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Technical Brief: TB015

Review of adult run size estimates for river lamprey and sea lamprey in the Severn Estuary, River Wye and River Usk.

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####### 2020 (DRAFT-02)

In TR456 Ed2 v10 (Cefas, 2019), the applicant compares predicted losses of sub-adult and adult river lampreys (*Lampetra fluviatilis*) and sea lampreys (*Petromyzon marinus*) to population estimates for these species for the Severn Estuary. The population estimates are comprised of the sum of river and sea lamprey spawner numbers for the River Wye and River Usk, as modelled by APEM (2010).

Following discussion with Defra Group partners[1], the Environment Agency confirmed that the potential impact of HPC would be assessed against modelled estimates of adult numbers for the River Wye SAC and River Usk SAC combined (APEM , 2010), these being the considered to be best available evidence for the species. The APEM population estimates (mean ± SD) for the Wye and Usk are as follows:

River lamprey

River Wye	Adult spawning run (number of adults)	88,442 ± 14,324
River Usk	Adult spawning run (number of adults)	27,667 ± 4,696

Sea lamprey

River Wye	Adult spawning run (number of adults)	12,200 ± 1,836
River Usk	Adult spawning run (number of adults)	3,069 ± 455

Mean values for population estimates have been used in the calculation of the Environment Agency's prediction of impingement numbers (predicted result), while a range of values (mean ± 2SD) were used in the uncertainty analysis.

In order to understand how these modelled spawning run estimates had been calculated and to determine whether they were still valid for use in 2019, river and sea lamprey population estimates from APEM (2010) were reviewed.

[1] Meeting in Reading on 15 November 2019 between Environment Agency, Natural England, Natural Resources Wales and the Marine Management Organisation, with some participants dialling in rather than attending in person.

CRITIQUE OF LAMPREY ADULT SPAWNING RUN ESTIMATES

RIVER LAMPREY

APEM (2010) used Markov Chain Monte Carlo (MCMC) simulations to estimate the mean number of spawning river lamprey adults in the Rivers Usk and Wye, in support of the Severn Tidal Power Feasibility Study Strategic Environmental Assessment. These estimates were based on 'best guesses' of 1% of available habitat per metre length of river for both optimal and suboptimal habitat. For each run of the model, ammocoete density was drawn at random from within the relevant ammocoete density distribution for each river. Ammocoete densities were apportioned according to a ratio of 37:100 river:brook lamprey.

Adult river lamprey numbers (Table x) were 'hind-cast' by calculating the density of adults that would have been required to have produced the modelled output density of ammocoetes:

Adult river lamprey density = river lamprey ammocoete density / (sex ratio × fecundity ×egg survival × survival from hatching to Yr1 ammocoete)

Table x. Modelled estimates (mean abundance ± SD) of adult river lamprey numbers in the River Wye and River Usk, produced by APEM (2010),

River	Adult number
Wye	88,442 ± 14,324
Usk	27,667 ± 4,696

Ammocoete density

Ammocoete densities used in the model derive from survey data collected in October/November 2005 by the Hull International Fisheries Institute (HIFI). Ammocoete densities used were calculated excluding sites where no *Lampetra* were caught. This could lead to populations being overestimated as ammocoete density would be lower had sites with 0 ammocoetes m^{-2} been included when calculating these averages.

Table x. Average density of *Lampetra* ammocoetes used by APEM. From Table 4.17 in APEM (2010).

	Habitat	*Lampetra* m^{-2}
River Wye	Optimal	20.4 ± 12.7
	Sub-optimal	14.0 ± 17.7
	Combined average	14.8 ± 17.1
River Usk	Optimal	43.1 ± 30.8
	Sub-optimal	10.2 ± 11.1
	Combined average	17.5 ± 21.7

Life history traits

Life history traits collated from the literature were used to construct a generic life table for river lamprey (APEM, 2010). This included information on: average age at metamorphosis (ammocoete and parasitic juvenile); metamorphosis success (ammocoete to parasitic juvenile); ammocoete survival; and sex ratio. Due to the paucity of information in the literature, life history traits used in the model could not always be from local populations, or from *Lampetra fluviatilis*, and may therefore be a source of inaccuracy.

