HINKLEY POINT C PERMIT VARIATION

EPR/HP3228XT/V004

Technical Brief: TB008

Fish Recovery and Return System Mortality Rates.

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Marine Contractor, APEM LTD.

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EXECUTIVE SUMMARY

The applied Fish Recovery and Return (FRR) mortality rates in TR456 Ed2 Rev10 (BEEMS, 2019) differ to those applied in the original Technical Report TR148 (BEEMS, 2012) and TR456 Ed2 Rev9 (BEEMS, 2018).

This Technical Brief reviews the different FRR mortality rates used for the project to date and the different methods used to determine the mortality rates.

The Technical Brief then recommends a method to set a FRR mortality rate for each species and a range around the FRR mortality rate for each species. The range set accounts for the uncertainty in the underlying evidence used to set the FRR mortality rate, and in the efficiency of the bespoke FRR system proposed for Hinkley Point C (HPC).

TR148

The mortality rates applied in TR148 were based on the Environment Agency's (EA) best practice guide to fish screening in the UK (Turnpenny & O'Keeffe, 2005). The best practice guide details three survival figures for different fish groups; pelagic (e.g. herring, sprat, shad) – 0%, demersal (e.g. cod, whiting and gurnards) – 50% and epibenthic (e.g. flatfish, eels, gobies, rocklings and crustaceans) – 80%.

TR456 Ed2 Rev9

The same best practice guide survival rates are applied in TR456 Ed2 Rev9 for the drum screens. Lower survival rates of 0% were applied to the pelagic and demersal species groups for the band screens however, due to a longer retention period of fish in the screen buckets of between 33 and 50 minutes due to the low screen rotation rate. 80% survival rates were still applied for epibenthic species impinged upon the band screens however, though no additional evidence was provided to support this as all available evidence identified later in this evidence report is for survival from drum screen impingement (Fawley, Sizewell, Pembroke and Le Blayais power stations).

Consideration is then given to the trash racks and the proportion of fish entrained into the intake that will pass through the trash racks and become impinged upon the drum or band screens. The proportion of flow passing through the drum and band screens was then used to apportion fish mortality rates for the two screen types. These two adaptations to the FRR mortality calculations resulted in higher mortality rates being considered for a number of species such as cod and plaice in particular.

TR456 Ed2 Rev10

The same approach adopted in TR456 Ed2 Rev9 to developing the FRR mortality rates at the drum screens and band screens are applied to TR456 Ed2 Rev10. A new factor is applied however, to account for the mortality of fish which do not pass through the trash racks. The number of each species which do and do not pass through the trash racks are used to calculate the numbers of those fish which would survive to maturity. The number of fish surviving to maturity is calculated using the Equivalent Adult Value (EAV) models and length-mortality relationships derived based on Gislason et al. (2010)[1].

The number of fish which would survive to maturity with and without the trash racks is then used to amend the FRR mortality rates for the presence of the trash racks. The example given is based on cod and the BEEMS Technical Report TR426 for cod. This

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[1] Gislason, H., Daan, N., Rice, J. C. and Pope, J. G. (2010) Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries 11: 149-158

new correction factor significantly reduces the applied mortality rates from TR456 Ed2 Rev9 for a number of species in particular, cod, plaice and thornback ray. It appears that salmon and sea trout have also had a mortality rate of 50% at the drum screens erroneously applied. As they are pelagic fish then they should be given a mortality rate of 100% at the drum screens, as applied in TR456 Ed2 Rev9 and shown in Table 1.

Table 1 Comparison of FRR mortality rates applied in the different impingement assessments. Reductions in the rates applied in the most recent TR456 Ed2 Rev10 are highlighted red.

