HINKLEY POINT C PERMIT VARIATION

EPR/HP3228XT/V004

Technical Brief: TB016

Review of adult run size estimates for Twaite Shad and Allis Shad in the Severn Estuary, River Wye and River Usk.

National Fisheries Service, Environment Agency.

Marine Contractor, APEM LTD.

2020 (DRAFT-06)

INTRODUCTION

Shads are members of the herring family of fishes (Clupeidae). Unlike other herrings, shads spawn in freshwater where their larvae develop before entering the sea as juveniles. There are two species of shad spawning in the UK, twaite shad (*Alosa fallax*) and allis shad (*Alosa alosa*). The two species are closely related and can interbreed to produce fertile offspring.

In the absence of barriers to migration, allis shad typically migrate further upstream than do twaite shad (although in the River Wye some twaite shad travel over 190 km to reach their spawning grounds). Geographical separation between allis and twaite shad is thought to have led to speciation and reduced hybridisation between the two shads. However, in many rivers, barriers to migration have prevented allis shad from migrating as far upstream as they might, and it is thought that this has resulted in extensive hybridisation between the two species with 'pure' twaite and 'pure' allis shad being relatively uncommon.

As part of the permit variation application (EPR/HP3228XT/V004) we need to compare the predicted losses from the Shad populations due to the predicted entrapment and associated mortality from Hinkley Point C's proposed cooling water system. To do this we need to estimate the size of the population the entrapment losses will occur from.

This document sets out the current evidence and data considered and the Environment Agency's proposals within this permit variation assessment.

Twaite Shad

Twaite shad are generally the smaller of the UK's two shad species, rarely exceeding 40 cm in length. They enter rivers to spawn in spring, usually between April and June. Spawning populations of twaite shad occur in four rivers in the UK; the Tywi, Usk, Wye and Severn (including its tributary the River Teme).

Twaite shad spawn at night in shallow areas near deeper pools, in which the fish congregate. The eggs are released into the water column, sinking into the gaps within coarse gravels and cobbles. After hatching the fry develop and slowly drift downstream. Higher numbers of juveniles tend to be produced in years when the summer (June/July) has stable flows and warm river temperatures. Summer flooding can result in high levels of juvenile mortality. Most juvenile twaite shad enter the sea in their first year of life, with smaller numbers following in their second year.

The 'at sea' distribution of juvenile shad is poorly understood and although it is likely they will have a preference for the shallower inshore areas, particularly when very small, it is still likely the whole estuary will be used at times as they grow and redistribute.

The Unlocking the Severn project has shown that adult Severn shad can cover great distances with acoustic detections found in north coast of Devon, Swansea Bay and

River Blackwater, Ireland (one twaite shad tagged in the River Severn entered the River Blackwater in December 2018). Accidental capture either recreationally or via bycatch can be found around the UK coast particularly the South West approaches, Irish Sea, South Coast and Thames estuary (Environment Agency, 2003; ICES 2014).

Upon reaching maturity, twaite shad return to rivers to spawn, with acoustic tagging data showing a low rate of straying to other rivers (≈1.5%, Unlocking the Severn Project). Twaite shad do not all mature at the same age. A proportion of males will first mature as three year olds, with others maturing in subsequent years. Similarly, a proportion of females first mature as five year olds with others maturing later. The maximum life-span for a twaite shad is around nine years.

Twaite shad are thought to have a staged migration through the Bristol Channel on their way to spawn, waiting for river temperature to rise to levels to stimulate freshwater migration (this also being linked to tidal cycle). Returning fish are likely to use the deep water channel on incoming tides and to seek refuge away from this channel (nearer to the HPC intakes) on ebb tides. It is probable that shad make the migration through the estuary over a number of weeks and may well be present in Bridgwater Bay for extended periods, not just a single pass.