- Sex ratio is included as a fixed value (0.47 male : 0.53 female) but is based on UK data.
- Fecundity is included as a fixed value (28,000), although literature cited ranges from 4,000 to 40,000 (APEM, 2010)
- Egg survival, the percentage of eggs expected to hatch, is assumed as 12% from a study of a land-locked sea lamprey population in Lake Huron, USA.
- Survival from hatching to a Yr1 ammocoete is taken as 74%. This is cited as being from Meeuwig *et al.* (2005) which unfortunately does not appear in the Reference list of APEM (2010) but may refer to a paper on Pacific and western brook lampreys (North American species of *Lampetra*).

Ratio of river lamprey to brook lamprey

A fundamental difficulty in assessing river lamprey numbers is that it is not possible to distinguish between ammocoetes of river lamprey *Lampetra fluviatilis* and brook lamprey *Lampetra planeri*. Unlike river lamprey, brook lamprey do not migrate to sea and their adult form does not feed.

APEM (2010) split population estimates made from *Lampetra* ammocoete densities, according to a 37:100 river:brook ratio i.e. 27% of ammocoetes were assumed to be river lamprey, 73% brook. This was based on the results of a 2003/04 survey across

Scotland, during which brook and river lamprey transformers were recorded together in 19 catchments. Ratios within the Scottish catchments ranged from 1:20 river:brook, to 10:3 river:brook. APEM (2010) took the average ratio across the 19 catchments (37:100) i.e. 27% river lamprey, 73% brook lamprey. This single average was then used in the 2010 model – a range of possible ratios was not included as part of the Monte-Carlo modelling.

The proportion of brook lamprey would be expected to be higher upstream of barriers to migration, although high flow years could lead to river lampreys reaching further upstream as barriers to migration become passable to them. However, a single ratio has been applied without any distinction between sites. This may be more of an issue on the Usk than the Wye, due to the greater number of barriers on that river (Nunn *et al*, 2017).

Nunn *et al.*, *(*2017) analysed the demography of sea lamprey populations in the Wye and Usk in relation to barriers to migration, but excluded river lamprey from the analysis due to it not being possible to separate the ammocoetes of river and brook lamprey in the field. Nunn (2008) describes similar work in the Yorkshire Ouse and Derwent catchments, where surveys for ammocoetes took place downstream of known river lamprey spawning grounds. All captured *Lampetra* were assumed to be river lamprey based on observations of spawning lampreys and the holding of ammocoetes in aquaria until transformation (Nunn *et al.*, 2008). One of the Yorkshire Ouse catchment sites surveyed by Nunn *et al.* (2008) had a ratio of 98:2 river:brook lamprey (from holding ammocoetes in aquaria).

Whilst the ratio of river to brook lampreys varies from site to site and between years, APEM have used a single, average value. We do not have any data from the Wye or the Usk to determine how appropriate the 37:100 river:brook lamprey ratio is for these rivers.

Adult spawner numbers are calculated by estimating how many adults it would have taken to generate given numbers of ammocoetes. Inaccuracies in the river:brook ammocoete ratio will therefore feed through to the estimate of adult spawner number. If the percentage of *Lampetra* ammocoetes that are river lampreys is higher than 27% then adult spawner number will be an underestimate. Conversely, if the percentage of *Lampetra* ammocoetes that are river lampreys is lower than 27% then adult spawner number will be overestimated.

