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BEEMS Scientific Position Paper SPP071/S

Shad (*Alosa fallax* and *Alosa alosa*) impingement predictions for HP C

Edition 3

Version and Quality Control

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Version	Change
Edition 3	Report brought up to date with latest scientific evidence that was not available for Edition 2. Twaite shad CIMP data updated after QA process, leading to increased EAV factor. Information on twaite shad impingement numbers from the RIMP programme added. RIMP data used for twaite shad impingement assessment.
Edition 2	Version submitted during DCO examination period after a request for clarification from Natural England. The twaite shad impingement prediction was amended to incorporate a worst case of 0 group and sub adult impingement.

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Executive summary

Allis shad (*Alosa alosa*) and twaite shad (*Alosa fallax*) both belong to the herring family and historically had a broad distribution along the Northeast Atlantic coast. Both species are anadromous; adults spend most of their lives in the marine environment, but migrate through estuaries to spawn in freshwater. Populations of both species have declined, their distribution has diminished, and they are both classified as species of conservation concern. Both are listed in Appendix III of the Bern Convention and Annexes II and V of the Habitats Directive.

At the time of the Hinkley Point C (HPC) DCO application impingement predictions for both species were provided in BEEMS Technical Report TR148.These predictions were obtained by raising shad impingement measurements obtained during the BEEMS comprehensive impingement monitoring programme (CIMP) at Hinkley Point B (HPB) in 2009/10 by the ratio of the cooling water flow rates of HPB and HPC to produce annual estimates of impingement numbers. Due to a lack of information at the time, an assumption was made that the catches of juvenile fish were equivalent to those of mature adults, i.e. the calculation took no account of natural mortality and assumed that the number of equivalent adults that would be expected to survive from the loss of a juvenile fish was one. This was an unrealistically conservative assumption, which is not valid for fish impinged as 0-group and that do not mature until they are 4–5 years old. That assumption was corrected in edition 2 of this report (SPP071/S) which was produced during the HPC DCO examination period.

Alosa fallax spawns in the Severn basin and there are regular records in the HPB routine impingement monitoring programme (RIMP) from 1981 of the impingement of predominantly 0-group (i.e. less than 1 year old) individuals. Juvenile fish descend into the estuary in August/September when they are about 3–4 months old, and most migrate to the sea by the time they are about 6-8 months old. During the intensive 12-month CIMP programme 95.5% of *A. fallax* were 0-group, 1.9% were 2-year old and 2.7% 4/5-year old.

A. Alosa does not spawn in the Severn or in the rivers in England and Wales that drain into the estuary, and only two sub adults (both 2–3 years old) were caught during the CIMP programme. The RIMP programme has not recorded any *A. alosa* in the 37 years of the programme.

This edition 3 report has been brought up to date with latest scientific evidence on shad that was not available at the time of the HPC DCO. In particular, data from the HPB RIMP programme has been used to improve confidence in the *A.fallax* impingement predictions.

This report supports BEEMS Technical Report TR456 which provides the most up to date (at January 2019) predictions of the effects of impingement at HPC and which has superseded BEEMS Technical Report TR148. The revised impingement predictions are shown below.

Predicted annual impingement effect on twaite shad (*A. fallax).*

Site	50th percentile number of fish impinged per annum.	50th percentile number of equivalent adults	Mean SSB (number of adults)	50th percentile impingement as percentage of mean SSB	95th percentile impingement as percentage of lower 95th percentile SSB[1]
HPB	685	4.5	165,788	0.0027%	0.0045%
HPC	658	4.3	165,788	0.0026%	0.0043%

Note 1: the upper twaite shad impingement effect estimate is a worst-case that represents a greater percentile than a 95th percentile.

Predicted annual impingement effect on allis shad (*A. alosa*).

Site	Predicted annual mean impingement numbers	Predicted annual mean adult equivalent numbers	Mean SSB (number of adults)	Mean impingement as a percentage of SSB	95th percentile impingement as a percentage of SSB
HPB	18	4.7	27,397	0.017%	0.035%
HPC	17.4	4.6	27,397	0.017%	0.034%

Sensitivity analyses have demonstrated that plausible variations in the values of natural mortality assumed in the equivalent adult calculations do not materially alter the conclusions.

1 Shad Biology and Life History

Allis Shad (*Alosa alosa*) and Twaite Shad (*Alosa fallax*) are anadromous clupeids that historically had a broad distribution along the Northeast Atlantic coast. Populations of both species have declined, their distribution has diminished, and they are both classified as species of conservation concern. Both are listed in Appendix III of the Bern Convention and Annexes II and V of the Habitats Directive.

Adult Twaite shad are generally 25–40 cm long; Allis shad grow faster and are generally 30–50 cm long. The two species can only be distinguished reliably by gill raker counts; *A. alosa* has >90, *A.fallax* <60 or by genetic analyses. The two species are known to interbreed to produce hybrids.

1.1 Allis Shad (*Alosa alosa*)

Alosa was historically 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, populations of *A. alosa* exist along the north-eastern Atlantic coasts in some large rivers of France (Loire, Gironde–Garonne–Dordogne, and Adour) and Portugal (Minho and Lima) (Rougier *et al* 2012).