Species	**Applied mortality rates %**		
	TR148	**TR456 Ed2 Rev9**	**TR456 Ed2 Rev10**
Sprat	100	100	100
Whiting	50	55	55
Sole	20	26	20
Cod	50	73	55
Herring	100	100	100
Bass		77	70
Plaice	20	64	43
Thornback ray		54	41
Blue whiting	50	55	55
Eel	20	20	20
Twaite shad	100	100	100
Allis shad	100	100	100
Sea lamprey	20	20	20
River lamprey	20	20	20
Salmon	50	100	55
Sea trout	50	100	55
Crangon crangon	20	20	20

Evidence of FRR survival rates

The FRR survival rates detailed in the EA best practice guide were based on unpublished Turnpenny data. No details are provided on the origin of this data within the EA best practice guide, the sites at which it was collected, the species and their life stages, the types of FRR system etc. It is understood, however, that the data is sourced from two key reports (Turnpenny, A., pers. comm.):

- **Turnpenny, A. W. H. and Taylor, C. J. L. (2000) An assessment of the effect of the Sizewell power stations on fish populations. Hydroecol. Appl. 1-2:87-134.** – The report documents the results of the precommissioning trials of Sizewell B, where the survival of fish entering the cooling water system and put back to sea via the trash return system and effluent was investigated using an experiment with a simulated trash return system at Sizewell B. This provides survival rates for a range of gadoids, flatfish, clupeids, bass and shrimp; and

- **Turnpenny, A. W. H. (1992) Fish Return at Cooling Water Intakes. Fawley Aquatic Research Laboratories Ltd report FCR 023/92. –** this report reviews the evidence from the UK, USA and Europe relating to dedicated fish return systems and their relative successes, and provides criteria for the design of FRR systems which are suggested would improve fish survival. This report does not provide any quantitative estimates of FRR system-survival for the species assessed by the EA best practice guidance, though does provide post-impingement survival rates by groups of species from Le Blayais power station on the Gironde Estuary which is fitted with a system to return shrimp.

It appears that the survival estimates within the EA best practice guide were therefore, largely adapted from Turnpenny and Taylor (2000) and an experiment at Sizewell B. The EA best practice guide uses generally lower survival rates than published in Turnpenny and Taylor (e.g. >80% for flatfish rather than the 96.1-100% survival found at Sizewell B) for many species, but higher for others (e.g. 50-80% for gadoids rather than 47.8% found at Sizewell B).

The trash return system at Sizewell B was specifically designed to return as many fish as possible back to the sea alive, incorporating fish buckets, higher-speed rotation for the drum screens, higher backwash water flow at an appropriate pressure, smooth-surfaced wash-water gullies, swept bends rather than sharp corners and avoiding discharge onto a hard surface (Turnpenny and Taylor, 2000). It should therefore, be considered to be representative of an FRR system, rather than just a trash return system. There is no empirical evidence that survival through the HPC FRR system will be any higher than through the Sizewell B trash and fish-return system and the values cited within the EA best practice guide and Turnpenny and Taylor (2000) should be considered to be a best-case, given the bespoke design of the Sizewell B FRR system. It should also be noted that no control fish were sampled for the Turnpenny and Taylor study, the handling of fish by the system may increase mortality rates, and additional predation upon FRR system exit is also not accounted for that may also increase mortality rates as noted in Turnpenny (1992).

Comparing the base mortality rates used by within TR456 Ed2 Rev10 with the values found by Turnpenny and Taylor (2000) at Sizewell B, as shown in Table 2 below, indicates that the majority of base mortality rates are higher than found at Sizewell B and therefore may be appropriate to use. Some (e.g. whiting) rates however, are lower than found at Sizewell B and cannot therefore be supported unless additional evidence can be provided to support their use. Residual uncertainty remains around the performance of the FRR system at Sizewell B given the simulated nature of the experiment in Turnpenny and Taylor (2000) and around the performance of the FRR system at HPC given the bespoke nature of the design.

Table 2 Comparison of base FRR mortality rates applied in the most recent TR456 Ed2 Rev10 (without correction for band screen and trash rack mortalities) with the FRR mortality rates found by Turnpenny and Taylor (2000). Species with higher mortality rates found by Turnpenny and Taylor (2000) are highlighted.

