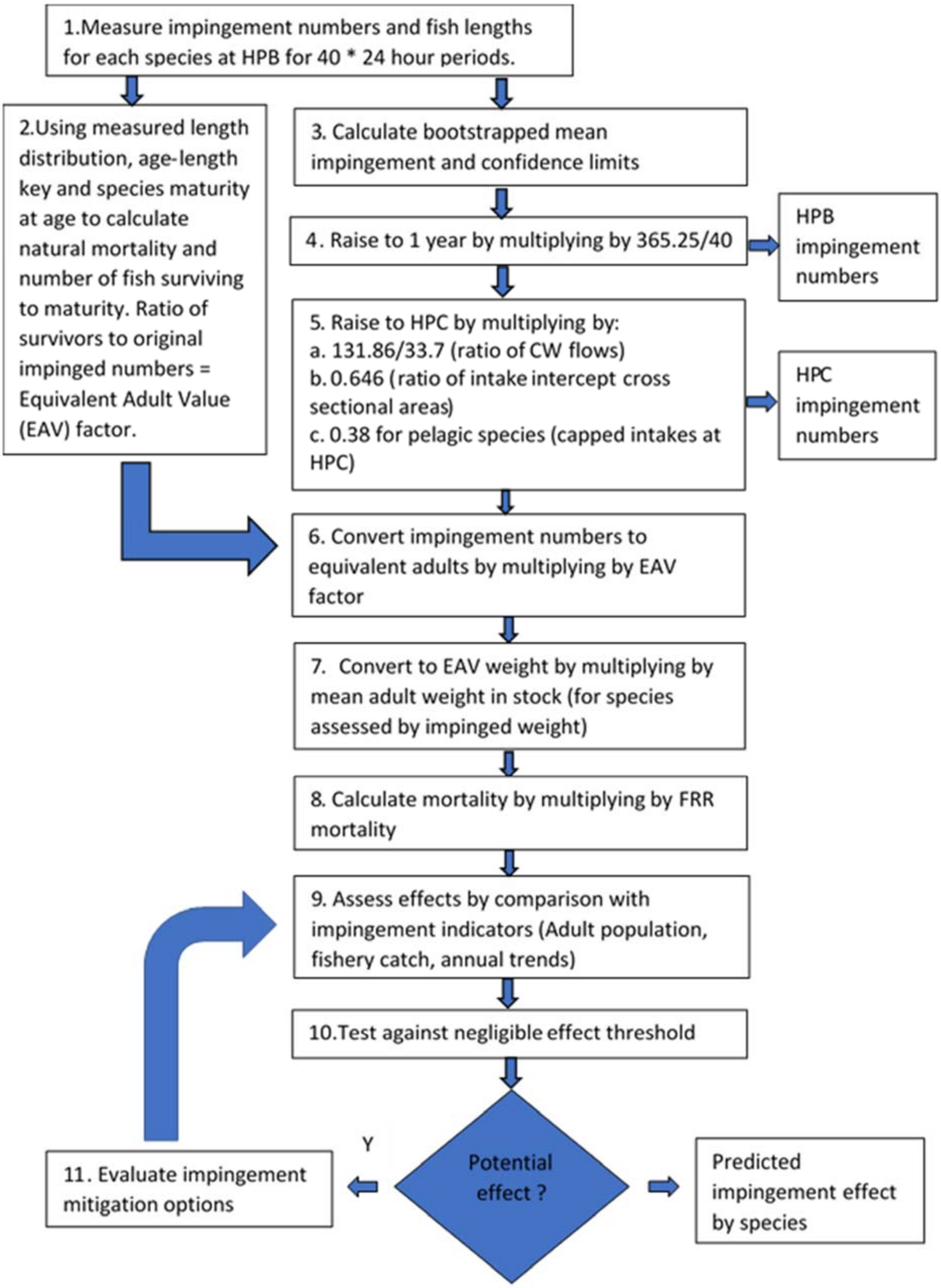


Figure 7 The CIMP impingement assessment process

5.1 Assessment of the significance of impingement effects

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.

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

b. **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 of the Parrett Estuary transitional water body.

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 11.

Table 11 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 11, 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 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.

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

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.

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.

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:

Bristol Channel Approaches pSAC

- Qualifying feature harbour porpoise, *Phocoena phocoena*

The test for the HRA assessment is whether the HPC impingement impact will produce a likely significant effect (LSE) on site integrity, assessed against the conservation objectives for the sites. The conservation objectives seek, subject to natural change:

- For the fish assemblage – to at least maintain the overall diversity of species and individual populations against an established baseline (that baseline has not been established).
- For the individual designated fish species – to ensure that populations are at least maintained and are at a level that is sustainable in the long term.

For both the assemblage and individual designated species the conservation objectives also seek to maintain associated prey populations.

For the harbour porpoise the draft conservation objectives seek to maintain fish prey populations. There is geographical and seasonal variation in porpoise diets that reflected the local availability of fish species. The conservation objectives would therefore be achieved by maintaining the fish assemblage.

Impingement surveys have detected 92 fish species at Hinkley Point but 68 species were rare and contributed two or fewer fish per year to the dataset. The number of fish sampled per year depends upon the sampling effort with the RIMP survey typically detecting 38 species per year whereas the CIMP survey sampled 62 species in 1 year. All of the SAC or Ramsar designated fish species have been sampled but with low numbers of eel and twaite shad and exceptionally rare samples of the other designated species (river and marine lamprey, allis shad, salmon and sea trout). The low numbers of these designated species is considered to be a reflection of the migratory behaviour of the species which renders them at very low to negligible risk of impingement (Sections 4.1, 4.6)

The assemblage is diverse and contains the characteristic species from all of the functional guilds, habitat groups and feeding guilds that would be expected of a European Atlantic seaboard estuary at this latitude (Elliott and Dewailly 1985). The site integrity test is therefore one of determining whether there is an LSE on the sustainability of fish populations.

5.1.1 What is meant by a sustainable fish population?

Fishing is the selective removal (or harvesting) of fish. Impingement is therefore a form of fishing but of lower selectivity (Section 4) and much lower impact magnitude. Fish populations grow and replace themselves and they are therefore renewable resources. In the absence of harvesting, the population size of a stock does not increase indefinitely and stabilises around a maximum that a given habitat can support (the carrying capacity); i.e. it is under density control. The scientific basis for the sustainable use of a renewable marine resource evolved during the first half of the 20th century and is based upon a fundamental ecological principle of density dependent population regulation. As the abundance of a density regulated population is reduced by harvesting, per capita net production increases (by means of increased rates of growth, survival and reproduction), until the population cannot compensate for additional mortality after which point the productivity of the stock decreases and eventually becomes at risk of collapse. The production generated by this compensation (known as surplus production) can be harvested on a sustainable basis on a year on year basis. (Rosenberg *et al* 2003). Sustainability can therefore be framed as ensuring a sustainable harvest rate; i.e. where the rate of abstraction is less than or equal to the rate at which the population can regenerate itself. Determination of that rate for different fish stocks has been an internationally coordinated endeavour for more than 70 years and has led to well established stock assessment principles.

For well monitored stocks (data-rich stocks) quantitative stock assessment can be carried out which produces spawning stock biomass reference points below which a stock is either at risk of becoming unsustainable or is in an unsustainable condition, together with limits on the maximum harvest rate. However, fisheries scientists are frequently required to advise on harvesting rates (also known as exploitation rates) of many data-limited stocks where an alternative precautionary approach is required. A number of analytical approaches are applied in such circumstances which are largely determined by the availability and quality of the data. The different approaches are essentially based upon:

a. Limiting fishing mortality (F) to no greater than the natural mortality (M) of the species (determined by the life-history of the species).
b. For stocks where there is a record of fish landings, limiting F to the average fishing mortality (or index of fishing mortality) that did not lead to stock decline.

(Source: Food and Oceans Canada 2001)

[Note: The harvesting rate as a percentage of SSB is given by: $1\text{-}e^{-F}$ and for many demersal and benthic species the adult M is in the range of 0.1 to 0.2]

Approach a. above is an internationally adopted management approach:

> *'Escapement strategies are used to manage short-lived species and exploitation rates of up to 20% are advised by ICES'* (*pers. comm.* Chief fisheries science advisor to Defra, 2018).
>
> *'Limiting the exploitation rate to 10-20% of the estimated spawning stock biomass will ensure that fishing does not cause the stock to decline to unsustainable levels'.* Giannini *et al* 2010.
>
> *'…a constant harvest rate of 20% of the spawning population became coastwide management policy …'. Hall et al 1988.*

M ranges from approximately 0.1 for some benthic species to >0.5 for some pelagic species at Hinkley Point (Appendix F); i.e. sustainable harvest rates vary with the lowest values being for long-lived, late maturating species. The sustainable harvest rate calculated from approach a. is an approximation to the maximum sustainable yield and as such is well above the biological reference point where the stock would be at risk of becoming unsustainable. On a precautionary basis a harvesting rate threshold of 10% SSB is appropriate as a screening threshold for potentially significant effects that may affect the sustainability of a fish stock.

5.1.2 Significance test for impingement effects applied at the time of the HPC DCO

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 SSB or fishery landings. Effects above this threshold would have required further investigations to determine whether significant effects were, in fact, present. The DCO assessment predicted that impingement would be less than 1% SSB (or the precautionary proxy of fishery landings) for all assessed species.

5.1.3 The 1% screening threshold for negligible effects in context

5.1.3.1 Natural variability of fish stocks

Fish stocks are subject to considerable annual 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 12. It can be seen that bass, cod, herring and twaite shad impingement numbers are highly variable (with changes of between 9 and 31:1 between years being measured whereas sprat and whiting numbers are less variable but even so display variations of between 4 and 3:1 between individual years.

Table 12 Measured year to year variations that have occurred in Hinkley Point fish population numbers in the period 2000-2017 (Source RIMP data).

Species	The 2 largest year to year changes in annual numbers from the RIMP annual dataset 2000-2017 (shown as the ratio of the impingement numbers in adjacent years)	
Bass	29.6	9.2
Cod	29.7	17.3
Herring	31.2	26.1
Sprat	4.2	3.7
Sole	9.3	2.8
Whiting	3.4	3.2
Twaite shad	18.5	17

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

5.1.3.2 Comparison with sustainable levels of harvesting rate for data rich stocks

In Section 5.1.1 the internationally accepted precautionary harvest rate of 10-20% SSB was described for species where little monitoring data exists. It is useful to consider a 1% negligible effects threshold in the context of sustainable harvest rates for data rich stocks which in many cases are much greater than 20% (see Table 13).

ICES produces estimates of the precautionary levels of fishing mortality beyond which sustainability is at risk (F_{pa}). Examples from ICES 2017 stock assessments are shown in Table 13. Set against such numbers, an impingement mortality of less than 1% from HPC is negligible.

Table 13 Sustainable fishing mortality values based upon a precautionary management approach for species relevant to Hinkley Point

Species	Sustainable fishing mortality reference values 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%

In particular, an additional 1% mortality in addition to the effects of fishing is in the noise for practical stock assessments and in practice such a level of effect is much smaller than that due to the uncertainty in the input parameters which are already assessed on a precautionary basis in the stock assessment.

5.1.3.3 An example of where screening thresholds for fish mortality have been applied for major infrastructure projects

A 10% screening threshold has been previously adopted by the Thames Tideway Strategy Group. This group comprised representatives from the Environment Agency, Port of London Authority, Thames Water and others and developed water quality standards for the regulation of dissolved oxygen levels in the Thames Tideway to protect fish from mortality associated with storm discharges through combined sewer outfalls (Turnpenny *et al.* 2004). The efficacy of different standards was compared using an ecotoxicological model, the Tideway Fish Risk Model (TFRM). The Turnpenny report argued that commercial fishery exploitation rates could be sustainable at >50% SSB, depending on the population dynamics of the species. Based upon the Turnpenny report, the TFRM considered annual mortality rates of up to 10 % to be sustainable for all species not subject to fishing mortality (i.e. the integrity of the population would not be threatened), and up to 30 % for longer-lived species such as bass (*Dicentrarchus labrax)* and salmon. The 10% value was also considered to be the practical minimum change likely to be detectable through ongoing routine WFD Transitional and Coastal (TrAC) water fish surveys.

The subsequent DCO application for the Thames Tideway Tunnel contained a review of the robustness of assumptions made in the TFRM including the definition of fisheries sustainability used in the model. The results of an independent expert peer review of the fisheries work were also provided (Thames Tidal Tunnel, 2013). The review conclusions were that the TFRM remained fit for purpose.

5.1.3.4 Conclusions on the appropriateness of a 1% SSB screening threshold for impingement effects

To have a negligible impact on a fish stock the predicted total anthropogenic harvest rate must be less than the value whereby the stock can replace itself on a year to year basis. For data poor species a precautionary level of 10%-20% SSB is considered sustainable in international fisheries management practice. ICES advises in the context of current management policy which is to manage all species within sustainable limits by 2020; and policy measures have been recommended to the European Commission, which is responsible for managing marine fisheries in Europe, and are now being implemented in order to meet this objective as soon as possible in relation to the 2020 target.

For species which are heavily exploited by fishing a lower effect threshold for impingement is considered appropriate and 1% negligible effect screening threshold for annual impingement for all species provides a precautionary level which is negligible compared with fishing mortality on exploited stocks and would have no effect on their sustainability. For non-exploited stocks such a level is highly precautionary on the basis of fish population dynamics and any observed decline in stock numbers would be due to other factors well beyond the influence of HPC impingement.

A precautionary level of 1% much less than the natural variability of any species at Hinkley Point which 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 by the results of this assessment in Table 43, the predicted impingement effects for HPC fitted with the planned LVSE intakes and FRR systems are much less than 1% SSB for all species with the largest calculated effect being a worst case mean of 0.077% of the fishery catch for thornback ray or 0.127% fishery catch as a 95th percentile. The predicted loss due to impingement at HPC was 0.6 tonnes. To put this level of impingement into context, the commercial landings for thornback ray in 2009 were 671 tonnes with discards of unwanted fish of approximately 84 tonnes (See notes to Table 23) i.e. The discards from the commercial fishery were 140 times the predicted impingement from HPC. There is no SSB estimate for thornback ray and the use of the fishery catch is a highly precautionary proxy for SSB i.e. the real impact on the stock is less than 0.038% SSB assuming a worst case 50% fishing mortality.

5.1.4 What does sustainability mean in an assemblage context?

For the individual designated species (shads, lampreys, eel, salmon and sea trout) the principle of maintaining a sustainable fish population is in principle straight forward but what does sustainability mean for an estuarine assemblage? The following facts are helpful in this context:

- The relative abundance of the species in the assemblage at Hinkley Point is changing with time (Sections 4.1, 11). Species composition is also changing but more slowly with an increasing prevalence of warm water species and a gradual reduction in the abundance of a number of species at the southern limit of their distribution due to climate change.
- There are very large diel, seasonal and interannual fluctuations in the population density of individual species at Hinkley Point (section 4.1, 4.4). Estuaries are amongst the most

fluctuating aquatic environments on earth, with the boundaries of natural variability, even for individual systems, seldom defined or recorded (Whitfield and Elliot 2002). The Severn is no exception and given its exceptionally dynamic nature, it is not surprising that no population baseline has been established for the assemblage.

- Individual species migrate into and out of the estuary in succession and the overwhelming majority spend most of their lifecycles outside of the SAC; there are very few truly estuarine resident species and these are not common at Hinkley Point (black goby, common goby, sand smelt, 3 spined stickleback) and all of these show either a statistically significant positive trend in abundance or no trend at the site, Appendix E).
- For most species only the juvenile life stage is exposed to impacts in the estuary and for most species the exposure to impingement risk at Hinkley Point is measured in weeks or a few months. Even within the estuary, species are mobile moving into and out of the regions of inner estuary whilst following prey or retreating from predators, seeking overwintering areas etc.
- The main influences on fish populations are outside the estuary either in reproductive success or survival against predation and fishing in coastal or oceanic waters in the case of marine species whose juveniles use the estuary (Whitfield and Elliott 2002).

In such circumstances, the concept of estuarine populations of the assemblage species has no biological meaning and the community reflects the state of each stock on a much broader spatial scale which is predominantly outside of the SAC. In just the same manner that the much larger effects of fishing are assessed against the spawning stock biomass of recognised fish stocks (Section 5.2), there is no scientific rationale for assessing the species at Hinkley Point in any other manner where such information exists.

5.2 Indicators for the assessment of impingement effects

5.2.1 Ecosystem modelling

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.

5.2.2 Fish stock assessments and population trend information

Ecosystem modelling to assess the effect of the predicted levels of HPC impingement (i.e. less than 1% SSB) 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 both unnecessary and disproportionately difficult to undertake for species where 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 considered 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 (or more accurately total international catch if discard data are available) can be used as a surrogate indicator. In TR148 local UK landings was used as a simplistic assessment indicator but it is recognised that this measure had significant limitations as UK landings generally 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 in this report 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 will rapidly collapse and fish stocks are managed under the EU Common Fisheries Policy with the objective of preventing such an outcome and maintaining the stock within safe biological limits. For a heavily exploited stock the total international fish catch can be used as a worst-case estimate of the fish population size. In cases where the population is not rapidly collapsing, this estimate will be an underestimate of the population size and will therefore produce an overestimate (normally a considerable overestimate) of the impingement effect.

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 impingement numbers are constant or rising under constant impingement pressure, using the precautionary approach for data poor stocks described in Section 5.1.1, the harvest rate (i.e. impingement mortality) is sustainable. In particular, prior to being taken offline in 2000, HPA abstracted more cooling water than HPB (44 as opposed to 33.7 cumecs) from the same intake location. If an impingement impact of the size of the HPA abstraction was having any effect on local fish populations then the closure should have been detectable in the impingement record. In practice no such effect can be detected. 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 most marine fish species, stock areas are large with widescale temporal and seasonal migrations and often considerable inter mixing between stocks. A Bridgwater Bay fish stock has no biological meaning for such 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 of the ICES SSB estimates (for cod and whiting) were transformed by Cefas into tentative and highly precautionary indicators of ‘local SSBs’ by scaling the ICES SSB by the local UK fishery catch. The purpose of this SSB scaling was to reflect the possibility that the stock identity for those 2 species might have been smaller than the 2010 ICES stock identities. In TR148 these ‘local SSBs’ were recognised as not being robust. In the subsequent 7-year period no evidence to substantiate the existence of these sub stocks has materialised and ICES has maintained the stock definition for cod and has, in fact, increased the spatial extent of the whiting stock unit based upon improved scientific evidence. The ‘local SSBs’ for cod and whiting used in TR148 are, 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 14).

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.

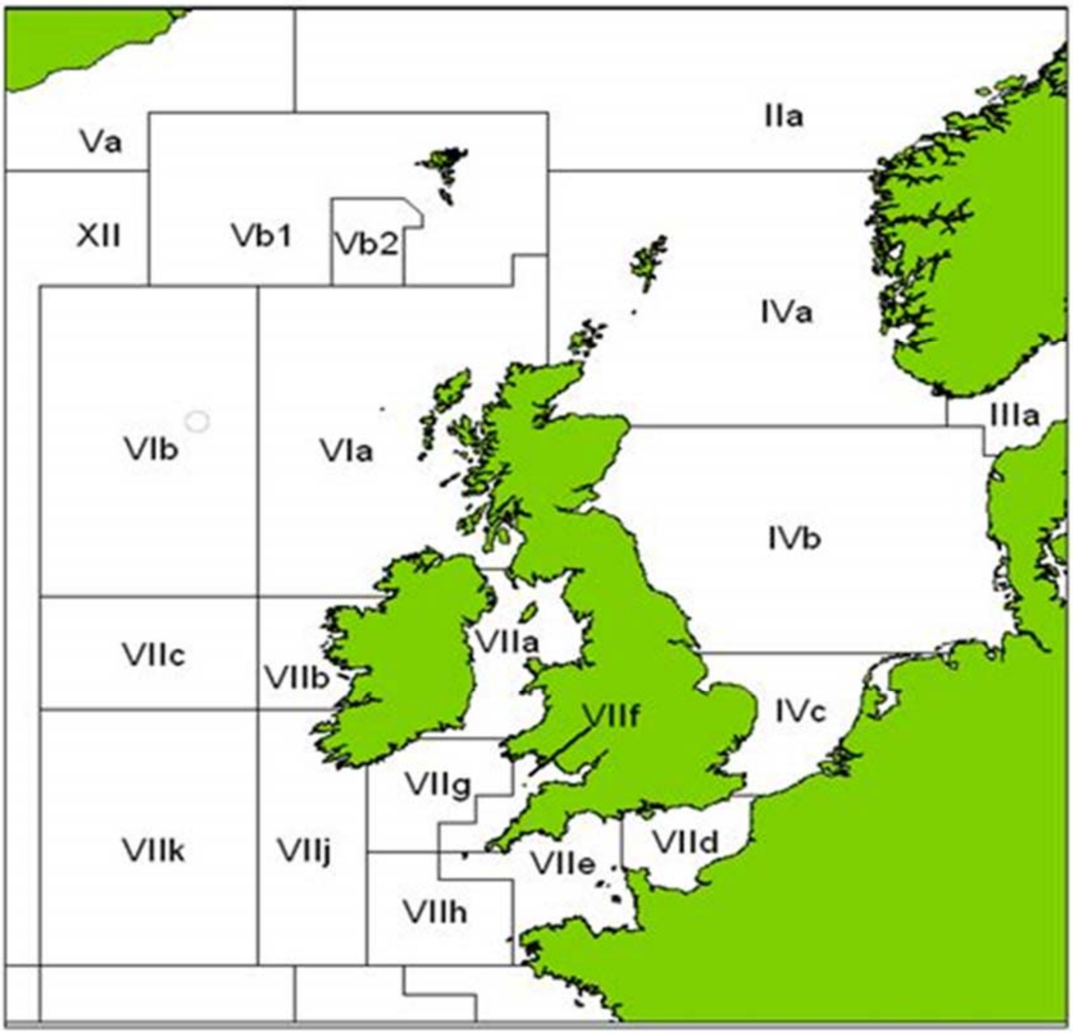


Figure 8 Map of ICES Divisions

Table 14 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 may be separate (BEEMS SPP089). The selected assessment indicator used in this report is the biomass of the population that congregates in the Bristol Channel approaches in October of each year (BEEMS SPP089). Examination of the age distribution in this population shows a lack of older mature fish (Cefas PELTIC survey biological information) and the stock therefore occupies a larger area and has a higher biomass than has been assumed for the HPC impingement assessment. The sprat assessment is therefore precautionary.

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

5.3 Calculation of Equivalent Adult Value (EAV) factors

The fish community at Hinkley point is predominantly made up of immature juveniles with only a small number of adult fish (Section 4.5). To undertake an impingement effects assessment, it is necessary to convert the number of juveniles into the number of adults that would survive to maturity ('equivalent adults') and add those to the number of fish that are mature at impingement. The procedure for calculating the number of equivalent adults is described in BEEMS Technical Report TR426.

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.

Empirical evidence and ecological theory indicate that the M of fish and invertebrate fishery resources scale with body mass or size. For a given species, early life history stages experience higher M than juvenile stages which, in turn, experience higher M than mature adults. Stress of reproduction and senescence may lead mortality rates to increase again in old fish (Brodziak *et a*l 2011).

Measurement of M involves following the different year classes of a species and determining the number of survivors in each year over several years until maturity. Analyses must factor in the effects of migration and ideally the population must not be commercially exploited otherwise it is difficult to disentangle natural and fisheries mortality. For many species such measurements are not practical and the measurements that do exist are largely for unexploited stocks.

The methods used to estimate and validate M at length for each species assessed in this report together with the computed EAVs are described in Appendix F. For impingement assessment purposes the 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.

For some species where there was uncertainty in the validation of the predicted M values a precautionary worst-case M value was calculated and also used to calculate an EAV. The results of these analyses are shown in Table 15. For some species the expected and worst case EAVs are the same. This was where the expected value was considered precautionary and there was no evidence that an even more worse case EAV was plausible (See Appendix F). For assessment purposes in this report the worst case EAVs have been used which will generate a precautionary estimate of impingement effects.

Table 15 Calculated EAVs for Hinkley Point fish species

Species	Expected EAV 2009	Worst case EAV 2009
Sprat	0.556	0.556
Whiting	0.099	0.142
Sole	0.236	0.236
Cod	0.0117	0.0117
Herring	0.113	0.113
Bass	0.121	0.121
Plaice	0.185	0.192

Thornback Ray	0.339	0.339

The revised EAV compared with the values used in TR148 are shown in Table 16.

Table 16 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.**	**Plausible worst case EAVs based upon CIMP measurements at Hinkley Point**
Sprat	1 (no data to compute at DCO)	0.556
Whiting	0.137	0.142
Sole	0.0538	0.236
Cod	0.0864	0.0117
Herring	0.4948	0.113
Bass	N/A	0.121
Plaice	0.0916	0.192
Blue Whiting (Whiting value used)	0.137	0.142
Thornback Ray	N/A	0.339
Eel, river lamprey, salmon, sea trout	1 (worst case – no data to compute true value which is <1)	1 (worst case – no data to compute true value which is <1 for any juvenile fish)
Marine lamprey	1(worst case – impingement consisted of adults with an EAV=1 and parasitic juveniles whose EAV was <1)	1 for adults, juveniles assessed directly against juvenile population estimates. i.e. EAVs are not relevant to the calculation for juveniles and a value of 1 has effectively been used.
Twaite shad	0.02768 (SPP071 Ed 2)	0.035 (SPP071 Ed 3)
Allis shad	0.2618 (SPP071 Ed 2)	0.2618 (SPP071 Ed 3)

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 SSB (See Section 5.2.2).

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 17.

Table 17 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.
3. Number in column 1 of the above table was the expected impingement numbers at HPC assuming no impingement mitigation (i.e. LVSE intakes and in this case AFD).

6.2 Updated impingement predictions produced during the DCO examination

Table 18 reflects the revisions to the cod and shad impingement predictions detailed in BEEMS Scientific Position Papers SPP065 and SPP071/S (Ed. 2), respectively. These updated predictions were produced during the DCO examination period and are the values that were assessed in the HPC ES, shadow HRA and WFD assessments.

Table 18 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	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	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%
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. In Table 18 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 (Ed. 2). The cod assessment approach in SPP065 was in response to the exceptional cod recruitment in 2009 and was essentially based upon RIMP impingement numbers in the period 2004-2008 which were a mean of 7.3% of those in 2009. Hence the unmitigated impingement numbers for cod in Table 17 of 371,097 were scaled to 27,090 in Table 18. This approach was recognised at the time to be an approximation and the SPP065 methodology has not been continued in this report, TR456.
3. Local fishery was defined as reported UK landings data in specified ICES rectangles – see TR148.
4. Number in column 1 of the above table was the expected impingement numbers at HPC assuming no impingement mitigation (i.e. LVSE intakes and in this case AFD).
5. LVSE intakes were assumed but no quantitative assessment of their expected benefit was provided in TR148.

Table 18 does not clearly show the predicted number of impinged fish at HPC after AFD mitigation. Table 19 reorganises the data so that the number of fish expected to be impinged can more readily be appreciated; there are no other changes to the table.

Table 19 HPC with AFD & FRR impingement predictions from Table 18 represented to more readily show the number of fish expected to be impinged at HPC (Column 4).

Species	Number	Entrapment risk AFD	Number impinged	EAV	FRR mortality	EAV number (After FRR)	EAV wt (t)	local fishery (t)	local SSB (t or number)	% of local fishery	% local SSB
Sprat	3,380,850	0.12	405,702	405,702	100%	405,702	3.16	0.19	NA	1665.5%	-
Whiting	2,102,759	0.45	946,242	129,635	50%	64,818	11.54	33.50	1613	34.4%	0.72%
Sole	602,776	0.84	506,332	27,241	20%	5,448	1.25	263.00	3240	0.5%	0.04%
Cod	27,090	0.45	12,191	1,053	50%	527	2.31	65.20	975	3.5%	0.24%
Herring	90,526	0.05	4,526	2,240	100%	2,240	0.28	119.40	NA	0.2%	-
Plaice	5,383	0.84	4,522	414	20%	83	0.04	84.00	952	0.0%	0.00%
Blue whiting	1,166	0.45	525	48	50%	24	0.00	37,900	5,360,000	0%	0.00%
Eel	1,304	1	1,304	1,304	20%	261	0.08	-	133.40	-	0.06%
Twaite	2,276	0.12	273	8	100%	8		-	184,000	-	0.00%
Allis shad	68	0.12	8	2	100%	2		-	700,000	-	0.00%
Sea lamprey	207	1	207	207	20%	41		-	15,269	-	0.27%
River lamprey	82	1	82	82	20%	16		-	116,109	-	0.01%
Salmon	0	1	0	0	50%	-		-	NA	-	-
Sea trout	0	1	0	0	50%	0		-	NA	-	-
crangon crangon	19,135,756	1	19,135,756	19,135,756	20%	3,827,151	5.70	-	NA	-	-

Note:

1. As per note 2 to Table 18, the predicted number of cod impinged in 2009 for comparison with the estimates presented in Section 7 was 371,097 (from Table 17) * 0.45 (AFD entrapment risk) = 166,994.