Figure 1. Records of *A. alosa* in the UK (from Hiscock & Jones, 2003)

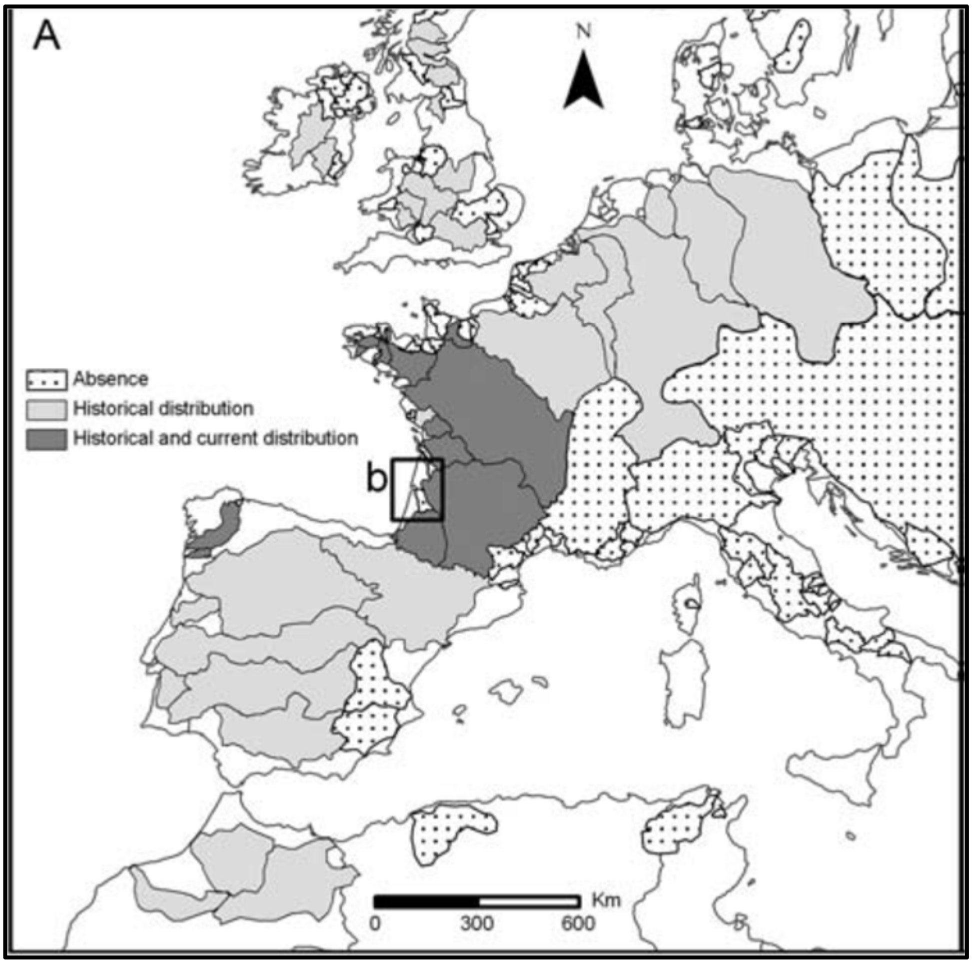

Figure 2: Historical and current distribution of self-sustaining allis shad populations (from Rougier *et al* 2012)

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 evidence of successful 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 from the Loire to Gironde populations (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 fidelity to breeding grounds, compatible with homing to natal spawning sites (Jolly *et al*., 2012)

The spawning migration into estuaries form the sea 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 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 schools in the surface layers of the water column during autumn and winter (Aprahamian *et al*., 2003, ICES 2015.)

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. During their period in the estuary juveniles tend to be found at the surface and close inshore (Taverny 1991). Castelnaud *et al.* (2001) reported juveniles to be ~ 10 times more abundant in the surface layers compared with samples taken 0.2 m above the bottom. Migration through the estuary will be via selective tidal stream transport on the ebb tide. In the marine phase allis shad are generally found in coastal waters in depths ranging from 10m to 150m and have been caught 600 – 700 km from their natal rivers (ICES 2015). The larvae grow rapidly to between 80 and 140 mm at age one. 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.

A.alosa only spawns in France and Portugal in any substantial numbers (the species has recently been reintroduced into the Rhine but the number of recruits are still small). There is no international stock assessment for *A. alosa* but some assessments are performed on specific French watersheds. The Gironde–Garonne–Dordogne basin had a notable commercial fishery at the end of the 20th century. The adult population (age 4+) was estimated to be 710 000, 798 000, and 834 000 in 1994, 1995, and 1996, respectively, with a mean exploitation rate by the commercial fishery of 44% (Lambert *et al*., 2001). Chanseau *et al.* (2005) reported that the commercial fishery in that basin caught approximately 500 t annually. However, in the first decade of the 21st century, there was a recruitment collapse probably due to over fishing and a fishery moratorium was imposed in the Gironde estuary from 2008 (Rougier *et al*. 2012). The estimated adult stock size in the basin was 27,397 in 2009 (Smeag 2018). The Loire watershed also has a breeding population of *A.alosa* and a small commercial fishery. The count of *alosa* was 2,557 in 2009 (Logrami 2016) but the video counting system does not cover all the tributaries of the Loire and cannot distinguish between *A. alosa and A. fallax*. The counters are located relatively high in the river basin at ranges of 260 – 663km from the sea and are, therefore, probably counting mostly *A.alosa*. It is also known that a substantial amount of spawning takes place downstream of the counters thereby underestimating adult numbers (Smeag 2018).