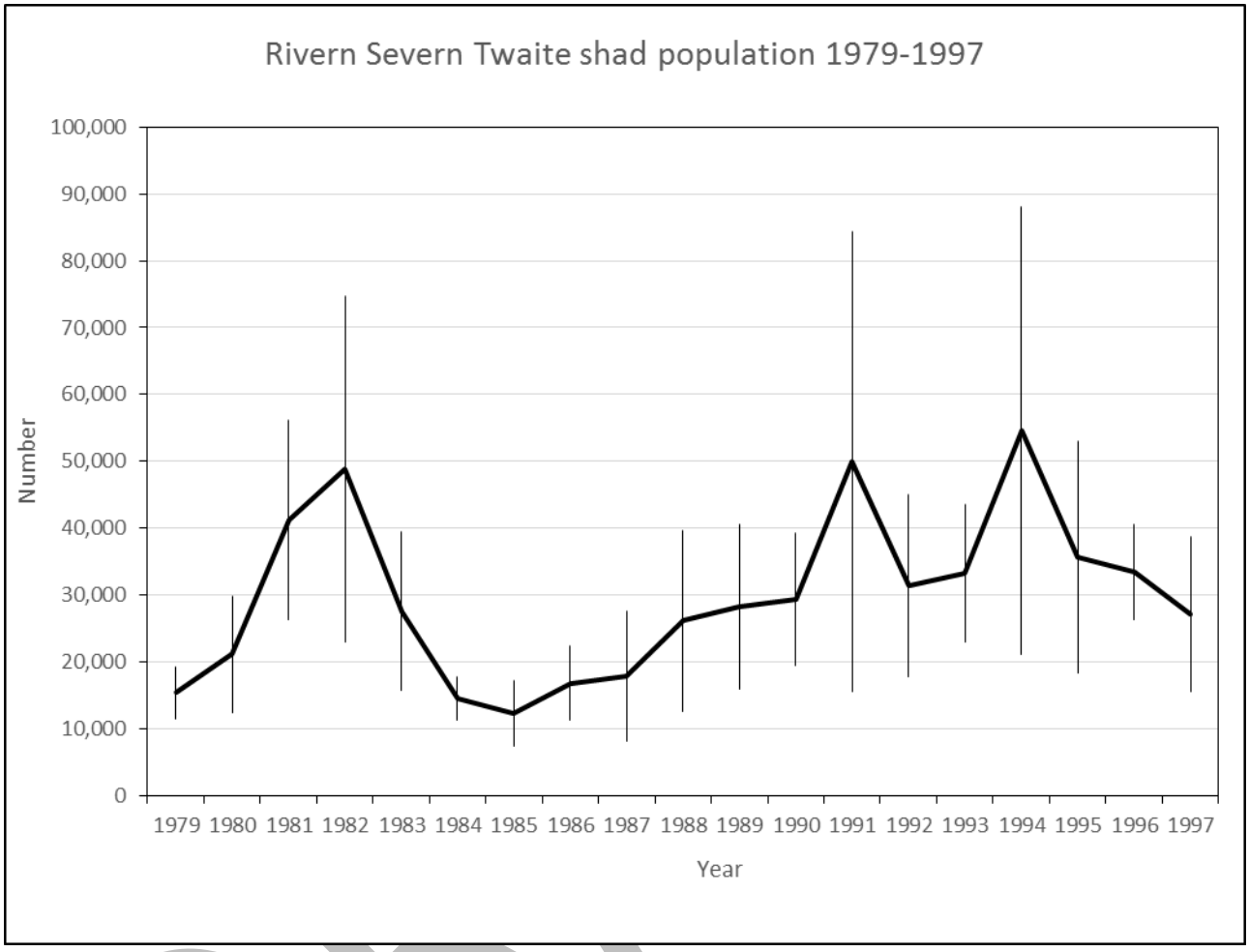
Repeat spawning appears common in the River Severn population, with around 60% of acoustically tagged adults returning to the river in a subsequent year (Unlocking the Severn). Studies on population genetic structure for both A. alosa and A. fallax have demonstrated strong fidelity to breeding grounds, compatible with homing to natal spawning sites (Jolly et al., 2012).

The deep water channel is probably used by exiting adults post spawning and recent preliminary acoustic tracking results have shown that tagged shad are spending extended periods (weeks rather than a single day) in Swansea Bay. This is presumably for feeding post spawning, as they first appear in the July following spawning (Swansea University unpublished data). Post spawning adults are considered likely to similarly use the large area of relatively slack water found in Bridgwater Bay for feeding and holding station before migrating further downstream.

Historically there has been only sparse population data for twaite shad in the Severn Estuary. Life-history parameters (including adult survival rates, sex ratio, number of eggs per female at weight/age, number of spawning events) collected from twaite shad caught as bycatch in the salmon putcher fishery up to 1997 have been used to predict the number of twaite shad within the River Severn River Basin District (RBD) (APEM, 2010). After 1997, a byelaw was introduced preventing the operation of putchers in the spring. This ended this method of data collection for shad as the putchers were no longer fishing at the time the adult shad would be migrating past in number.

Putchers are a series of baskets on a frame extending out into the estuary, designed to trap adult salmon as they drop back with the ebb tide during their upstream spawning migration.

Graph 1. Adult population size of shad returning to the River Severn based on bycatch at the Severn Estuary putcher ranks 1979-1997 (APEM, 2010).