6.2.1 Conclusions on impingement effects drawn at DCO

In all cases where estimates of the SSB were available, the predicted impingement effects shown in Table 18, at less than 1% of the SSB, were considered 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 18 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 20 and to evaluate the environmental effects of HPC with no AFD system fitted.

Table 20 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 have increased, others have decreased. (Sections 5.2.2 and 8.1.6)
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 (Sections 5.3, 8.1.3)
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 (Appendix A).
d.	Added assessments for six additional species not included at the time of DCO (bass, thornback ray, flounder, thin lipped grey mullet, five-bearded rockling and sand goby).	Provides confidence that the assessment is fully representative of the effects of HPC impingement on the fish assemblage (Sections 4.3, 7.3.1)
e.	Quantitative analysis of the expected impact of the HPC LVSE intake heads on impingement. This was not addressed in TR148.	By not taking account of the design of the HPC intake heads the previous impingement estimates were unrealistically conservative. The revised estimates are considered more reliable but still conservative as they do not take into account the full impact of the HPC intake design and location.
f.	Revised impingement numbers from the CIMP programme and use of a statistically more robust bootstrapping procedure to calculate the mean and confidence limits on the impingement estimates. A comprehensive uncertainty analysis using Monte Carlo simulation process has been undertaken. A significantly expanded analysis on the effects of interannual variability in impingement numbers has been included. A more robust statistical analysis of trends has been undertaken on the RIMP data. The CIMP data have been subject to enhanced quality assurance which has resulted in increased numbers	Provides substantially more confidence in the reliability of the impingement predictions Appendix D Section 9 Section 8 Appendix E

	for 16 fish species in the raw CIMP impingement dataset.	
g.	Revised mean weights used to convert the number of equivalent adult fish into impingement weight.	More reliable impingement predictions. Results in increases in predicted impingement impacts for some species (Section 8.1.4).
h.	Provision of assessments for species that were not detected during the CIMP survey (Salmon and Sea Trout) using the RIMP dataset.	Substantially increased confidence in the DCO assessment that the impingement effect on these designated species is negligible Section 7.3.2)

7.1 Revised HPB mean impingement predictions (assessed from the CIMP dataset)

Table 21 shows the predicted annual mean impingement at the existing HPB station that has no impingement mitigation measures fitted.

Table 21 Revised HPB mean impingement assessment from the CIMP dataset.

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	970,458	0.556	539,575	100%	539,575	8.4	-	N/A	-	N/A
Whiting	541,942	0.142	76,956	100%	76,956	22.9	6572	34918	0.35%	**0.066%**
Sole, Dover	143,998	0.236	33,984	100%	33,984	12.0	805	2857	1.49%	**0.420%**
Cod	95,310	0.012	1,115	100%	1,115	5.3	3292	5092	0.16%	**0.104%**
Herring	27,478	0.113	3,105	100%	3,105	0.2	627	-	**0.03%**	-
Bass	8,191	0.121	991	100%	991	1.1	5657	18317	0.02%	**0.006%**
Plaice	1,292	0.192	248	100%	248	0.1	1089	4707	0.01%	**0.002%**
Ray, Thornback	780	0.339	265	100%	265	0.9	755	-	**0.11%**	-
Whiting, Blue	288	0.142	41	100%	41	0.006	37900	5360000	0.00%	**0.000%**
Eel	309	1	309	100%	309	0.1	-	133	-	**0.076%**
Shad, Twaite	550	0.035	19	100%	19		-	165,788	-	**0.012%**
Shad, Allis	18	0.262	5	100%	5		-	27,397	-	**0.017%**
Lamprey, Marine	46	1	46	100%	46		-	15,269	-	**0.151%**
Lamprey, River	18	1	18	100%	18		-	116,109	-	**0.016%**
Salmon	0			100%						-
Sea trout	0			100%						-
Crangon crangon	4,525,055	1	4,525,055	100%	4,525,055	6.74				

Notes:

1. Predictions based upon HPB CW flow of 33.7 cumecs
2. EAVs are calculated as described in Appendix F. Worst case EAVs are used.
3. There is no survey estimate of sprat SSB for 2009. The evidenced assessments provided in Section 8.2.1 provide HPC impingement predictions for the 4 year period 2013-2016 inclusive.
4. The shad SSB excludes the River Tywi population.
5. The Thornback ray fishery is landings of 671T+25% discards at 50% survival = 755 T (unwanted catch estimate is from Cefas, Dr J. Ellis *pers. comm.* November 2018)
6. The marine lamprey impingement consisted of 50% adults and 50% parasitic juveniles. These proportions of the impingement numbers shown above have been assessed against the respective population estimates from Table 29 (for the Wye and Usk) and the EAV factor has not, therefore, been used. I.e. juveniles =23/11.183M =0.0002% of juvenile population, adults =23/15269 =0.151% SSB.

7.2 Revised HPC mean impingement predictions with LVSE intakes but with no FRR fitted (assessed from the CIMP dataset)

Table 22 Revised HPC mean impingement assessment assuming LVSE intakes but ***no*** *FRR system fitted. – from CIMP dataset.*

Species	Number impinged	EAV	EAV Number	EAV wt (t)	Fishery (t)	SSB (t or number)	% of fishery	% of SSB
Sprat	932,129	0.556	518,264	8.0	-	N/A	-	N/A
Whiting	1,369,835	0.142	194,517	58.0	6572	34,918	0.88%	**0.166%**
Sole, Dover	363,976	0.236	85,898	30.3	805	2,857	3.77%	**1.061%**
Cod	240,909	0.012	2,819	13.4	3292	5,092	0.41%	**0.263%**
Herring	26,393	0.113	2,982	0.2	627	-	**0.03%**	-
Bass	20,704	0.121	2,505	2.8	5657	18,317	0.05%	**0.015%**
Plaice	3,266	0.192	627	0.2	1089	4,707	0.02%	**0.004%**
Ray, Thornback	1,973	0.339	669	2.2	755	-	**0.29%**	-
Whiting, Blue	728	0.142	103	0.0	635000	2,781,230	0.00%	**0.000%**
Eel	782	1	782	0.3	-	133	-	**0.193%**
Shad, Twaite	528	0.035	19		-	165,788	-	**0.011%**
Shad, Allis	18	0.262	5		-	27,397	-	**0.017%**
Lamprey, Marine	117	1	117		-	15,269	-	**0.382%**
Lamprey, River	46	1	46		-	116,109	-	**0.040%**
Salmon	0							-
Sea trout	0							-
Crangon Crangon	11,437,723	1	11,437,723	17.04				

Notes

1. Predictions based upon HPC CW flow of 131.86 cumecs
2. EAVs are calculated as described in Appendix F. Worst case EAVs are used.
3. There is no survey estimate of sprat SSB for 2009. The evidenced assessments provided in Section 8.2.1 provide HPC impingement predictions for the 4 year period 2013-2016 inclusive.
4. The shad SSB excludes the River Tywi population.
5. The Thornback Ray fishery is landings of 671T+25% discards at 50% survival = 755 T (unwanted catch estimate is from Cefas, Dr J. Ellis *pers. comm.* November 2018)
6. The marine lamprey impingement consisted of 50% adults and 50% parasitic juveniles. These proportions of the impingement numbers shown above have been assessed against the respective population estimates from Table 29 (for the Wye and Usk) and the EAV factor has not, therefore, been used. I.e. juveniles =58.5/11.183M =0.0005% juvenile population, adults =58.5/15269 =0.382% SSB

For all species in Table 22 the predicted HPC impingement without FRR systems fitted as a percentage of SSB or the fishery landings/catch is less than the 1% negligible effects threshold with the minor exception of sole where the predicted impingement is 1.06% SSB.

7.3 Revised HPC mean impingement predictions with LVSE intakes and FRR systems fitted (assessed from CIMP dataset).

Table 23 shows the predicted impingement levels with HPC fitted with LVSE intakes and Fish Recovery and Return (FRR) systems. The derivation of the FRR mortality is described in Appendix A.

Table 23 Revised HPC mean impingement assessment assuming that LVSE intakes and FRR systems are fitted to HPC (from the CIMP dataset)

Species	Number impinged	EAV	EAV Number	FRR mortality	EAV number after mitigation	EAV wt (t)	Fishery (t)	SSB (t or number)	% of fishery	% of SSB
Sprat	932,129	0.556	518,264	100%	518264	8.0	-	N/A	-	N/A
Whiting	1,369,835	0.142	194,517	55%	106012	31.6	6572	34,918	0.481%	**0.090%**
Sole, Dover	363,976	0.236	85,898	20%	17523	6.2	805	2,857	0.768%	**0.217%**
Cod	240,909	0.012	2,819	55%	1559	7.4	3292	5,092	0.225%	**0.145%**
Herring	26,393	0.113	2,982	100%	2982	0.2	627	-	**0.031%**	-
Bass	20,704	0.121	2,505	70%	1747	2.0	5657	18,317	0.035%	**0.011%**
Plaice	3,266	0.192	627	43%	266	0.09	1089	4,707	0.008%	**0.002%**
Ray, Thornback	1,973	0.339	669	41%	271	0.9	755	-	**0.118%**	-
Whiting, Blue	728	0.142	103	55%	56	0.008	635000	2,781,230	0.000%	**0.000%**
Eel	782	1	782	20%	156	0.05	-	133	-	**0.039%**
Shad, Twaite	528	0.035	19	100%	19	-	-	165,788	-	**0.011%**
Shad, Allis	18	0.262	5	100%	5	-	-	27,397	-	**0.017%**
Lamprey, Marine	117	1	117	20%	23	-	-	15,269	-	**0.077%**
Lamprey, River	46	1	46	20%	9	-	-	116,109	-	**0.008%**
Salmon	-	0	-	55%	0	-	-	0	-	-
Sea trout	-	0	-	55%	0	-	-	0	-	-
Crangon Crangon	11,437,723	1	11,437,723	20%	2,287,545	3.41	-	0	-	-

Notes:

1. Predictions based upon HPC CW flow of 131.86 cumecs
2. EAVs are calculated as described in Appendix F. Worst case EAVs have been used.
3. There is no survey estimate of sprat SSB for 2009. The evidenced assessments provided in Section 9 provide HPC impingement predictions for the 4-year period 2013-2016 inclusive.
4. This table provides an assessment of 2 species not included in the DCO submission; bass and thornback ray.
5. The shad SSB excludes the River Tywi population.
6. The Thornback ray fishery is landings of 671T+25% discards at 50% survival = 755 T (unwanted catch estimate is from Cefas, Dr J. Ellis *pers. comm.* November 2018).
7. The marine lamprey impingement consisted of 50% adults and 50% parasitic juveniles. These proportions of the impingement numbers shown above have been assessed against the respective population estimates from Table 29 and the EAV factor has not, therefore, been used. I.e. juveniles =11.7/11.183M =0.0001% juvenile population, adults =11.7/15269 =0.077% SSB.
8. As described in section 4.3, salmon and sea trout were not detected in the CIMP survey but have been detected rarely in the RIMP survey. An assessment for both species is provided in Section 7.3.2.

With the FRR systems installed the predicted impingement for all fish species shown in Table 23 is much less than the negligible effects threshold of either 1% of SSB or 1% of landings/catch in the commercial fishery for herring and thornback ray. The predicted impingement effects ranged from a maximum of 0.217% SSB for sole to less than 0.001% SSB for blue whiting. At such levels HPC would would not have an effect on the sustainability of any of the species.

7.3.1 HPC Impingement assessment (with FRR fitted) of species with no SSB or catch estimates

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

- Thin lipped grey mullet
- Flounder
- Five-bearded rockling
- Sand goby
- The brown shrimp, *Crangon crangon*

These five 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 has increased exponentially over the 37-year RIMP survey period. None of the five 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 currently 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 23 is therefore not possible for these 5 species and instead trend analysis of HPB impingement data has been used.

Figure 9 to Figure 13 illustrate the 37-year trend for the five species using annual impingement numbers at HPB with particularly strong trends visible in annual data for thin lipped grey mullet, five-bearded rockling and brown shrimp. The monthly fish data have been analysed using the seasonal Mann Kendal trend test and all show a statistically significant positive trend over the period (Appendix E).

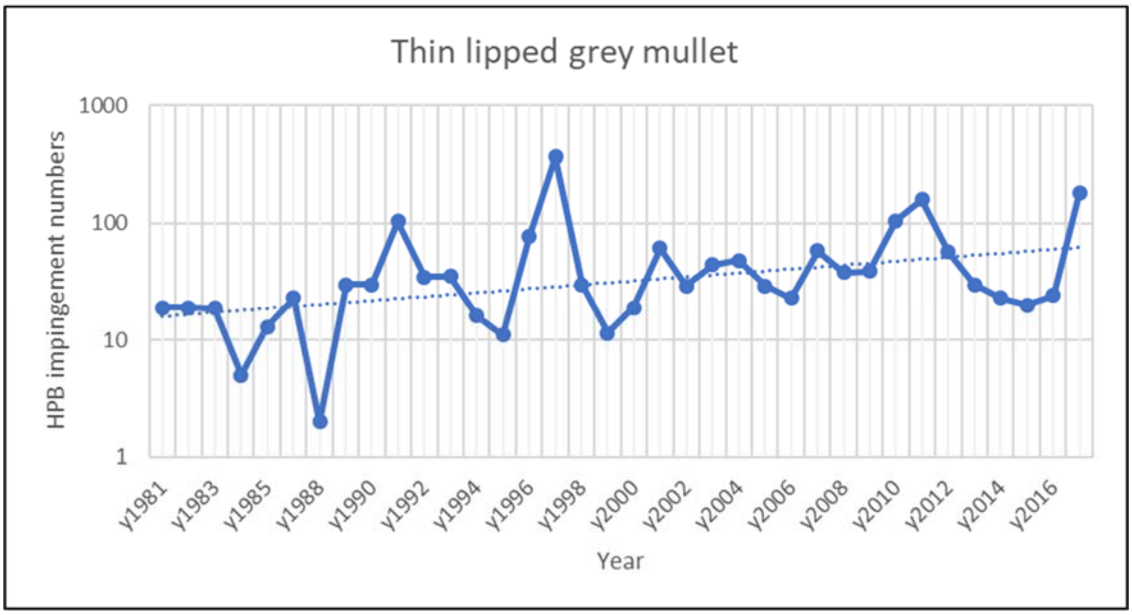


Figure 9 Trend for grey mullet (Liza ramada) (Seasonal MK: Tau=0.192 , p<0.001, Significant positive trend, Appendix E).

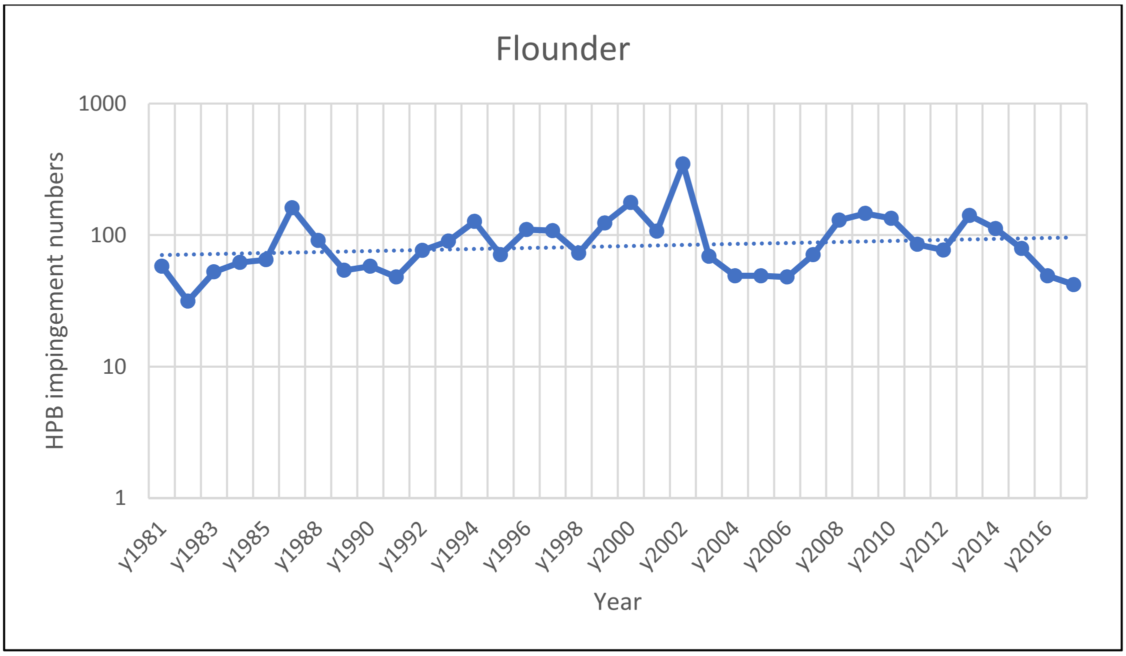


Figure 10. Annual trend for flounder (Platichthys flesus). (Seasonal MK: Tau=0.127, p=0.006, Significant positive trend, Appendix E)

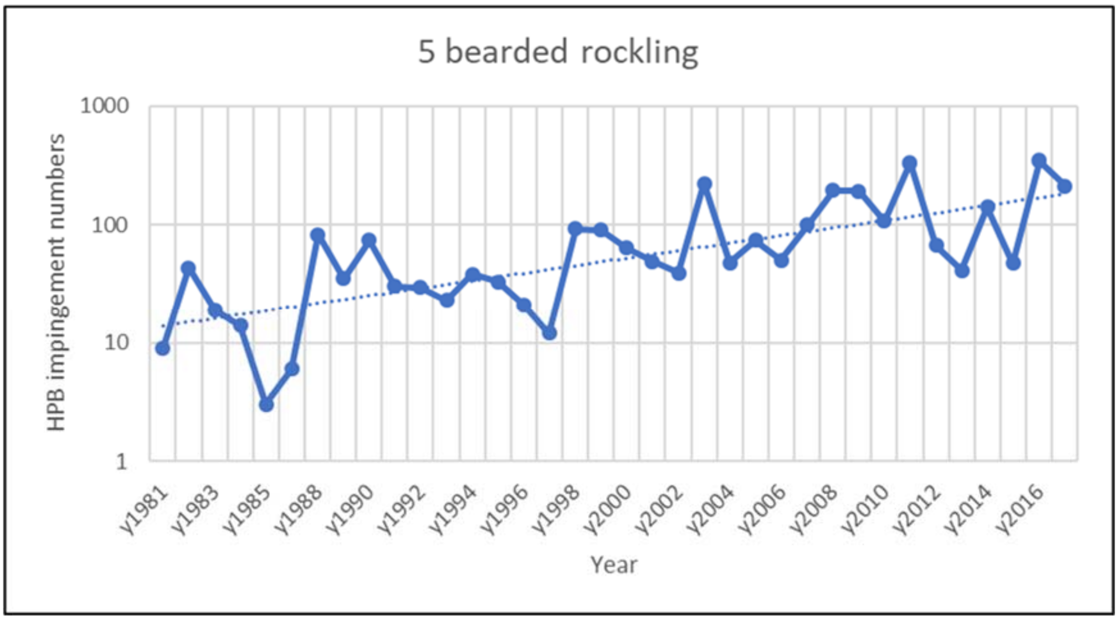


Figure 11. Annual trend for five-bearded rockling (Ciliata mustela). (Seasonal MK: Tau=0.304, p<0.001, Significant positive trend, Appendix E).

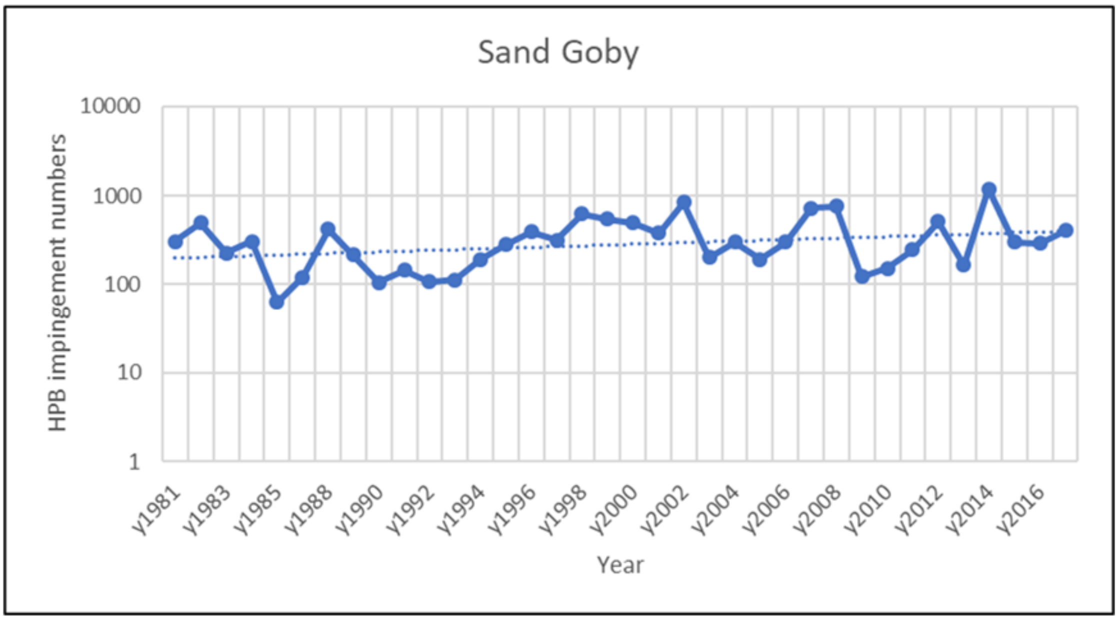


Figure 12. Annual trend for Sand Goby (Pomatoschistus minutus). (Seasonal MK: Tau=0.152, p=0.019, Significant positive trend, Appendix E)

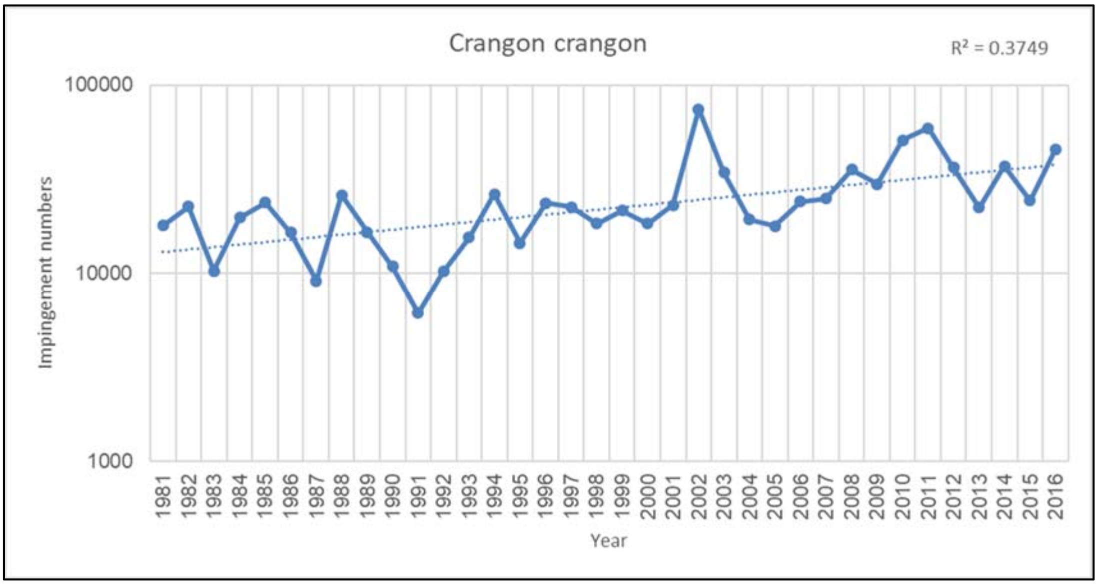


Figure 13 Annual trend for Brown shrimp (Crangon crangon)

These five 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 detectable 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 the improved intake head design and FRR mitigation the equivalent impacts will reduce as shown in Table 24.

Table 24 Effect of fitting an FRR to HPC for each of the 5 species listed.

Species	Estimated HPC mean Impingement number without FRR	Estimated HPC FRR mortality (based upon size of largest individuals impinged at HPB	HPC mean impingement post FRR assuming EAV=1 for all species	Equivalent unmitigated abstraction (cumecs) = FRR mortality *HPC CW abstraction (132 cumecs)* 0.646 (Section 3.1.1)
Mullet	142,026	55%	77,404	46
Flounder	138,948	43%[1]	59,748	37
Five-bearded rockling	88,078	20%	17,616	17
Sand Goby	47,283	20%	9,457	17
Brown shrimp *(Crangon crangon)*	11,437,723	20%	2,287,545	17

Note 1: FRR mortality for flounder assumed to be that for plaice based upon similar morphometrics.

7.3.1.1 Evidence for no predicted effect on the species listed in Table 24.

From the trend evidence the following conclusions can be drawn:

i. The abundance of all five species at Hinkley Point has a statistically significant positive trend. From well-established principles for the sustainable management of fish populations, if the impingement numbers are constant or rising under constant impingement pressure, using the precautionary approach for data poor stocks described in Section 5.1.1, the harvest rate (i.e. impingement mortality) is sustainable. i.e. if the mortality due to HPB (at approximately 33.7 cumecs) was unsustainable the population would show a decline.
ii. When HPA closed down an abstraction of 44 cumecs was removed from the Hinkley Point intakes. If an impingement impact of the size of the HPA abstraction was having any effect on local fish populations then the closure should have been detectable in the impingement record. In practice no such effect can be detected. (Appendix E). The populations of the five species are, therefore, not sensitive to at least a 44 cumec change in abstraction. The equivalent abstraction for HPC will be less than 44 cumecs for 4 of the 5 species with only mullet experiencing a slightly higher equivalent abstraction at 46 cumecs. Given the statistically strong trend in mullet numbers the 46 cumecs from HPC is not expected to have any effect on the mullet population level
iii. The equivalent unmitigated abstraction in all five cases is less than 97 cumecs of abstraction that has ceased operation since 1989 and it can, therefore, be expected that the operation of HPC would have no effect on the population trend for all five species.
iv. Finally, the impingement impact on 3 of the species at HPC will be less than that of HPB at 33.7 cumecs. When HPC becomes operational, impingement effects on these species will drop compared with the DCO baseline. For mullet and flounder the net increase in impingement will be 12.3 and 3.3 cumecs respectively, both are of which are far less than the 44 cumecs impingement pressure that was exerted by HPA and which had no effect on population numbers.

7.3.2 Assessment of salmon and sea trout impingement

Salmon and sea trout were not detected in the high sampling intensity CIMP survey at HPB but both have been detected rarely in the HPB RIMP programme (Sections 4.1, 4.6):

- The maximum annual salmon impingement (i.e. of adults since loss of juveniles would have a much lower impingement effect due their low EAV) was one adult salmon in 1987, one in 1989 and one in 2002 (all kelts that had already spawned).
- Only one sea trout has been detected in the 37 years of the RIMP – one adult in 2017.

In Section 4.2 it was explained that a total of one non-pelagic fish caught in one six-hour sample, in one month of the RIMP would scale up to a theoretical HPC maximum impingement prediction of 385 fish (making the highly unlikely assumption that the same fish density would occur for each 6-hour period of every day of the month). What interpretation should therefore be placed on a single salmon catch in one year? The use of a scaling factor of 385 to scale up annual RIMP estimates to estimates of impingement at HPC is statistically invalid for such low probability events. The reasons for this conclusion are explained below and an alternative more robust assessment is presented.

7.3.2.1 Salmon

The Environment Agency (EA) and Natural Resources Wales (NRW) make an annual assessment of spawning escapement in the 64 principal salmon rivers of England and Wales (Cefas 2017). The assessed rivers of relevance to Hinkley Point impingement include the Severn, Wye and Usk. The EA/NRW assessment also includes an estimation of the annual number of adult spawners per river and the time series for these three rivers goes back to 1997 (Table 25). The adult salmon population in the 3 rivers has been relatively stable over the 21-year period but with an apparently increasing trend in the later years of the time series (Figure 14).