1.2 Twaite Shad (*Alosa fallax*)

Alosa fallax is distributed along most of the west coast of Europe from the eastern Mediterranean Sea to southern Norway and in the lower reaches of large rivers along these coasts that are accessible to the fish (i.e. rivers that lack barriers to migration). The species has declined substantially across Europe and in the UK; it is now known to breed only in the Severn River Basin District (RBD – in the Severn, the Wye, the Usk and the Tywi) and in the Solway Firth. There are also apparently non-breeding populations in the UK off the southern and eastern coasts, at Looe Bay, Hastings and Sizewell (Jolly *et al*., 2012). The decline of the *A. fallax* population has not been as severe as that of *A.alosa*, probably because of its ability to use spawning sites closer to the sea than those of *A. alosa*; sites that are not, therefore, subject to the barriers to migration that block *A. alosa* from accessing its traditional spawning sites (Maitland & Hatton-Ellis, 2003)

Alosa fallax, unlike *A. alosa*, may spawn several times during their lives (i.e. they are iteroparous; Maitland & Hatton-Ellis, 2003). The seaward migration of juvenile *A. fallax* is different from that of *A. alosa* in that *A. fallax* is reported to spend more time in the estuarine environment before moving into the marine environment. The latter’s habitat is coastal and estuarine and in the Gironde, the species repeatedly re-enters the lower reaches of the estuary before making an up-estuary migration to spawn at sexual maturity (Lochet, 2008).

Aprahamian & Lester (2001) provide estimates of the mean weight at age of *A. fallax* in the River Severn which are reproduced below. These estimates were determined from 5090 fish collected between 1979 and 1998. The maturity at age data in Table 1 are from Aprahamian *et al.* 2003.

Table 1. Mean weight (g) and maturity at age for *A. fallax*

Parameter	Value								
	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9
Male (g)	4.8	50.0	176.8	321.6	399.9	461.0	530.8	529.8	569.6
Female (g)	6.1	63.3	220.2	430.4	593.6	713.3	770.7	839.5	950.2
Mean weight (g) assuming 50:50 sex ratio	5.45	56.6	198.5	376	497	587	651	685	760
Dry weight (g) assuming dry weight =20% wet weight	1.09	11.3	39.7	75.2	99.4	117.4	130.2	136.9	152
Cumulative Maturity (M)	0%	0.7%	31.5%	82.4%	99.0%	99.8%	99.9%	100%	100%
Cumulative Maturity (F)	0%	0%	2.2%	35.4%	84.2%	98.7%	100%	100%	100%
Combined cumulative maturity assuming 50:50 sex ratio	0%	0.35%	16.9%	58.9%	91.6%	99.3%	100%	100%	100%

Modelling of the *A. fallax* population in the Severn RBD by APEM in 2010 (DECC 2010) indicates an average population size of approximately 92,000 female shad. Given a sex ratio of unity, the total mean population of *A. fallax* aged 3–9 years in the Severn RBD is therefore estimated at 184,000, although annual variation in year-class strength may result in estimates ranging between 112,000 and 596,000. On considerations of shad migratory behaviour and relative geography, the River Tywi population is not considered vulnerable to impingement at Hinkley Point and the shad SSB for impingement assessment purposes has had that population removed, reducing the mean SSB to 165,788 adults and the lower 95th percentile SSB to 100,800 (Section 9.1.6, TR456).

2 HP B Impingement Monitoring Data

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 and the BEEMS comprehensive impingement monitoring programme (CIMP) conducted at HPB in 2009/10 (BEEMS Technical Report TR456).

The RIMP sampling method consists of 6 hours of sampling (in one day) off 2 of HPB's 4 drum screens every month i.e. 72 hours sampling per annum. Sampling is conducted during daylight, midway between springs and neaps, from high water on the ebb tide.

The CIMP programme ran from February 2009 to February 2010 and consisted of 40 sampling dates selected on a pseudo random basis, stratified into 10 samples per quarter. Each sample was taken for 24 h and, therefore, sampled fish impinged on both ebb and flood tides during day and night. i.e. 960 hours sampling per annum or >13 times the RIMP sampling effort. The design of the survey and the large number of sampling hours means that much lower variance estimates of the density of protected species could be made than with the RIMP survey. The CIMP data have been used as the main source for the HPC impingement predictions provided in TR456.

2.1 Shad impingement in the RIMP programme

The long-term RIMP programme at HP B has recorded variable numbers of *A. fallax* (Figure 3) in most years but no *A. alosa*.

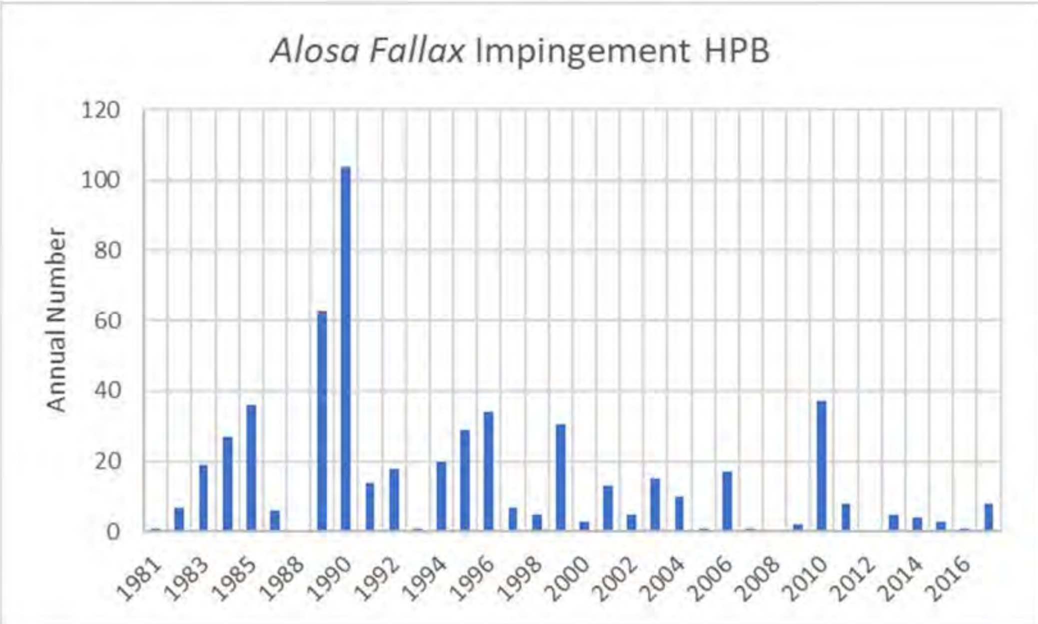

Figure 3 Unscaled annual impingement numbers for *A.fallax* in the RIMP programme.