Survey data subsequent to those used to produce estimates of river lamprey spawner number

River Usk Population Attribute Condition Assessment for Brook, River and Sea Lamprey 2011

Garrett *et al.* (2012) reports a total of 35 sites were surveyed in the River Usk catchment in 2005. Very few sites in the Usk catchments had optimal habitat and sub-optimal habitat was dominant throughout the catchment. *Lampetra* ammocoetes were found at 25 of 35 sites (71%) sampled on the River Usk. This assessment of the population attribute undertaken for the first monitoring cycle (2001-2006) concluded that the targets for *Lampetra* attributes were met and the population

attribute was considered ‘favourable’. An assessment of the other attribute targets for flow and water quality was also made. These data along with the population assessment was used to make an overall assessment of the *Lampetra* SAC feature as favourable n.b this is combined *Lampetra* with no distinction between river and brook lampreys.

For the second reporting cycle (2007-2012), Garret *et al.* (2012) reports on lamprey specific electric fishing surveys carried out at 30 sites on the River Usk in 2011 (by Environment Agency Wales staff). The *Lampetra* species population met the target for age structure, distribution and catchment density (**6 ammocoetes m^{-2}**, target > 5 m^{-2}) but failed to meet the target for density in optimal habitats (**9 ammocoetes m^{-2}**, target >10 m^{-2}) (n.b. compare this to the values used by APEM (2010) of 43.1 m^{-2} optimal, 10.2m^{-2} sub-optimal and 17.5m^{-2} combined average). The overall assessment was that the *Lampetra* population failed to meet all the mandatory criteria and so the population attribute was classed as **Unfavourable**. Other attributes relating to river habitat i.e. water quality and flow were not assessed in Garrett *et al.* (2012). Garrett notes that in the previous assessment (2005-2006, conducted by HIFI) the population attribute was assessed as Favourable, so this new assessment indicated a possible decline in the population n.b this is combined *Lampetra* with no distinction between river and brook lampreys. Caution is recommended though as the apparent decline could be influenced by monitoring methodology, and only 42% of samples overlapped between surveys. On a site by site basis, 9 sites decreased in density (for both habitat types) whilst 5 sites increased, but 8 of the 9 sites that decreased in density showed double digit decreases, whereas only 1 of the sites that increased in density showed a double digit increase. The biggest decrease at a site was from 176 *Lampetra* per m^2 to 6 per m^2.

River Wye and Usk lamprey monitoring 2013

APEM undertook electric fishing for lampreys in 2012 and 2013 (APEM, 2014). The densities of *Lampetra* ammocoetes, in both the Wye and Usk, in 2013 were significantly higher than for the 2012 surveys, and the Usk had uniformly higher densities than the Wye in both years. For both of the rivers, *Lampetra* exhibited a wide distribution throughout the survey reach, and analysis of length frequency suggested numerous year classes, indicating successful year by year recruitment.

The Usk densities met the conservation target of ten individuals m^{-2}, and the Wye almost met this criterion in 2013, while both rivers failed to meet the target in 2012 (Table 4). The variation in lamprey numbers between the two survey years could be due to unusual weather conditions that occurred in the UK during 2012. In 2012, England and Wales saw their wettest nine-month sequence (April to December) since instrumental records began in 1766. This wet period was preceded by severe drought conditions at the start of 2012 (January to March). Ammocoetes are known to be displaced during spates which are likely to have regularly occurred during 2012.

APEM (2014) notes that between-year variability limits the ability of previous surveys to have made conclusive statements on condition assessment (e.g. 2005 and 2011 surveys were based on one year of surveys in a six-year reporting cycle).

Again it is worth comparing 2012 and 2013 densities (Table 4) with those used in the APEM (2010) model, optimal habitat (Wye) = 20.4 ± 12.7, optimal habitat (Usk) = 43.1 ± 30.8 (Table 2).

Table 4. Mean *Lampetra* ammocoete densities for **optimal** habitat surveyed in the Wye and Usk during 2012 and 2013 (target is for 10 ammocoetes m^{-2})(From Table 3.7 in APEM (2014))

	Mean ammocoete density (individuals m^{-2})	
Survey Year	**River Wye**	**River Usk**
2012	4.7	6.3
2013	9.2	10.2

River Wye SAC lamprey population condition assessment. Monitoring Round 2013 to 2018.