Table 25 Number of salmon spawners (adults) by river and by year)

Year	Severn	Usk	Wye	Total
1997	4,011	6,528	4,663	15,203
1998	2,096	5,574	5,631	13,301
1999	2,083	5,465	5,816	13,365
2000	2,700	4,237	7,952	14,888
2001	3,354	5,954	8,219	17,527
2002	2,013	2,562	6,636	11,211
2003	3,977	4,464	3,403	11,844
2004	3,705	6,462	7,491	17,658
2005	5,170	5,746	4,720	15,635
2006	4,069	4,407	7,209	15,684
2007	2,522	3,970	8,629	15,121
2008	3,479	5,784	8,051	17,314
2009	2,549	3,414	3,704	9,667
2010	2,551	2,519	3,772	8,843
2011	4,658	4,896	5,213	14,766
2012	3,269	7,799	8,450	19,518
2013	4,507	7,778	4,658	16,943
2014	2,863	4,247	3,696	10,807
2015	7,830	9,405	6,097	23,332
2016	5,665	13,001	8,676	27,343
2017	5,139	9,471	8,966	23,576
Mean				15,883
Standard deviation				4,673

Source: Environment Agency/Natural Resources Wales.

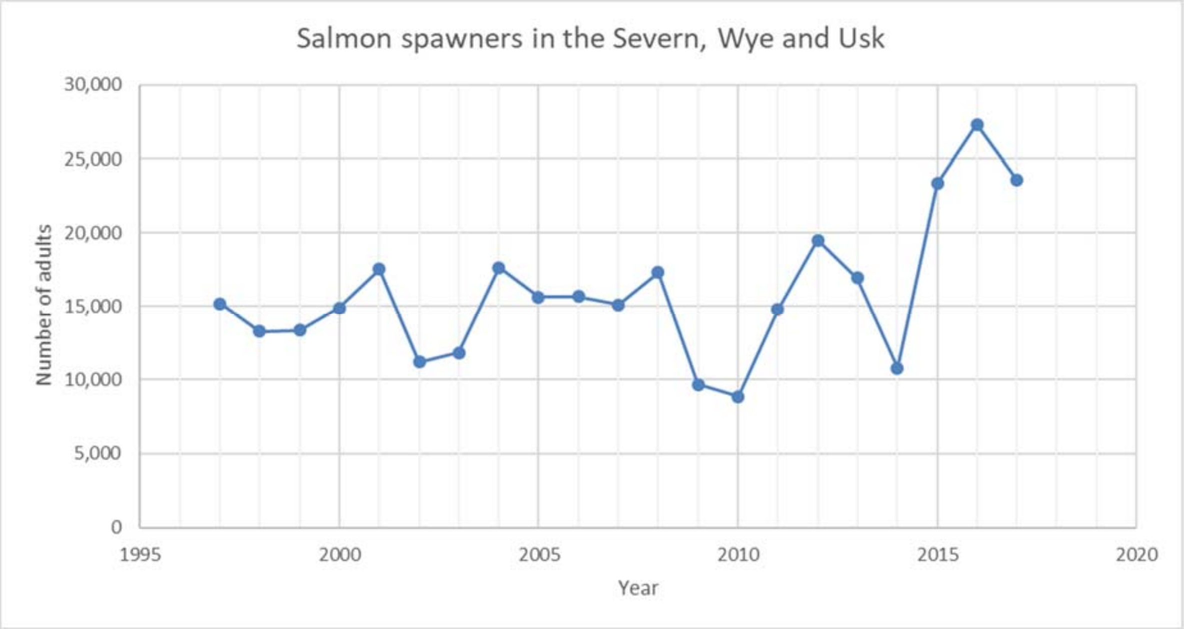


Figure 14 Adult Salmon trend from 1997 -2017

In period 1997 to 2017 one adult salmon was caught in the RIMP programme in 2002. The combined adult population in 2002 was 11,211 (Table 25) and the population was lower than this in only three out of the 21 years. The adult salmon population was at a low point in 2002 and was higher in most years subsequently. The number of kelts detected in the RIMP programme in the years subsequent to 2002 would, therefore, have been expected to greater than the one fish detected in 2002 but instead none were detected in any year.

The population in the CIMP year (2009) and in 2002 were similar (11,211 in 2002, 9,667 in 2009; i.e. 86% of the 2002 population) and therefore the number of kelts impinged in the 2 years would have been expected to be roughly the same. However, the CIMP programme sampled approximately 27 times as much cooling water as the RIMP in the winter period when the salmon was impinged (13.3 times increase in sampling effort between the CIMP and the RIMP on double the number of pumps). The kelts were detected on the ebb tide and. the CIMP sampled 13.3 times as much water as the RIMP on the ebb and, on average, approximately 11.4 salmon (after adjusting for the adult population ratio between the 2 years by multiplying by 86%) would have been expected in the CIMP programme if simple scaling of the RIMP result was valid. However, none were detected. This provides evidence that it is not appropriate to scale up the RIMP by the number of 6h periods in the month for such rare events. The theoretical scaling ratio for transforming RIMP impingement numbers into HPC annual numbers is 192 (i.e. the 24h raising factor (section 4.2) divided by 2 for ebb tides only). Based on the above analysis, the scaling factor is <u>at least</u> 11.4 times less; i.e. one fish in the RIMP = 16.8 fish at HPC

However, this is not a robust analysis as it does not take into account that no adults were detected in the other 20 years of the RIMP time series between 1997 and 2017.

The RIMP data for salmon showed an average annual density over the 21-year time series (1997-2017) of 0.048 fish per annum at HPB producing a scaled up annual average impingement at HPC of 0.8 salmon per annum. The mean number of adults per year was 15,883 over the time series and therefore the predicted mean HPC impingement effect of 0.8 salmon was 0.005% SSB (assuming that the HPC FRR offered no benefit to salmon) or 0.012% SSB as a worst case assuming the SSB was at 2 standard deviations below the mean.

In the 37-year RIMP programme a total of three adult salmon were detected (1987,1989,2002) but there is no salmon SSB estimate for the three assessed rivers before 1997. Assuming the same mean SSB level as in 1997-2017, the mean impingement was 3/37 adults per annum at HPB or 1.36 fish per annum at HPC. This represents 0.0086% SSB or 0.021% SSB assuming the salmon SSB was at 2 standard deviations below the mean. This is considered a worst-case interpretation of the RIMP salmon data.

7.3.2.2 Sea Trout

The sea trout impingement statistics are even more extreme than those for salmon with only a single adult fish detected in the 37 years of the RIMP in 2017. Using the same scaling ratio as in Section 7.3.2.1 the mean adult density in the period was 0.027 fish per annum at HPB producing a scaled up maximum annual impingement at HPC of 0.45 adult fish per annum.

There is no adult stock estimate for the sea trout originating from rivers that drain into the Bristol Channel (Severn, Wye, Usk, Taff). With the exception of the Usk, these rivers are considered to be poor sea trout rivers with the Wye and the Severn having negligible runs of sea trout. The Usk and the Severn tributaries are considered good non-migratory trout rivers (NRA 1995). The lack of adult stock information is due to the unique biology of sea trout which is the same species as brown trout (*Salmo trutta*). Genetic differences between *Salmo trutta* populations appear to occur only when populations are physically isolated from each other. All *Salmo trutta* that are not isolated (e.g. in lakes or prevented from movement by physical barriers) migrate annually, the smaller brown trout migrates within a river system but, depending upon the suitability of life cycle conditions in the river, a percentage of brown trout metamorphose into much larger sea trout which migrate to sea to feed, returning to spawn in freshwater. In some rivers all trout are sea trout, and in many all are brown trout. Whether trout migrate to sea can change with time as riverine or marine conditions become more or less favourable. Sea trout usually exist in association with brown trout, and in many cases the two fractions interbreed (NRA 1995). Brown trout can, and frequently do produce sea trout progeny.

The 2016 sea trout catch statistics for the rivers Severn, Wye, Usk and Taff (EA 2017) showed a declared rod catch of 193 fish (Table 26). The 5-year mean catch from 2012-2016 was 215 fish. After correction for under-reporting (Shields *et al* 2006) the 5-year mean catch was 234 fish.

Table 26 Sea trout fisheries statistics (rod catch)

River	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Mean
Severn	14	32	25	55	20	69	18	17	15	17	20	**27.5**
Wye	42	39	48	39	25	58	54	41	32	84	60	**47.5**
Usk	184	129	191	100	119	113	132	94	70	80	103	**119.5**
Taff/Ely	12	45	115	69	54	162	126	8	23	69	10	**63.0**
Total	**252**	**245**	**379**	**263**	**218**	**402**	**330**	**160**	**140**	**250**	**193**	**257.5**

The relationship between catch and spawning stock has been found to vary from river to river and in a study on five rivers Shields *et al* 2006 found that the ratio varied from 20.5% on the Lune to 2.8% on the Dee. The authors considered that this variation was most likely due to human factors such as accessibility, angler opportunity or target fish preference. Using this range of ratios for the rivers draining into the Bristol Channel, the combined stock size varied between 1141 and 8357 fish, implying a worst case HPC impingement of between 0.04% to 0.0054% SSB.

7.4 Impingement effect conclusions

The analyses presented in Section 7.3 for HPC with LVSE intakes and FRR systems fitted demonstrate that for all of the species assessed, which are representative of both the fish assemblage and all of the HRA designated conservation species, that impingement would have a negligible effect.

In terms of WFD water body status in the transitional waters of the estuary, HPC impingement at much less than 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 5.1). 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.

The next sections of this report consider the effects of uncertainty in the assessment (Section 8) and interannual variations in impingement (Section 9) to determine whether these could materially affect the negligible effect conclusions reached in Section 7.3.

8 Uncertainty Analysis

8.1 The principle sources of uncertainty

The HPC impingement estimates presented in Section 7.3 of this report are subject to uncertainty which is a function of:

a. The measurement of impingement at HPB via the CIMP programme - ΔI
b. Scaling HPB impingement to HPC using the ratio of cooling water flows at the 2 stations and the ratio of intake cross sectional intercept areas. – ΔS
c. The predicted EAVs for each species - ΔEAV
d. The estimated mean weight of adult fish used to convert impingement EAV numbers in to EAV weights – ΔW
e. The FRR mortality - ΔFRR
f. The SSB or international catch estimates used as impingement indicators - ΔSSB

Each of the terms has in principle an associated probability density function (pdf), Δ.

Impingement effect = $(\Delta S * \Delta I * \Delta EAV * \Delta W * \Delta FRR) / \Delta SSB$

If the form of the pdfs are known, confidence limits around the mean impingement effect can be calculated by Monte Carlo analysis. However, the problem with this approach is that it assumes that each of the variables are independent random variables. In practice some of the variables in the impingement calculation are highly correlated. For example, when impingement numbers increase following a recruitment event, the increased number of juveniles reduces the EAV. This inverse correlation is demonstrated in Section 9. For this report correlations between the variables were ignored which means that the derived estimates of uncertainty are precautionary.

8.1.1 Estimates of HPB impingement numbers used to compute HPC impingement

The predicted mean impingement levels at HPC and the associated 95 percentile confidence limits from the CIMP programme 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 27).

Table 27 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

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

HPC impingement estimates are derived from the ratio of the HPC to HPB total cooling water flows. As explained in Annex A the ratios used in this assessment are conservative.

An assumption that HPC will abstract the same amount of fish per cumec as HPB is unreasonably conservative. As described in Section 3.2 the design of the HPC intakes is expected to reduce fish abstraction per cumec of cooling water flow at HPC to:

a. 64.6% of HPB rate per cumec for all species due to the reduced intercept cross sectional area of the HPC intakes; and
b. 38% of HPB rate per cumec for pelagic species (sprat, herring, twaite and allis shad) due to the use of capped intakes at HPC (this is in addition to the 64.6% factor due to the reduced intercept cross sectional area of the HPC intake heads).

These impingement reduction factors are considered conservative because they do not take account of all of the design advantages of the HPB intakes (Section 3.1.1):

- An expected lower density of fish at the HPC intakes which are 3km offshore. Fish in the vicinity of the HPC intakes will be in much deeper water at low tide than at HPB and therefore less vulnerable to impingement.

- the height of the HPC intakes at 1m off the seabed is expected to reduce impingement of benthic fish.

8.1.3 Confidence in calculated Equivalent Adult Value (EAV) factors

The derivation of EAVs is discussed in Appendix F where it is shown that EAVs are dependent upon the assumptions made for the natural mortality (M) of the different species. It is not possible to produce probability distributions for EAVs by species. Instead, the worst case EAVs have been used for assessment purposes which will produce conservative estimates of impingement effect.

For twaite shad, only 34 fish were impinged during the entire CIMP programme (one adult, one sub adult and 32 0 group fish). This sparse dataset led to the use of a simpler calculation for M and of the EAV (BEEMS SPP071 ed. 3) but one which produced good agreement with published M estimates for adult shad. The calculated EAV was heavily influenced by the one adult caught in the year and as described in Section 5.1.3.1, year to year variations in twaite shad numbers are high and this creates uncertainty around an EAV and an impingement effect estimate based upon only one year of data. In order to determine whether these were important issues in reality, data from the RIMP programme were also assessed and the results are reported in Section 9.

For river 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 for the juvenile component of the impingement catch.

For marine lamprey impingement has been assessed for the juveniles and adults separately and EAV estimates are, therefore, not required (Note 1 to Table 29). For salmon and sea trout an EAV of 1 has been used.

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

8.1.4 Mean weight of adult fish in the fish stock

The mean weight of adult fish used to convert EAV numbers to EAV weights is shown in Table *28*. These are the weights of mature adults in the SSB. As both the SSB and mean weight calculation use the same data sources and the same assumptions, any related uncertainties in the HPC impingement calculation cancel each other out and no uncertainty term for this parameter is therefore necessary.

Table 28 Mean adult weights

Species	Weight kg
Sprat	0.0155
Whiting	0.298
Sole, Dover	0.353
Cod	4.746
Herring	0.065
Bass	1.123
Plaice	0.32
Ray, Thornback	3.28
Whiting, blue	0.135
Eel	0.329
Shad, Twaite	N/A
Shad, Allis	N/A
Lamprey, Marine	N/A
Lamprey, River	N/A
Salmon	N/A
Sea Trout	N/A
Crangon Crangon	0.00149

Notes:

1. Sprat adult weight is from the Cefas PELTIC survey biological data and represents the weight at 75% maturity (considered representative by expert judgement of the landed fish in the commercial landings)
2. For whiting, sole, cod, bass, plaice and blue whiting, mean weight is (maturity at age * mean weight at age * numbers at age)/total number of mature fish from ICES statistics.
3. Herring, thornback ray – mean adult weight is the weight at 75% maturity (considered representative by expert judgement of the landed fish in the commercial landings).
4. For silver eel the adult weight of 0.329 kg per fish was derived assuming a 50:50 sex ratio, that males mature at 89.9g and that females mature at 568.9g (Aprahamian, 1988)

5. Species with weights shown as N/A are assessed by number not weight.

8.1.5 FRR mortality

This report has used FRR mortality estimates largely derived from the EA science report Turnpenny and O'Keeffe 2005 which summarised results achieved at stations designed in the 1980s and 1990s. From measurements made at power stations it is known that some of the recommended values in the EA report are conservative for example we have assumed a base rate of 20% mortality for Dover sole but measurements at SZB on a non-optimised 'trash return' system achieved 4% mortality. The HPC FRR systems have been specifically engineered to increase the likelihood of survival of species that were considered not to survive well in older designs (e.g. eels and lampreys). The assumed FRR mortality rates have also taken account of specific design features of the HPC system that will reduce survival for some species (the trash racks in front of the drum and band screens). Conservative assumptions have been made on the survival of fish in the HPC band screens (e.g. assuming no survival for gadoid and some demersal species). Finally, the HPC FRR system is unchlorinated which will significantly improve fish survival.

Taking account of all of the above factors, it is considered that the figures used for fish mortality in the HPC FRR system are conservative and that no further uncertainty factor can be included in the assessment. Predictions are provided for HPC with and without the FRR systems to enable the estimated benefit of the HPC FRR system to be clearly understood. Table 22 demonstrates that HPC would have a predicted negligible effect on all but one assessed species even without an FRR system fitted (sole marginally exceeded the 1% negligible effects threshold with a predicted impingement effect of 1.06% SSB).

8.1.6 SSB estimates used as impingement indicators

For the commercial fish species assessed in this report ICES stock estimates have been used where possible. The sources of the stock estimates and the associated confidence limits are documented in Table 29.

The analytical processes used in ICES assessments of the relevant commercial stocks only provide confidence limits for plaice and bass. The Chair of the ICES WGCSE working group (Dr T Earl *pers. comm.*) has used expert judgement to estimate conservative confidence limits for whiting, sole and cod (i.e. 50% of mean SSB, 200% of mean SSB).

Confidence limits are provided for the sprat survey biomass estimates from the Cefas PELTIC surveys.

For herring and thornback ray no SSB estimates are available and landings have been used as a highly precautionary proxy for stock size. The landings are official statistics and as such do not have confidence limits and are considered reliable. For some stocks there has been also been discarding which has not been recorded as landings. More recently since the EU discard regulations came into force undersize or other unwanted catch is landed and recorded in official statistics as 'unwanted catch'. For thornback ray a Cefas estimate of discards has been provided as in the 2009 assessment year bycatch discarding is known to have taken place.

Confidence limits are available for the twaite shad, river and sea lamprey adult populations (expressed as numbers of fish) from work by APEM as documented in BEEMS Technical Report TR148 and reproduced in Appendix G of this report. After consideration of the twaite shad stock, as a precautionary measure the River Tywi adult stock number has been removed from the stock estimate as it is not considered likely that that stock will be vulnerable to impingement at HPC based upon relative geography.

Table 29 Values and sources for SSB/catch indicators

Species	Mean SSB (T or number)	Source	Confidence limit L95%	Confidence limit U95%	Source
Sprat	7,736 for 2013 (Table 30)	Cefas PELTIC Survey SPP089	3961	11351	Cefas PELTIC Survey
Whiting	34,918	ICES WGCSE 2017	17459	69836	Expert judgement Chair WGCSE
Sole	2,857	ICES WGCSE 2017	1429	5714	Expert judgement Chair WGCSE
Cod	5,092	ICES WGCSE 2017	2546	10184	Expert judgement Chair WGCSE
Herring	627 Landings	ICES HAWG 2017	None – official record		
Bass	18,317	ICES WGCSE 2017	15812	20822	ICES WGCSE
Plaice	4,707	ICES WGCSE 2017	2141	10349	ICES WGCSE
Thornback Ray	755 catch	ICES WGCSE 2016 landings, Discards Cefas	None – official record		ICES WGCSE
Blue whiting	2,781,230	ICES North East Atlantic WG	None.		Impingement numbers are so small that it is of no value to compute confidence intervals.
Eel	133	CEFAS using EA data Appendix G	66.5	266	Cefas freshwater fisheries team expert judgement
Twaite Shad	165,788 (Number of adults - Excluding River Tywi)	APEM, Appendix G	100,800	536,400	APEM, Appendix G
Allis Shad	27,397 (Number)	Syndicat Mixte d'Etudes et d'Aménagement de la Garonne, SPP071	13,699	54,794	Expert judgement Cefas
River lamprey	Adults 116,109 Parasitic juveniles 14.525M (Numbers)	APEM, Appendix G	78,069 12.159M	154,149 16.892M	APEM, Appendix G
Marine Lamprey[1]	Adults 15,269 Parasitic juveniles 11.183M (Numbers)	APEM, Appendix G	10,687 10.167M	19,851 12.2M	APEM, Appendix G These are underestimates as they only include the Usk and the Wye populations and not the Severn.
Salmon	9,667 (Number)	EA/NRW	No annual CIs available		
Sea Trout	No SSB available, Catch	EA 2017 (see Section 7.3.2)	No annual Cis available		

	numbers from EA 2017.				

Notes:

1. Marine Lamprey do not home to their natal river (Section 4.1) and when seeking a river to reproduce they find a suitable local river based upon detection of pheromones from juvenile marine lampreys in freshwater. Marine lampreys in their parasitic feeding form are widely dispersed by their prey to at least the continental shelf and the returning adults caught at Hinkley point could therefore have spawned in a range of regional rivers in the western UK, Ireland and France. The parasitic juvenile populations of the Wye and Usk are relevant worst-case comparators for seaward migrating parasitic juveniles (i.e. escapement). The returning adults are likely to come from a much wider stock area. The Wye and Usk adult population shown in Table 29 therefore represents the spawning population for those rivers not the larger regional SSB. However, this is appropriate for determining effects on the HRA designated populations and the predicted number of impinged adults has been compared against the adult population for those rivers. By assessing the adult and juvenile populations separately, EAVs are not relevant to the calculations i.e. a value of 1 has effectively been used.

8.2 Uncertainty assessments – SSB and impingement numbers

For this assessment the Monte Carlo analysis has been simplified (at the expense of overestimating the mean effect and its associated confidence limits) by using worst case values for:

- HPB to HPC scaling factor
- EAVs

The FRR mortalities rates are considered worst case in that the performance figures selected are worse than those reported for modern plant in the scientific literature. An absolute worst case can be gauged by considering the predicted impingement results with and without an FRR fitted.

Fish weight is accurately measured and since the same data are used in the SSB calculation any errors in this term will cancel out in the uncertainty analysis.

The uncertainty in the effect of HPC impingement on a particular stock can be therefore 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. The analysis process is described in Appendix I and the results are shown in Table *32*. The results are expressed as the HPC impingement divided by the SSB or catch as a percentage.

8.2.1 Sprat

For sprat there is no SSB estimate for 2009 so the uncertainty on the sprat impingement is calculated using the RIMP data (Table 30) for the years that SSB estimates are available from the PELTIC survey (SPP089).

Table 30 Uncertainty on the sprat impingement assessments for 2013-2016

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
2013/14	7736	24.4%	3,958	1.6	2.9	0.021%	0.072%
2014/15	21292	17.6%	13,789	2.8	5.0	0.013%	0.036%
2015/16	55331	14.7%	39,075	2.1	3.8	0.004%	0.010%
2016/17	8944	6.8%	7,731	2.4	4.1	0.026%	0.053%

Notes:

1. The RIMP sprat data are too sparse to calculate bootstrapped confidence limits so the upper 95th percentile impingement numbers have been set at 1.75 times the mean impingement number (as per Table 27). For sprat the worst-case impingement effect has been calculated by dividing the upper 95th percentile impingement numbers by the lower 95th percentile SSB estimate. This produces a precautionary effect estimate which is of lower probability than a 95th percentile.

2. 2013 was the first year of the sprat survey and as the survey design has improved, the Coefficient of Variation has dropped.

8.2.2 Species assessed from the CIMP data

Table 31 Uncertainty on the HPC impingement assessments with LVSE intakes but no FRR systems fitted calculated by Monte Carlo analysis, Calculated as percentage of SSB or international landings.

Species	Mean effect %	L95 %	U95 %
Whiting	0.186	0.088	0.348
Sole	1.178	0.487	2.408
Cod	0.291	0.106	0.644
Herring	0.031	0.018	0.050
Bass	0.015	0.012	0.019
Plaice	0.004	0.000	0.011
Thornback Ray	0.292	0.174	0.480
Blue whiting	0.000	0.000	0.000
Eel	0.215	0.092	0.422
Twaite shad	0.012	0.005	0.022
Shad, Allis	0.017	0.000	0.053
Lamprey,marine	0.391	0.073	0.829
Lamprey, river	0.038	0.000	0.107

Table 32 Uncertainty on the HPC impingement assessments with LVSE intakes and FRR systems fitted calculated by Monte Carlo analysis

Species	Mean effect %	L95 %	U95 %
Whiting	0.101	0.048	0.190
Sole	0.240	0.099	0.491
Cod	0.161	0.059	0.356
Herring	0.031	0.018	0.050
Bass	0.011	0.008	0.013
Plaice	0.002	0.000	0.005
Thornback Ray	0.118	0.071	0.194
Blue whiting	0.000	0.000	0.000
Eel	0.043	0.018	0.084
Twaite shad	0.012	0.005	0.022
Shad, Allis	0.017	0.000	0.053
Lamprey,marine	0.078	0.015	0.166
Lamprey, river	0.008	0.000	0.021

Notes:

1. Herring and Thornback Ray have no uncertainty around the catch estimate, the only uncertainties are in impingement numbers.

8.3 Summary

As explained above, the results of the uncertainty analyses in Table 32 are considered precautionary. The negligible effects threshold of 1% of the SSB or international catch was not exceeded for any species as a mean or an upper 95th percentile. These results reinforce the conclusions of Section 7.3 that the effects of HPC impingement (with FRR systems fitted) are negligible.

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

The quantitative impingement assessments presented in Section 7.3 and Section 8 are based upon the results of the one-year CIMP programme at HPB with the exception of sprat, salmon and sea trout which were assessed from the RIMP data. Impingement numbers fluctuate annually in line with the natural variabilities of the local fish populations. The question that then arises is do these annual fluctuations have any material effect on the predicted HPC impingement effects detailed in Section 8.2? The largest changes in impingement occur when a significant annual recruitment event occurs and an atypically large number of 0 group fish are impinged at Hinkley Point. Such events are the most likely to cause concern over impingement numbers. 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 higher than those from the CIMP survey and the number of impingement measurements are only sufficient to construct the reliable length distributions required for the EAV calculations for a small number of abundant species.

The purpose of this section is not to provide a description of interannual variation in fish numbers; that is already described in Sections 4 and 5.1.3.1. Instead this section uses data from the RIMP programme for different species where the annual impingement numbers fluctuate in different manners and analyses whether these changes could produce any material change to the CIMP derived impingement predictions for those species. The aim of the analyses is to determine whether there is a risk for any species of exceeding the 1% negligible effects threshold and it is, therefore, appropriate to focus the interannual effects analysis on those species that have the highest impingement effects as a percentage of SSB/fishery catch. The greatest concern from an environmental perspective is not to underestimate impingement effects. With the use of the CIMP dataset this could occur if the sampling year corresponded to a year of exceptionally low population numbers relative to the mean over a number of years as determined from the RIMP dataset. (Clearly such an approach can only be applied to years with non-zero impingement). The aim of the interannual variability analysis was therefore to identify:

- The magnitude of the potential worst case underestimation error; and
- for the species analysed, whether any correction needs to be applied to the impingement estimates derived from the CIMP data in Table *32*.

The five species with the highest predicted impingement effects as a percentage of SSB in Table *32* are shown rank order in Table 33.

Table 33 Top five species in terms of predicted HPC impingement effect

Species	Mean impingement effect calculated from the CIMP dataset
Sole	0.240%
Cod	0.161%
Thornback ray	0.118%
Whiting	0.101%
Marine lamprey	0.078%

In addition, herring and sprat, were included in the analysis because of the measured high year to year variability in herring impingement (Table 12) and because sprat was the most abundant species in the CIMP dataset. As noted in the uncertainty analysis in Section 8.1.3, there were concerns over the reliability of the twaite shad assessment based upon the one year CIMP dataset and so this species has also been included in this interannual variability assessment.

Species	Mean impingement effect calculated from the CIMP dataset
Herring	0.031%
Sprat (from Table 30)	0.016%
Twaite shad	0.012%

It is not possible to accurately calculate the effects of interannual variability for marine lamprey from the RIMP data as only 2 parasitic juvenile fish were caught in the 37 years of the programme and for most years the catch was zero. The mean annual catch was 0.054 parasitic juvenile fish per year which scales up to a mean of 20.8 per year at HPC (worst case RIMP scaling factor =385 from Section 4.2). The estimated total population of parasitic juveniles in the Wye and Usk is 11.18 million (Table 29), implying a mean impingement effect on juvenile marine lamprey of 0.0002% from the RIMP dataset.

A similar problem with a lack of data in the RIMP dataset exists for thornback ray where the impingement rate in the RIMP was very low with annual catches in the seven years from 2009/10 of 1, 1, 1, 1, 2, 6 and 5 fish respectively. With such low impingement numbers, variance on the impingement numbers is high and it is not possible to construct accurate length distributions thereby leading to low precision EAVs. Nevertheless, an indication of potential effects is provided in Section 9.6.

For each of the other five species an assessment was performed using a range of years that were selected to include years with very high impingement numbers in order to ensure that the worst-case effects of interannual variation were bracketed. The RIMP impingement numbers were processed in the same manner as the CIMP data (i.e. the data analysed for each 12-month period is from February to January inclusive), 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. The natural mortality equation used to calculate the EAVs for each species was scaled by the same correction factor that was used for the CIMP data (Appendix H).

9.1 Dover sole

Table 34 Predicted HPC impingement effect for Dover sole in the period 2008- 2016 (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
2008/09	531	204,263	0.178	36,359	20%	7,417	2.62	3176	0.082%
2009/10	409	157,332	0.196	30,837	20%	6,291	2.22	2857	0.078%
2010/11	940	361,595	0.139	50,262	20%	10,253	3.62	3098	0.117%
2011/12	340	130,790	0.194	25,373	20%	5,176	1.83	3290	0.056%
2012/13	418	160,794	0.114	18,331	20%	3,739	1.32	3176	0.042%
2013/14	215	82,705	0.171	14,143	20%	2,885	1.02	2735	0.037%
2014/15	204	78,474	0.124	9,731	20%	1,985	0.70	2689	0.026%
2015/16	282	108,479	0.134	14,536	20%	2,965	1.05	2561	0.041%
2016/17	588	226,189	0.121	27,369	20%	5,583	1.97	2525	0.078%

Notes:

1. EAVs calculated as per Appendix F (Gislason correction factor 2)
2. Mean adult weight per fish: 0.353kg

Mean impingement effect for sole in the period 2008-2016 was 0.062% mean SSB.