In the 37 years of the RIMP survey just six adult *A.fallax* (in the range 395-460mm total length) were sampled (2 in April 1991, 1 in April 1992, 1 in November 1993, 1 in April 1996 and 1 in April 2015). It is not known whether these fish were mature but, given their size and the impingement month, it is possible that the five fish caught in April were migrating to freshwater to reproduce. The overwhelming majority of the impinged *A.fallax* were 0-group with only a few older than 1 year old. For example, in the period 2000-2017, all fish were less than 105 mm standard length (i.e. the expected length at about 15 months old) with the exception of the one adult caught in 2015. For each year class, individuals were first caught in August or September when they were 3-4 months old. That year class left the estuary generally by March of the following year but occasionally a few fish left as late as August. The largest recruitment peak in the period was in 2010. The CIMP measurements were from 2009; a year with a low number of recruits.

The small number of impinged adult twaite shad is not surprising as these fish are expected to migrate up estuary using energetically efficient selective tidal stream transport (STST) near to the sea surface on the flood tide in the deeper waters of the Bristol Channel. Adults returning to sea after spawning are also considered to use the same migration route but on the ebb tide. As such adults would be largely invulnerable to impingement at Hinkley Point. The HPC intakes are located in deeper water than those at HPB (but still more than 10 km from the deep-water channel in the estuary) and would be expected to further reduce adult impingement at that station (TR456 Section 3.1.1).

Two twaite shad were impinged during 2009 in the RIMP programme compared with 34 during the CIMP programme for the same year. In contrast, in 2010 37 fish were sampled in the RIMP. These 37 fish were all 0-group in the size range 30 to 75mm standard length with 88% sampled in the period August to December 2010. The 2010 twaite shad recruitment event was the third largest in the 37-year history of the programme.

2.2 Shad impingement made measurements during the CIMP programme

2.2.1 *A.fallax*

The predicted HPB annual CIMP impingement data for *A. fallax* are shown in Table 2. These data are based upon the measured impingement numbers at HPB and are not those resulting from the bootstrapping procedure used in TR456).

Table 2. HP B CIMP data: Scaled *A. fallax* impingement numbers by standard length from Feb 2009 to Jan 2010.

Std length mm	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Totals
10-14				33.1									33.1
15-19													0.0
20-24													0.0
25-29													0.0
30-34													0.0
35-39													0.0
40-44													0.0
45-49								30.0	31.0				61.0
50-54								28.6	31.0	20.0			79.6
55-59	14.0			46.7				10.0	38.8	10.0	21.0		140.5
60-64	42.0	14.0		13.7				10.0	38.8	20.0	55.1		193.5
65-69													0.0
70-74													0.0
130-134								10.0					10.0
295-299			14.1										14.1
Totals	56.0	14.0	14.1	93.5	0.0	0.0	0.0	88.6	139.5	50.0	76.1	0.0	531.7

Note: The 1 measured fish in the size range 10-14mm in May 2009, which when scaled up led to an estimate of 33.1 fish, was either a washout from a river or possibly a misidentification. The data have been left in the analysis as part of the subcontractor's supplied dataset. Removing this sample makes no material difference to the results of the subsequent analysis of the number of fish surviving to maturity.

The breakdown of the impinged *A. fallax* by age group is shown in Table 3.

Table 3 Scaled up annual number of *A.fallax* at HPB broken down by age group

Age	Number	% of total
0-group	507.6	95.5%
2-group	10	1.9%
4/5-group	14.1	2.7%
Total	**531.7**	**100%**

A total of 95.5% of the impinged *A. fallax* were 0-group fish. One fish (representing 1.9% of the raised distribution) was 1 or 2 years old (conservatively considered age 2 for this analysis) and one fish (weighing 0.35kg and representing 2.7% of the distribution) was 4 or 5 years old dependent upon whether it was male or female (conservatively considered 5 for this analysis). The pattern reflects the known spawning behaviour of *A. fallax* in the Severn, with the first juveniles appearing in the estuary at HP B in August/ September when they would have been approximately 3-4 months old. Most of these 0-group fish would have migrated out to sea by December, and the balance would have left the estuary by June, when they would have been 1 year old. The length–weight relationship of the young of year is shown in Table 4.

Table 4 Measured *A. fallax* length–weight relationship from 2009/10 CIMP data

Month	Mean standard length (mm)	Mean weight (g)
September	51.4	1.54
October	54.6	1.70
November	58.2	2.54

2.2.2 A.alosa

Despite the greatly increased sampling compared to the RIMP programme, the CIMP programme only detected the two individual *A.alosa* listed in Table 5.

Table 5 *A.alosa* captured in the 1-year CIMP programme

Month	Standard length (mm)	Weight (kg)
February 2009 – 1 fish	301	0.344
March 2009 – 1 fish	260	0.198

Both fish were immature sub adults aged between 2 or 3 years. There is no evidence of *A.alosa* spawning in the watershed of the estuary and , as expected, no juveniles were detected during the CIMP.