Lampetra ammocoetes were recorded in NRW electric fishing surveys (specifically for lampreys) in 2013, 2014 and 2015 (Table 5, Garrett, 2017). There were no known barriers to migration downstream of the sample sites.

Table 5. River Wye lamprey electric fishing survey effort 2013 – 2015.

Year	Number of sites	Number of *Lampetra* ammocoetes
2013	30	404
2014	3	47
2015	15	320

Lampetra met the criteria for distribution under near natural conditions although with low confidence because of the sampling bias (most samples were in the River Irfon), no formal artificial barrier assessment and the inability of the survey technique to distinguish between brook and river lamprey.

Lampetra larvae were present at 82% of the sample sites with suitable habitat and within the natural range and so the population exceeded the minimum target of 50%.

Twenty eight sites have been surveyed twice or more since conservation monitoring began in 2005 and *Lampetra* larvae had been detected more than once at 18 sites (64%). Habitat has remained described as either Optimal or Sub-Optimal at all 28 sites.

The *Lampetra* larvae were present at 64% of sites that had been previously surveyed, despite no changes in habitat quality being recorded (NRW's target is for *Lampetra* to be present at ≥90% of repeat sites). Distinct size classes were present providing evidence of recent recruitment.

No *Lampetra* larvae were observed at eight sites (18%, n = 45) and the highest density was 29.33 (WO32, Afon Irfon, SAC unit 7). The mean was 5.56 m^{-2} ± 6.28 m^{-2} (s.d). The Wye *Lampetra* population narrowly met the catchment density (abundance) target (>5 m^{-2}). It is again useful to compare these densities to those used in the APEM (2010) model, 20.4 ± 12.7 (optimal), 14.0 ± 17.7 (combined average), 14.8 ± 17.1 (sub-optimal).

Garrett (2017) summarises monitoring of sea lamprey population in the Wye as:

> Cycle 1 (2001 – 2006): brook and river lamprey population failed to meet the distribution target with medium confidence (it was noted that many of the upper reaches may reflect unsuitable habitat). In addition the targets for flow and SRP were not met. River & brook lamprey were reported as "**Unfavourable – unclassified**".
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> Cycle 2 (2007 – 2012): all the attribute targets for brook and river lamprey population and the water quality (Chemistry, Suspended Solids) and flow were met, however, water quality (Biology & SRP) failed the attribute targets. River morphology was not assessed. So overall the feature condition is reported as "**Unfavourable – unclassified**".
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> Cycle 3 (2013 – 2018): To date (June 2017) only one of the environmental attributes has been assessed. The habitat structure on the Wye has been assessed on data collected for the River Habitat Survey programme. The river habitat failed to meet all the sub-attribute targets although the confidence level in the assessment is low due to the small sample size (Garrett, 2017). Brook & river lamprey population met the larval lamprey density and age structure thresholds but failed on of the spatial extent attribute target therefore overall the whole population is assessed as Fail. There is insufficient analysis of the remaining supporting environmental attributes to undertake a classification of the whole feature (June 2017).

Conclusions

A review of the APEM (2010) model has found that:

- The proportion of river to brook lamprey ammocoetes is based on an average of transformer data from different catchments (in Scotland) and is unlikely to be representative of the situation in the Usk and Wye (which may differ from each other due to differing effects of barriers to migration). However, no better data are available with which to apportion *Lampetra* larvae into river and brook fractions.
- The ammocoete densities used as the basis of the model are likely to be over-estimates as sites where no ammocoetes were found were excluded. Ammocoete densities used in the model are notably higher than those reported for subsequent surveys.
- Surveys conducted more recently than those on which the model is based have continued to show the Wye and the Usk to be above the threshold for *Lampetra* ammocoete density. There is some evidence for population decline based on the distribution of *Lampetra* within the catchments.
- The areas of ammocoete habitat that are used to produce ammocoete population estimates are based on estimates of available optimal and sub-optimal habitat in each river.
- Life history parameters have been derived from available literature, although in several instances these are from non-UK rivers, or from different *Lampetra* species and so may not be representative of UK river lamprey populations.