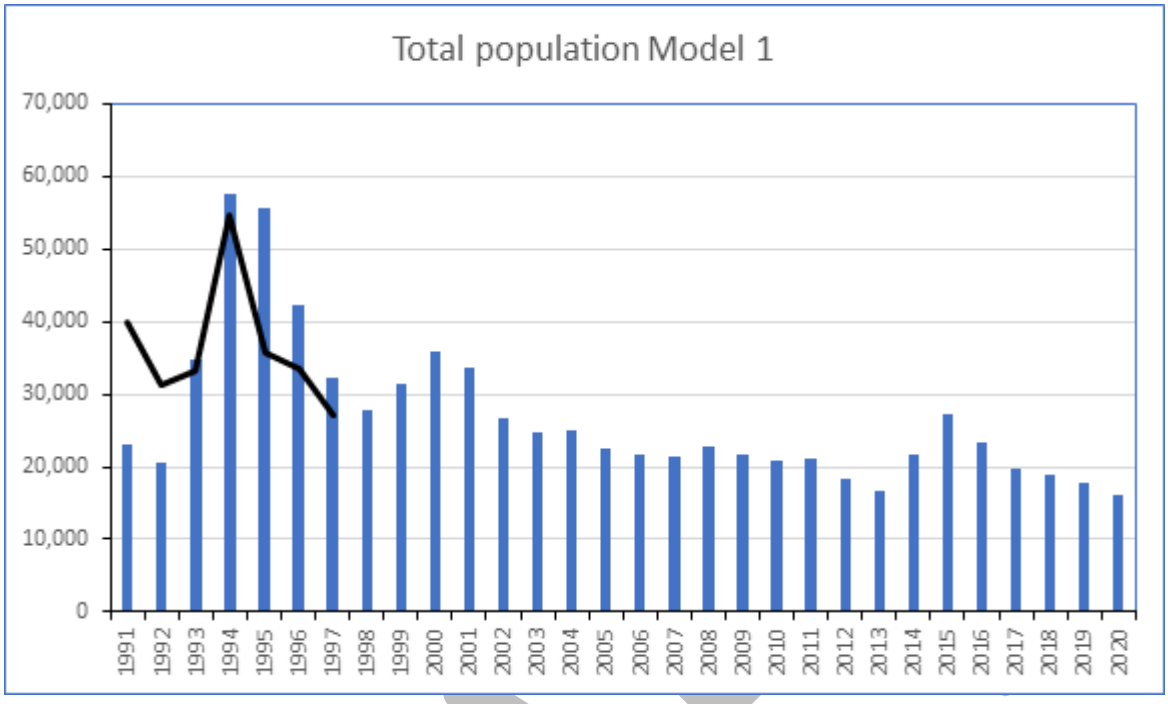


Using this time series alone the River Severn average adult population size over the period (1979-1997) was; 29,740 adults (range 12,338– 54,552).

The population of shad in the Upper Severn Estuary will comprise of adults return to the rivers Severn, Wye and Usk. If the run for the river Severn is scaled up in relation to current accessible spawning area for the species, the rough proportion are obtained; the river Wye population is likely to be twice the size of that of the river Severn, while the river Usk is likely to be equal in size to the river Severn population.

APEM has continued to model the shad population using the entrainment data from the long. Inter-year survival rates now being refined using data from the Unlocking the Severn project. This model is available for the years 1991 to 2019. There is some overlap with the putcher-based modelling (1991 – 1997). Although the general trends shown by the two models were the same during this overlap period, the RIMP based model produced lower estimates of twaite shad numbers (minimum ≈ 20,000 to maximum ≈ 57,000) than the putcher-based model (minimum ≈ 28,000 to maximum ≈ 54,000).

Graph 2. Adult population size of shad returning to the River Severn based on RIMP based model 1991-2020 (APEM, 2019).



Using this modelled time series alone (1991-2019) the adult shad population averages over the period for the River Severn (1991-2019) was; 26,844 adults (range 17,796 – 58,000). If you consider the last 10 years of data (2009-2019) it predicts the mean population has declined further to 20,346 (range 16,000 – 27,500).

The Unlocking the Severn project (2017-2021) through its resistivity counter and citizen science programme at Upper Lode Weir at Tewkesbury also gives a run size 2017, 2018 & 2019 for the River Severn which shows that the decline in adult shad numbers is continuing (***Table 1***).

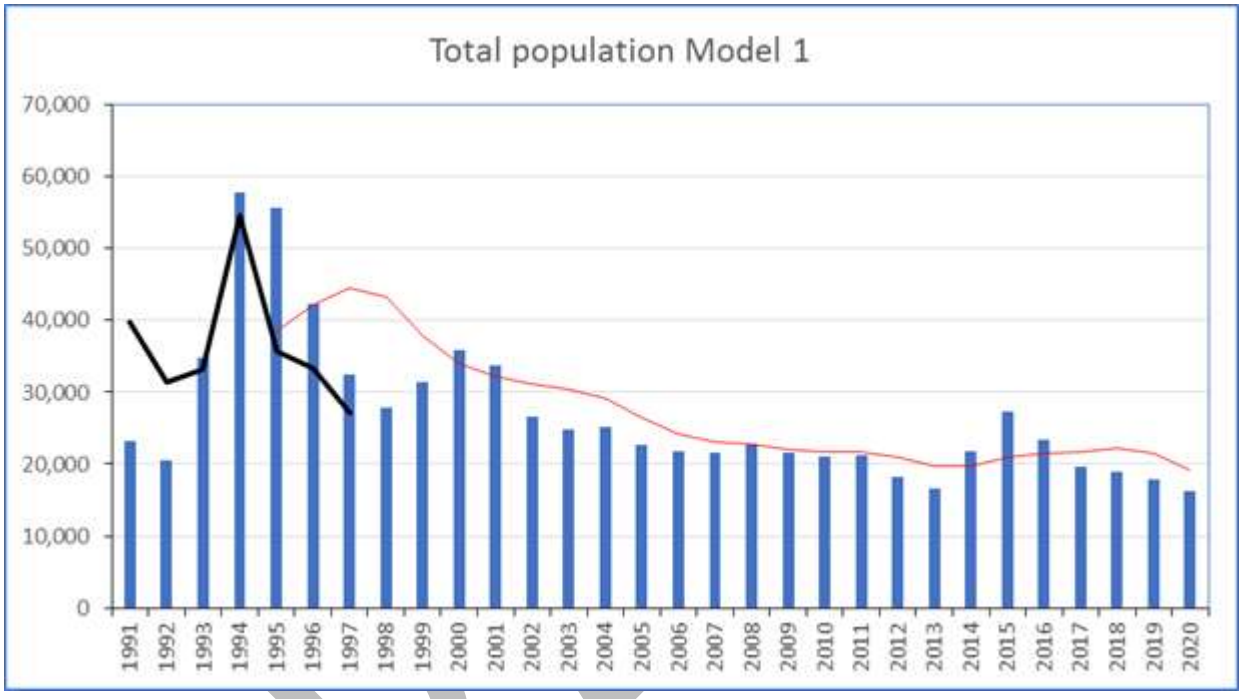
Table 1. River Severn twaite shad population estimates from the Unlocking the Seven Project (EA, 2020)