3 Impingement Predictions

At the time of the HPC DCO application predictions of shad impingement were provided in BEEMS Technical Report TR148, by raising the shad CIMP impingement records by the cooling water flow rates of HPB and HPC to produce annual estimates of impingement numbers under normal operating conditions. Due to a lack of information at the time, an assumption had to be made that the catches of juvenile fish were equivalent to those of mature adults, i.e. the calculation took no account of natural mortality and assumed that the number of equivalent adults that would be expected to survive from the loss of a juvenile fish was 1. (Further explanation of equivalent adult values (EAVs) may be found in TR456). This was an unrealistically conservative assumption, which is not valid for fish impinged as 0-group and that do not mature until they are 4–5 years old. That incorrect assumption was corrected in Edition 2 of this report (SPP071/S) which was produced during the HPC DCO examination period.

Natural mortality, *M*, is very high during fish egg and larval stages and decreases as their age increases, approaching a steady state until it rises rapidly towards the end of life (Jennings *et al*., 2001). *M* may vary with size, sex, parasite load, fish density, food availability and predator numbers. For most marine fish species, comprehensive data on these parameters are not available, so models have been developed that provide estimates of *M* from the parameters that explain the majority of the observed variability. A review of many such models is given by Siegfried and Sansó (2012).

There are no estimates in the literature of natural mortality for 0-groups of either *A. alosa* or *A. fallax* but estimates are available for mature adults. This is not an uncommon situation in fisheries science and in the absence of species-specific data, Peterson & Wroblewski's (1984) model, as described by McGurk (1986), relating the instantaneous natural mortality (*M*) of marine species to the dry weight (*W*, as 20% of wet weight) has been used in this report.

$$M = 5.26 \times 10^{-3} W^{-0.25} \text{.} \qquad \text{(Equation1)}$$

This model was selected for the study because of its proven good fit between model predictions and observational data in McGurk (1986) and in the Siegfried and Sansó review. Importantly for this application, however, it requires estimates of parameters for which feasible estimates exist for the Severn population of *A. fallax*. Aprahamian (1988) calculated a value for *M* for mature *A. fallax* of 0.53±0.18 (1 s.d.) based upon commercial catch per unit effort data for the period 1979–1981 from the Severn. Equation (1) produces a value of 0.61 using data from Table 1 for fish aged 5 years.

Using Equation (1) and the measured weights of impinged shad at HP B, the instantaneous rates of natural mortality for both shad species were estimated and the EAV factors calculated.

3.1 Impingement predictions for twaite shad (*Alosa fallax*)

3.1.1 Predicted EAV for twaite shad

Using natural mortality equation (1) above, the age–weight relationship in Table 1 and data from the fish impingement at HPB in Table 2, the estimated value for natural mortality at age of *A. fallax* in the Severn is shown in Table 6.

Table 6 Calculated natural mortality of *A. fallax* in the Severn.

Parameter	Age	M (d^{-1})	M (year^{-1})
M_0	5 months (October)	6.76×10^{-3}	2.47
M_1	1	5.15×10^{-3}	1.88
M_2	2	$2,87\times10^{-3}$	1.05
M_3	3	2.10×10^{-3}	0.76
M_4	4	1.79×10^{-3}	0.65
M_5	5	1.67×10^{-3}	0.61

Note: Using mean weight at age, Table 6 underestimates male mortality and overestimates female mortality (females weigh more than males at the same length across the whole size spectrum of the population), but the differences in estimated values of M are not large (e.g. at age 5 the difference in M is in the range 0.58–0.64. and at age 1 the difference is in the range 1.83–1.94).

Using these mortality estimates, the survival of *A. fallax* from when the fish are impinged until the start of year 4 (the year when more than 50% of the fish will be mature) is shown in Table 7.

The 0-group fish were assumed to enter Bridgwater Bay in October when they were 5 months old and the number surviving to year 4 was given by Equation (2) (the standard survival equation for populations subject only to natural mortality) to be 0.59%.

$$N_4 = N_0 \mathrm{e}^{-7/12\,M_0} \mathrm{e}^{-M_1} \mathrm{e}^{-M_2} e^{-M_3} .$$ Equation (2)

$$N_4 = N_2 \mathrm{e}^{-M_2} e^{-M_3} .$$ Equation (3)

The number of year 2 fish surviving to year 4 was calculated using Equation (3) to be 16.37% and to be conservative all of the impinged fish from year 4 onwards were assumed to be adults.

Table 7 Calculated number of *A. fallax* equivalent adults at age at HPB from the CIMP data

Age	Number impinged at HPB	Survival to year 4	Number of equivalent adults
0 group (assumed to be 5 months old)	507.6	0.59%	3.0
1 group	0	2.50%	0
2 group	10.0	16.37%	1.6
4/5 group	14.1	100%	14.1
Totals	**531.75**	**3.52%**	**18.7**

An equivalent adult value for *A. fallax* of 0.03524 in 2009 was, therefore, used for impingement prediction purposes (Table 8)

3.1.2 Impingement calculations for twaite shad from CIMP data

The predicted annual impingement of twaite shad is shown in Table 8 and has been calculated using the method described in Section 5 of TR456 as follows:

i. Impingement is assessed against the numbers of spawning adults (165,788 – Section 9.1.6, TR456) and so no estimate of the adult weight is required.

ii. The assumed FRR mortality is 100%.

iii. The bootstrapped mean impingement at HPB is 550 fish, upper 95th percentile 925 fish. The unmitigated (i.e. before taking account of the design of the HPC intakes) bootstrapped mean impingement at HPC is 2152 fish, upper 95th percentile 3619 fish. (Calculated from CIMP data, Appendix D, TR456)

iv. To account for the expected reduction in impingement resulting from the design of the HPC intakes, the unmitigated bootstrapped HPC impingement number is multiplied by 0.646 (effect of reduced intake intercept cross-sectional area) and 0.38 (effect of capped intakes on pelagic fish). (Section 3.1.1, TR456).

v. EAV = 0.03524 (Section 3.1.1 this report)

Table 8 Predicted annual mean impingement of equivalent adult *A.fallax* in 2009/10 from the CIMP programme as equivalent adults and as a percentage of SSB.