Data collected after publication of APEM Ltd (2010) recorded minimum ammocoete density in the Wye of 4.7 *Lampetra* m^{-2} (APEM, 2014) and in the Usk of 6.0 to 6.3 *Lampetra* m^{-2} (Garrett *et al*., 2012, APEM, 2014). For both rivers, these minimum ammocoete densities are around one third of the combined (optimum and sub-optimum) densities used in the calculation of the APEM Ltd (2010) adult number estimates. Ammocoete densities were used to calculate spawner number according to the equation (APEM, 2010):

Adult river lamprey density = river lamprey ammocoete density / (sex ratio × fecundity ×egg survival × survival from hatching to Yr1 ammocoete)

Consequently, run sizes using these ammocoete densities from APEM (2014) and Garrett *et al.* (2012), assuming other terms remained constant, would be around:

River Wye: (4.7 / 14.8) * 88,442 = 28,086

River Usk: (6.0 / 17.5) * 27,667 = 9,486

Wye + Usk: 28,086 + 9,486 = 37,572

The repeated sampling of the Markov Chain Monte Carlo simulation from within the ranges of possible values mean that this rough calculation is not going to give exactly the same answer as the model would if run using the more recent density data.

Although there are areas in which the model could be improved, APEM (2010) still provides useful information against which entrapment losses at HPC can be quantitatively assessed. No better estimates of life history parameters, or river:brook lamprey ammocoete ratios are available at the present time and we can regard APEM (2010) as the best available evidence against which to carry out a quantitative assessment. Qualitative consideration of how entrapment losses might affect the population of river lamprey, in the event that adult numbers could perhaps be as low as one third of the APEM (2010) estimate, should also be included when assessing the river lamprey feature.

SEA LAMPREY

APEM (2010) used Markov Chain Monte Carlo (MCMC) simulations to estimate the mean number of spawning sea lamprey adults in the Rivers Usk and Wye, in support of the Severn Tidal Power Feasibility Study Strategic Environmental Assessment. These estimates were based on 'best guesses' of 1% of available habitat per metre length of river for both optimal and suboptimal habitat. For each run of the model, ammocoete density was drawn at random from within the relevant ammocoete density distribution for each river.

Adult sea lamprey numbers (Table x) were 'hind-cast' by calculating the density of adults that would have been required to have produced the modelled output density of ammocoetes:

Adult sea lamprey density = sea lamprey ammocoete density / (sex ratio × fecundity ×egg survival × survival from hatching to Yr1 ammocoete)

Table x. Modelled estimates (mean abundance ± SD) of adult sea lamprey numbers in the River Wye and River Usk, produced by APEM (2010).

River	Adult number
Wye	12,200 ± 1,836
Usk	3,069 ± 455

Ammocoete density

Ammocoete densities used in the model derive from survey data collected in October/November 2005 by the Hull International Fisheries Institute (HIFI). Ammocoete densities used were calculated excluding sites where no sea lamprey ammocoetes were caught. This could lead to populations being overestimated as ammocoete density would be lower had sites with 0 ammocoetes m^{-2} been included when calculating these averages.

Table 4. Average density of sea lamprey ammocoetes used by APEM. From Table 4.17 in APEM (2010).