Year	River Severn run (best estimate)
2017	30019
2018	17065
2019	14723

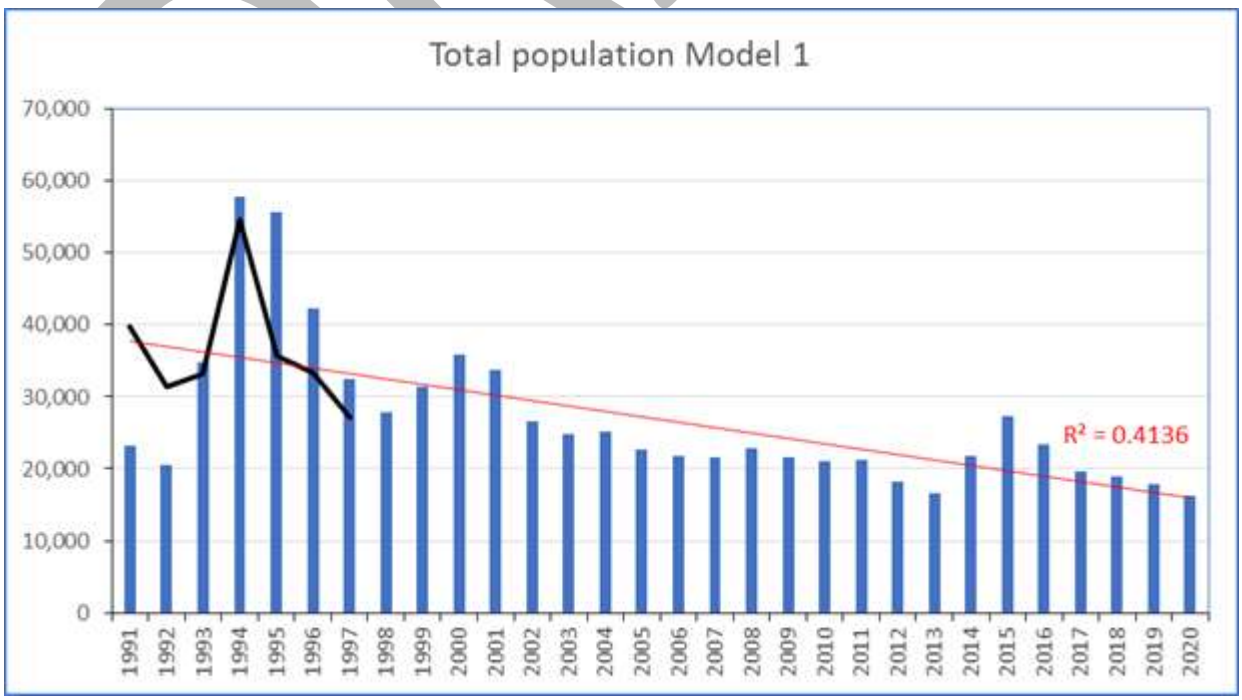
There has been a significant decline in twaite shad in the period 1981-2017 (**Graph *3.* 5-year moving average line of adult population size of shad returning to the River Severn based on RIMP based model 1991-2020 (APEM, 2019).*Graph 3 & 4***) (HPB came online in 1976) and this is against a background decline in total power station abstractions volumes throughout the Bristol Channel. Since 1999 and the introduction of the spring byelaws to protect multi-sea-winter salmon stocks the operation of putcher baskets in the upper Severn estuary has been prohibited until

after 1st June, substantially reducing the bycatch and mortality of shad on their spawning run. Even with this mortality pressure removed, and the cessation of the abstraction at Oldbury Power Station (10% of all the fish by number abstracted at this site were twaite shad), the stock of the Severn has not improved and continues to decline (***Graph 5***).

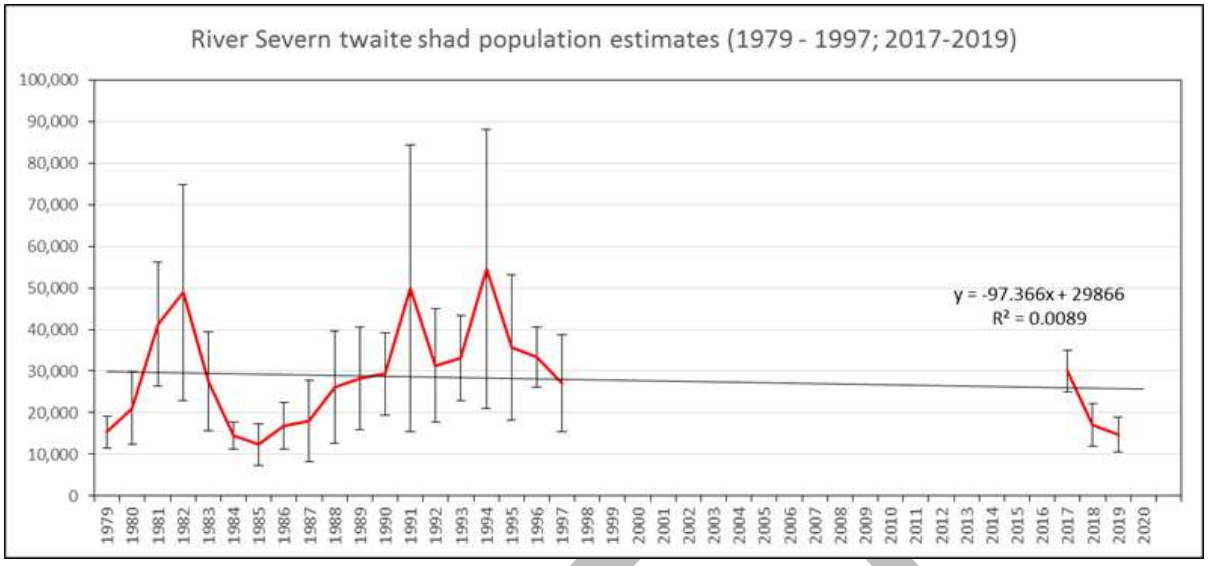
Graph 3. 5-year moving average line of adult population size of shad returning to the River Severn based on RIMP based model 1991-2020 (APEM, 2019).