	Predicted annual mean number of fish impinged	Mean number of equivalent adults	Adult Population (Mean SSB)	Mean impingement as percentage of mean SSB
HPB	550	19.4	165,788	0.012%
HPC	528	18.6	165,788	0.011%

Using the uncertainty analysis methodology described in Section 9 of TR456 that considered the variation in impingement numbers and in SSB, the uncertainty around the HPC impingement effect is shown in Table 9.

Table 9 Uncertainty on the HPC annual impingement assessment for twaite shad calculated by Monte Carlo analysis – LVSE intakes and FRR fitted (from Table 32 TR456).

	Annual mean impingement as percentage of SSB	**Lower 95th percentile**	**Upper 95th percentile**
HPC	0.012%	0.0052%	0.022%

Note: The slight differences in the mean impingement estimates between Table 8 and Table 9 result from the random nature of the data sampling processes used in the Monte Carlo analyses. Every run of the analysis routine produces slightly different results.

3.1.3 Sensitivity of adult impingement predictions to estimates of natural mortality (M)

Models for natural mortality only provide an approximation to the value of *M* experienced by fish populations at any given age. Although there are observational data to confirm that the value of *M* derived for mature *A. fallax* is reasonable, no such data exist for 0-group juveniles. *M* is known simultaneously to have its largest value, to vary most rapidly with age, and to be subject to its greatest uncertainty for eggs and larvae. However, the youngest fish modelled here are 5-month-old juvenile *A. fallax* which, while subject to greater mortality than larger, older fish, are beyond the age that experiences the exceptionally high mortality attributable to predation at the very young stages. The most uncertain estimate for this species is M_0, the natural mortality that the fish experience when they first appear in the estuary (assumed to be at age 5 months in Table 6). To test the sensitivity of the impingement predictions in Table 8, they were recalculated using values of M_0 of 50% or 25% of that shown in Table 6.

Table 10. Predicted equivalent adult *A. fallax* impingement at HP C with variations in natural mortality

Sensitivity test case	**Predicted mean number of equivalent adults lost through impingement at HP C**	**Mean impingement as a % of SSB**	**Comment (assuming LVSE intakes and FRR fitted)**
Base case as per Table 6	18.6	0.011%	*M* calculated as per Equation (1)
M_0*0.5	21.9	0.013%	
M_0*0.5, M_1*0.75	25.6	0.015%	M_1 adjusted to produce a plausible mortality curve i.e. where $M_0 > M_1$
M_0*0.25 M_1*0.75	29.9	0.018%	Not plausible, because at this level of reduction, *M* at 5 months would be identical to *M* at 5 years

The results in Table 10 demonstrate that the predicted losses of adult *A. fallax* remain negligible as a percentage of the estimated mean spawning population size of 165,788 even after allowing for plausible uncertainties in the value of *M* for juvenile fish. In this case the EAV for *A. fallax* is driven by the number of fish greater than or equal to 4 years old.

It should be noted that for *A. alosa,* the likely impact on predicted equivalent adult losses attributable to plausible variations in the expected values of *M* would be less than for *A. fallax* because of the age of impinged fish (3 years old). At age 3 the uncertainties in M are much lower than those for 0-group fish and the consequential impact on predicted adult impingement is, therefore, much less.

3.1.4 Sensitivity to assumed age of maturity

In section 3.1.1 the assumed age of maturity was 4 years old. If the calculations are repeated with an age of maturity of 3, the EAV changes from 3.5% to 4.5% and the HPC impingement increases from 0.011% SSB to 0.014% SSB.

3.1.5 RIMP derived impingement estimate

The predicted impingement numbers presented in Table 8 are based upon the 1 year 2009-10 CIMP survey. There a several issues with this prediction that taken together create potential concerns about its reliability:

- The data in Table 7 show that the calculated EAV was heavily influenced by the one adult caught in the year;
- There were only 34 twaite shad impinged during the entire CIMP programme; and
- As described in Section 5.1.3.1 of TR456, year to year variations in twaite shad numbers are high and this creates uncertainty around 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. The reduced number of sampling hours per month of the RIMP compared with the CIMP survey means that the impingement estimates for rare conservation species calculated from the RIMP are subject to more variance than those from the CIMP on a single year basis. Nevertheless, by analysing sufficient data an improved estimate of mean impingement levels can be obtained and in this case the 18-year period from 2000 to 2017 was assessed (Figure 4). In that period only 1 adult was sampled in 2015, in all other years the fish were 0-group except for one 1-group in 2004 and one in 2011. There was no measured trend in the population in the period (Appendix E, TR456). (Note: it would not have been possible to use RIMP data prior to 1995 for this analyses because fish lengths were not measured for all sampled fish prior to that year)

The year 2010 had the 3rd highest shad recruitment in the 37-year programme and all of the fish sampled in that year were 0-group with an approximate EAV of 0.0059 (Table 7).