Species	Turnpenny and Taylor (2000) FRR mortality rates	Cefas TR456 FRR mortality rates
European plaice	0%	20%
Dover sole	3.9%	20%
Atlantic cod	6.4%	50%
European seabass	10.8%	50%
Whiting	52.2%	50%
European sprat	100%	100%
Atlantic herring	100%	100%
Brown shrimp	5.7%	20%

More recently, EPRI have undertaken a number of laboratory studies on FRR survival for larval and juvenile fish (EPRI, 2010). The studies generally focus on freshwater species as the larvae were easily obtained. Larval fish laboratory studies determined that survival rates were significantly reduced during the transition from yolk-sac to post-yolk-sac larvae. Survival rates were then seen to increase with fish length once larvae reached a size of approximately 12mm depending on species. For all species tested survival at fish lengths above 12mm ranged from 70 to 100%. These results correlated with those from similar studies (EPRI, 2006, 2009 & 2010 and Black, 2007) including for larger juvenile fish >50mm which saw post-impingement survival rates in excess of 90% regardless of species. It was noted however, that the test species (bigmouth buffalo, bluegill, golden shiner, common carp and white sucker) were hardier than the pelagic species usually constituting the majority of fish impinged at coastal power stations.

Further EPRI reports are available on fish return system optimisation, design and operation/maintenance. However the reports are not freely available. Although abstracts are provided for the documents it is not clear if they contain updated information of FRR fish survival rates that would be compatible with the HPC scenario.

Survivability studies of impinged fish at Pembroke Power Station that pass through the FRR system at the station have also been reviewed:

- Jacobs (2016) The survivability of biota impinged on Pembroke Power Station cooling water screens. Report to RWE Generation UK plc. Document No: JUKL/B1810700/R56 – 24-hour survivability study conducted during February 2016.

- Jacobs (2015) The survivability of biota impinged on Pemborke Power Station cooling water screens. Report to RWE Generation UK plc. Document No: JUKL/B1810700/R36 – 24-hour survivability study conducted during February 2015.

These studies have identified survival rates of a range of different species as presented in Table 3. Note that other species were captured by the studies and their survivability was assessed, but the numbers of each species captured were considered by the Jacobs' authors to be insufficient to report proportional survival rates.

Table 3 Pembroke Power Stations impingement survival data from 2015 and 2016 24-hour survival studies, and comparison with base survival rates used in TR456 Ed2 Rev10.

Taxa	2015 survival proportion	2016 survival proportion	Mean 2015 and 2016 survival proportion (weighted)	Base survival rates used in TR456 Ed2 from EA Best Practice Guidance
Sand smelt	16% (n=19)	33% (n=110)	30%	0%
European seabass	38% (n=21)	None recorded	38%	50%
Gadidae	78% (n=23)	54% (n=24)	66%	50%
Clupeidae	0% (n=11)	0% (n=374)	0%	0%
Gobiidae	84% (n=43)	100% (n=2)	85%	80%

Comparing the data from the Pembroke Power Station survivability studies with the base survival rates used in TR456 Ed2 Rev10, indicates that some species had higher survivability at Pembroke Power Station (gadoids, gobies and sand smelt) whereas European seabass had lower survivability and clupeids had the same survivability.

There is currently no other available evidence to suggest amendment to the base survival rates used in TR456 Ed2 Rev10 (with the exception of whiting, whose survival rates should be reduced, and European seabass, whose survival rates should be reduced, on a precautionary basis), though there may be evidence in existence, and uncertainties remain within the application of these base survival rates to the HPC FRR system.

Finally, for the FRR mortality rates cited above to be relevant for use for HPC, it must be ensured that the system is designed appropriately through the detailed design phase. The detailed design should ensure the risk of failed recovery of fish to the FRR launders, due to individuals falling from the buckets back into the screenwell, is minimised. Failed recovery introduces the requirement for repeated handling of the fish and thus increased stress and potential mortality (Turnpenny Horsfield Associates, 2012[2]).