	Habitat	Sea lamprey m^{-2}
River Wye	Optimal	21.5 ± 20.7
	Sub-optimal	1.6 ± 1.9
	Combined average	10.8 ± 16.9
River Usk	Optimal	5.3 ± 6.5
	Sub-optimal	0.2 ± 0.1
	Combined average	4.0 ± 6.0

Life history traits

Life history traits collated from the literature were used to construct a generic life table for sea lamprey (APEM 2010). This included information on: average age at metamorphosis (ammocoete and parasitic juvenile); metamorphosis success (ammocoete to parasitic juvenile); ammocoete survival; and sex ratio. Due to the paucity of information in the literature, life history traits used in the model could not always be from local populations, or from *Petromyzon marinus*, and may therefore be a source of inaccuracy.

- Sex ratio is included as a fixed value and is based on that estimated for the Dordogne and Garonne Rivers in 2003 and 2004 (0.93 male : 1 female).
- Fecundity is included as a fixed value (171,000), although literature cited ranges from 124,000 to 300,000 (APEM, 2010).
- Egg survival, the percentage of eggs expected to hatch, is assumed as 12% from a study of a land-locked sea lamprey population in Lake Huron, USA.
- Survival from hatching to a Yr1 ammocoete is taken as 74%. This is cited as being from Meeuwig *et al.* (2005) which unfortunately does not appear in the Reference list of APEM (2010) but may refer to a paper on Pacific and western brook lampreys (North American *Lampetra* species).

Survey data subsequent to those used to produce estimates of sea lamprey spawner number

River Usk Population Attribute Condition Assessment for Brook, River and Sea Lamprey 2011

Garrett *et al.* (2012) reports a total of 35 sites were surveyed in the River Usk catchment in 2005 . Very few sites in the Usk catchments had optimal habitat and sub-optimal habitat was dominant throughout the catchment and *Petromyzon* ammocoetes were found at 8 of 35 sites (22%) sampled. Ammocoete density in the catchment, overall, was 2.27 ammocoetes m^{-2}, greater than the LIFE target of >0.1 m^{-2}. All population attribute targets for sea lamprey were met and the population attribute was assessed as favourable (with low confidence due to the presence of barriers to migration). Assessment of attribute targets for flow and water quality however resulted in an overall assessment of unfavourable for the sea lamprey feature.

For the second reporting cycle (2007-2012), Garrett *et al.* (2012) reports on lamprey specific electric fishing surveys carried out at 30 sites on the River Usk in 2011 (by Environment Agency Wales staff). Only three sea lamprey ammocoetes were caught and the feature was assessed as being ‘unfavourable’ with low confidence.

River Wye and Usk lamprey monitoring 2013

Sea lamprey ammocoetes were extremely scarce throughout the electric fishing surveys. In 2012 only seven sea lampreys were caught in the Wye (20 sites) and three in the Usk (20 sites)(APEM, 2014). In 2013, 15 were caught in the Wye and eight in the Usk (APEM, 2014). Although values were below the target values, they were described as being comparable to other similar rivers, and ascribed to the difficulty of successfully sampling sea lamprey ammocoetes (APEM, 2014). Insufficient numbers of sea lamprey were captured during the quantitative electric fishing surveys for population estimates and analysis to be undertaken (APEM, 2014).

To obtain data from outside the river margins, where electric fishing takes place, airlifting surveys were also undertaken in 2013, which sample deeper water. 11 sea lamprey ammocoetes were caught in the Wye by airlifting (32 samples at 12 sites), but none were caught in the Usk (28 samples at 8 sites) (APEM, 2014).

River Wye SAC lamprey population condition assessment. Monitoring Round 2013 to 2018.

Sea lamprey ammocoetes were recorded in NRW electric fishing surveys (specifically for lampreys) in 2013, 2014 and 2015 (Table 6, Garrett, 2017). There were no known barriers to migration downstream of the sample sites.

Table 6. River Wye lamprey electric fishing survey effort 2013 – 2015.

Year	Number of sites	Number of sea lamprey ammocoetes
2013	22	13
2014	3	2
2015	14	33

NRW's performance indicator for population spatial extent is that distribution should reflect that under near-natural conditions. Due to there being no known barriers to migration downstream of the sample sites, Garrett (2017) concludes that this criterion is met, but with low confidence due to small sample size and limited sample distribution (sampling was focussed on the River Irfon). Neither ammocoete densities nor prevalence data were assessed.