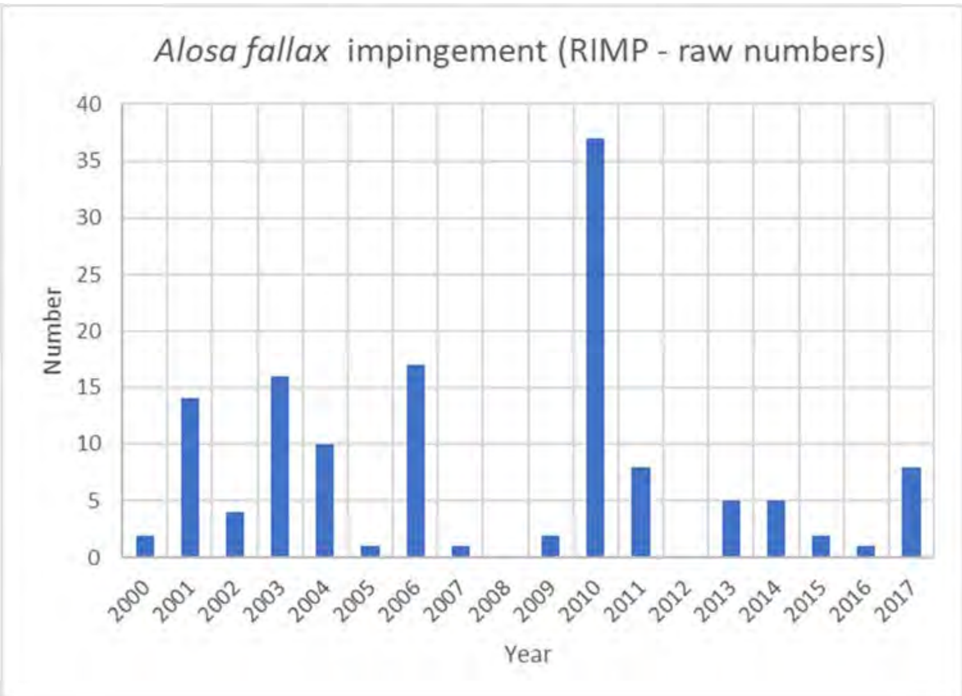

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Figure 4. Unscaled annual impingement numbers for *A. fallax* from the HPB long term impingement dataset

Table 11 shows the predicted mean impingement effect at HPC from the RIMP data, calculated using the procedure described in Appendix H of TR456.

Table 11 Predicted HPC impingement as number of fish and percentage of SSB using the RIMP dataset for 2000-2017

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. 2004/05 EAV derived from nine 0 group fish and one adult fish : EAV =(9*0.59%+1*2.5%)/10 =0.0078
2. 2011/12 EAV derived from seven 0 group fish and one adult fish : EAV =(7*0.59%+1*2.5%)/8 =0.083
3. 2004/05 EAV derived from one 0 group fish and one adult fish : EAV =(9*0.59%+1*2.5%)/2 =0.503

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 worst-case of 146 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 therefore, in accordance with statistical convention, the median (50th percentile) has been reported as the typical value. Table 12 shows the predicted impingement frequency statistics.

Table 12 HPC Impingement frequency for twaite shad derived from RIMP measurements

Frequency percentile	Number of equivalent adults	Impingement percentage of mean SSB	Impingement percentage of lower 95th percentile SSB
50.0%	4.3	0.0026%	0.0043%
90.0%	19.9	0.012%	0.020%
95.0%	49.2	0.030%	0.049%

The median effect (50th percentile) was 4.3 equivalent adult fish representing 0.0026% of mean SSB or 0.0043% of the lower 95th percentile SSB estimate of 100,800 adults. The 95th percentile effect was 49.2 equivalent adult fish representing 0.030% of mean SSB or 0.049% of the lower 95th percentile SSB estimate of 100,800 adults. These are considered the most approriate statistics for twaite shad impingement predictions at HPC. The mean values shown in Table 11 represent an 88th percentile event that falls between the probability distributions of juveniles and adults and which is is not found in the dataset.

3.1.6 Comparison between RIMP and CIMP derived impingement predictions for twaite shad.

The 2009 CIMP impingement estimate for HPC (Table 8) was 18.6 fish or 0.011% mean SSB, whereas the RIMP estimate was 1.7 fish or 0.001% mean SSB. This difference was primarily due to one adult fish being caught in the CIMP (none were caught in the RIMP in 2009). If that one adult had not been caught the HPC CIMP annual impingment prediction would drop to approximately 4.6 fish (0.0028% mean SSB). The remaining difference was due to one 2-year old being caught in the CIMP which increased the prediction from approximately 3 fish (0.0018% mean SSB) to 4.6 fish (0.0028% mean SSB) i.e. without those two fish the RIMP and CIMP predictions for 2009 were highly similar (0.001% versus 0.0018% mean SSB respectively). This analysis highlights the issues that can arise if just one year of data is used for predictions for this species with rare adult outliers.

The analyses in this report have shown HPC impingement predictions of 0.011% of mean SSB from the 1-year CIMP data and 0.0026% of mean SSB as a 50th percentile from 18 years of RIMP data. Given the interannual variabiliity and, in particular, the relative sensitivity of the predictions to rarely impinged adults the prediction from the multi year RIMP dataset is considered to provide a more reliable prediction of the HPC impingement effect on twaite shad. Both estimates are substantially less than the 1% negligible effect threshold (TR456).

Table 13 summarises the predicted impingement effects for twaite shad at HPB and HPC derived from the RIMP dataset.

Table 13 Predicted annual impingement of *A.fallax* from the RIMP programme

Site	50th percentile number of fish impinged per annum	50th percentile number of equivalent adults	Mean SSB (number of adults)	50th percentile impingement as percentage of mean SSB	95th percentile impingement as percentage of lower 95th percentile SSB
HPB	685	4.5	165,788	0.0027%	0.0045%
HPC	658	4.3	165,788	0.0026%	0.0043%

Notes:

1. The 95th percentile impingement for HPC is from Table 12. The lower 95th percentile SSB estimate is 100,800 adults (Section 1.2)
2. The MonteCarlo uncertainty analysis described in Section 3.1.2 has not been repeated using the RIMP data and column 5 of Table 13 is therefore a worst-case estimate that represents a higher percentile than the 95th percentile value.