Worst case potential impingement underestimation factor: 2.4 in 2014/15 (calculated by mean impingement in data series/lowest impingement prediction = 0.062%/0.026%)

The sole impingement numbers in 2010 were the highest in the 18 year period between 2000 and 2017.

9.2 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 10 years shown in Table 35 ranged from a calculated 0.006% to 0.083% SSB. The calculated effect from the CIMP data in 2009 was 0.09% of SSB (Table 23).

The whiting impingement numbers in 2009 were the highest in the18 year period between 2000 and 2017.

Table 35 Predicted HPC impingement effect for whiting in the period 2007- 2016 (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
2007/08	2,173	835,900	0.128	106,995	55%	58,312	17.38	29709	0.058%
2008/09	2,445	940,532	0.140	131,674	55%	71,763	21.39	25724	0.083%
2009/10	2,941	1,131,331	0.135	152,730	55%	83,238	24.80	34918	0.071%
2010/11	680	261,579	0.135	35,313	55%	19,246	5.74	49971	0.011%
2011/12	511	196,569	0.142	27,913	55%	15,212	4.53	78700	0.006%
2012/13	2015	775,121	0.098	75,962	55%	41,399	12.34	85208	0.014%
2013/14	2483	955,150	0.170	162,375	55%	88,495	26.37	79409	0.033%
2014/15	1387	533,545	0.191	101,907	55%	55,539	16.55	68013	0.024%
2015/16	837	321,974	0.176	56,667	55%	30,884	9.20	86890	0.011%
2016/17	2292	881,677	0.126	111,091	55%	60,545	18.04	66195	0.027%

Notes:

1. EAVs calculated as per Appendix F (Gislason correction factor 1.25)
2. Mean adult weight per fish: 0.298kg

Mean impingement effect for whiting in the period 2007- 2016 was 0.034% SSB.

Worst case potential impingement underestimation factor: 5.5 in 2011/12 (calculated by mean impingement in data series/lowest impingement prediction = 0.034%/0.006%)

9.3 Cod

Table 36 shows the predicted impingement effects of HPC in 2007-2016 on cod. The EAVs were calculated in the same manner as described in Appendix F such that the assessment methodology is consistent with the CIMP assessment. The impingement numbers for 2011/12 and 2012/13 are an illustration of the practical limitations in using the RIMP data for species that are sampled in low numbers that was referred to in the introduction to this section. With only 12 and 6 fish respectively sampled in each year it is not possible to construct an accurate length distribution and therefore a reliable EAV. However, inspection of the data indicates that the expected effects would probably be less than 0.005% SSB in both years because of the very low number of impinged fish and the high SSB in both years.

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 are 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 36).

Table 36 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
2007/08	64	24,619	0.050	1,241	54.5%	676	3.21	5121	0.063%
2008/09	33	12,694	0.055	694	54.5%	378	1.80	5455	0.033%
2009/10	661	254,271	0.014	3,484	54.5%	1,899	9.01	5092	0.177%
2010/11	32	12,310	0.070	857	54.5%	467	2.22	4956	0.045%
2011/12	12	4,616	-		54.5%			9064	N/A
2012/13	6	2,308	-		54.5%			13628	N/A
2013/14	190	73,088	0.015	1,096	54.5%	597	2.84	9604	0.030%
2014/15	27	10,386	0.033	345	54.5%	188	0.89	4929	0.018%
2015/16	38	14,618	0.020	298	54.5%	163	0.77	5327	0.014%
2016/17	32	12,310	0.021	255	54.5%	139	0.66	7043	0.009%

Notes:

1. EAVs calculated as per Appendix F (Gislason correction factor 1.89)
2. Mean adult weight per fish 4.746kg

Mean impingement effect for cod in the period 2007- 2016 was 0.049% mean SSB (excluding 2011 and 2012).

Worst case potential impingement underestimation factor: 5.2 in 2016/17 (calculated by mean impingement in data series/lowest impingement prediction = 0.049%/0.009%)

The mean impingement estimate from the RIMP data (0.049% mean SSB) was one third of that predicted from the 1-year CIMP survey (0.145% mean SSB).

In 2009 despite the largest cod recruitment event in the 37 years of the RIMP programme, the HPC impingement effect of 0.177% mean SSB calculated from the RIMP data was much less than 1% of mean SSB i.e. a negligible effect.

9.4 Sprat

An SSB for sprat is not available for 2009 and therefore it has not been possible to calculate an impingement effect from the CIMP data for that year in Table 23.

From 2013 Cefas has been conducting an annual survey that covers the Bristol Channel approaches (BEEMS SPP089) 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 37 shows the calculated HPC impingement effect based upon the use of the RIMP data and measured population biomasses (The sprat SSB in each year was calculated by multiplying the PELTIC sprat biomass by the EAV of the PELTIC population).

The impingement numbers in 2014/15 were the highest in the 18 year period between 2000 and 2017.

Table 37 Predicted HPC impingement effect for sprat in the period 2013- 2016 (FRR fitted)

Year	RIMP annual numbers	Predicted HPC annual numbers	Calculated EAV	EAV number	FRR mortality	EAV number after mitigation	EAV wt (t)	Mean SSB (t)	% of SSB
2013/14	2050	299,662	0.352	105,481	100%	105,481	1.6	7,736	0.021%
2014/15	5093	744,478	0.246	183,142	100%	183,142	2.8	21,292	0.013%
2015/16	3157	461,480	0.300	138,444	100%	138,444	2.1	55,331	0.004%
2016/17	2358	344,685	0.440	151,661	100%	151,661	2.4	8,944	0.026%

Notes:

1. EAVs calculated as per Appendix F (Gislason correction factor 1.9)
2. Mean adult weight per fish: 0.0155 kg

Mean impingement effect for sprat in the period 2013- 2016 was 0.016% mean SSB.
Worst case potential impingement underestimation factor: 4.2 in 2015/16 (calculated by mean impingement in data series/lowest impingement prediction = 0.016%/0.004%)

9.5 Herring

Table 38 shows the predicted impingement effects of HPC in 2008-2016 on herring. There is no SSB for the herring stock and therefore a worst-case impingement indicator of international catch has been used. As described in Section 5.2 this indicator produces a considerable overestimate of the real impingement effect as landings are less than the SSB otherwise the stock would collapse. Landings reflect commercial considerations as well as the stock biomass; e.g. the French fleet landings declined from 78% of the landings in 2009 to 0.2% in 2016 (decline from 489T to 1T), whereas the English landings tripled in the same period (increase from 138T to 431T). These changes were not driven by changes in herring biomass but were the result of commercial decisions by fishers.

Table 38 Predicted HPC impingement effect for herring in the period 2008 - 2016 (FRR fitted)

Year	RIMP annual numbers	Predicted HPC annual numbers	Calculated EAV	EAV number	FRR mortality	EAV number after mitigation	EAV wt (t)	Landings (t)	% of landings
2008/09	269	39,322	0.047	1,848	100%	1,848	0.12	-	N/A
2009/10	190	27,774	0.123	3,416	100%	3,416	0.22	627	0.035%
2010/11	1023	149,539	0.011	1,645	100%	1,645	0.11	701	0.015%
2011/12	64	9,355	0.194	1,815	100%	1,815	0.12	814	0.014%
2012/13	450	65,780	0.077	5,065	100%	5,065	0.33	553	0.060%
2013/14	337	49,262	0.096	4,729	100%	4,729	0.31	411	0.075%
2014/15	30	4,385	0.257	1,127	100%	1,127	0.07	873	0.008%
2015/16	556	81,274	0.070	5,689	100%	5,689	0.37	382	0.097%
2016/17	83	12,133	0.539	6,540	100%	6,540	0.43	432	0.098%

Notes:

1. EAVs calculated as per Appendix F (Gislason correction factor 2)

2. Mean adult weight per fish: 0.065 kg
3. No landings data available for 2008

Mean impingement for herring in the period 2009- 2016 was 0.050% international landings.

Worst case potential impingement underestimation factor: 6.0 in 2014/15 (calculated by mean impingement in data series/lowest impingement prediction = 0.050%/0.008%)

The variation in EAVs is due to interannual variation in the number of 0-group fish. In years with high recruitment (e.g. 2010 and 2015) 0-group fish dominate the annual impingement which reduces the EAV. In years with low recruitment (2011, 2014 and 2106) the percentage of older fish is much higher producing a larger EAV.

9.6 Thornback ray

As stated in the introduction to Section 9, very few thornback ray were collected during the RIMP programme due to the low density of the population combined with the low monthly sampling duration of the RIMP programme. The low number of fish means that the variance on the annual impingement numbers is high and accurate length distributions cannot be computed which reduces the precision of the EAV estimate. In the 7 years shown in Table 39 only 17 fish were caught – one 6+ year old adult, four 2 group, five 1 year group and seven 0 group fish. Thornback ray are 50% mature at year 5 i.e. all but one fish were immature in the RIMP dataset.

The predicted impingement effect ranged from a calculated 0.0015% of the fishery catch in 2012/13 to 0.144% fishery catch in 2010/11. The calculated effect from the CIMP data in 2009 was 0.118% of the fishery catch (Table 32). The RIMP derived result distribution is highly skewed due to the impingement of the one adult in 2010/11 and the calculated mean impingement of 0.033% fishery catch over the period is therefore misleadingly high. In such circumstances, a statistically more representative typical effect is the median impingement effect at 0.008% SSB.

The mean value from RIMP data indicate that the CIMP impingement prediction is overestimated by a factor of 3.6 (mean CIMP/mean RIMP from data series) but due to the low numbers of fish impinged in the RIMP in 2009-2012 and the distorting effect of the 1 adult impinged in 2010, the confidence in the annual effect predictions from the seven year RIMP data series shown in Table 39 is low. On a precautionary basis, no correction to the CIMP derived prediction has, therefore, made in this report.

Table 39 Indicative HPC impingement effect for thornback ray in the period 2009- 2015 (FRR fitted)

Year	RIMP annual numbers	Predicted HPC annual numbers	Calculated EAV	EAV number	FRR mortality	EAV number after mitigation	EAV wt (t)	Landings (T)	Catch (T)	% of Catch
2009/10	1	385	0.25	95	0.2	19.0	0.062	671	755	0.008%
2010/11	1	385	1.00	385	1	384.7	1.262	780	878	0.144%
2011/12	1	385	0.24	91	0.2	18.1	0.059	944	1062	0.006%
2012/13	1	385	0.08	31	0.2	6.1	0.020	1165	1311	0.0015%
2013/14	2	769	0.05	37	0.2	7.3	0.024	1048	1179	0.0020%
2014/15	6	2308	0.17	387	0.2	77.3	0.254	790	889	0.032%
2015/16	5	1923	0.38	730	0.2	146.0	0.479	893	1005	0.037%
Mean										**0.033%**
Median										**0.008%**

Notes:

1. EAVs calculated as per Appendix F (Gislason correction factor 2)
2. Mean adult weight per fish: 3.28 kg
3. All measured fish would pass through HPC trash racks apart from the one adult in 2010/11.

9.7 Twaite shad

Table 40 shows the predicted impingement effects of HPC in 2000-2017 on twaite shad derived in BEEMS SPP071 ed.3. The SSB is expressed as the number of adults at 165,788 (Table 29) in the rivers Usk, Wye and Severn (including its tributary the River Teme) but excluding the river Tywi.

Table 40 Predicted HPC impingement effect for twaite shad in the period 2000-2017 (FRR fitted)

Year (Feb - Jan)	RIMP annual numbers	Predicted HPC annual numbers	Calculated EAV	Equivalent adults from juveniles	Adults at impingement	Total EAV number	Percentage of mean SSB
2000/01	2	292	0.0059	1.7	0	1.7	0.0010%
2001/02	14	2,046	0.0059	12.1	0	12.1	0.0073%
2002/03	4	585	0.0059	3.5	0	3.5	0.0021%
2003/04	16	2,339	0.0059	13.8	0	13.8	0.0083%
2004/05	10	1,462	0.0078	11.4	0	11.4	0.0069%
2005/06	1	146	0.0059	0.9	0	0.9	0.0005%
2006/07	17	2,485	0.0059	14.7	0	14.7	0.0089%
2007/08	1	146	0.0059	0.9	0	0.9	0.0005%
2008/09	0	0	0.0059	0.0	0	0.0	0.0000%
2009/10	2	292	0.0059	1.7	0	1.7	0.0010%
2010/11	37	5,409	0.0059	32.0	0	32.0	0.0193%
2011/12	8	1,169	0.0083	9.7	0	9.7	0.0059%
2012/13	0	0	0.0059	0.0	0	0.0	0.0000%
2013/14	5	731	0.0059	4.3	0	4.3	0.0026%
2014/15	5	731	0.0059	4.3	0	4.3	0.0026%
2015/16	2	292	0.5030	0.9	146.2	147.1	0.0887%
2016/17	1	146	0.0059	0.9	0	0.9	0.0005%
2017/18	8	1,169	0.0059	6.9	0	6.9	0.0042%
Mean	7.4	1,080		6.6	8.1	14.8	**0.0089%**
Median	4.5	658		3.9	0	4.3	**0.0026%**

Notes:

1. EAVs calculated in SPP071 ed. 3.

The predicted impingement effect is highly influenced by the rare impingement of adults. For 17 out of the 18 years in the dataset the predicted HPC impingement ranged from 0% to 0.019% of mean SSB (the latter being in 2010, the year with the highest impingement numbers in the 18-year period) However, in 2015 when only two fish were caught at HPB (one 0-group fish and one adult), the predicted effect was 0.089% of mean SSB. Due the low sampling frequency in the RIMP, the one adult scaled up to a predicted 95 fish at HPC assuming that the adult catch rate was the same for every 6-hour period in the month of April. This is considered highly improbable given that zero adults were caught in the other 17 years of the time series. For such a skewed data distribution, with rare outliers, mean values are highly misleading and statistical convention is to report median (50th percentiles) as typical values (SPP071)

The analyses in this report have shown HPC impingement predictions of 0.011% of mean SSB from the 1-year CIMP data (Table 23) and 0.0026% of mean SSB as a 50th percentile from 18 years of RIMP data. SPP071 concludes that the CIMP prediction is an overestimate of impingement effect for twaite shad due interannual variabiility and, in particular, the relative sensitivity of the predictions to rarely impinged adults. The median prediction from the multi year RIMP dataset is considered to provide a more reliable prediction of the HPC impingement effect. Both estimates are substantially less than the 1% negligible effect threshold.

The sparse dataset and the sensitivity to the rare impingement of adult fish means that there is low confidence in an estimate of a worst case potential impingement underestimation factor. Based on the lowest non-zero impingement effect from the RIMP data of 0.0005% SSB and a median effect of 0.0026% SSB, the worst-case underestimation could be a factor of 5.0. This factor has not been used for assessment purposes and the impingement effect has been directly estimated from the RIMP data.

50th percentile impingement for twaite in the period 2000- 2017 was 0.0026% of mean SSB.

9.8 Summary

In order to determine whether interannual fluctuations in fish impingement numbers have any material effect on the predicted HPC impingement effects detailed in Section 8.2, the five species with the highest predicted impingement effects as a percentage of SSB/fishery catch in 2009 (sole, cod, thornback ray, whiting, marine lamprey) plus the pelagic species of herring, sprat and twaite shad were selected for multiyear impingement analysis using the RIMP dataset.

The aims of this analysis were to identify:

- the magnitude of the potential worst-case impingement underestimation error caused by use of the CIMP 1-year dataset due to interannual variability; and
- for the species analysed, whether any correction should to be applied to the impingement predictions derived from the CIMP data in Table 32.

Due to the lack of data in the RIMP dataset for marine lamprey (in most years the annual impingement catch was zero) it was not possible to undertake a full assessment of the effects of interannual variability for this species. The predicted annual mean impingement from the 37-year RIMP dataset was 0.0002% SSB, well below the estimate of 0.077% SSB from the 1-year CIMP dataset. On a precautionary basis, no correction to the CIMP derived prediction has been made in this report. For marine lamprey the numbers impinged in the RIMP survey (2 in 37 years) demonstrate that the species is not at significant risk from impingement. In Section 4.1 it was explained that due to their migration strategy, marine lamprey are not expected to be impinged at HPB and even less so at HPC due to the deep water at the HPC intakes.

Similarly, the RIMP dataset for thornback ray was also sparse. In this case there were sufficient data to make an indicative prediction of mean impingement from the RIMP dataset of 0.033% of the fishery catch compared with 0.118% from the CIMP dataset. The RIMP data indicate that the CIMP impingement prediction is overestimated by a factor of 3.6 but due to the low numbers of fish impinged in the RIMP, confidence in the annual effect predictions is low, especially for years in which only 1 fish was impinged. On a precautionary basis, no correction to the CIMP derived prediction has, therefore, been made in this report.

Results for the other six species are summarised in Table 41.

Table 41 Summary of interannual variability analyses. The mean impingement figures are the percentage of SSB or international landings (for herring).

Species	No years in interannual assessment	Mean impingement from interannual RIMP data	Median effect from RIMP	Mean impingement from 1 y CIMP data (2009)	Ratio of CIMP: mean RIMP	Worst case impingement underestimation factor
sprat	4	0.016%	0.017%	N/A	N/A	4.2
whiting	10	0.034%	0.026%	0.090%	2.65	5.9
sole	9	0.062%	0.056%	0.217%	3.51	2.4
cod	8	0.049%	0.031%	0.145%	2.98	5.2
herring	9	0.050%	0.047%	0.031%	0.62	**6.0**
twaite shad	18	0.0089%	0.0026%	0.011%	1.24	**5.0**

Note:

1. The CIMP mean impingement effect in column 5 is from Table 23 (Predicted HPC impingement with FRR fitted)
2. The worst-case impingent underestimation factor for twaite shad is derived from the RIMP median impingement estimate. Confidence in this factor for twaite shad is low and the factor has not been used for assessment purposes in this report.

The conclusions from the interannual variability analyses were:

a. For all of the eight species and all of the years analysed the variation in annual impingement numbers did not change the overall conclusion that predicted impingement effects remained much less than the 1% negligible effect threshold.
b. The worst case potential underestimate of impingement effects that could have resulted from the use of the 1-year CIMP programme was a factor of 6.0 for herring (in 2014/15). i.e. if the CIMP had been undertaken in that year the predicted mean impingement effect would have been expected to be a factor of approximately 6 below the multiyear mean from the RIMP. The predicted impingement effects from HPC from the CIMP are so low that the application of that factor to any of the species in Table 23 that were not analysed for interannual variability, could not change the overall conclusion of negligible impingement effect from HPC.

The CIMP derived predictions of impingement effect for sole, cod and whiting were overestimated by factors of 3.5, 3.0 and 2.65 respectively. The herring prediction was underestimated by a factor of 1.63. These factors have been applied to predictions in Table 32 *to produce the finalised HPC impingement effect predictions in*

c. Table 43.

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 sprat.

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. The impingement numbers in 2014 were the highest in the 18 year period between 2000 and 2017.

In October 2014 the biomass of the sprat population in the Bristol Channel Approaches (that migrates in and out of the Bristol Channel in November – January) was 57,236 t (from the Cefas PELTIC survey described in BEEMS SPP089). The 50th percentile weight of those fish was approximately 2.3g per fish (from Cefas PELTIC survey biological data); i.e. the local population comprised approximately 24.9 billion fish. Impingement at HPC would have taken an estimated 0.744 million fish (Table 37) i.e. 0.003% of the number of fish in the population in the Bristol Channel Approaches.

The ecological effect of such impingement levels would be completely negligible given, for example, the natural variability in sprat numbers of 560% between 2013 and 2015 (BEEMS SPP089) to which predators are already adapted. Due to their abundance sprat are major source of prey for local piscivorous fish and for harbour porpoise. To put the annual HPC sprat catch into context it is equivalent to the annual dietary requirement of between 1.4 and 6.3 harbour porpoise based upon the measured dietary requirements of 750 – 3250g fish per day from Kastelein *et al* 1997.

The same principle applies to other potential prey fish at Hinkley Point. If the impingement effect on the adult population is negligible then the corresponding effect on the number of juveniles will be also negligible because of the reciprocal manner in which the EAV calculation works; i.e. the number of juveniles in the population is vastly greater than the number of adults.

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-year 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 There have been exponential increases in the numbers of herring, sole, sprat, five-bearded rockling, grey mullet and the important prey species *Crangon crangon*, accompanied by declines in the number of eel, dab, poor cod and pout. Appendix E shows that over the 37-year period of the RIMP survey 29 out of the 87 fish species show a statistically significant population trend (19 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.

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 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 effects of interannual variability and assessment uncertainties described in sections 9 and 8 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 Discussion and Conclusions

The impingement assessment undertaken in this report is evidence-based and makes use of the most up-to-date fisheries science and data.

The 21 species assessed are representative of the fish assemblage at Hinkley Point because:

a. they represent 98.3% of the total fish impingement numbers during the CIMP programme;

b. they contain all of the conservation species listed as HRA interest features;

c. they contain examples from all functional guilds with the exception of freshwater species which, as would be expected, are rarely found at Hinkley Point;

d. they contain examples from all the feeding guilds and habitat groups;

e. they contain all of the indicator species found at Hinkley Point that are assessed in the WFD “fish” biological quality element in transitional waters; and

f. they contain the key prey species that supports the fish food web at Hinkley Point.

12.1 Rationale for the continued use of a 1% negligible effects threshold

Fish populations grow and replace themselves and they are therefore renewable resources. In the absence of harvesting, the population size of a stock does not increase indefinitely and stabilises around a maximum that a given habitat can support (the carrying capacity); i.e. it is under density control. The scientific basis for the sustainable use of a renewable marine resource evolved during the first half of the 20th century and is based upon a fundamental ecological principle of density dependent population regulation. As the abundance of a density regulated population is reduced by harvesting, per capita net production increases (by means of increased rates of growth, survival and reproduction), until the population cannot compensate for additional mortality after which point the productivity of the stock decreases and eventually becomes at risk of collapse. The production generated by this compensation (known as surplus production) can be harvested on a sustainable basis on a year on year basis. (Rosenberg *et al* 2003). Sustainability can therefore be framed as ensuring a sustainable harvest rate; i.e. where the rate of abstraction is less than or equal to the rate at which the population can regenerate itself. Determination of that rate for different fish stocks has been an internationally coordinated endeavour for more than 70 years and has led to well established stock assessment principles.

To have a negligible impact on a fish stock the predicted total anthropogenic harvest rate must be less than the value whereby the stock can replace itself on a year to year basis. For data poor species a precautionary level of 10%-20% SSB is considered sustainable in international fisheries management practice.

For species which are heavily exploited by fishing a lower effect threshold for impingement is considered appropriate and 1% negligible effect screening threshold for annual impingement for all species provides a precautionary level which is negligible compared with fishing mortality on exploited stocks and would have no effect on their sustainability. For non-exploited stocks such a level is highly precautionary on the basis of fish population dynamics and any observed decline in stock numbers would be due to other factors well beyond the influence of HPC impingement.

A precautionary level of 1% much less than the natural variability of any species at Hinkley Point which 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 by the results of this assessment in

Table 43, the predicted impingement effects for HPC fitted with the planned LVSE intakes and FRR systems are much less than 1% SSB for all species

12.2 The impingement assessment process

The predicted effects of HPC impingement with and without FRR systems were calculated in Section 7 of this report from the 1-year CIMP dataset with the exception of sprat, salmon and sea trout which were assessed from the RIMP dataset. The predicted impingement effects in all cases were less than the 1% SSB/fishery catch negligible effects threshold.

The impingement predictions were then subject to a comprehensive and precautionary uncertainty analysis in Section 8. These analyses did not identify any species where the negligible effects threshold of 1% of the SSB or international catch was exceeded for either mean or 95th percentile HPC impingement predictions (Table *32*).

Impingement numbers fluctuate annually in line with the natural variabilities of the local fish populations. The largest changes in impingement occur when a significant annual recruitment event occurs and an atypically large number of 0 group fish are impinged at Hinkley Point. In order to determine whether interannual fluctuations in fish impingement numbers could have any material effect on the predicted HPC impingement effects from the uncertainty analyses, the five species with the highest predicted impingement effects as a percentage of SSB/fishery catch in 2009 (sole, cod, thornback ray, whiting, marine lamprey) plus the pelagic species of herring, sprat and twaite shad were selected for multiyear impingement analysis using the RIMP dataset.

The aims of this analysis were to identify:

- the magnitude of the potential worst-case impingement underestimation error caused by use of the CIMP 1-year dataset; and
- whether any correction should to be applied to the impingement predictions derived from the uncertainty analyses.

The conclusions from the interannual variability analyses were:

a. For all of the eight species and all of the years analysed the variation in annual impingement numbers did not change the overall conclusion that predicted impingement effects remained much less than the 1% negligible effect threshold.
b. The worst case potential underestimate of impingement effects that could have resulted from the use of the 1-year CIMP programme was a factor of six for herring. i.e. if the CIMP had been undertaken in that year the predicted mean impingement effect would have been expected to be a factor of approximately six below the multiyear mean from the RIMP. The predicted impingement effects from HPC from the CIMP are so low that the application of that factor to any of the species that were not analysed for interannual variability, could not change the overall conclusion of negligible impingement effect from HPC.

The CIMP derived predictions of impingement effect for sole, cod and whiting were overestimated by factors of 3.5, 3.0 and 2.65 respectively. The herring prediction was underestimated by a factor of 1.63. These factors were applied to predictions from the uncertainty analyses to produce the finalised HPC impingement effect predictions in Table 42 and

c. Table 43.

12.3 HPC impingement predictions

12.3.1 HPC impingement predictions with no mitigation measures fitted.

The predicted effects of HPC impingement with no LVSE intake heads, no FRR systems and no AFD system are shown in

Table 43. With no impingement mitigation at HPC, further investigation would be required into the impacts on sole, marine lamprey plus mullet, flounder, five-bearded rockling, sand goby and brown shrimp to determine whether any significant effects were likely.

Table 42 HPC impingement predictions with no mitigation measures fitted.

Common Name	*Species*	Mean effect	Upper 95%ile effect	Impingement indicator
Sprat	*Sprattus sprattus*	0.065% (Using RIMP data)	0.175%	PELTIC SSB for 2013- 2016
Whiting[4]	*Merlangius merlangus*	0.108%	0.205%	SSB for 2009
Sole, Dover[4]	*Solea solea*	0.524%	1.062%	SSB for 2009
Cod[4]	*Gadus morhua*	0.151%	0.333%	SSB for 2009
Mullet, thin lipped grey	*Liza ramada*	3 * HPA impact. Further investigation required to determine any effect		RIMP trend analysis

Flounder	*Platichthys flesus*	3 * HPA impact. Further investigation required to determine any effect		RIMP trend analysis
Five-bearded rockling	*Ciliata mustela*	3 * HPA impact. Further investigation required to determine any effect		RIMP trend analysis
Herring[4]	*Clupea harengus*	0.204%	0.330%	International catch for 2009
Sand Goby	*Pomatoschistus minutus*	3 * HPA impact. Further investigation required to determine any effect		RIMP trend analysis
Bass	*Dicentrarchus labrax*	0.024%	0.029%	SSB for 2009
Plaice	*Pleuronectes platessa*	0.007%	0.018%	SSB for 2009
Ray, Thornback	*Raja clavata*	0.451%	0.742%	International catch for 2009 + Cefas discard estimate.
Whiting, Blue	*Micromesistius poutassou*	0.000%	0.000%	SSB for 2009
Eel	*Anguilla anguilla*	0.333%	0.650%	Independent stock estimate[1]
Shad, Twaite	*Alosa fallax*	0.011% (Using RIMP data)[3]	0.018%	Independent stock estimate[1]
Shad, Allis	*Alosa alosa*	0.069%	0.216%	Independent stock estimate[2]
Lamprey, Marine	*Petromyzon marinus*	0.604%	1.285%	Independent stock estimate[1,5]
Lamprey, River	*Lampetra fluviatalis*	0.062%	0.163%	Independent stock estimate[1]
Salmon	*Salmo salar*	Less than 0.013%. (Using RIMP data).	Less than 0.031%	EA/NRW estimates
Sea trout	*Salmo trutta*	Less than 0.008%. (Using RIMP data)	Less than 0.062%	Extrapolated from rod catch for 2012-2016
Brown shrimp	*Crangon crangon*	3 * HPA impact. Further investigation required to determine any effect		RIMP trend analysis

Notes:

1. Appendix G.
2. BEEMS SPP071 edition 3.
3. 50th percentile impingement effect from SPP071 edition 3.
4. Corrected by results of interannual variability analyses
5. Marine lamprey effect is number of impinged adults assessed against adult population of the Wye/Usk (see note 6 to Table 23).