Revised FRR mortality assessment

A review of the following aspects of the method for setting the FRR mortality rates of each species assessed in TR456 Ed2 Rev10 was undertaken:

- *The fineness ratios used to define the proportion of fish passing through the trash racks* – in many cases full references are not provided for the morphometric calculations used to define the proportion of fish which would pass through the trash racks. In addition, wider evidence on fineness ratios is available for many species and this has been identified.
- *The correction factor for the mortality of fish not passing through the trash racks* – both previous corrections in TR456 Ed2 Rev9 and TR456 Ed2 Rev10 have used values generated from the numbers of equivalent adults surviving with and without the trash rack, and the size of these individuals. This is considered to be double counting the EAV method and should not be used, as the fish lost are multiplied by the EAV factor again separately within the TR456 Ed2 Rev10 assessment. Instead, we consider that identifying the raw numbers of fish entering the intake which would not come back out alive via the FRR system should be calculated, through apportioning fish to impingement upon the trash racks, drum screens and band screens. The EAVs of the fish which would not be returned alive via the FRR system can then be calculated separately.

The original FRR mortality rates as set out within Turnpenny and O'Keeffe (2005) and used in TR148 have not be revised, as these currently still stand as the Environment Agency's general best practise guidance.

These 'base rates' were used to set revised FRR mortality rates as provided in Table 4 below to address the aspects described above. The calculation of FRR mortality rates was been conducted as follows, and is an amendment to the method in Appendix B of TR456 Ed2 Rev10:

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[2] Turnpenny Horsfield Associates (2012) Trials to assess the effectiveness of band- and drum-screen fish recovery and return systems for silver eel and adult river lamprey. Stage 1. Report 544R0105. Prepared for E.ON New Build and Technology Ltd., Environment Agency, RWE Npower.

Eq.1 $$M_{FRR} = (P_t \cdot M_t) + \left((1 - P_t) \cdot (P_d \cdot M_d)\right) + \left((1 - P_t) \cdot (P_b \cdot M_b)\right)$$

Where:
M_{FRR} *= FRR mortality*
P_t *= Proportion of fish impinged at HPB which are too large to fit through the 50mm trash racks at HPC. Calculated independently for each species using published fineness ratios.*
M_t *= Trash rack mortality, i.e. the mortality of fish which enter the intake but are too large to pass through the 50mm trash rack. Assumed to be 100% for all species.*
P_d *= Proportion of fish which become impinged on the drum screens. Assumed to be 91% for all species.*
M_d *= Drum screen mortality rate. Assumed to be either 20% for epibenthic species, 50% for demersal species and 100% pelagic species.*
P_b *= Proportion of fish which become impinged on the band screens. Assumed to be 9% for all species.*
M_b *= Band screen mortality rate. Assumed to be 100% for demersal and pelagic species and 20% for epibenthic species.*

Using Atlantic cod as an example, the calculation would be:

$$M_{FRR} = (0.0387 \cdot 1) + \left((1 - 0.0387) \cdot (0.91 \cdot 0.5)\right) + \left((1 - 0.0387) \cdot (0.09 \cdot 1)\right)$$

$$M_{FRR} = 0.5626085$$

Where:
P_t *= 0.0387*
M_t *= 1*
P_d *= 0.91*
M_d *= 0.5*
P_b *= 0.09*
M_b *= 1*

Table 4 Revised FRR mortality rates based on updated fineness ratios and trash rack passage method.