3.2 Impingement predictions for allis shad (*Alosa alosa*)

As no allis shad were detected during the entire RIMP programme and only two in the high resolution CIMP programme, the numbers of allis shad are considered so low that impingement effects on the species at Hinkley Point are considered to be negligible. In particular, there was no evidence of adults nor recently spawned juvenile fish and the 2 impinged sub adults are considered part of the widely dispersed feeding population on the continental shelf that will not return to natal rivers to spawn until they reach approximately 5 years old. If juveniles had spawned in any of the rivers feeding the estuary, the CIMP programme should have been sensitive enough to detect them when they migrated through the estuary to sea.

Despite the negligible impingement at HPB, as allis shad are protected under the Habitats Directive an assessment is provided in this report to put these rare impingement events into a population context using the available data from the CIMP and other published data. This evidence is an expanded and updated version of that provided in edition 2 of this report.

3.2.1 Predicted EAV for allis shad.

The weight of the two *A.alosa* caught in the CIMP survey was 198 g and 301 g, giving a mean value of *M* from Equation (1) of 0.72 year^{-1} (range 0.69–0.76) but with only two impinged fish that value of *M* is uncertain. Based on the size and weight of the measured fish (for which the sex was unknown), they were either 2 or 3 years old. Assuming losses through natural mortality alone (i.e. neglecting any mortality in fisheries bycatch), a conservative age of 3 and maturity at age 5, the expected survival of the 2 fish to maturity would be approximately 26%, i.e. the equivalent adult value (EAV) factor is 0.262 or for every 4 subadults impinged, approximately 1 adult would have been expected to survive to maturity.

It is not possible to make any substantive comments about the size distribution of *A. alosa* that might occur off Hinkley Point on the basis of the two fish caught during the CIMP survey. In the Solway Firth where populations of *A. alosa* in breeding condition have been recorded, the age of immature fish caught using commercial stakenets between 1989 and 1994 was in the range 2+ to 4+, with fork lengths of approximately 236–440 mm, a mean length of 343 mm and mean weight of 528 g (Maitland & Lyle, 2005). If such a size distribution was representative of the *A. alosa* present off Hinkley Point, the mean survival of a 3-year-old fish at age 5 would be 27.5%, i.e. not materially different from the calculation based upon the two fish impinged at HP B.

It is conceivable that the size distribution of *A. alosa* at Hinkley Point could be greater than that assumed above, as the Solway stakenet fishery catches could have under sampled smaller fish. However, if this was the case, the true mean length would have been smaller, resulting in reduced mean survival probability at age 5. Equally, despite the absence of evidence in the scientific literature, it is conceivable that there could be mature fish aged 5+ years present in the vicinity of Hinkley Point. However, such mature fish would be using selective tidal stream transport to migrate up estuary on the surface in the deep-water channel and therefore would be highly unlikely to be impinged at either HPB or HPC. On balance, it is therefore considered appropriate to base survival estimates on the value of *M* value derived from the two fish impinged during the CIMP survey (0.72 for 3 old olds and 0.62 subsequently for 4 year olds).

3.2.2 Impingement prediction for allis shad

The predicted impingement of *A. alosa* reported is shown in Table 14 together with the number of equivalent adults surviving, corrected for the EAV factor of 0.262 The sub adults at Hinkley Point are likely to have come from the French spawning population. Taking only the Gironde population of 27,397 adults in 2009 (Section 1.1 of this report), the HPC mean impingement would have represented a negligible 0.017% SSB.

Table 14. Predicted annual impingement of *A.alosa* at HPB and HPC from the CIMP dataset as number of equivalent adults and percentage of SSB

Site	Predicted annual mean impingement numbers	Predicted annual mean adult equivalent numbers	Mean SSB (number of adults)	Mean impingement as a percentage of SSB	95th percentile impingement as a percentage of SSB
HPB	18	4.7	27,397	0.017%	0.035%
HPC	17.4	4.6	27,397	0.017%	0.034%

Note: The 95th percentile impingement is from the uncertainty analysis in Section 9, TR456

4 Conclusions

After correcting the predicted impingement losses for natural mortality before the juvenile and immature shad at risk from impingement at Hinkley Point enter the adult population, the impingement predictions for HPB and HPC are listed in Table 15 and Table 16.

Table 15 Predicted annual impingement effects for twaite shad (*A. fallax)* – from RIMP data.

Site	50th percentile number of fish impinged per annum.	50th percentile number of equivalent adults	Mean SSB (number of adults)	50th percentile impingement as percentage of mean SSB	95th percentile impingement as percentage of lower 95th percentile SSB[1]
HPB	685	4.5	165,788	0.0027%	0.0045%
HPC	658	4.3	165,788	0.0026%	0.0043%

Note 1: the upper twaite shad impingement effect estimate is a worst-case that is greater than a 95th percentile (Section 3.1.6).

Table 16 Predicted annual impingement effects for allis shad (*A. alosa)* – from CIMP data.

Site	Predicted annual mean impingement numbers	Predicted annual mean adult equivalent numbers	Mean SSB (number of adults)	Mean impingement as a percentage of SSB	95th percentile impingement as a percentage of SSB
HPB	18	4.7	27,397	0.017%	0.035%
HPC	17.4	4.6	27,397	0.017%	0.034%

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