Graph 4. Linear regression line of adult population size of shad returning to the River Severn based on RIMP based model 1991-2020 (APEM, 2019).



Graph 5. Linear regression line of adult population size of shad returning to the River Severn fitted to putcher fishery data and Unlocking the Severn project data.



As multiple spawners the shad population is heavily dependent on good spawning years to maintain the population and years of good juvenile recruitment are heavily dependent of warm, stable flow conditions (May-July) in the spawning rivers. These conditions may only occur once in the life time of a shad meaning the shad population are very cyclical (a high population is generally followed by a number of years of decline before the next good recruitment year becomes evident in the population). In recent times the prevalence of more extreme weather events, particularly in the summer months (e.g. major summer floods in 2007) has meant the recruitment of shad has been poor (last recognised high recruitment year 2010). This has resulted in the population decline over the long term.

Although a good spawning year occurred in 2018, fish born in that year will not become adults until 2021 at the earliest. Prior to 2018, the last good spawning occurred in 2010 and adults resulting from this spawning are now reaching the end of their lives. In order to be sustainable, the Severn population needs a good spawning year at least once every seven years.

Allis Shad

Allis shad reach larger sizes than twaite shad, typically 30-50 cm as adults, entering rivers during the spring. Unlike twaite shad, allis shad may only spawn once before dying, although there is some uncertainty whether shad towards the northerly edge of their range (including the UK) may spawn more than once.

Allis shad 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). Males migrate upstream first, followed by females one or two weeks later.

Most juveniles migrate rapidly through the estuarine environment to reach the marine environment by December of their first year and then believed to 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).

Spawning occurs in freshwater at night over substrata ranging from mud to sandy gravel at depths of 0.15–9.5 m. Eggs 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. 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 a long historic record of a substantial allis shad population from the river Severn in the archives, which can be dated back to at least the 13th Century. This commercially important population disappeared rapidly with the construction of the navigation weirs in the 1840's onwards that blocked of this species access to their spawning areas as far up river as the Welsh borders. In evolutionary terms this is very recent and there is growing evidence that a small population has been retained.

This is to be suspected as the fish need only spawn infrequently to sustain a remnant population. The high discharge on the river Severn does mean that migration pathways may be available in wet years to allow fish over these navigation weirs. Even when conditions do not allow, the two shad species will hybridise if forced to use the same spawning area and the offspring are fertile hybrids, so even if "pure" allis shad are not present than the genes persist in the environment allowing the population to re-establish if the barriers to their migration are removed.

The Unlocking the Severn project (EU LIFE Nature Programme (LIFE15/NAT/UK/000219) and Heritage Lottery Fund (HLF-15-04573)) will allow allis shad or their hybrids to do just this from 2021 when all the barriers are either removed or will have fish passes designed for shad installed.

As part of this project a study of the genetics of the River Severn shad has been conducted, including analyses of shad genetics in other rivers around the UK. Basic genetic tests (mitochondrial (Cyt b) and nuclear (Nif-1)) on a limited amount of eggs

collected downstream of the barrier of Powick Weir on the river Teme indicated that up to 3% may be allis shad.

The results were repeated on a new sample of eggs and adult genetic material collected from fish used for acoustic tagging. This was performed using 24 microsatellites and this time no “pure” allis shad were confirmed but it did show that 31.8% were hybrids between allis and twaite shad with 68.2% considered pure twaite shad. The highest level of allis shad in a hybrid was found in a single egg collected in 2017 with the result of 55% twaite and 45% allis.

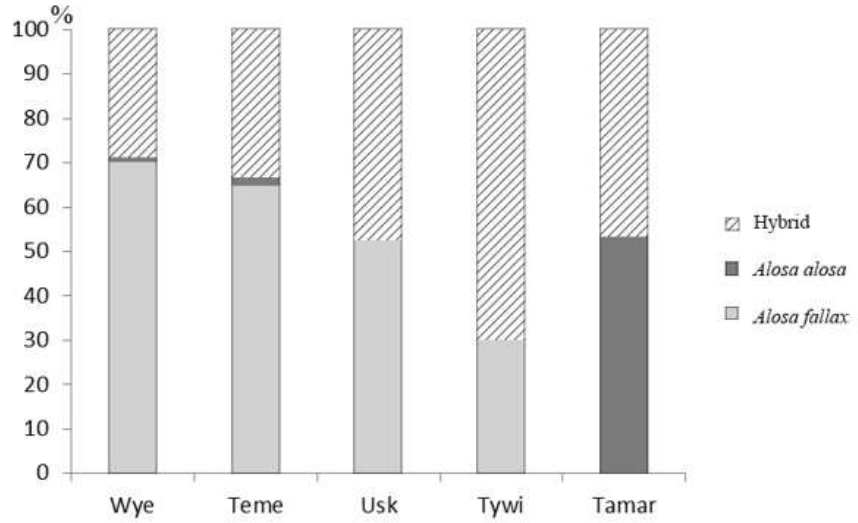
It should be noted that samples were collected relatively low in the river i.e. below where ‘pure’ allis shad might be expected to spawn, in the absence of barriers. Also, scientific literature suggests that 48 nuclear loci would be needed to distinguish between allis and twaite shad to a 100% level of confidence.