Species	FRR mortality rate as applied in TR456 Ed2 Rev10	Revised assessment								% change from TR456 Ed2 Rev10
		M_t - Trash rack mortality rate	M_d - Drum screen mortality rate	M_b - Band screen mortality rate	P_t [1]	Fineness ratio	P_d [2]	P_b [3]	M_{FRR}	
European sprat	100%	100.00%	100.00%	100.00%	0.00%	4.75*	91.00%	9.00%	100.00%	0%
Whiting	55%	100.00%	50.00%	100.00%	1.45%	3.92*	91.00%	9.00%	55.16%	0%
Dover sole	20%	100.00%	20.00%	20.00%	0.00%	13.55**	91.00%	9.00%	20.00%	0%
Atlantic cod	55%	100.00%	50.00%	100.00%	3.87%	3.92*	91.00%	9.00%	56.26%	2%
Atlantic herring	100%	100.00%	100.00%	100.00%	0.00%	4.75*	91.00%	9.00%	100.00%	0%
European seabass	70%	100.00%	50.00%	100.00%	13.86%	3.67*	91.00%	9.00%	60.81%	-13%
European plaice	43%	100.00%	20.00%	20.00%	0.00%	13.55**	91.00%	9.00%	20.00%	-53%
Thornback ray	41%	100.00%	50.00%	100.00%	0.00%	22.25***	91.00%	9.00%	54.50%	33%
Blue whiting	55%	100.00%	50.00%	100.00%	25.59%	3.92*	91.00%	9.00%	66.14%	20%
European eel	20%	100.00%	20.00%	20.00%	0.00%	16.00*	91.00%	9.00%	20.00%	0%
Twaite shad	100%	100.00%	100.00%	100.00%	1.53%	4.75*	91.00%	9.00%	100.00%	0%
Allis shad	100%	100.00%	100.00%	100.00%	100.00%	4.75*	91.00%	9.00%	100.00%	0%
Sea lamprey	20%	100.00%	20.00%	20.00%	25.89%	16.00*	91.00%	9.00%	40.71%	104%
River lamprey	20%	100.00%	20.00%	20.00%	0.00%	16.00*	91.00%	9.00%	20.00%	0%
Atlantic salmon	55%	100.00%	100.00%	100.00%	33.33%	4.65*	91.00%	9.00%	100.00%	82%
Sea trout	55%	100.00%	100.00%	100.00%	100.00%	4.65*	91.00%	9.00%	100.00%	82%
Brown shrimp	20%	100.00%	20.00%	20.00%	0.00%	NA	91.00%	9.00%	20.00%	0%
Sand goby	NA	100.00%	20.00%	20.00%	0.00%	5.70*	91.00%	9.00%	20.00%	NA
Lesser sandeel	NA	100.00%	20.00%	20.00%	0.00%	10.20*	91.00%	9.00%	20.00%	NA
European flounder	NA	100.00%	20.00%	20.00%	0.00%	13.55**	91.00%	9.00%	20.00%	NA
Sand smelt	NA	100.00%	100.00%	100.00%	0.00%	5.29*	91.00%	9.00%	100.00%	NA

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*Turnpenny, A. W. H. (1981) An analysis of mesh sizes required for screening fishes at water intakes. Estuaries, 4: 363-368.
**Arnold, G. P., and Weihs, D. (1978). The hydrodynamics of rheotaxis in the plaice (Pleuronectes platessa L.). Journal of Experimental Biology, 75: 147-169.

***Mnasri, N., Boumaiza, M., Ben Amor, M. M. and Capape, C. (2009) Polychromatism in the thornback ray, Raja clavata (Chrondichthyes: Rajidae) off northern Tunisian coast (central Mediterranean). Pan-American Jounral of Aquatic Sciences 4: 572-579.
[1] Given the vertical bar nature of the trash racks at HPC, larger flatfish could pass through them if orientated vertically. Therefore a fineness ratio of body length against body depth is appropriate, and has been applied. This differs from the fineness ratio used by Cefas in TR456 v2, which did not account for the minimum dimension of flatfish being their body depth.

[1] **P_t - Proportion of fish that were impinged at HPB that would not pass through 50mm trash rack at HPC.**

[2] **P_d - Proportion of fish passing through trash racks impinged on drum screens.**

[3] **P_b - Proportion of fish passing through trash racks impinged on band screens.**

Uncertainty analysis

To account for the residual uncertainty in estimating FRR survival rates at HPC as described above, ranges have been developed to account for the potential range of FRR survival rates following impingement upon the drum screens that might occur for the species under consideration. This range encompasses the data from Turnpenny and Taylor (2000) at Sizewell B, the data on observable injuries following impingement in the absence of an effective FRR system at Fawley Power Station from Turnpenny (1992) and the existing drum screen FRR mortality rates within the EA best practice guide (Turnpenny and O'Keeffe, 2005). Furthermore, consideration is given to the more recent survivability studies at Pembroke Power Station (Jacobs, 2015; 2016) and the potential for a very small proportion of fragile species to have a chance of surviving passage through the FRR system.