12.3.2 HPC impingement predictions with LVSE intakes and FRR systems fitted.

The predicted effects of HPC impingement with LVSE intakes and FRR systems fitted but no AFD are shown in

Table 43. The effects are all less than the negligible effects threshold of 1% of the relevant SSB or international landings. The largest predicted impingement effect of HPC on any species is a mean of 0.118% fishery catch for thornback ray or 0.194% fishery catch as a 95th percentile (and based upon analysis of the RIMP data this prediction may have been overestimated by a factor of more than three – see Section 9.6).

Table 43 Predicted HPC Impingement effects (LVSE intakes and FRR fitted) – from uncertainty analysis (Section 8), corrected by results of interannual variability analyses (Section 9.7) for whiting, sole, cod and herring.

Common Name	*Species*	Mean effect	Upper 95%ile effect	Impingement indicator

Sprat	*Sprattus sprattus*	0.016% (from RIMP data)	0.043%	PELTIC SSB for 2013- 2016
Whiting[4]	*Merlangius merlangus*	0.038%	0.072%	SSB for 2009
Sole, Dover[4]	*Solea solea*	0.069%	0.140%	SSB for 2009
Cod[4]	*Gadus morhua*	0.054%	0.119%	SSB for 2009
Mullet, thin lipped grey	*Liza ramada*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis
Flounder	*Platichthys flesus*	Population trend increasing. Negligible effect predicted		RIMP trend analysis
Five-bearded rockling	*Ciliata mustela*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis
Herring[4]	*Clupea harengus*	0.050%	0.081%	International catch for 2009
Sand Goby	*Pomatoschistus minutus*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis
Bass	*Dicentrarchus labrax*	0.011%	0.013%	SSB for 2009
Plaice	*Pleuronectes platessa*	0.002%	0.005%	SSB for 2009
Ray, Thornback	*Raja clavata*	0.118%	0.194%	International catch for 2009 + Cefas discard estimate.
Whiting, Blue	*Micromesistius poutassou*	0.000%	0.000%	SSB for 2009
Eel	*Anguilla anguilla*	0.043%	0.084%	Independent stock estimate[1]
Shad, Twaite	*Alosa fallax*	0.0026% (from RIMP data)[3]	0.0043%	Independent stock estimate[1]
Shad, Allis	*Alosa alosa*	0.017%	0.053%	Independent stock estimate[2]
Lamprey, Marine	*Petromyzon marinus*	0.078%	0.166%	Independent stock estimate[1]
Lamprey, River	*Lampetra fluviatalis*	0.008%	0.021%	Independent stock estimate[1]
Salmon	*Salmo salar*	Less than 0.0086%. From RIMP data.	Less than 0.020%	EA/NRW estimates
Sea trout	*Salmo trutta*	Less than 0.0054%. From RIMP data.	Less than 0.04%	Extrapolated from rod catch for 2012-2016
Brown shrimp	*Crangon crangon*	Population trend increasing. Negligible effect predicted.		RIMP trend analysis

Notes:

1. Appendix G.
2. BEEMS SPP071 edition 3.
3. 50th percentile impingement effect from SPP071 edition 3.
4. Corrected by results of interannual variability analyses
5. Marine lamprey effect is number of impinged adults assessed against adult population of the Wye/Usk (see note 6 to Table 23).

12.4 The HPC impingement predictions in context

12.4.1 Commercially exploited species

For all of the commercial species assessed in this report (sprat, whiting, sole, cod, herring, bass, plaice, thornback ray and blue whiting the predicted worst-case impingement from HPC is much less than the 1% negligible effects threshold. HPC will therefore, have a negligible effect on the long-term sustainability of these fish stocks.

Using the results from Section 7, the total impingement weight for the assessed fish species at HPC in 2009 was predicted to be 56.4 tonnes compared with the equivalent impingement weight for HPB of 51.0 tonnes. HPB impingement losses are in the baseline for Hinkley Point. As HPB is expected to cease operation before HPC becomes fully operational the net increase in impingement losses from HPC will only be 10.6% above the baseline. To put this figure into context when HPA was operational with HPB the impingement level was 131% above the baseline but this additional mortality had no measured effect on the fish populations at Hinkley Point as gauged by the statistical trend analysis of RIMP data.

In an impingement study prepared for the Public Inquiry into the Sizewell B new nuclear power station the annual catch of Sizewell A was estimated to be 66 tonnes which was noted at the time to be ‘less than that of a single small, inefficient trawler’ and therefore of minor significance (Turnpenny and Taylor 2000).

For the commercial species assessed in this report the total catch in the assessment year of 2009 was 653,797 tonnes compared with the predicted HPC impingement total of 56.4 tonnes (Table 23). Excluding the very large commercial catch of blue whiting which distorts the figures and the sprat catch for which an accurate commercial catch figure is not available, for the other seven assessed species the commercial catch was 18,797 tonnes whereas a precautionary estimate of the HPC impingement is 48.4 tonnes or a negligible 0.26% of the commercial catch.

Considering the sustainability of the commercial species found at Hinkley Point, it is clear that fishing overwhelmingly represents the greatest effect. Marine fisheries are managed in Europe under the EU Common Fisheries Policy (CFP) that has the objectives to ensure that fishing and aquaculture are environmentally, economically and socially sustainable and that they provide a source of healthy food for EU citizens. Its goal is to foster a dynamic fishing industry and ensure a fair standard of living for fishing communities. The CFP recognises that whilst maximising catch is important that there must be limits, and the policy seeks to ensure that fishing practices do not harm the ability of fish populations to reproduce. The current policy stipulates that between 2015 and 2020 catch limits should be set that are sustainable and maintain fish stocks in the long term. For some stocks that have been overfished in the recent past and where the adult stock is highly dependent on annual recruitment, it is likely that the CFP policy will not be fully met by 2020. However, ICES is advising the EU commission on fishing limits that will bring each stock within sustainable limits as quickly as possible and appropriate actions are being taken; e.g. the recent temporary moratorium on most fishing for bass.

If a stock is fished unsustainably it is clear that it is the fisheries management policy that will determine the sustainability of the stock not the impact of HPC; e.g. for cod the commercial landings in 2009 were 3292 tonnes whereas a precautionary estimate of the effect of HPC fitted with FRR systems would have been 7.4 tonnes or 0.22% of the cod landings. To put the predicted HPC effect into an alternative context, the discard rate (unwanted fish which are not included in the landings figure or the 2017 cod SSB assessment) has typically been in the range 10-15% of landings in recent years (ICES WGCSE 2017) equivalent to greater than 300 tonnes per annum based upon the 2009 landings figure. i.e. the cod discards were 41 times the predicted impingement from HPC. For cod HPC impingement would have a negligible effect on the sustainability of the stock.

12.4.2 HRA designated species

The predicted HPC effects on the 7 HRA designated fish species are summarised in Table 44 and range from 0.078% SSB for marine lamprey to less than 0.0026% SSB for twaite shad.

International best practice in fisheries management is that a harvesting rate of 1% would have a negligible effect on the sustainability of a fish stock. The worst-case predicted impingement effect for the HRA designated species is for marine lamprey at 0.078% SSB i.e. approximately 13 times lower than the 1% threshold. At this level there is high confidence that HPC impingement will not affect the sustainability of the population.

Table 44 Predicted effects of HPC with LVSE intake heads and FRR systems fitted on HRA designated species

Species	% SSB (mean)	% SSB (upper 95th percentile)
Eel	0.043%	0.084%
Shad, twaite	0.0026%	0.0043%
Shad, allis	0.017%	0.053%
Lamprey, marine	0.078%	0.166%
Lamprey, river	0.008%	0.020%
Salmon	<0.0086%	<0.021%
Sea trout[1]	<0.0054%	<0.040%

Note: 1. Figures for sea trout are the expected range, not the mean and 95th percentile

Table 45 compares the predictions of HPC annual impingement numbers for each of seven HRA designated species with the numbers predicted during the DCO examination (Table 18). In all cases, with the exception of allis shad, the predicted impingement numbers at HPC are lower than those predicted during the Appropriate Assessment of HPC. The allis shad impingement prediction differs by a negligible 2.6 fish per year between the two assessments, with the revised assessment being a negligible 0.017% SSB.

Table 45 Comparisons of updated predicted equivalent adult mortality with those provided for the HPC DCO/HRA

Species	Predicted annual mean adult losses (number of fish) per annum at HPC	
	This report	Shadow HRA at DCO
Eel	156	261
Shad, twaite	4.3	8
Shad, allis	4.6	2
Lamprey, marine	11.7	41
Lamprey, river	9	16
Salmon	<1.36	Not assessed
Sea trout	<0.45	Not assessed

Considering each species in turn:

1. Eel – The predicted effect is considered precautionary as it assumes that all of the eels caught at HPB were mature silver eels with an EAV of 1. However, the sampled population would have included immature yellow eels which would have a lower EAV. An AFD system would have no effect on impingement rates for this species at HPC.

2. Twaite shad. The impingement effects have been based upon a multi-year RIMP assessment due the potential uncertainties of using the 1- year CIMP dataset for a species with a low impingement rate in the CIMP, high year to year variability in numbers and where the

predicted results are highly sensitive to the number of rarely impinged adult fish. (SPP071 edition 3).

3. Allis shad – The predicted HPC impingement effect is considered highly precautionary as it was based upon only 2 fish caught at HPB (one fish in two separate months) and assuming a statistically unlikely scaling factor to arrive at HPC predictions. No allis shad were detected during the 37-year RIMP programme. The two fish caught in the CIMP programme were not migrating in the Severn and were stray, immature sub adults that were part of the widely dispersed juvenile population that feeds at sea. They were most likely part of the French breeding population. The location of the HPC intakes in deeper water means that the impingement rate for this pelagic species is expected to be lower than the predictions in Table 44.

4. Marine lamprey. The HPC impingement effect is considered precautionary as it was based upon only 4 fish caught at HPB in the assessment year and a precautionary SSB. Marine lamprey do not home to natal rivers. They are dispersed over a wide spatial area up to at least the continental shelf by their parasitic feeding strategy and the returning adult fish sampled at Hinkley Point are likely to originate from a much wider stock than the Wye/Usk.

   There are no available data on the hearing ability of lampreys and given they are considered to be the most primitive of the extant vertebrate and that their ear is accordingly unique in its structure, there is no evidence to suggest how the ear responds to sound or even if sound is relevant to them at all (Dong Energy 2013, Popper 2005). There is, therefore, no evidence that marine lamprey (and river lamprey) would respond to the sound fields generated AFDs and an AFD would, therefore, offer no impingement mitigation for this species.

5. River lamprey. There is no evidence that an AFD system would have any effect on impingement rates of this species. The predicted impingement losses are conservatively estimated at a mean of 6 fish per annum The EAV for this species has not been evaluated and has assumed to have a precautionary value of 1.

6. Salmon. The HPC impingement losses for this species are predicted to be less than 1.36 fish per annum (and that is without considering the benefits of the HPC FRR systems). The design and location of the HPC intakes means that salmon are not expected to be impinged a HPC. These design features have not been taken fully into account in this assessment and the predicted losses are so low that it is considered appropriate to screen this species out of the Appropriate Assessment for HPC.

7. Sea trout. The HPC impingement losses for this species are predicted to be less than 0.45 fish per annum (and that is without considering the benefits of the HPC FRR systems). The design and location of the HPC intakes means that sea trout are not expected to be impinged at HPC. These design benefits have not been taken fully into account in this assessment and the predicted losses are so low that it is considered appropriate to screen this species out of the Appropriate Assessment for HPC.

12.4.3 Species assessed by trend analysis

Five species were assessed by trend analysis:

- Thin lipped grey mullet
- Flounder
- Five-bearded rockling
- Sand goby
- The brown shrimp, *Crangon crangon*

These 5 species are not conservation species and are widely distributed geographically. From the trend evidence the following conclusions can be drawn:

a. The abundance of all 5 species at Hinkley Point has a statistically significant positive trend. From well-established principles for the sustainable management of fish populations, if the impingement numbers are constant or rising under constant impingement pressure, using the precautionary approach for data poor stocks described in Section 5.1.1, the harvest rate (i.e. impingement mortality) is sustainable. i.e. if the mortality due to HPB (at approximately 33.7 cumecs) was unsustainable the population would show a decline.

b. When HPA closed down an abstraction of 44 cumecs was removed from the Hinkley Point intakes. This impingement reduction cannot be detected in the RIMP impingement record (Appendix E). The populations of the five species are, therefore, not sensitive to at least a 44 cumec change in abstraction. The equivalent abstraction for HPC will be less than 44 cumecs for 4 of the 5 species with only mullet experiencing a slightly higher equivalent abstraction at 46 cumecs. Given the statistically strong trend in mullet numbers the 46 cumecs from HPC is not expected to have any effect on the mullet population level.

c. The equivalent unmitigated abstraction in all five cases is less than 97 cumecs of abstraction that has ceased operation since 1989 and it can, therefore, be expected that the operation of HPC would have no effect on the population trend for all five species.

d. Finally, the impingement impact on 3 of the species at HPC will be less than the current HPB at 33.7 cumecs. When HPC becomes operational, impingement effects on these species will drop compared with the DCO baseline. For mullet and flounder the net increase in impingement will be 12.3 and 3.3 cumecs respectively, both are of which are far less than the 44 cumecs impingement pressure that was exerted by HPA and which had no effect on population numbers.

12.4.4 The Severn Estuary SAC fish assemblage

For each of the individual HRA designated species (shads, lampreys, eel, salmon and sea trout) the principles of what is a sustainable fish population are well understood. Section 5.1.4 discussed the context surrounding the sustainability of the SAC estuarine assemblage:

- The assemblage is changing with time in terms of relative species abundance and species composition in response to climate change.
- There are very large diel, seasonal and interannual fluctuations in the population density of individual species at Hinkley Point. Estuaries are amongst the most fluctuating aquatic environments on earth, with the boundaries of natural variability, even for individual systems, seldom defined or recorded. The Severn is no exception and given its exceptionally dynamic nature, it is not surprising that no population baseline has been established for the assemblage.
- Individual species migrate into and out of the estuary in succession and the overwhelming majority spend most of their lifecycles outside of the SAC; there are very few truly estuarine resident species and these are not common at Hinkley Point (black goby, common goby, sand smelt, 3 spined stickleback) and all of these show either a statistically significant positive trend in abundance or no trend at the site, Appendix E).
- For most species only the juvenile life stage is exposed to impacts in the estuary and for most species the exposure to impingement risk at Hinkley Point is measured in weeks or a few months. Even within the estuary, species are mobile moving into and out of the regions of inner estuary whilst following prey or retreating from predators, seeking overwintering areas etc.
- The main influences on fish populations are outside the estuary either in reproductive success or survival against predation and fishing in coastal or oceanic waters in the case of marine species whose juveniles use the estuary.

In such circumstances, the concept of estuarine populations of the assemblage species has no biological meaning and the community reflects the state of each stock on a much broader spatial scale which is predominantly outside of the SAC. In just the same manner that the much larger effects of fishing are assessed against the spawning stock biomass of recognised fish stocks (Section 5.2), there is no scientific rationale for assessing the species at Hinkley Point in any other manner where such information exists.

The fish assemblage at Hinkley Point is diverse and contains all of the characteristic species from all the functional guilds, habitat groups and feeding guilds that would be expected of a European Atlantic seaboard estuary at this latitude. The 21 species assessed in this report are representative of the fish assemblage at Hinkley Point. In all cases the predicted HPC impingement was much less than the 1% negligible effect threshold and the populations of each of the species shows either a positive rising trend or no trend. It is therefore concluded that impingement at HPC with LVSE intakes and FRR systems fitted will have no effect on the sustainability of the populations that make up the assemblage. In particular there will be no significant effect on:

i. the conservation species listed as HRA interest features;

ii. the number of functional guilds, feeding guilds and habitat groups present at Hinkley Point;

iii. the abundance of the species present in these guilds and groups; and

iv. the key prey species that supports the fish food web at Hinkley Point.

It is therefore concluded that HPC impingement will have no significant effect on the assemblage nor on the integrity of the SAC.

12.5 Conclusion

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

The test for the HRA assessment is whether the HPC impingement impact will produce a likely significant effect (LSE) on site integrity, assessed against the conservation objectives for the sites. The conservation objectives seek, subject to natural change:

- For the fish assemblage – to at least maintain the overall diversity of species and individual populations against an established baseline (that baseline has not been established).
- For the individual designated fish species – to ensure that populations are at least maintained and are at a level that is sustainable in the long-term.

For both the assemblage and individual designated species the conservation objectives also seek to maintain associated prey populations.

For the harbour porpoise the draft conservation objectives seek to maintain fish prey populations. There is geographical and seasonal variation in porpoise diets that reflected the local availability of fish species. The conservation objectives would therefore be achieved by maintaining the fish assemblage.

The evidence presented in this report which is both precautionary and which has been subjected to exhaustive uncertainty analyses shows that HPC without an AFD fitted would have no adverse effect on site integrity for any of the designated sites.

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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 15.

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.

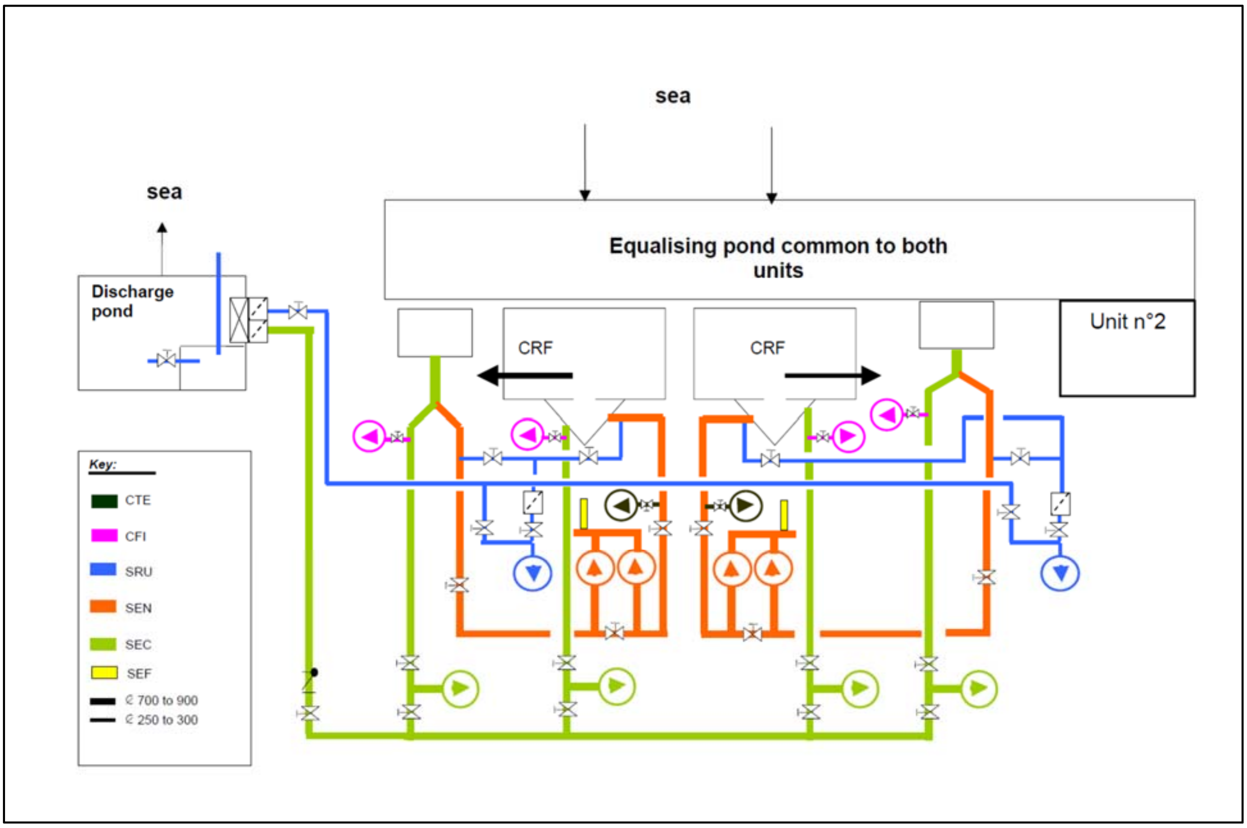

Figure 15 Illustrative schematic of EPR cooling water circuits for each unit (Source EDF CNEPE E.T.DOMA/09 0119 A1 Approved). The equalising pond shown in the figure is the station forebay and HPC has 1 forebay for each unit.

Note that the SRU system (Ultimate Cooling Water System, UCWS) shown in Figure 15 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 46 details the minimum flow at MSL (mean sea level) through the drum screens and Table 47 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 46 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 47 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 48 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 49 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 49).

Table 49 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 50 shows the largest fish sampled during the HPB comprehensive impingement monitoring programme and their calculated widths. The fish species are those species from Table 23 which the HPC FRR is intended to benefit.

Table 50 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

Table 50 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 50, 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 each of the fish with widths shown in red is shown in Table 50, the predicted maximum width of fish that will be able to pass through the 50mm trash rack bars at HPC is shown in Table 51.

Table 51 Calculated maximum width of fish to pass through the 50mm trash rack bars at HPC

Species	Maximum Total Length measured at HPB (mm)	Calculated maximum width (mm) at HPB	Max fish width (mm) at HPC
Cod	709	96.5	64
Sole	449	127	84
Bass	657	93.2	62
Plaice	382	161	107
Thornback ray	952	626	418

3.1.2 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 49).
Assumed FRR mortality for cod impinged via band screens =100% (band screen mortality)
Worst case percentage of CW flow through band screens =9% (Table 46).

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

With Gislason correction factor of 1.89, using the EAV spreadsheet in BEEMS Technical Report TR426 for cod:
Number of survivors without trash rack= 1079.4
Numbers of survivors with trash rack = 1060.0

FRR mortality with the trash rack = 1- (1-FRR-NTR)* survivors with trash rack/survivors without trash rack
= 1-(1-0.545) * 1060/1079.4 = 53.3%

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 52 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 52 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 52 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 23 of this report to increase from 0.077% of the fishery catch to 0.086% 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 total survivors cell in the TR426 spreadsheet, record the number of survivors with the full measured length distribution. Then record the total number of survivors with the any fish over the maximum total length (TLmax50) removed from the length distribution.
3. Calculate the revised FRR mortality from:

FRR mortality with the trash rack = 1- (1-FRR-NTR)* survivors with trash rack/survivors without trash rack

Where:

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

Appendix C Morphometric calculations

Table 53 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. 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 and confidence limits were multiplied by 365.25/40 to give an annual estimate of HPB intake numbers. To estimate HPC intake numbers, the HPB result was multiplied by 131.86/33.7, to scale to the pumping capacities of the new and old stations. (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

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

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Table 54 Predicted unmitigated impingement numbers at HPB and HPC (from bootstrapped data). Note HPC data does not include the reduced impingement expected from the design of the HPC intakes.

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. 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.

Here, we extend the previous analysis on the RIMP dataset to account for any existence of different distributions in fish populations in different months of the year. We implement the Seasonal Kendall Test (SKT) for trends which is insensitive to seasonality in the data. This test is conducted by computing the Mann-Kendall (MK) test separately for each month, i. Denote the set of n (n_i=37 for our series observations in the i^{th} month) by Y_{ij} (j=1,…,n_i) and the set of m_i observations which occur in a later year than Y_{ij} by Y_{ik} (k=1,…,p_i). We then calculate the statistic

$$MK_i = \sum_{j=1}^{n} \sum_{k=1}^{m} sgn(Y_{ij}, Y_{ik})$$

where sgn is an indicator function for month i. This function takes on the values of 1, 0 or -1 according to the sign of the difference in $Y_{ij} - Y_{ik}$.

To facilitate comparison, we report the test statistic standardised by the number of paired comparisons $n_i(n_i - 1)/2$.

$$tau_{SK} = \sum_{i} \frac{MK_i}{n_i(n_i - 1)/2}$$

To facilitate comparison, we report the test statistic standardised by the number of paired comparisons $n_i(n_i - 1)/2$.

$$tau_{SK} = \sum_{i} \frac{MK_i}{n_i(n_i - 1)/2}$$

Thus, if there is a perfect increasing series then the statistic will have value +1; if there is a perfect decreasing series then the statistic will have value -1.

Under the alternative hypothesis of some form of trend (not specifying positive or negative trend) p-values are calculated using a z-test, dividing the test statistic by its standard deviation. We use the *rkt* package (Marchetto 2017) in R version 3.5.1 (R Development Core team, 2018) to compute these p-values, which corrects for missing values and correlation between months. To minimise the number of spurious trends, no statistics were computed for species with less than three observations in each period (1981-1999, 2000-2017 or 1981-2017). This threshold effectively reduced the number of species with 22 species found to have less than three observations in the 36-year period. An additional eight species were found to have less than five observations, but we adopt a conservative approach so as not to eliminate species of interest.

The Seasonal Kendall's trend test is not 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. Where a statistically significant trend is observed, we therefore plot 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 a 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.

Results

Separate seasonal Kendall test statistics and associated p-values for each of the 87 species in 1981-1999, 2000-2017 and for the full time period 1981-2017 have been calculated. The results are shown in the table 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 several species with statistically significant trends as shown in the table and the direction of the trend can be determined from the sign of the statistic (tau) and plots (Figure 16). To ease interpretation, additional large plots are drawn for each species, omitting zero values for improved clarity but retaining LOESS smooths inclusive of zero values (Figure 17 -Figure 21).

Table 55 Calculated Seasonal MK statistics. Results with significant trends highlighted in bold text. A positive value of tau indicates a positive trend and a negative value a negative trend. Some species were observed less than three times during a given time period and no statistics are therefore calculated for them. For clarity, any species with less than three observations in 1981-2017 is omitted from the table.