The researcher concluded that “we can’t say that allis shad are completely absent rather we may not be able to find them through our small sample size and because of their low presence in the system”.

The genetic signal of allis shad is strongly present in the river Severn shad population though and it seems reasonable on the limited genetic results alone to take a precautionary view that 3% of the total Severn (Teme) shad population may be “pure” Alosa alosa and 1% of the Wye shad population may be “pure” Alosa alosa. Whilst it may be coincidental, it is worth noting that around 3% of the shad caught in the CIMP were identified as Alosa alosa.

It is interesting to note that the one recognised breeding allis shad population in the UK (river Tamar) also shows a high level of hybrids of approximately 30% between allis and twaite shad.

Graph 6. Initial results of species apportionment between Alosa fallax, Alosa alosa and hybrids of the two.



Video recording equipment installed at Upper Lode weir, Tewkesbury, to validate a resistivity fish counter has provided evidence of allis shad within the River Severn. A subsample of this video was reviewed and this has captured images of large shad (>450mm) that are migrating upstream. Staff resources prevents reviewing substantial amounts of the video data but the two images below are examples of the large shad recorded.

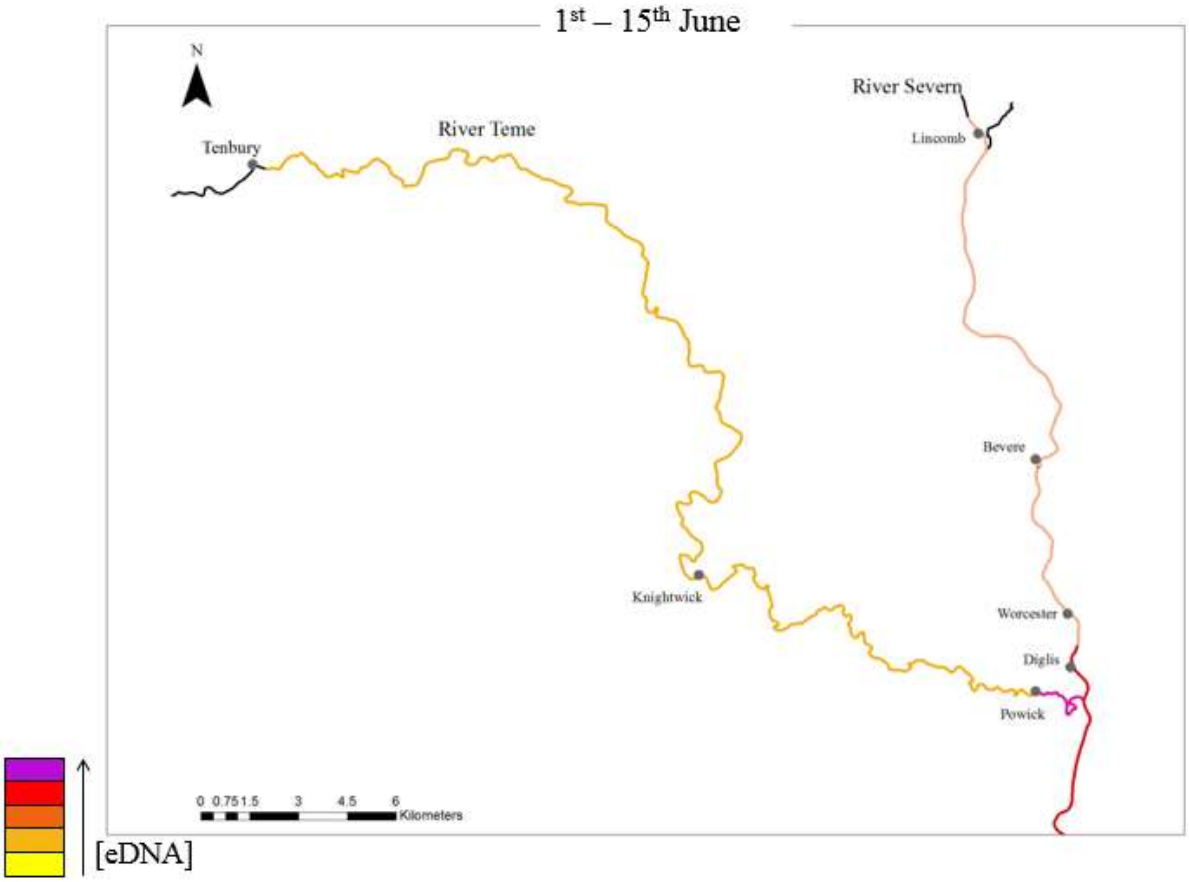
Example pictures of two large shad (possible allis (Alosa alosa)) recorded at the camera at the resistivity counter at Upper Lode Weir, Tewkesbury, note space between resistivity strips are 450mm. Top row, image on left possible allis shad with more typical sized twaite shad for comparison on right.

Allis shad generally only spawn once (unlike twaite) dying after spawning. Although few dead shad are recorded, there has been one example of one moribund large shad captured on film in late July downstream of Powick old bridge. The timing and state of the fish is consistent of a spawned out allis shad.