The data sets this evidence is based on would have incorporated a varying degree of barotrauma effects within the degree that could potential be expected at HPC.

It is proposed to distribute values within this range with a uniform distribution within the uncertainty assessment as there is not sufficient evidence to generate any other distribution form.

The range of FRR mortality rates (M_{FRR}) using the above datasets is provided in Table 5 below. This mortality rate does not include additional mortality due to predation, which may be significant for the fish coming out of the FRR system alive, but for which insufficient evidence exists to robustly quantify at this stage. Mortality rates from band screen and trash rack impingement are proposed to remain unchanged from those stated in Table 4.

Table 5 Range of potential FRR mortality rates at HPC considering the range of available evidence within the scientific literature (Turnpenny, 1992; Turnpenny and Taylor, 2000; Turnpenny and O'Keeffe, 2005; Jacobs, 2015; Jacobs, 2016 and TR456 Ed2 Rev10).

Species	**Realistic best case M_d**	**Realistic worst case M_d**	**Realistic best case M_{FRR}**	**Realistic worst case M_{FRR}**
European sprat	95.00%	100.00%	95.45%	100.00%
Whiting	34.00%	100.00%	40.81%	100.00%
Dover sole	3.90%	20.00%	5.35%	20.00%
Atlantic cod	6.40%	50.00%	18.12%	56.26%
Atlantic herring	89.00%	100.00%	89.99%	100.00%
European seabass	10.80%	94.00%	30.08%	95.30%
European plaice	0.00%	20.00%	1.80%	20.00%
Thornback ray	35.00%	50.00%	40.85%	54.50%
Blue whiting	34.00%	50.00%	55.31%	66.14%
European eel	10.00%	20.00%	10.90%	20.00%
Twaite shad	95.00%	100.00%	95.52%	100.00%
Allis shad	95.00%	100.00%	100.00%	100.00%
Sea lamprey	10.00%	20.00%	33.97%	40.71%
River lamprey	10.00%	20.00%	10.90%	20.00%
Atlantic salmon	95.00%	100.00%	96.97%	100.00%
Sea trout	95.00%	100.00%	100.00%	100.00%
Brown shrimp	5.70%	20.00%	6.99%	20.00%
Sand goby	10.00%	20.00%	10.90%	20.00%
Lesser sandeel	10.00%	20.00%	10.90%	20.00%
European flounder	10.00%	20.00%	10.90%	20.00%
Sand smelt	70.00%	100.00%	72.70%	100.00%

Table 6. Conclusion Results

	FRR Mortality factor		
	Used in Applicant's assessment	**Used in the Environment Agency's assessment**	
Species		Predicted	Uncertainty Range
European sprat	1.00	1.00	0.95 – 1
Whiting	0.55	0.55	0.41 – 1
Dover sole	0.20	0.20	0.05 – 0.2
Atlantic cod	0.55	0.56	0.18 – 0.56
Atlantic herring	1.00	1.00	0.9 – 1
European seabass	0.70	0.61	0.3 – 0.95
European plaice	0.43	0.20	0.02 – 0.2
Thornback ray	0.41	0.55	0.41 – 0.55
Blue whiting	0.55	0.66	0.56 – 0.66
European eel	0.20	0.20	0.11 – 0.2
Twaite shad	1.00	1.00	0.96 – 1
Allis shad	1.00	1.00	N/A
Sea lamprey	0.20	0.41	0.34 – 0.41
River lamprey	0.20	0.20	0.11 – 0.2
Atlantic salmon	0.55	1.00	0.97 – 1
Sea trout	0.55	1.00	N/A
Brown Shrimp	0.20	N/A	N/A

Example images of fish handled by an estuarine/coastal debris return system

To inform the assessment of fish as polluting matter, some example images are provided below of fish impinged upon estuarine/coastal power station band screens and handled by a return system. It should be noted that the band screens at this power station are debris return systems and are not designed for fish return and as such have only debris ledges and not fish buckets. Fish are generally intact. Abrasions, lacerations and other external injuries can however, be observed depending on the design and operation of the screens.

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