		1981-2017			*1981-1999*		*2000-2017*		
Species	*Common name*	tau	p	Inter-pretation	tau	p	tau	p	No. fish
Agonus cataphractus	Hooknose (Pogge)	0.074	**0.014**	**Significant**	0.053	0.225	0.092	**0.038**	248
Alosa fallax	Shad,Twaite	-0.097	**0.043**	**Significant**	0.03	0.704	-0.046	0.298	555
Ammodytes tobianus	Sand eel, Common	0.006	0.608		-0.008	0.627	-0.002	0.952	28
Anguilla anguilla	Eel	-0.188	**0**	**Significant**	-0.075	0.079	-0.044	0.105	330
Aphia minuta	Goby, Transparent	0.007	0.851		-0.049	0.283	0.004	0.957	534
Atherina boyeri	Sand smelt	0.025	0.125		0.028	0.195	0.004	0.884	34
Blennius gattorugine	Blenny, tompot	-0.003	0.607		0.008	0.453			6
Callionymus lyra	Dragonet	-0.001	0.982		0.037	0.13	-0.054	**0.035**	95
Callionymus reticulatus	Reticulated dragonet	0.021	**0.008**	**Significant**			0.04	**0.015**	15
Capros aper	Boarfish	0.021	**0.015**	**Significant**			0.041	0.025	18
Ciliata mustela	Rockling,5-Bearded	0.304	**0**	**Significant**	0.23	**0.007**	0.19	**0.048**	2987
Ciliata septentrionalis	Rockling, Northern	0.037	**0.034**	**Significant**	0.034	0.175	0.018	0.513	115
Clupea harengus	Herring	0.309	**0**	**Significant**	0.071	**0.048**	0.129	0.123	4257
Conger conger	Conger	0.029	0.478		0.049	0.268	-0.026	0.739	336
Crenimugil labrosus	Mullet, thick lipped grey	-0.011	0.469		0.041	0.171			75
Crystallogobius linearis	Goby,Crystal	-0.013	0.022	**Significant**	-0.007	0.548			8
Ctenolabrus rupestris	Wrasse, Goldsinny	-0.01	0.081		-0.008	0.416			6

Cyclopterus lumpus	Lumpsucker	-0.044	**0.005**	**Significant**	-0.057	**0.031**	-0.01	0.531	113
Dicentrarchus labrax	Bass	0.136	**0.037**	**Significant**	0.232	**0.009**	-0.048	0.64	3272
Engraulis encrasicolus	Anchovy	-0.007	0.285		-0.01	0.43			7
Entelurus aequoreus L	Pipefish,Snake	0.059	0.133		-0.004	0.901	-0.056	0.435	748
Eutrigla gurnardus	Gurnard,Grey	0.151	**0.002**	**Significant**	0.133	**0.028**	0.082	0.282	768
Gadus morhua	Cod	0.171	**0.001**	**Significant**	0.206	**0.005**	0.05	0.517	2159
Gaidropsaurus vulgaris Cloquet	Rockling,3-Bearded	0.011	0.245				0.003	0.897	13
Gasterosteus aculeatus L	Stickleback,3-Spined	0.041	0.083		0.036	0.068	-0.051	0.244	69
Gobius niger L	Goby,Black	-0.004	0.781		0.002	0.926	-0.052	**0.021**	27
Gobius paganellus	Goby, Rock	0.022	**0.003**	**Significant**			0.025	0.098	10
Hyperoplus lanceolatus Lesauvage	Sandeel, Greater	0.004	0.647				-0.021	0.251	8
Labrus bergylta Ascanius	Wrasse, Ballan	-0.012	0.255		-0.008	0.66	-0.017	0.199	16
Lampetra fluviatalis L	Lamprey,River	-0.004	0.63		0.029	**0.039**			9
Limanda limanda L	Dab	-0.124	**0.001**	**Significant**	-0.048	0.377	0.009	0.831	1717
Liparis liparis L	Sea snail, Common	-0.005	0.9		-0.073	0.13	0.076	0.22	3393
Liza aurita	Mullet, Golden	0.001	0.937		0.032	0.056	-0.053	**0.032**	24
Liza ramada Risso	Mullet, Thinlipped grey	0.192	**0**	**Significant**	0.023	0.717	0.09	0.186	1835
Lophius piscatorius L	Angler fish	-0.007	0.393		-0.027	0.059	0.014	0.186	21
Maurolicus muelleri Gmelin	Pearlsides	0.024	0.232		0.074	**0.006**	-0.047	0.14	58
Merlangius merlangus	Whiting	0.151	**0.019**	**Significant**	0.272	**0.004**	0.001	1	54938
Merluccius merluccius L	Hake	-0.175	**0**	**Significant**	-0.093	0.153			198
Micromesistius poutassou	Blue Whiting	0.013	0.226				-0.022	0.252	68
Molva molva	Ling	-0.002	0.751						4
Mullus surmuletus L	Mullet,Red	0.013	0.298		0.014	0.384	-0.04	**0.049**	121
Platichthys flesus	Flounder	0.127	**0.006**	**Significant**	0.174	**0.009**	0.024	0.736	3372
Pleuronectes platessa	Plaice	0.056	**0.044**	**Significant**	0.07	**0.045**	-0.024	0.589	207
Pollachius pollachius L	Pollack	-0.039	0.144		-0.013	0.747	-0.05	0.217	146
Pomatoschistus microps	Goby, Common	0.076	**0.017**	**Significant**	0.02	0.409	0.02	0.743	157

Pomatoschistus minutus	Goby,Sand	0.152	**0.019**	**Significant**	0.149	0.12	0.025	0.8	12530
Pomatoschistus pictus Malm	Goby,Painted	0.023	0.168		0.02	0.264	0.01	0.741	61
Psetta maxima L	Turbot	0.014	0.337		0.01	0.546	-0.01	0.704	31
Raja clavata L	Ray, Thornback (Roker)	-0.002	0.937		-0.01	0.798	0.022	0.491	92
Raniceps raninus L	Tadpolefish	-0.009	0.137		-0.014	0.177			5
Salmo salar L	Salmon	-0.008	0.235		-0.004	0.685			9
Scophthalmus rhombus L	Brill	-0.024	**0.041**	**Significant**	-0.024	0.282			21
Scyliorhinus caniculus	Dogfish, Lesser spotted	0.127	**0**	**Significant**	0.005	0.849	0.109	**0.039**	114
Solea solea	Sole (Dover sole)	0.327	**0**	**Significant**	0.233	**0.001**	0.139	0.072	9595
Spinachia spinachia L	Stickleback,15-spined	-0.001	0.91		-0.002	0.881	-0.004	0.772	8
Spondyliosoma cantharus L	Sea bream,Black	-0.015	**0.023**	**Significant**	0.004	0.767			7
Sprattus sprattus	Sprat	0.231	**0**	**Significant**	0.124	**0.032**	0.218	**0.006**	66056
Syngnathus acus L	Pipefish, Greater	0.008	0.756		0.089	**0.017**	-0.093	**0.006**	45
Syngnathus rostellatus Nillson	Pipefish, Nillson's	0.003	0.876		-0.025	0.328	-0.015	0.684	86
Trachurus trachurus L	Scad (Horse mackeral)	-0.005	0.678		0.005	0.76	0.009	0.55	19
Trigla lucerna L	Gurnard, Tub	-0.005	0.802		-0.013	0.667	0.044	0.137	67
Trisopterus esmarkii	Pout,Norway	-0.053	0.083		0.003	0.96	-0.021	0.574	308
Trisopterus luscus L	Pout	-0.176	**0.011**	**Significant**	0.007	0.943	-0.307	**0.003**	4150
Trisopterus minutus L	Poor cod	-0.135	**0.037**	**Significant**	-0.084	0.334	-0.101	0.321	7281

References

Marchetto, A. (2017) rkt: Mann-Kendall Test, Seasonal and Regional Kendall Tests, R package version 1.5, https://CRAN.R-project.org/package=rkt

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/.

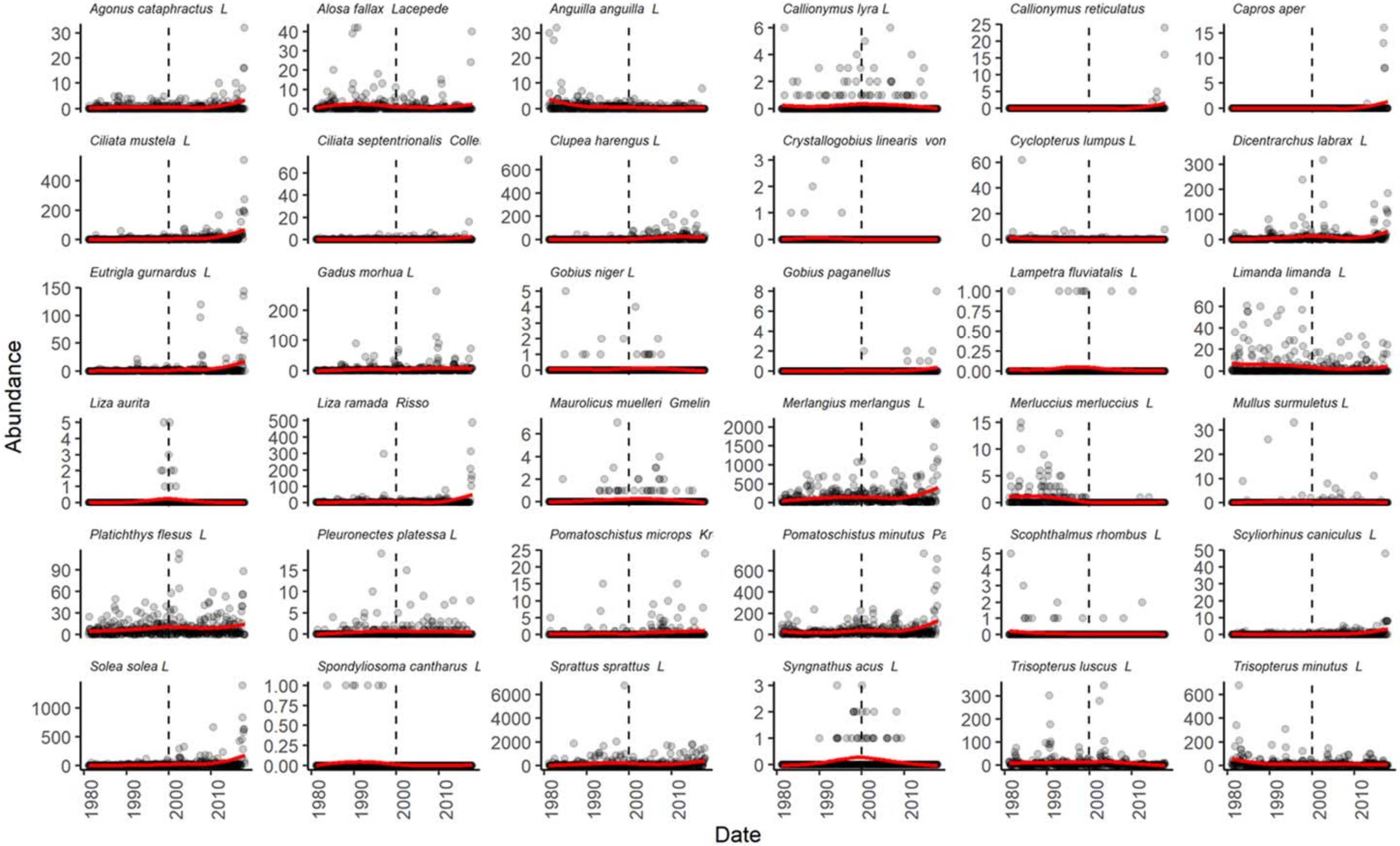


Figure 16 Species Plots where any significant trend was detected in any of the time periods (p-value<0.05). One single loess smooth is drawn for each species. The grey dashed vertical line indicates December 1999

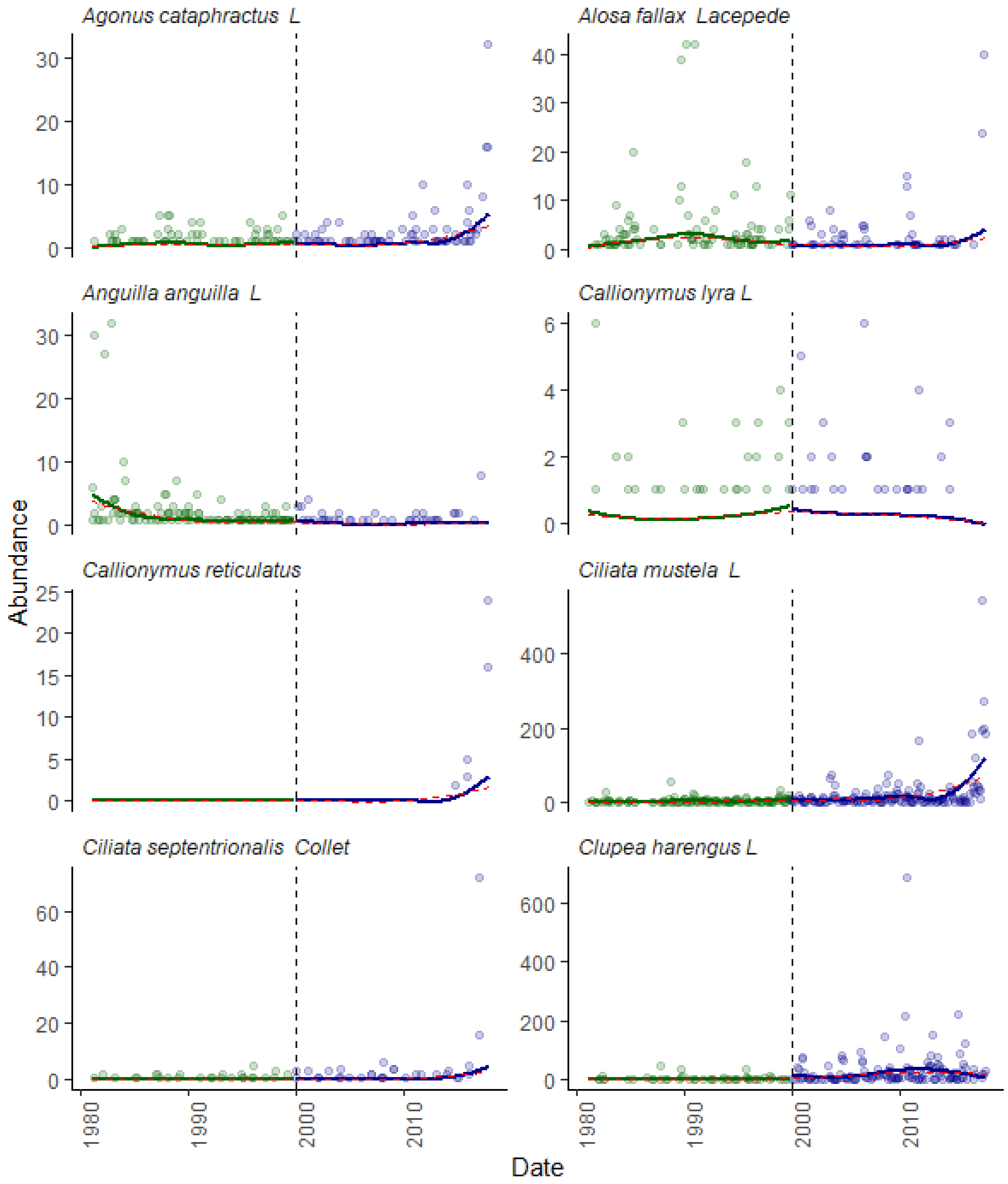


Figure 17. First of the species plots illustrating the species counts and loess smooths applied to the full period (1981-2017, red, dashed lines), 1981-1999 in green and 2000-2017 in blue. The grey dashed vertical line indicates December 1999. Zero values omitted for clarity.

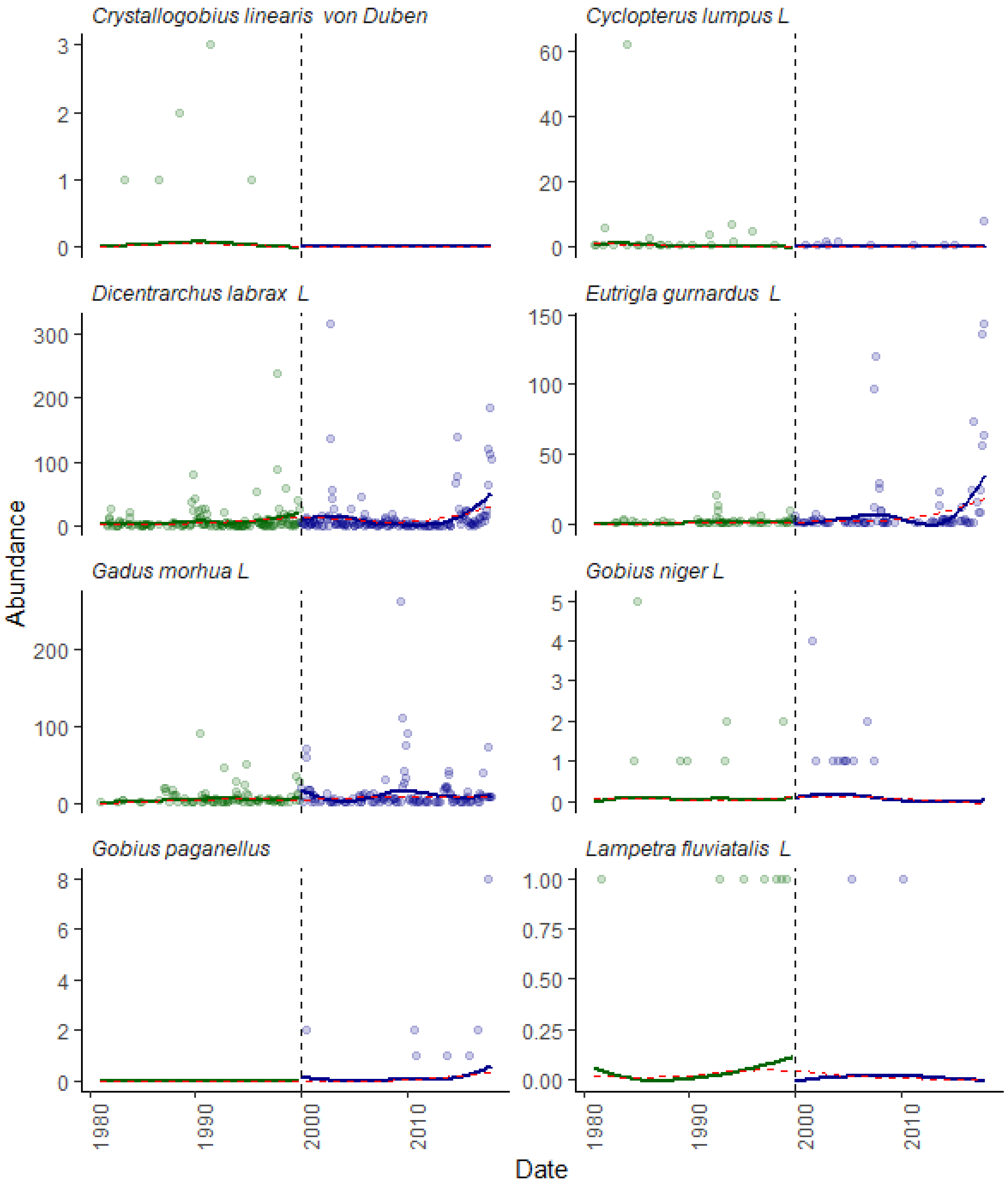


Figure 18. Second of the species plots illustrating the species counts and loess smooths applied to the full period (1981-2017, red, dashed lines), 1981-1999 in green and 2000-2017 in blue. The grey dashed vertical line indicates December 1999. Zero values omitted for clarity.

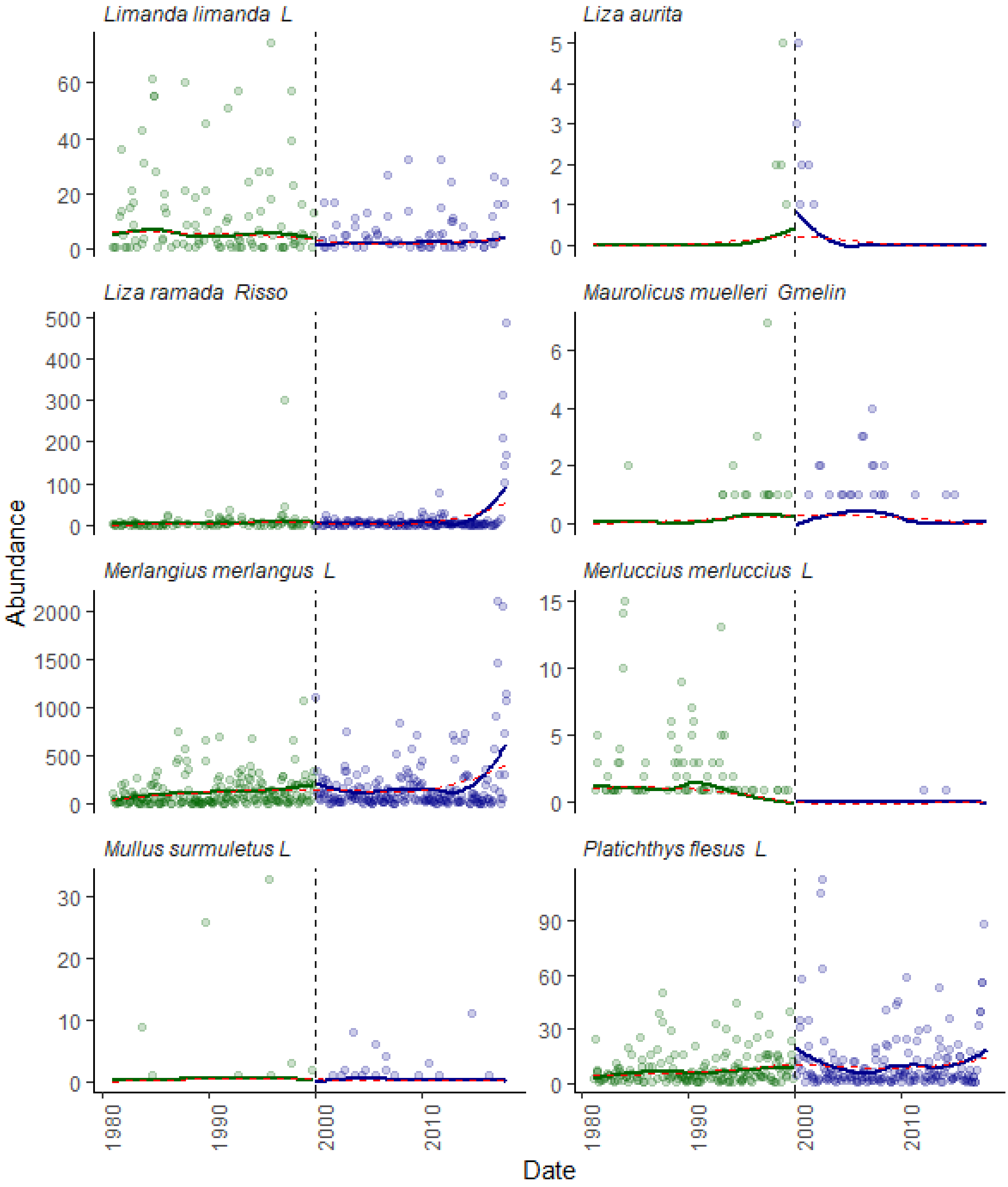


Figure 19. Third of the species plots illustrating the species counts and loess smooths applied to the full period (1981-2017, red, dashed lines), 1981-1999 in green and 2000-2017 in blue. The grey dashed vertical line indicates December 1999. Zero values omitted for clarity

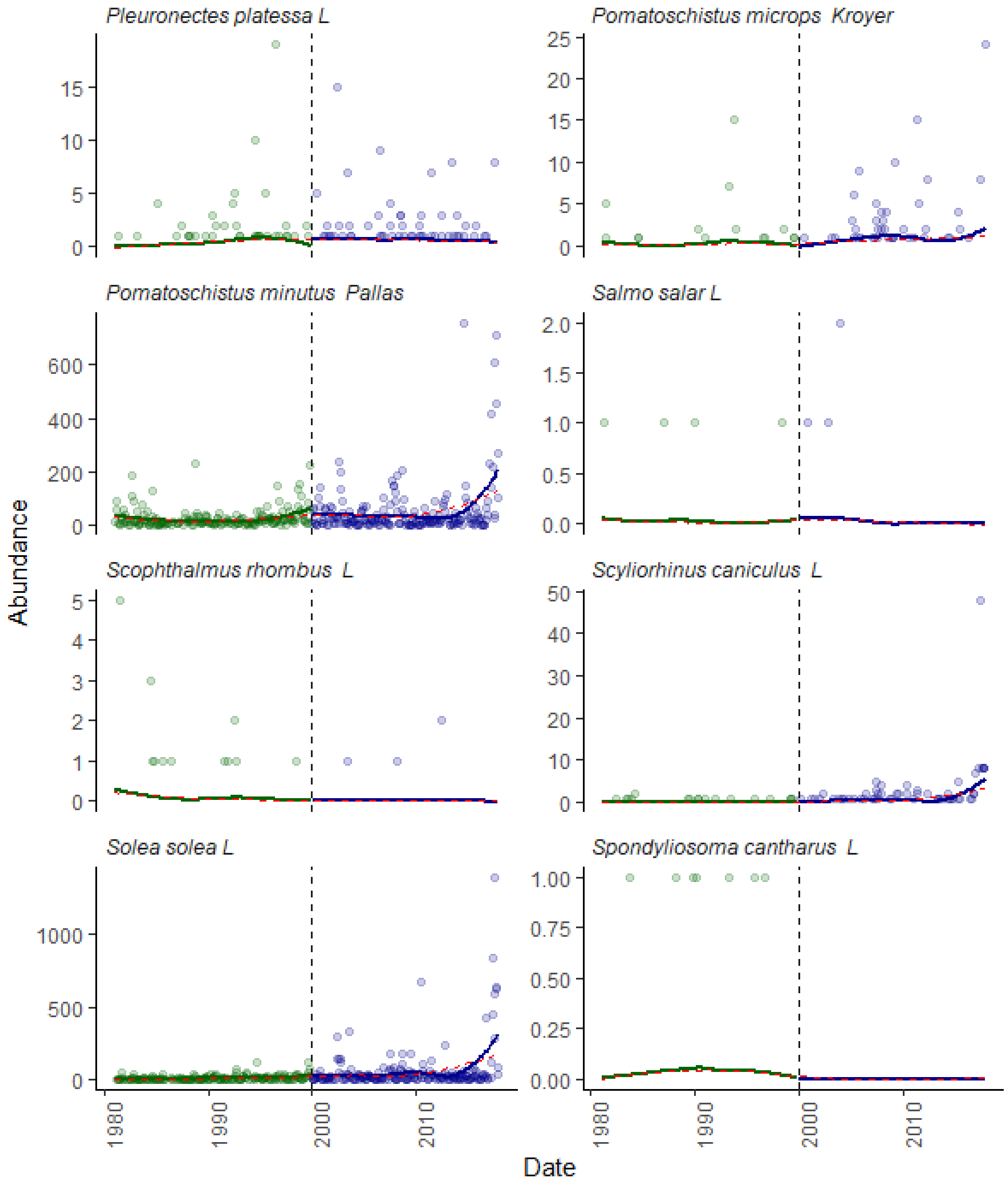


Figure 20. Fourth of the species plots illustrating the species counts and loess smooths applied to the full period (1981-2017, red, dashed lines), 1981-1999 in green and 2000-2017 in blue. The grey dashed vertical line indicates December 1999. Zero values omitted for clarity

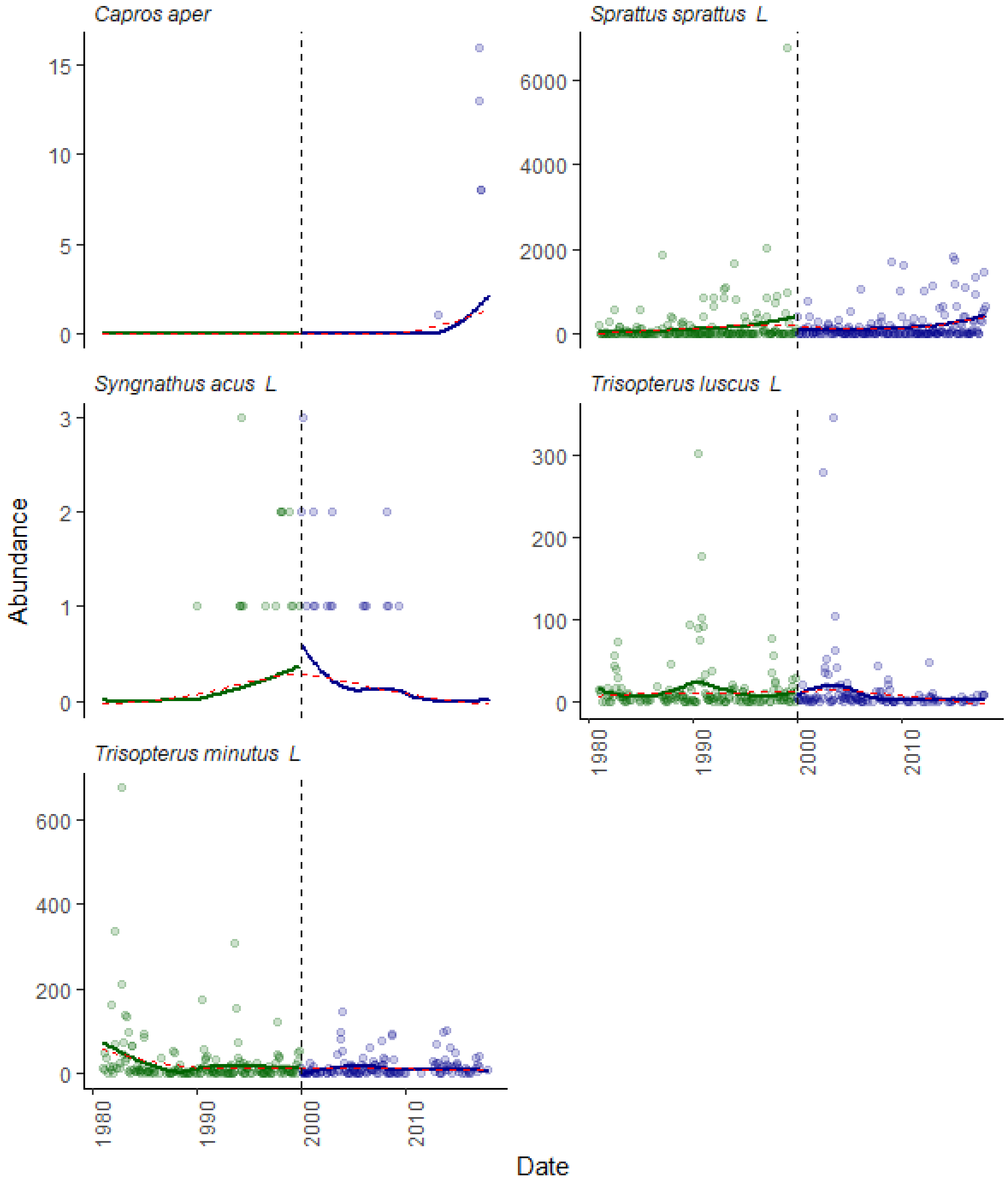


Figure 21. Fifth of the species plots illustrating the species counts and loess smooths applied to the full period (1981-2017, red, dashed lines), 1981-1999 in green and 2000-2017 in blue. The grey dashed vertical line indicates December 1999. Zero values omitted for clarity.

Appendix F Calculation and validation of appropriate natural mortality and EAV values for species impinged at Hinkley Point.

Estimates of Natural Mortality (M) are fundamental to fisheries stock assessment and for multispecies ecological studies. M is very difficult to measure directly and to overcome the shortage of fish stock specific M values, fisheries scientists have developed at least 30 different estimators for determining M using a variety of species specific lifecycle parameters.