Picture of suspected dying "post spawning" Allis shad (total length estimated 500mm+ photographed below Old Powick Bridge on the river Teme in the month of July

Finally, it was assumed that shad were unable to get over the navigation weirs but our water eDNA samples have shown in all years where results are currently available (2017/18) that shad eDNA has been found in June up to Tenbury Wells on the river Teme and the final navigation weir at Lincomb weir on the man Severn. Although eDNA is not a quantitative method and cannot confirm abundance the concentration of eDNA is highest below the two main barrier to migration at Powick and Diglis weir on the river Teme and Severn respectively. However the signal is definitely present higher up the catchment which might be the result of the few allis shad still return that have the best ability to pass these barriers to migrate to higher up the catchment to spawn, particularly during periods of increased river discharge. None of the acoustically tagged twaite shad have migrated above Diglis and Powick Weirs in 2017/18. Two acoustically tagged shad were detected above Diglis Weir in 2019 during a period of elevated flows in June, showing that if conditions are suitable a small number of shad can pass this barrier.

Map 1. eDNA distribution of shad in the Severn catchment in June 2017. This shows that eDNA concentration is highest below the first barriers at Powick and Diglis weir but shad eDNA signal is detectable for a considerable distance upstream of these points, possibly a result of the present of the larger allis shad penetrating the catchment.



The rivers Wye and Usk have never been known for their allis shad population from the historical records, a possible reason for this is their slightly colder average river temperature compared to the river Severn. Anglers do report the capture of exceptionally large shad occasionally from the river Wye, but these captures are rarely verifiable so if an allis shad population is present then it is likely to be even smaller than that on the river Severn.

Acoustic results from shad originally tagged in the river Severn in 2018 and returning in 2019 have shown that straying between catchment is very low. Only two individuals of 37 acoustic tagged shad that returned after a year out at sea entering the river Wye (none entered the rivers Usk or Tywi). One of these immediately returned to the estuary and then into the river Severn to continue its spawning migration. Therefore the straying rate could be as low as <3%. Although sub adult allis shad do roam the ocean it seems that the source of the individuals caught at HPB as part of RIMP dataset are much more likely to be from a local source rather than a geographical distant west coast of France population. The genetic results

have also shown that it is impossible to truly separate shad species from physical features alone (e.g. gill rakers). It is therefore possible that higher numbers of juvenile allis shad may contribute to the HPB RIMP dataset then currently reported. This could only be addressed by undertaking genetic analysis of shad entrained at HPB.

Review of Application

Within the permit variation application (EPR/HP3228XT/V004) the twaite shad population has also been derived from the same life cycle model (APEM, 2010), but only data up to 2010 has been considered. Resulting in a total mean population estimate (aged 3–9 years) in the Severn River Basin District of 184,000, although annual variation in year-class strength may result in estimates ranging between 112,000 and 596,000. Furthermore on consideration of shad migratory behaviour and relative geography, the applicant considered the River Tywi population is not considered vulnerable to impingement at Hinkley Point C and removed this proportion of the population from the population estimate, resulting in the figures below (***Table 2***).

The applicant suggests in TR456 Ed 2 (BEEMS, 2019a) that the 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, and they were most likely part of the French breeding population.

Therefore the Allis shad population estimates used within the applicant's assessment were derived from studies based on the Gironde–Garonne–Dordogne basin population. The application references Scientific Position Paper SPP071S (BEEMS, 2019b) which stats "the estimated adult stock size in the basin was 27,397 in 2009 (Smeag, 2018)".

Table 2. Shad population estimates used within permit variation application.

	Population at risk of entrapment at HPC
Twaite Shad population estimate	165,788
Allis Shad population estimate	27,397

Proposals

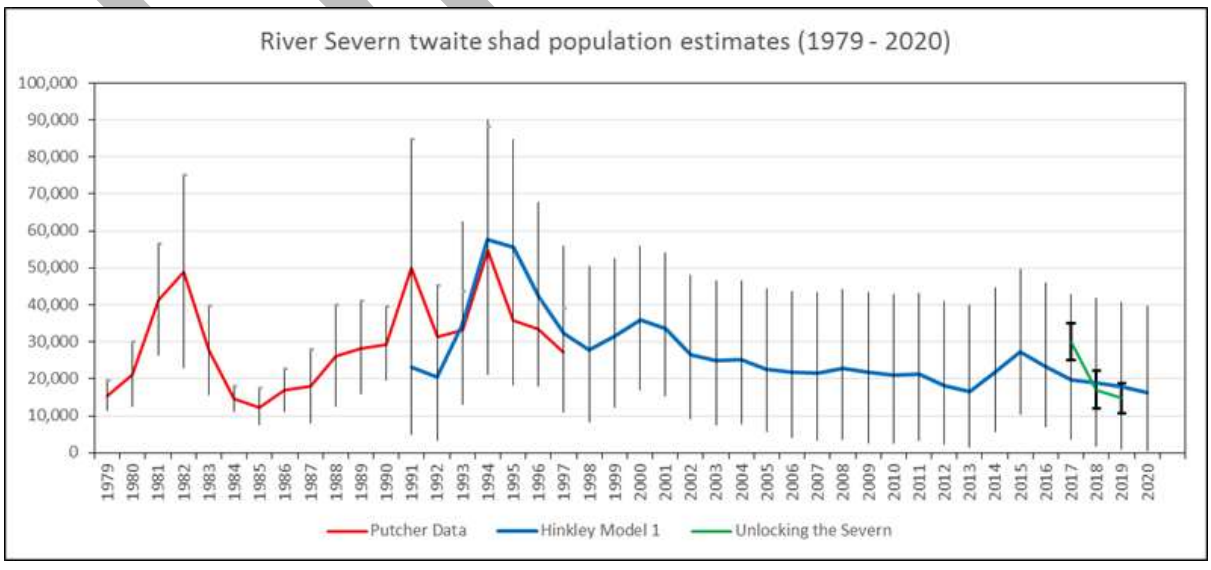
Three sets of data have be analysed giving the mean population predictions of twaite shad within the Severn Estuary below (**Table *3***).