Garrett (2017) further summarises monitoring of sea lamprey population in the Wye as:

> Cycle 1 (2001 – 2006): sea lamprey met all the population targets (but failed to meet the targets for flow and SRP. The phosphorus target failure was not believed to cause a problem for sea lamprey as the sites which failed were all in the upper reaches of the catchment. The feature was reported as "**Favourable – unclassified**" with medium confidence.
>
> Cycle 2 (2007 – 2012): none of the sea lamprey population attribute targets were met and in addition, the water quality (Biology) also failed. The environmental attribute targets water quality (Chemistry, Suspended Solids & SRP) and flow were met but the river morphology targets were not assessed. So overall the feature condition is reported as **Unfavourable - unclassified**. This represents a decline from the previous assessment**.**
>
> Cycle 3 (2013 – 2018): To date (June 2017) only one of the environmental attributes has been assessed. The habitat structure on the Wye has been assessed on data collected for the River Habitat Survey programme. The river habitat failed to meet all the sub-attribute targets although the confidence level in the assessment is low due to the small sample size (Garrett, 2017).

Nunn *et al*. (2017) Demography of sea lamprey ammocoete populations in relation to potential spawning-migration obstructions

For the River Wye, the same survey data upon which the modelling in APEM (2010) was based (collected October and November 2005) were subsequently analysed further, with respect to weirs acting as barriers to migration (Nunn *et al*., 2017). The majority of the Wye catchment should be accessible to spawning lampreys, there being only four potential obstructions, all in the upper reaches.

In total, 423 sea lamprey ammocoetes were captured in the River Wye at mean ± SD densities of **2.3 ± 10.7 ammocoetes m^{-2}**, while in optimal habitats, densities were **16.8 ± 15.2 ammocoetes m^{-2}**. Densities were sufficient to allow a classification of favourable condition (≥0.1 m^{-2}, overall, and ≥0.2 m^{-2}, optimum), although densities were significantly lower in Reach Two, which was upstream of a putative barrier to migration (Table 2). The percentage of sites with sea lamprey (prevalence) was also lower in Reach Two. A minimum of three age classes of sea lamprey ammocoetes was recorded as far as 200 km upstream of the mouth of the River Wye in Reach 1, including in the River Irfon, a major tributary, but just one year class in Reach 2. Although present, low numbers of 0+ individuals were recorded in the tributary rivers (Nunn *et al.*, 2017).

Using the original condition assessment criteria of Harvey & Cowx (2003) the sea lamprey population in the River Wye was judged to be in favourable condition at the catchment scale, but using adjusted criteria to allow comparisons between reaches, none of the reaches in the River Wye would be classed as being in favourable condition, mainly due to the low prevalence of sea lamprey ammocoetes and reductions in the number of age classes upstream of putative barriers to migration (Nunn *et al.*, 2017).

Table 2. River Wye Data from Nunn *et al.* (2017)

Wye Catchment	**Mean density (overall) m^{-2}**	**Mean density (optimum habitat) m^{-2}**	**Prevalance (% of sites)**	**Number of age classes**	**Population condition**
Favourable if:	≥0.1	≥0.2	≥66%	≥3	
Reach 1	15.0	27.3	59	>3	Unfavourable
Reach 2 (u/s barrier)	0.2	n/a	14	1	Unfavourable
Reach 2a (River Irfon)	2.0	2.2	43	>3	Unfavourable
Reach 2b (River Ithon)	2.7	n/a	40	>2	Unfavourable

Conclusions

A review of the APEM (2010) model has found that:

- The ammocoete densities used as the basis of the model are likely to be over-estimates as sites where no ammocoetes were found were excluded. Ammocoete densities used in the model differ from those quoted in Nunn *et al.* (2017) which are based on the same survey data.
- Ammocoete density varies significantly between reaches; high density reaches may mask areas of lower lamprey density (Nunn *et al*, 2017)
- Re-analysis of the 2005 survey data, looking at reach rather than catchment scale and using revised condition assessment data, showed sea lampreys in unfavourable condition in the Wye, (four out of four reaches), and in unfavourable condition in the Usk, (three out of four reaches) due to low prevalence of ammocoetes and reductions in the number of age classes upstream of putative barriers to migration (Nunn, 2017).
- Electric fishing of 30 sites on the River Usk in 2011 resulted in only three sea lamprey ammocoetes being caught. Sea lamprey were assessed as being unfavourable with low confidence.
- In 2012 insufficient numbers of sea lamprey were captured during quantitative electric fishing surveys for population estimates and analysis to be undertaken.
- In the River Wye (2013 – 2018), sea lamprey appeared present over their expected spatial extent but this was ascribed low confidence due to small sample size and limited sample distribution.
- The areas of ammocoete habitat that are used to produce ammocoete population estimates are based on estimates of available optimal and sub-optimal habitat in each river.
- Life history parameters have been derived from available literature, although in several instances these are from non-UK rivers, or from *Lampetra* species and so may not be representative of UK sea lamprey populations.

Nunn *et al.* (2017) presented overall sea lamprey densities of 2.3 ± 10.7 ammocoetes m^{-2} and 1.9 ± 8.9 ammocoetes m^{-2} for the Rivers Wye and Usk respectively. These contrast with the values of 10.8 ± 16.9 ammocoetes m^{-2} and 4.0 ± 6.0 ammocoetes m^{-2} given in APEM (2010), being 21% of the APEM (2010) density for the Wye and 48% of the APEM (2010) density for the Usk. Ammocoete densities were used to calculate spawner number according to the equation (APEM, 2010):

Adult sea lamprey density = sea lamprey ammocoete density / (sex ratio × fecundity ×egg survival × survival from hatching to Yr1 ammocoete)

River Wye: (2.3 / 10.8) * 12,200 = 2,598

River Usk: (1.9 / 4.0) * 3,069 = 1,458

Wye + Usk: 2,598 + 1,458 = 4,056

The repeated sampling of the Markov Chain Monte Carlo simulation from within the ranges of possible values mean that this rough calculation is not going to give exactly the same answer as the model would if run using the more recent density data.

Although there are areas in which the model could be improved, APEM (2010) still provides useful information against which entrapment losses at HPC can be quantitatively assessed. No better estimates of life history parameters are available at the present time and we can regard APEM (2010) as the best available evidence against which to carry out a quantitative assessment. Qualitative consideration of how entrapment losses might affect the population of sea lamprey, in the event that adult numbers could perhaps be as low as one quarter of the APEM (2010) estimate, should also be included when assessing the sea lamprey feature. The low numbers of sea lamprey ammocoetes recorded in surveys since 2005 also need to be considered as these may indicate that the number of spawning sea lamprey may have decreased, or that adult spawning runs show a high degree of year-to-year variability.

Table 1. Conclusion results of adult Lamprey population estimates.

Species	Population	Used in Applicant's assessment	Used in Environment Agency's assessment	
			Predicted	Uncertainty Range*
River Lamprey	Severn Estuary**	116,109	116,109	78,069 – 154,149
	River Wye	88,442	88,442	59,794 – 117,090
	River Usk	27,667	27,667	18,275 – 37,059
Sea Lamprey	Severn Estuary**	15,269	15,269	10,687 – 19,851
	River Wye	12,200	12,200	8,528 – 15,872
	River Usk	3,069	3,069	2,159 – 3,979

*Uncertainty range = Mean ± two standard deviations

**Severn Estuary population = Wye population + River Usk population
NB: as Lamprey do not home only the estuarine population will be assessed against HPC's predicted entrapment.

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