Two equations are important to this work:

1. The basic form of the fish mortality equation

$$N_{t+1}=N_t\,e^{-Z\Delta t}$$

where:

ΔT = time interval – usually 1 year in fish stock assessment

N_t is the abundance at the start of the time period, N_{t+1} is the abundance after time interval Δt

Total mortality Z = Fishing mortality F + Natural Mortality M (noting that both F and M are species and fish size dependent)

2. The von Bertalanffy growth equation given by:

$$L_t = L_\infty(1-e^{-K(t-t_0)})$$ (von Bertalanffy 1951)

where L_t is the fish length at time t, L_∞ is the asymptotic length - the mean length the fish of a given stock would reach if they were to grow indefinitely, K is the growth rate parameter, or the rate at which L_∞ is approached and t_0 the age of the fish at zero length if it had always grown in a manner described by the equation. (Note K and L_∞ are correlated)

F.1 The utility of the various M estimators for EAV purposes

The published natural mortality estimators break down into 3 main types:

1. Age dependent – using the maximum observed age (Tmax)
2. Those derived from life history parameters from the von Bertalanffy growth equation
3. Estimators based upon ecological theory

The majority of these equations have been derived from regression analysis using measured values of M for a selection of species (mostly from the NE Atlantic and North Sea). Many aspects of fish physiology scale with the size of the organism – metabolism, food intake, growth, reproduction and mortality (Gislason *et al* 2008, McGurk 1986), however most of the natural mortality equations only provide estimates of M for mature adult fish. For stock assessment purposes estimates of M are required for the exploitable part of the population when the population is either mature or partially mature. The natural mortality equation for fish is L shaped (unless the species is unexploited, and fish survive to senescence when the equation becomes U shaped) and most natural mortality occurs in juveniles. As fish approach adulthood, the rate of change of M with size reduces before M increases again for the oldest (and largest) fish. An incorrect assumption for M in a fish stock assessment will bias estimates of fishing mortality and stock abundance and an extremely high exploitation rate can be unintentionally be recommended in cases where M is overestimated. Stock size estimates are much less sensitive to underestimates of M (Clark 1999) and it is, therefore, common practice to set a conservative (low) value of M for stock assessment purposes. In single species stock assessments the fact that an M equation only produces a single (size independent) estimate of M for adult fish is, therefore, not considered to be a major issue. For mixed species assessments, where immature non-target species are vulnerable to fishing, the use of a size independent M estimate is more problematical. For EAV estimation where the purpose is to transform the number of impinged juveniles into equivalent adults, a single estimated value of M for adults is of no value.

F.1.1 Age dependent relationships

Age dependent estimators provide a single estimate of mortality for mature adult fish and only provide estimates of M for unexploited populations. The difficulty in their use is that estimates of Tmax are required from before the population was exploited (assuming that a validated aging methodology was available at the time). Even where such measurements are available Tmax is often uncertain due to the difficulty of sampling the oldest (and therefore rarest) fish in a population. Typical formulae include Hoenig (1982,1983).

Using these formulae predicted M varies with species but not the size of the individual animal so M would be the same for an 0 group 6cm cod as an adult 60 cm cod if the formulae were used inappropriately (The formulae are only intended to produce estimates for adult fish).

F.1.2 Estimators based upon life cycle parameters

These are of 2 types:

- Size independent estimators based upon K and L_∞ (Pauly 1978,1980 which also factored in seawater temperature), Griffiths and Harrod 2007)
- Estimators that are based upon fish length, K and L_∞ (Gislason *et al* 2010 and a closely related reanalysis Charnov *et al* 2012)

Measurements have shown that there is a strong correlation between M and growth and the maximum organism size. Fish that grow slowly to a large size have a low M, fish that rapidly reach maturity at a small size have a high M. However demersal species that grow to a large maximum size have a higher juvenile mortality than smaller demersal species which have protective features against predation (e.g. flat body shape, spines etc. (Gislason 2008)

F.1.3 Estimators based upon ecological theory

These estimators are based upon the weight (or length via a length/weight transformation) of a fish and are independent of species (Peterson and Wroblewski 1984, McGurk 1986 and Lorenzen 1996); i.e. the predicted M from such estimators for a 6g sprat would be the same as that for a 6g cod.

F.2 Evaluation of the different M estimators

Fisheries scientists have studied the strategies and life cycle parameters that fish communities adopt in order to maintain themselves over the long term i.e. so that over the long-term members replace themselves on a one for one basis over their lifetimes. Observations have shown that subject to natural variability, fish communities maintain their composition in terms of the number and types of species for many decades and probably much longer and there must, therefore, be mechanisms to stop the community evolving to a small number of successful species. A study of the North Sea fish community (Gislason *et al* 2008) found that assumptions that M was based solely upon size or upon L_∞ and K were able to reproduce the observed community stability and to do so M had to be a function of L_∞, K and fish length to reproduce the observed stability.

The authors found that mortality varied between demersal and pelagic species with small demersal species having a lower M than larger species (smaller fish had adaptations to reduce predation eg being flat, having spines, venom etc which larger species do not possess). For pelagic species smaller species have higher growth rates and higher M than larger pelagic species. ie the strategy that smaller pelagic fish adopt is to minimise the time they spend at sizes more vulnerable to predation by a high growth rate.

For EAV determination it is necessary to produce M estimates at size and therefore none of the estimators that produce estimates for adult fish are useful for this task; the only estimators that are useful are life cycle models incorporating length (Gislason *et al* 2010, Charnov *et a*l 2012) or those based on ecological theory (McGurk 1986, Lorenzen 1996). The question then becomes which formula is the most reliable for a specific species and is that formula reliable enough for EAV determination.

Kenchington 2014 critically reviewed 30 M predictors of the 3 types outline above. He concluded that none of the formulae can provide accurate M estimates for every species and none appears to sufficiently precise for use in analytical stock assessment (specified by Kenchington to be within ± 20% of the true value.)

Kenchington noted that:

- only 2 formulae provided confidence intervals (the size based Gislason equation and Cubillos et al 1999 – the latter being non-size based and reliant on K and t_0 life cycle parameters)
- of the regression based formulae only Gislason applied rigorous criteria to select M measurements
- of the lifecycle parameter based models Gislason showed promise and generally performed well for teleosts
- neither Gislason nor Lorenzen/McGurk provided realistic M for old fish when they entered senescence. However, this is not an issue for EAV determination at Hinkley Point because the impinged fish are overwhelmingly juveniles)

Kenchington's evaluation methodology requires some comment. Firstly, Kenchington assumed that for stock assessment purposes M needed to be known within an accuracy of ±20% accuracy and this was then adopted as the standard against which to judge the performance of the M estimators in the study. This may well be an aim for stock assessment (but one that is probably not achieved in practice) but for EAV purposes what is required are best median estimates of M together with plausible worst-case values (i.e. the lowest plausible estimates as a low M produces high EAVs and therefore high impingement estimates) which can then be used to set bounds on the expected impingement effects.

Secondly to evaluate each estimator he compared the predicted median M against ' known' M (without stating the expected limits of accuracy for such known M values) for 13 highly diverse species that included deep water lanternfish, seahorses, porbeagle, shark, tuna, scallops, two Sebastes species (rockfish that are amongst the longest lived on earth, and two lutjanus species (tropical reef/mangrove snappers) and sandeel but only 2 fish species (plaice and anchovy) that could be considered to be similar to the typical species on which UK fisheries stock assessments have been historically focussed. Kenchington did not use M at size measurements to test the size based formulae and simply used 2 different lengths 'spanning the range of sizes seen in the studies that produced the known M'. He then determined whether the predicted range of M encompassed the measured M. However, without further information on the length distribution in the known population this does not give anything other than a crude estimate of the precision of the estimator – a mean estimate would have been far more informative.

Using this method Kenchington concluded that the ecological theory based estimators (e.g. Lorenzen) could not be recommended but it should be noted that the Lorenzen estimator passed the Kenchington test for anchovy and plaice.

Kenchington noted that the Gislason estimator was promising but needed to be subject to testing on a wider group of species. He also noted that Gislason *et al* 2010 reported that the 95% confidence intervals around the outputs of their estimator stretched to one quarter to four times the estimated M. In summary, Kenchington's analysis is useful in that it:

- narrowed down the range of potentially useful M estimators
- confirmed that Gislason was the most promising of the size based estimators

- demonstrated that if a size based estimator is used uncritically on species that exhibit very different lifecycle parameters than the majority of the species used in the original regression analyses that there was a risk that unrepresentative M estimates will be generated.

F.3 Method used for estimating M for EAV purposes at Hinkley Point

After consideration of what was required (a size based M estimator) and the extensive published literature it is concluded that the best option for the calculation of M for fish species at Hinkley Point was the Gislason recommended formula (Gislason *et al* 2010) for estimating the natural mortality of marine and brackish water fish:

$$ln(M) = 0.55 * 1.61ln(L) + 1.44ln(L_\infty) + ln(K)$$

where

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

In undertaking the current impingement assessment early work used the Gislason *et al* 2010 and Lorenzen 1996 size based formulae. However, after consideration of the critical analysis in Kenchington 2014 and particularly that in Gislason *et al* 2008, use of the Lorenzen formula has not been carried forward in this assessment. This is not to state that the Lorenzen equation is necessarily incorrect, indeed for some species and some fish sizes the M estimates are not dissimilar to those produced by Gislason *et al* 2010 but that the evidence is that Gislason M estimates should be more reliable. It should also be noted that ICES uses the Lorenzen formula for some Celtic sea species.

Gislason noted that the spread of the individual estimates of M produced by the model was large and with a model RMSE of 0.72, the 95% confidence interval of a predicted M will range from approximately 25% to 410% of its predicted median value. Table 56 shows the results of applying M/4 and M*4 to the EAV methodology described in BEEMS Technical Report TR426 for the Hinkley Point CIMP data. For each species the table shows the mean EAV prediction (using the uncorrected Gislason M estimate) and alternative predictions with M scaled by 2 different correction factors (CF). In the table, a CF of 4 means that the Gislason M estimate was divided by 4 (i.e. producing a low estimate of M), a CF of 0.25 means that the Gislason estimate was multiplied by 4.

For impingement assessment purposes the 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. For sensitivity testing purposes it is low M values that are, therefore, of interest.

Table 56 Sensitivity of the calculated EAV for Hinkley Point species to estimates of M

	EAV			
Hinkley Point Species	Mean M (CF=1)	M with a CF=4	M with a CF = 0.25	Worst case EAV ratio (M with CF=4/median M)
Sprat	0.412	0.727	0.27	1.8
Whiting	0.099	0.488	0.014	4.9
Sole	0.076	0.466	0.007	6.1
Cod	0.0022	0.05895	0.00039	26.8
Herring	0.027	0.308	0.011	11.4
Bass	0.1076	0.4235	0.0367	3.9
Plaice	0.132	0.334	0.096	2.5
Thornback Ray	0.208	0.549		2.6

Table 56 shows that the difference between the calculated EAV with a median M and a worst-case M/4 (i.e. CF=4) is more than an order of magnitude for cod and herring. For the other species in the table the EAV is much less sensitive to estimates of M.

Whilst it is possible to use the worst-case M values to compute EAVs, this approach risks creating an unrealistically high impression of the HPC impingement effects and it is therefore important that M is estimated as accurately as possible for each assessed species. From the foregoing assessment of M estimators it is clear that M values produced by the Gislason equation cannot be used for EAV estimation without validation and, dependent upon the results of the validation, appropriate correction. A combination of approaches is used in this report to validate the M estimates from the Gislason equation. The ideal position would be to use measured M values for the stock of interest but, as described previously, for most species such data do not exist nor due to the difficulty of performing the necessary measurements, are they likely to become available in the near future. For EAV estimation the accuracy of the M values for juvenile fish are important but most of the M measurements that exist are for adult mature fish.

For ICES stock assessment purposes reliable, conservative estimates of M are important. ICES uses expert groups to regularly and systematically review the assessment process for each stock and as fisheries science has developed a variety of approaches for estimating M have been adopted. The most advanced approach is for North Sea assessments where ICES uses a multi species model to directly calculate predation (the dominant part of natural mortality) and retrospective M estimates from this model are now routinely prepared for North Sea cod, herring, whiting and sprat. In other stock areas ICES uses the results from empirical M estimators that the relevant expert group judges to be most appropriate based upon the scientific evidence for the stock. For example, in the Celtic Sea region ICES uses the Lorenzen 1996 equation to estimate age (size) dependent mortality for some demersal roundfish and flatfish. For other species ICES working groups have used size independent M estimates derived from a variety of formulae; e.g. Pauly 1980, Then *et al* 2015 that provide M estimates that are considered representative of measured values for adult fish.

The procedure used to validate the Gislason predictions used in this report makes use of several evidence strands:

i. For those species where suitable M measurements exist, comparing measurements of M at specific sizes with predicted values and then computing a correction factor to scale the Gislason values as necessary.
ii. Where data exist, comparing ICES modelled M at age data for with the Gislason estimates for that species
iii. For all species comparing the Gislason predicted adult M with ICES assumptions of adult M that have been derived by expert judgement. As a cross check comparing the worst case Gislason M/4 values with ICES estimates of adult M.

Due to their complex life cycles EAV predictions have not been prepared for eel, river lamprey, salmon or sea trout and a worst-case assumption of an EAV of 1 has been has been used for each of these species in this report. An EAV of 1 will only be correct for adult fish, for juveniles such an assumption will overestimate impingement effects.

For marine lamprey a precautionary EAV has been estimated in Section F.12 of this appendix.

For twaite shad there are insufficient impingement data to undertake the analytical procedure to calculate an EAV described in BEEMS Technical Report TR426 and a simplified but conservative assessment has been undertaken as described in BEEMS SPP071/S edition 3. This calculates M using the McGurk 1986 equation which is more conservative than Gislason and agrees with published M estimates for adult twaite shad.

The remainder of this Appendix provides the results of the Gislason evaluation for each assessed species at Hinkley Point.

F.4 Cod EAV

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

- Data provided in the Gislason *et al* 2010 supplementary data of measured values of M for North Sea cod (Table 57)
- Modelled M outputs for North Sea cod in 2009 from the ICES WGSAM 2017 multispecies model

Table 57 Gislason measured M for North Sea cod v uncorrected Gislason predictions

L (TL) cm	l∞ cm	K	Gislason M	Measured M	Correction factor
12	132	0.2	7.18	3.8	1.89
27.8	134	0.1	0.95	1.1	0.86
33.7	132	0.2	1.36	0.55	2.48
41.9	134	0.1	0.49	0.2	2.45
54.5	68.6	0.17	0.21	0.4	0.52
60	115	0.1	0.22	0.1	2.21
62	65	0.3	0.28	0.18	1.53
73.6	100.3	0.15	0.20	0.3	0.65
80.4	129	0.13	0.21	0.33	0.64
					1.47 mean

Source of measured data: Gislason *et al* 2010 Supplementary data.

Figure 22 Measured M versus computed Gislason M for North Sea cod

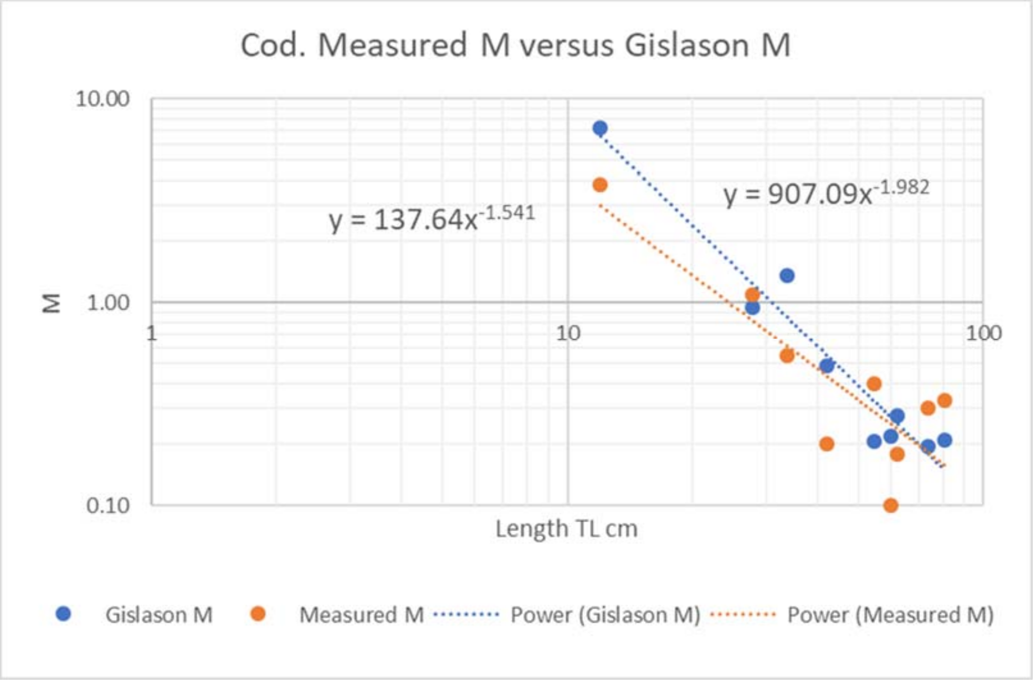


Figure 22 shows that Gislason M predictions agree with measured M values for adult cod but that for smaller fish the Gislason M values are higher than the measured M values. The ratio of the Gislason to measured M increases with decreasing fish length according to the relationship shown in Figure 23.

Figure 23 Gislason correction factor computed from the ratio of the best fit trendlines in Figure 22.

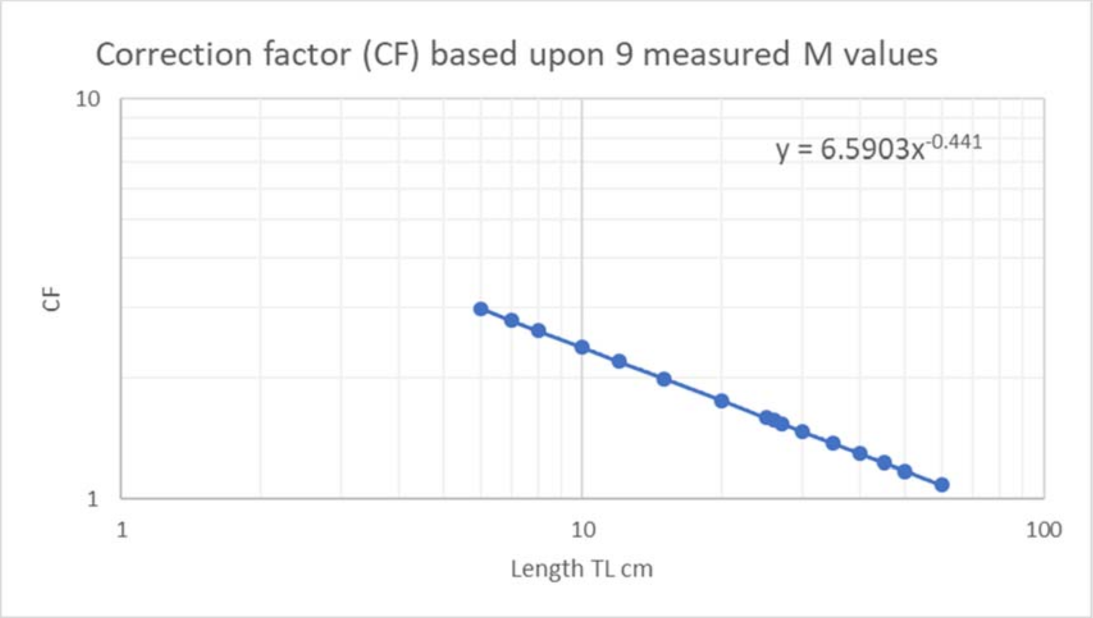


Table 58 ICES modelled M estimates for North Sea cod for 2009 from North Sea multispecies model versus Gislason M

Age	**L (TL) cm**	2009 modelled M	Gislason M	Ratio Gislason/ Modelled M	
1	28.6	1.167	1.77	1.52	
2	42.8	0.935	0.93	0.99	
3	59.1	0.304	0.55	1.81	
4	72.3	0.2	0.40	1.99	
				1.58	mean

Sources:
Modelled M: ICES WGSAM 2017 Stock Annex for ICES North Sea SMS configuration
Age length key: CEFAS North Sea Groundfish data.

Table 59 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 = 1.47	0.00619
CF = 1.58	0.00747
CF = 1.89	0.01174
Variable CF	0.00854

Conclusions

- The uncorrected Gislason formula produces M values that are higher than the measured values and the adult M value is implausibly high
- The mean correction factor for the 9 measured M values was 1.47, producing an EAV of 0.0062
- The correction factor for the smallest measured cod (at 12cm TL) was 1.89, producing the highest EAV at 0.0117
- The calculated correction factor varies with length (e.g. CF=3.1 at 6cm TL, CF= 2.2 at 12cm TL). Applying this variable CF produces the most accurate M estimates and produces an EAV of 0.0085.
- Assuming a worst-case CF of 4 provides implausibly low values of M (0.11 for a 3 year old adult compared with ICES expected value of 0.3)
- The mean fit with the ICES modelled M values of M was a correction factor of 1.58.
- As a worst case, a correction factor of 1.89 was selected. The predicted M for adult fish at age 3 and 4 with this CF are lower than would be expected but this, combined with the result from applying a variable correction factor makes the EAV estimate of 0.0117 conservative.

F.5 Herring

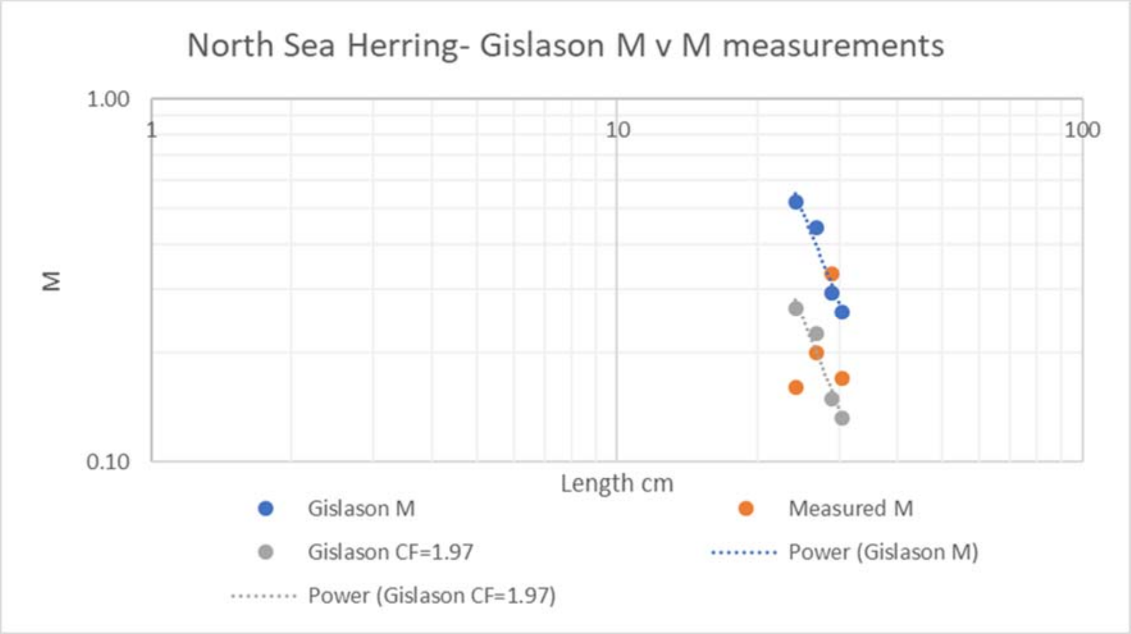
There are only a few herring M measurements (Table 60) and the values that exist are for a narrow length range of adult fish. The measurements were made upon an exploited stock and will have been subject to uncertainty in separating natural mortality from fishing mortality.

Table 60 Measured M values for North Sea herring against uncorrected Gislason M predictions

L (TL) cm	**l∞ cm**	**K**	**Gislason M**	**Measured M**	**Correction factor**	
24.2	30	0.38	0.52	0.16	3.3	
26.8	29.5	0.39	0.44	0.20	2.2	
29	30.4	0.28	0.29	0.33	0.9	
30.4	36	0.21	0.26	0.17	1.5	
					1.97	mean

Figure 24 shows that the Gislason M predictions for herring appear to be too high by a mean factor of approximately 2 but the lack of measurements for small fish mean that this factor is not certain.

Figure 24 Comparison of M measurements and Gislason M predictions for North Sea Herring



In the North Sea Subarea IV and VIId herring stock assessments ICES is using the results of a multispecies model (ICES HAWG 2018) which takes account of predator prey relationships to derive M at age (Table 61). These results are plotted against the uncorrected Gislason predictions in Figure 25. From these data a mean correction factor for the Gislason equation of 1.99 is appropriate for herring. This is a considered to be a conservative estimate because the ICES modelled M value for 0 group herring is only for the second half of the year and the modelled M value of 1.016 is, therefore, an underestimate of the full year mean M.

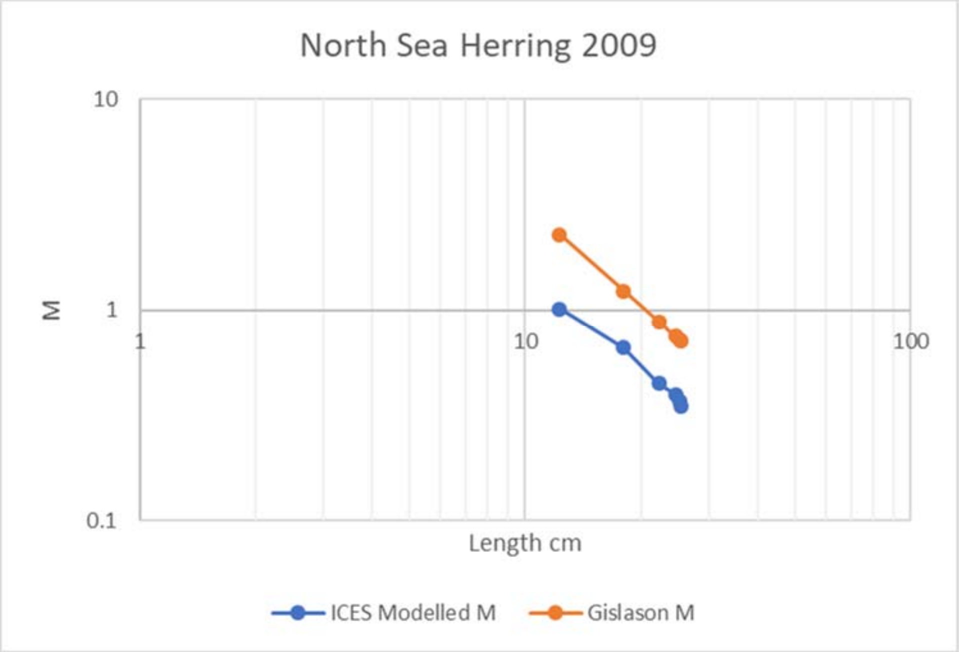
Table 61 ICES modelled M values for 2009 versus Gislason M predictions for North Sea herring

Age	L TL cm	ICES Modelled M	Gislason M	Ratio Gislason/ Modelled M	
0	12.3	1.016	2.29	2.25	
1	18	0.682	1.24	1.82	
2	22.2	0.449	0.88	1.97	
3	24.5	0.397	0.75	1.90	
4	25.1	0.368	0.73	1.97	
5	25.4	0.349	0.71	2.04	
				1.99	mean

Notes:

1. Modelled M from ICES HAWG 2018, Age 0 M prediction is for 2nd half of the year, not the full year i.e. M for the full year is greater.
2. Total Length L is from Cefas North Sea Groundfish Survey data

Figure 25 ICES modelled herring M for 2009 versus uncorrected Gislason M predictions



Conclusions

- The uncorrected Gislason formula produces M values that are higher than the measured and the more recent multispecies modelled M values for North Sea herring. The uncorrected adult M value is implausibly high at approximately 0.9.
- Comparison with M measurements indicates a correction factor of approximately 2 is appropriate but the few data that are available are all clustered around a small, adult size range and extrapolation to smaller fish lengths is uncertain. The M measurements may also be suspect due the difficulty of disentangling fishing from natural mortality at the time.
- Comparison with the modelled M used in the herring North Sea assessment also indicates a correction factor of 2 for the Gislason predictions producing an EAV of 0.113. A correction factor of generates a credible M value for 2 year old adult fish of 0.44 compared to the modelled 0.45.
- Assuming a worst-case CF of 4 provides implausibly low values of M (0.22 for a 2 year old adult compared with ICES expected value of 0.45).

The available evidence indicates that a correction factor of 2 is conservative for herring generating an EAV of 0.113.