Table 3. Twaite shad population estimates model from various data sets.

Data set and date range	Population numbers for Severn Estuary	
	Mean	Range (min - max)
Putcher Rank data (1979-1997)	118,960	49,350 – 218,206
RIMP data (1991-2019)	107,374	71,184 – 232,000
RIMP data (2009-2019)	81,382	64,000 – 110,000
Unlocking the Severn Project Data (2017-2019)	82,409	58,892 – 120,076

By overlaying the yearly population estimates from each data set and the confidence range around those estimates (***Graph 7***) we can consider an appropriate approach to devise the most suitable estimate of the population during 2009 to assess against the impingement data recorded during the CIMP (2009/10).

Graph 7. River Severn twaite shad population estimates (1979 - 2020)



Comparing the trends predicted from each of the data sets (***Graph 7***), the estimate the model predicts from the RIMP data (Hinkley Model 1, Blue line) for 2009 can be

regards as the best estimate of the population expected within that year. However it can be seen that this model appears to smooth the population estimate and does not represent the inter-annual variation represented in the putcher and Unlocking the Severn Project (UTSP) data.

The Environment Agency therefore propose to use the mean Twaite Shad population estimate from APEM's model (Hinkley Model 1) for 2009 as the best estimate of the population, and to represent the potential variance that could have influenced that population for that particular year, use the 95% confidence limits around this estimate within an uncertainty analysis assessment (***Table 4***). The width of these confidence intervals from the model are a factor of the relationship between certain parameter used within the model, partially as a result of the low sampling resolution of the RIMP. Currently there is no further evidence to narrow these confidence limits between the time the putcher data ceased and the UTSP data commenced (1998-2016). However, as we see from the UTSP data, these population estimates vary above and below the Model 1 mean over a short time period, they do not stray outside the confidence interval (**Graph *7***).

Table 4. River Severn twaite shad population estimate and confidence limits for 2009 from Hinkley Model 1 (APEM, 2020)

	Mean Estimate	**Lower 95% CI**	**Upper 95% CI**
River Severn Twaite shad population estimate	21,674	2,569	43,301

Proportioning this population between the contributing rivers according to the current accessible spawning areas within each, presents the following river population estimates (***Table 5***).

Table 5. Twaite shad population estimates apportioned to the contributing rivers.

	Severn Estuary Population	River Wye Population	River Usk Population	River Severn Population
Percent of Estuary Population	100%	50%	25%	25%
Mean Population	86,696	43,348	21,674	21,674
Uncertainty Range (min - max)	10,276 – 173,204	5,138 – 86,602	2,569 – 43,301	2,569 – 43,301

The total entrapment losses predicted at HPC will be applied to each of the population as there is no feasible way of predicting the proportion of the losses that may occur from each of the populations. However interpreting these losses against the population estimates it must be acknowledged that these represent a worst case scenario, as it is unlikely that the total entrapment loss will occur from just one of these proportioned populations.

As stated above, we believe there is sufficient evidence to support the position that a small allis shad population remains in the Severn Estuary sustained from a local spawning stock. And, unless new evidence becomes apparent we currently conclude that this allis shad population is principally confined to the River Severn and River Wye. We think it is precautionary to assume that the "pure" allis shad population is likely to be in the range of 1-3% of the annual shad run of the River Severn. Obviously if hybrids are taken into consideration, allis shad genes are present in around 30% of the river Severn shad population and this may well ultimately contribute to the re-establishment of a much larger allis shad population in years to come after the access to the historic spawning area of allis shad is re-connected after 170+ years as a result of the work of the Unlocking the Severn project.

Based on the last 10 years of data presented above for twaite shad, and on the basis of a relic population of allis shad in the River Severn, comprising 3% of the number of twaite shad present, and also a relic population in the River Wye comprising 1% of the number of twaite shad present. The table below presents the current estimates of allis shad populations in the Severn Estuary and contributing rivers (

Table 6).

Table 6. Allis shad population estimates apportioned to the contributing rivers.

	Severn Estuary Population	River Wye Population	River Usk Population	River Severn Population
Percent of Estuary Population	100%	50%	0%	50%
Percent of the number of Twaite Shad present	3% of River Severn + 1% of River Wye	1%	0%	3%
Mean Population	1083	433	0	650
Uncertainty Range (min - max)	128 – 2165	51 - 866	N/A	77 - 1299

Table 7. Conclusion results of adult shad population estimates.

Species	Population	Used in Applicant's assessment	Used in Environment Agency's assessment	
			Predicted	Uncertainty Range
Twaite Shad	**Severn Estuary**	165,788	86,696	10,276 – 173,204
	River Wye	N/A	43,348	5,138 – 86,602
	River Usk	N/A	21,674	2,569 – 43,301
	River Severn	N/A	21,674	2,569 – 43,301
Allis Shad	**Severn Estuary**	27,397	1,083	128 – 2165
	River Wye	N/A	433	51 - 866
	River Usk	N/A	N/A	N/A
	River Severn	N/A	650	77 - 1299

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