F.6 Plaice

Table 62 and Figure 26 show the comparison between the measured M for plaice versus the uncorrected Gislason predictions. The measured M has 2 sources, Gislason *et al* 2010 supplementary data for the adult fish and McGurk 1986 for the juvenile plaice (The McGurk data comprise 7 separate measurements from 5 areas in the Celtic and North Seas.

Table 62 Plaice: Measured M versus Gislason predicted M

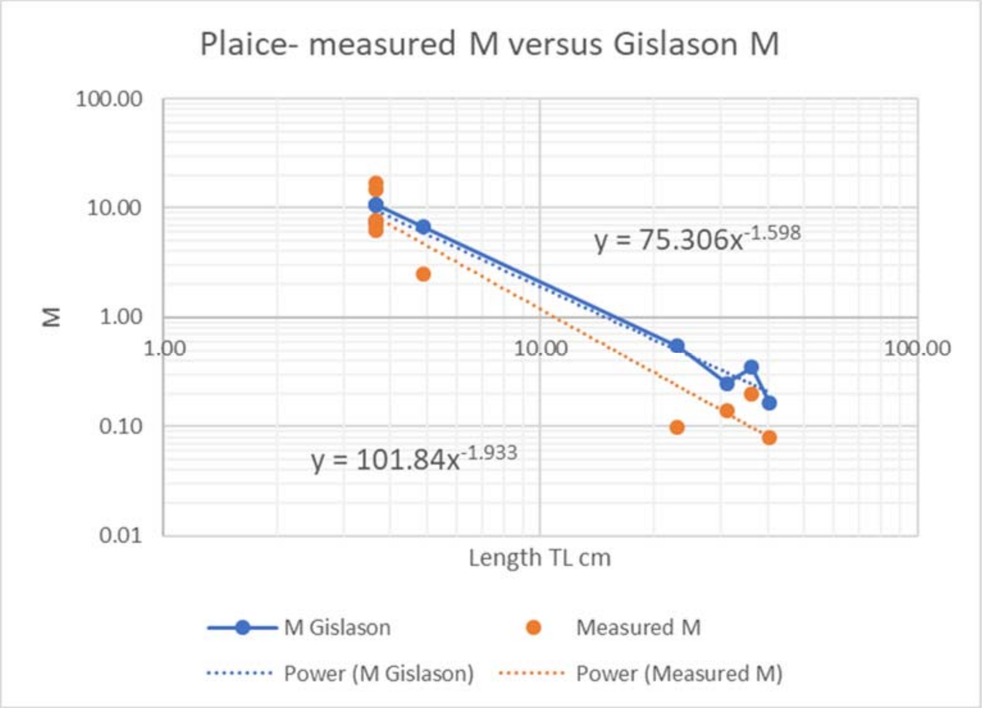
L cm	L_∞ cm	K	M Gislason	Measured M	Ratio: Gislason/ measured M	Source of measured M
3.65	54.4	0.110	7.49	6.2	1.21	McGurk
3.65	54.4	0.110	7.49	16.80	0.45	McGurk
3.65	65.0	0.122	10.73	7.67	1.40	McGurk
3.65	65.0	0.122	10.73	14.98	0.72	McGurk
3.65	65.0	0.122	10.73	6.94	1.55	McGurk
4.90	65.0	0.122	6.68	2.484	2.69	McGurk
23.1	65.0	0.122	0.55	0.10	5.56	McGurk
31.2	45.0	0.150	0.25	0.14	1.75	Gislason
36.3	46.0	0.260	0.34	0.20	1.72	Gislason
40.5	70.0	0.080	0.16	0.08	2.03	Gislason
					1.91	mean

The Gislason predictions are generally higher than the measured values although at small sizes the differences between the 2 datasets reduces and the predicted correction factor is in the range 0.45 to 1.4. The mean correction factor for the Gislason equation from Table 62 is 1.9.

Table 63 Hinkley Point EAV for plaice with different correction factors to the Gislason equation.

Correction factor (CF) applied to the Gislason calculated values of natural mortality (M)	Hinkley Point plaice EAV	Predicted M year 5 fish (L=29.3cm)
Original Gislason i.e. CF=1	0.132	0.30
CF = 1.91	0.185	0.16
CF = 2	0.192	0.15
CF = 3	0.264	0.10
CF = 4	0.334	0.07

Figure 26 Plaice – measured M versus Gislason predicted M



Conclusions

- The uncorrected Gislason formula produces M values that are higher than the measured M values for plaice and the adult M value is implausibly high at approximately 0.3.
- Comparison with M measurements indicates that a mean correction factor of approximately 1.9 is appropriate with a predicted smaller correction for 0 group fish. The EAV at CF=1.9 is 0.185.
- Assuming a worst-case CF of 4 provides implausibly low values of M (0.07 for a 5 year old adult compared with ICES expected value of 0.12 (ICES WGCSE 2018 plaice VIIfg). A CF between 2 and 3 would more closely fit the ICES estimate but as noted previously stock assessments use precautionary M values.

The available evidence indicates that a CF of 2 for plaice is conservative. The EAV at this value is 0.192.

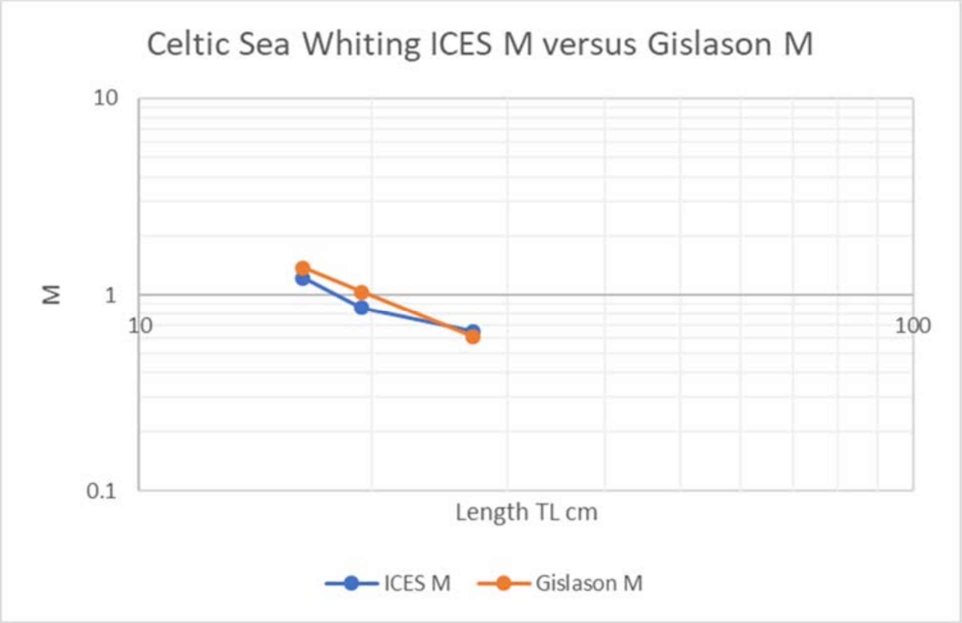
F.7 Whiting

There are no M measurements for whiting. For the VII b-k whiting assessment ICES assume that M varies with age according to Lorenzen 1996 i.e. M is a function of weight. (ICES WGCSE 2017 Whiting 7b-k)

Table 64 Comparison of ICES assumed M values for whiting against Gislason M

L TL cm	Age	ICES M	Gislason M	Ratio: Gislason/ ICES M
16.3	0	1.22	1.38	1.13
19.4	1	0.86	1.04	1.21
27	2	0.65	0.61	0.94
			Mean	1.09

Figure 27 Comparison of ICES assumptions for whiting M against Gislason M



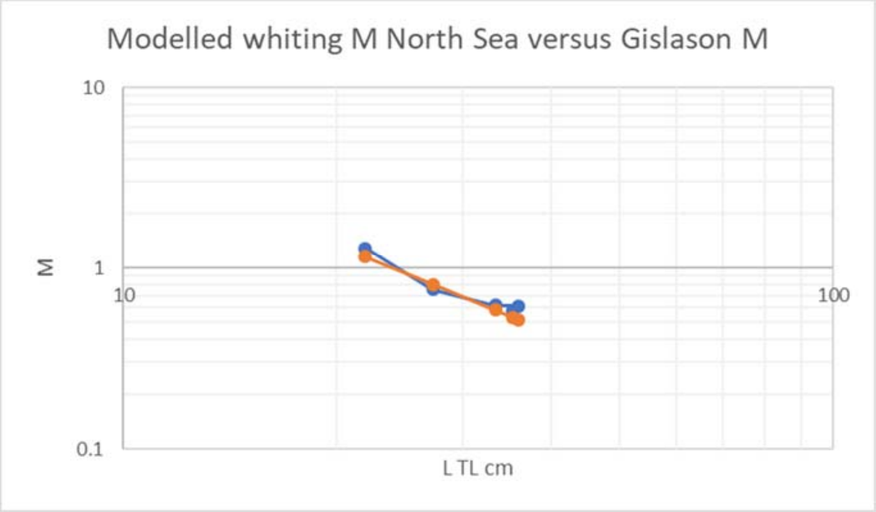
In the North Sea ICES use the result of a multi species model to estimate M at age. Table 65 shows the results of comparing the modelled M results for 2009 against the Gislason M predictions for the North Sea.

Table 65 Modelled M versus Gislason M for North Sea whiting

L TL cm	Age	Modelled M in 2009	Gislason M	Ratio Gislason/ modelled M
21.9	1	1.288	1.151	0.89
27.3	2	0.755	0.807	1.07
33.4	3	0.62	0.583	0.94
36.0	4	0.615	0.517	0.84
35.4	5	0.574	0.531	0.93
			Mean:	0.93

Modelled M from ICES WGSAM 2014

Figure 28 Modelled M for North Sea whiting versus Gislason M estimates



Conclusions

- The uncorrected Gislason formula produces mean M values approximately 9% higher than the ICES M estimates for the Celtic Sea. The Gislason values are 13% higher than the equivalent ICES value for 0 group fish. In the North Sea the uncorrected Gislason estimates are approximately 7% below the ICES M values which were derived from a multi species model that estimated predation rather than relied on an M estimator.
- Assuming a worst-case CF of 4 provides implausibly low values of M (0.15 for a 2 year old adult compared with ICES expected value of 0.61 (ICES WGCSE 2017 whiting VIIbc,7e-k).

The available evidence indicates that the Gislason M values for whiting do not need correction. This would indicate the EAV for Hinkley Point whiting is 0.099. As a worst case a CF for whiting is 1.25 is conservative. The EAV at this value is 0.142

F.8 Thornback Ray

There are no M measurements for thornback ray. Thornback ray have slow growth, a late age at first maturity and a low adult natural mortality (Considered to be approximately 0.1 by Cefas elasmobranch specialists). Ryland and Ajayi 1984 estimated that M was 0.16 for adult thornback ray in Camarthen Bay, derived from the Pauly 1980 regression equation.

In the VIIafg stock area Thornback ray are 100% mature at age 6 with an approximate length of 80cm.

Table 66 Effect of applying different correction factors to the Gislason equation and the resulting adult M estimate

Correction factor (CF) applied to the Gislason calculated values of M	Hinkley Point plaice EAV	Predicted M year 6 fish (L=80cm)
Original Gislason i.e. CF=1	0.197	0.175
CF = 2	0.339	0.09
CF = 3	0.447	0.055
CF = 4	0.528	0.045

Conclusions

- The uncorrected Gislason formula produces M values that are higher than the expected M values for adult thornback rays at approximately 0.175 compared with an expected range of 0.1 to 0.15
- A CF of 2 produces an adult M of approximately 0.9 which is considered conservative.
- Assuming a worst-case CFs of 4 or 3 provide implausibly low values of M (0.045 or 0.055 for a 6 year old adult compared with expected values of 0.1 to 0.15).
- The available evidence indicates that a CF of 2 for thornback ray is conservative. The EAV at this value is 0.339.

F.9 Bass

There are no M measurements for bass. Up to and including the published 2017 WGCSE Bass assessment, ICES used an M of 0.15 for adult fish but after a 2 year comprehensive review of the available evidence the working group adopted a value of 0.24 in 2018 for all ages based upon an M estimator using the observed maximum age of bass in the stock (Then *et al* 2015, ICES WKBASS 2017).

Table 67 The effect of applying different correction factors to the Gislason equation for bass and the resulting estimates of adult M

Correction factor (CF) applied to the Gislason calculated values of M	Hinkley Point bass EAV	Predicted M year 10 fish (L=52.5cm)
Original Gislason i.e. CF=1	0.121	0.17
CF = 1.1	0.133	0.15
CF = 2	0.242	0.09
CF = 4	0.433	0.04

Conclusions

- On the basis of the Gislason adult M values (at age 10 in accordance with ICES assumptions), no corrections are indicated for the Gislason equation which produces an M estimate of 0.17 which is well below that now in use by ICES of 0.24.
- Assuming a worst-case CFs of 2 or 4 provide implausibly low values of M (0.09 or 0.04 for a 10 year old adult compared with an expected value of 0.24).
- To increase the predicted M value to 0.24 at age 10 would require a CF 0f 0.7 producing a corresponding EAV of 0.087, however, it was decided to maintain a precautionary EAV produced by the uncorrected GIslason equation.
- The available evidence indicates that a CF of 1 for bass is conservative. The EAV at this value is 0.121.

F.10 Sprat

A single M measurement is available for North Sea sprat of 1.21 for juvenile 4.3g fish (McGurk 1996). The original reference does not provide all of the relevant life cycle parameters so these have been extracted from Fishbase for North Sea sprat. Taking into the account the uncertainty in the life cycle parameters, the Gislason calculated M is within the range 1.55 to 1.89 producing a correction factor of 1.29 to 1.51 for the 8.6 to 8.7cm fish.

More recently ICES has produced estimates of M from a North Sea multi species model which calculates predation rather than using a M estimator. The outputs for that model are shown below for 2009.

Table 68 Sprat – Modelled M in 2009 versus Gislason M

Age	Length TL cm	Modelled M 2009 Sprat	Gislason M	Ratio
1	10.7	0.982	1.537	1.56
2	12.2	0.654	1.244	1.90
3	13.35	0.597	1.076	1.80
			mean:	1.76

Source: ICES WGSAM 2017. Stock annex for ICES North Sea SMS configuration.

A comparison with the modelled M values indicates a mean correction factor of 1.76 with a worst-case correction of 1.9 for a 2 year old fish.

Conclusions

- The uncorrected Gislason formula produces an M value that is 1.29 to 1.51 higher than the single measured M value for North Sea sprat and produces M values for adult sprat at 3 and 5 years old of 1.05 and 0.97 which are considered implausibly high.
- Comparison with modelled M measurements indicates that a mean correction factor of approximately 1.8 for adult fish is appropriate with a predicted smaller correction for 0 group fish. The EAV at CF=1.9 is 0.556. Applying this correction factor to the Celtic Sea results in a predicted M for 3 year old fish of 0.28 which is considered to be low and therefore conservative.
- Assuming a worst-case CF of 4 provides implausibly low values of M (0.13 for a 3 year old adult).

The available evidence indicates that a CF of 1.9 for sprat is conservative. The EAV at this value is 0.556.

F.11 Sole

There are no M measurements for sole. For sole assessments in the Celtic Sea region ICES uses an age independent M of 0.1 set as a conservative value.

The uncorrected Gislason equation produces an M of 0.28 for an adult 6 year old sole which is considered to be too high by stock assessment experts.

A correction factor of 4 produces an M of 0.07 for a 6 year old fish which is considered too low. Sole has a flat body shape to reduce juvenile predation as does plaice. Worst case M for sole would be expected to be similar to plaice and thornback Ray i.e. with a correction factor of 2.

Conclusions

- The uncorrected Gislason formula produces an M value that is 2.8 times higher than the ICES assumed M value for adult fish of 0.1. The ICES age independent value has been set conservatively.
- Comparison with species which have similar adaptions to reduce juvenile predation (plaice and thornback ray) indicates that the worst-case correction factor adopted for these species of 2 is appropriate. A correction factor of 2 produces an estimated M for 6 year old sole of 0.14.
- Assuming a worst-case CF of 4 provides values of M (0.07 for a 6 year old adult) which are considered to be too low.

The available evidence indicates that a CF of 2 for sprat is conservative. The EAV at this value is 0.236.

F.12 Marine Lamprey

Natural mortality of marine lampreys prior to spawning is poorly understood. Natural mortality of adult marine lampreys introduced into two Lake Ontario tributaries ranged from 6 to 30 % and mortality from predation ranged from 1 to 11 % (cited in Hansen *et a*l 2016). The maximum age (Tmax) of marine lampreys is estimated to be 11 years (Fishbase). Using Kenchington's recommended formula for calculating M for adult fish of 4.3/Tmax (Kenchington 2014) would imply an M of 0.39 equivalent to a mortality of 32% per year. Kenchington showed that this formula provided reliable results for a wide range of fish taxa but it has not been validated for marine lampreys as field measurements of M do not exist. For this report we have, therefore, not assumed a value for juvenile mortality and have instead calculated the effect of HPC on the juvenile parasitic and adult phases separately with an assumed EAV of 1 for each phase.

In the CIMP programme two juveniles and two adults were impinged.

F.13 EAV Summary

Table 69 Summary of EAVs derived in this Appendix for Hinkley Point fish species

Species	EAV	Gislason CF	Worst case EAV	Gislason CF
Sprat	0.556	1.9	0.556	1.9
Whiting	0.099	1	0.142	1.25
Sole	0.236	2	0.236	2
Cod	0.0117	1.89	0.0117	1.89
Herring	0.113	2	0.113	2
Bass	0.121	1	0.121	1
Plaice	0.185	1.9	0.192	2
Thornback Ray	0.339	2	0.339	2
Marine Lamprey	1.0			

Appendix G Impingement Effect – Fish Stock Indicators (Conservation species – adapted from the 2010 DCO reports 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 a more conservative estimate of 80%.

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. For impingement purposes, based upon geography, it has been assumed that juvenile shad migrating to sea from the River Tywi are not vulnerable to impingement at HPC. After deduction for the adult population in the Tywi, the mean population has been assumed to be 165,788 individuals.

Twaite shad are vulnerable to mechanical damage, 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 marine (or 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 marine lamprey ammocoete population (APEM, 2010). Although river and marine 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 marine 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		**Marine lamprey**
Adults			
Usk:	27,667 ± 4,696	Usk:	3,069 ± 455
Wye:	88,442 ± 14,326	Wye:	12,200 ± 1,836
Total:	**116,109**	**Total:**	**15,269**
Parasitic juveniles			
Usk:	3,424,610± 309,754	Usk:	2,245,978 ± 90,767
Wye:	11,100,707 ± 873,381	Wye:	8,937,418 ± 417,532
Total:	**14,525,317**	**Total:**	**11,183,396**

Lampreys are poor swimmers and there is no evidence that they would benefit from AFD impingement mitigation techniques. 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% in this report.

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.

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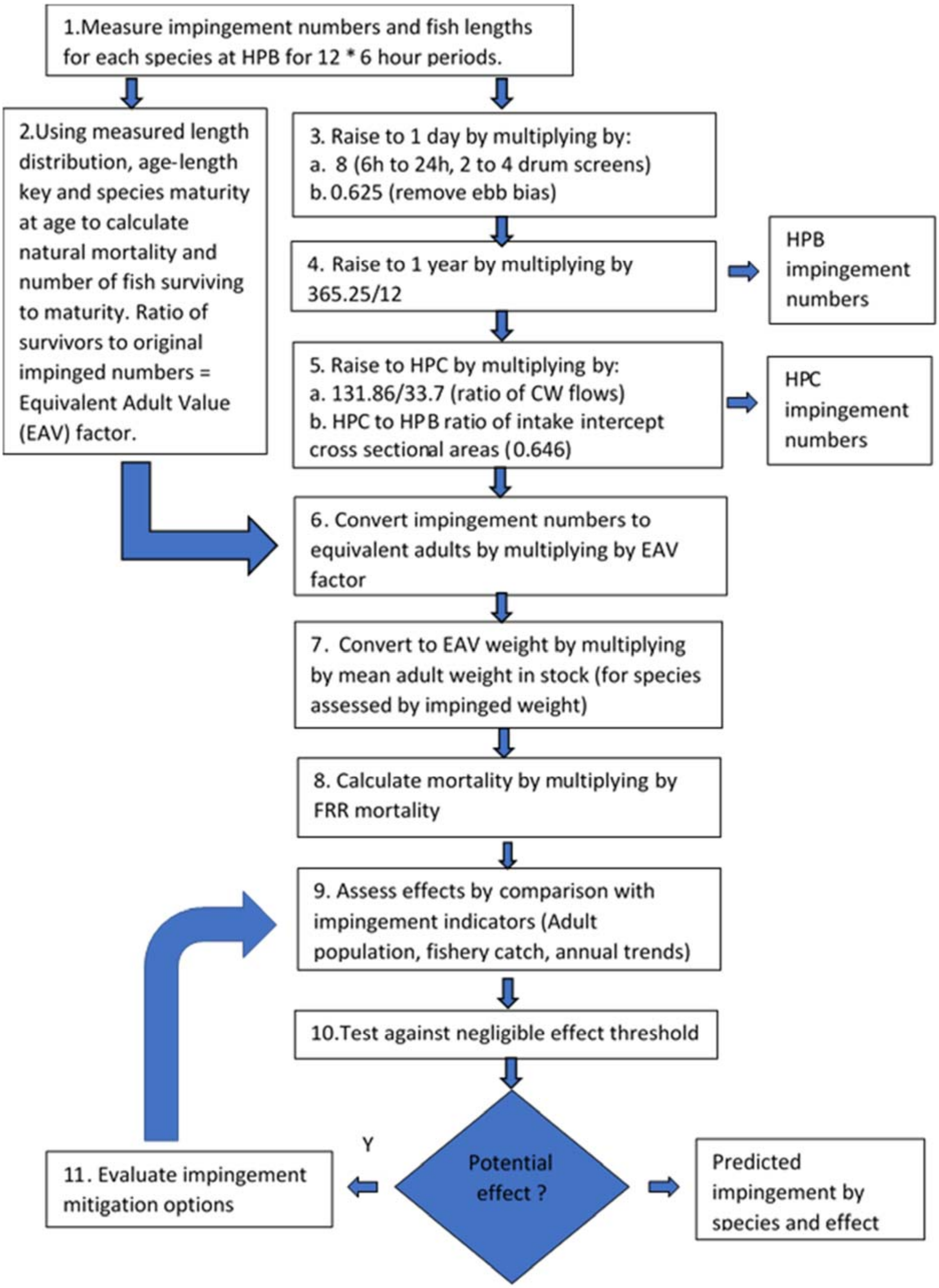
Appendix H Impingement Assessment – RIMP data



Appendix I Uncertainty Analysis Methods

A Monte Carlo uncertainty analysis was carried out to assess the uncertainty in the % impingement effect (i.e. impingement mortality/SSB as a percentage). For the first stage of this process, estimates of variability in impingement numbers were calculated using bootstrapping. Then each bootstrap iteration was used as input to the % effect calculation and combined with an SSB value generated from a distribution representing the uncertainty in SSB. The resulting confidence interval for the % impingement effect therefore includes variation in SSB and sampling variation within the year impingement sampling was carried out.

Bootstrapping

The data were resampled with replacement within each quarter of the year to match the data collection procedure (10 visits per quarter). Then, for each of 100,000 bootstrap iterations, the sum of the 40 sampled values was calculated. 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 and confidence limits were multiplied by 365.25/40 to give an annual estimate of HPB intake numbers. To estimate HPC intake numbers, the HPB result was multiplied by 131.86/33.7, to scale to the pumping capacities of the new and old stations, multiplied by 0.646 to account for the HPC to HPB ratio of intake intercept cross sectional areas and multiplied by 0.38 for pelagic species only to account for the use of capped intake heads. (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 v3.5.1 (R Core Team, 2018) using package 'boot' (Canty and Ripley, 2017).

Note that for the uncertainty analysis the bootstrapping reported in Appendix D of this report was rerun – the only changes were the number of bootstrap iterations and the version of the R software.

Including uncertainty in SSB

Mean SSB values and 95% confidence limits were sourced from ICES working group reports, independent estimates and expert judgement by ICES working group staff. The statistical distribution to simulate SSB values from was based on the relationship between the mean and confidence interval (CI). For species where the CI was symmetrical about the mean, a normal distribution was used; for the other species the CI was skewed so a log normal distribution was used. Parameters for the simulation distributions were defined to match the literature mean and lower limit. (The equation used are in the section below). For the log normal distributions, our resulting simulation upper limits were less than the input SSB values. This was because the input values were from assessment models that did not produce exact log normal distributions. In these cases, our approach is conservative as the simulation has less chance of producing an extremely high SSB value (and therefore a small population effect) than the published interval (particularly for twaite shad where the published interval is very skewed).

For each species, 100,000 samples were drawn from the SSB distribution, using the R function *rnorm* or *rlnorm*. Each was combined with one bootstrap iteration of impingement numbers within the % effect calculations to produce a distribution of the % effect estimates. From this, the mean % effect was calculated, along with a 95% interval (the 2.5 to 97.5 percentiles). Results were also calculated excluding the uncertainty in SSB to illustrate its effect on the final results.

Equations used to derive simulation parameters from published intervals

The SSB values provided were the mean, m, lower 95% confidence limit, $L95$ and upper 95% confidence limit, $U95$.

To simulate from a normal distribution, the mean, μ and standard deviation, σ are needed.

By definition:

$\mu = m$

$L95 = m - 1.96\ \sigma$

So,

$\sigma = (m - L95) / \sigma$

To simulate from a log normal distribution, the mean on the log scale, *meanlog* and standard deviation on the log scale, *sdlog* are needed.

By definition:

log(*L95*) = *meanlog* - 1.96 * *sdlog*

m = exp(*meanlog* + 0.5 * *sdlog*^2)

Therefore,

meanlog = log(*L95*) + 1.96 * *sdlog*

log(*m*) = *meanlog* + 0.5 * *sdlog*^2

substituting for *meanlog*,

log(m) = log(*L95*) + 1.96 * *sdlog* + 0.5 * *sdlog*^2

rearranging,

0.5 * *sdlog*^2 + 1.96 * *sdlog* + (log(*L95*) - log(*m*)) = 0

which is solved for *sdlog* using the positive root from the quadratic formula:

$$sdlog = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

with a = 0.5, b = 1.96, c = (log(*L95*) - log(*m*))

Note, the 97.5th quantile from a standard normal distribution is shown as 1.96 above for simplicity, full accuracy was used in the calculations.

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Appendix J Intercept cross-sectional area of the HPB and HPC intakes

To calculate the relative risk of impingement for fish traveling in the tidal flow at Hinkley Point it is necessary to calculate the area that the intakes present orthogonal to the axis of the tidal flow.

J.1 HPC.

Each HPC intake is aligned with the tidal flow and has two capped intake surfaces that are 2m tall. The horizontal zone of influence of each intake surface is assumed to be 2m (this is highly precautionary as modelling shows that the flow field will be undisturbed at 2m range). Each intake therefore presents a cross sectional area to the tidal flow of approximately two times two by two metres i.e. 8m^2. Total for 4 heads is 32 m^2.

J.2 HPB

The radius of the HP intake caisson (Radius) is 19.5m. The caisson is divided into 6 equal sectors of approximately 60º. The axis of the HP intake structure is aligned to approximately 350º i.e. 10º west from north. (Angle alpha =10º). (Source EDF Energy)

The ebb tide has an average direction of 80º. i.e. 10º north of east. (Angle beta =10º). (Source BEESM Technical Report TR052

The HPB intake surface is not facing directly into the ebb and instead its axis is nearer to south east. The intake is also curved. The intake presents a width orthogonal to the ebb given by Radius* Sin(60-alpha-beta) = 19.5 * sin (40) = 12.53m.

The height of the HPB intake surface is 5.8m i.e. the vertical cross-sectional area is 72.7 m^2.

The horizontal intake surface has an assumed zone of influence of 1.5 m vertically above the intake i.e. flooded cross sectional area of 18.8 m^2. The assumption of a 1.5m zone of influence is precautionary and less than that of the HPC intakes because of the theoretically lower intake velocity. However, it is known that fish are particularly vulnerable to vertical velocities and the 1.5m zone of influence may be underestimated.

As the HPB intakes are situated in shallow water, towards low water the exposed surface area of the intakes varies with the tide. The cross-sectional area of the HPB intake was calculated over an entire spring-neap cycle to calculate the mean intercept cross-sectional area of the intake. The results are shown in Table 70.

Table 70 Comparison of calculated intake intercept cross sectional areas presented to fish being transported in the tidal streams at HPC and HPB.

Tidal state	HPC intakes (4) total cross-sectional intercept area m^2	HPB intake mean cross sectional intercept area m^2	HPC/HPB intercept area ratio
Neaps	32	52	0.615
Springs	32	47	0.681
Over a spring/neap cycle			0.646