MONITORING OF ALLIS SHAD AND SMELT IN TAMAR ESTUARIES EC18234

A report from:

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MONITORING OF ALLIS SHAD AND SMELT IN TAMAR ESTUARIES – EC18234

Executive summary

In April 2015, the Marine Biology Association (MBA) and Environment Agency (EA) were commissioned by Natural England (NE) to investigate the distribution of allis shad (Alosa alosa) and smelt (Osmerus eperlanus), protected as features in the Plymouth Sound and Estuaries Special Area for Conservation (SAC) and Tamar Estuary Sites Marine Conservation Zone (MCZ) respectively.

Allis shad are rare in the UK and populations are declining in Europe. The only confirmed spawning sites for allis shad are in the Tamar Estuary. This site is also an important area for spawning populations of smelt. The UK smelt population is depleted and protecting estuaries used by the species is important because they can become locally extinct from isolated estuaries and will not return. The main threats to Allis shad and smelt include pollution, over-exploitation, habitat destruction/degradation and barriers to migration. Natural England is responsible for reporting to government on the condition of these species. Prior to this study allis shad and smelt populations were poorly researched within the site. In spring/summer 2015 the EA surveyed the spawning distribution of allis shad in the upper Tamar Estuary and River and the upper Lynher Estuary and River. The EA monitored the allis shad adult spawning migration at Gunnislake Fish Trap and Gunnislake Fish Counter cameras. In August 2015 a boat-towed plankton net survey was undertaken by MBA/EA in the upper Tamar estuary from Gunnislake to Cotehele to look for allis shad and smelt larvae. No young shad were found though smelt were present between Okeltor Boathouse, upstream of Calstock and Cotehele. Allis shad eggs were not found in the Lynher River or Estuary or in the River Tamar; allis shad eggs were only found at one spawning site in the upper Tamar Estuary at Cottage Run. Allis shad eggs were present from late May until early July 2015 and none were recorded migrating upstream at Gunnislake Weir in 2015, suggesting that all spawning occurred at one site downstream of the weir. Low flows at Gunnislake Weir in 2015 (due in part to a leaking sluice gate in a bypass channel) are thought to have deterred upstream allis shad migration.

The EA collated all existing allis shad records from the Tamar and Lynher Rivers and Estuaries held in their archive. Records were provided to NE from adult allis shad caught at

Gunnislake Fish Trap, seen on Gunnislake Fish Counter cameras, caught by anglers and salmon netsmen, sightings, records of carcasses found and the distribution of spawning sites from egg surveys. A review was also undertaken by the EA of previous allis shad spawning migrations on the Tamar. An analysis was undertaken of the environmental conditions associated with the adult run at Gunnislake Weir and the environmental conditions associated with spawning records, based upon egg surveys in the River Tamar and estuary. The estimated size of the allis shad run into the River Tamar at Gunnislake Weir is presented as are observations on the allis shad spawning run, including size measurements, sex-ratio, estimated age and spawning history of individuals on the spawning migration.

The EA undertook egg surveys between February and April 2016 to monitor the smelt spawning distribution and timing of the spawning run in the upper Tamar and Lynher Estuaries. A pair of fyke nets was used by the EA at Impham Meadow in the upper Tamar Estuary, to determine the timing of the smelt spawning run and describe the makeup of the smelt spawning migration. Smelt eggs were not recorded on the Lynher. Very small numbers of live smelt eggs were recorded in the Upper Tamar Estuary below Cottage Run Weir between mid-March and early April 2016. However, the number of eggs found did not suggest that smelt had spawned in great numbers if at all at Cottage Run; it is possible that the small number of smelt eggs found were deposited by the tide. The reasons for an apparent absence of smelt spawning in the upper Tamar Estuary in spring 2016 are unclear. High flows during February 2016 may have resulted in smelt spawning further down the estuary. However, environmental conditions in March and April appeared to be favourable so it is possible that a change in the spawning substrate at Cottage Run since the 1970s has resulted in this site being unsuitable for smelt spawning. A small number of smelt in spawning condition were caught in the fyke net in mid-March 2016, suggesting that smelt were attempting to spawn in the upper Tamar Estuary.

Trawling for adult smelt was first undertaken by beam trawling from Morwellham Quay to Pentillie Quay in August 2015 with smelt present from the upper reaches to Cotehele. In November 2015 the sampling covered the same area and smelt were present around Cotehele and Halton Quay (upper). The sampling had to be cancelled in December and in January a comparison between beam trawling and otter trawling suggested the latter probably caught more smelt where it could be operated. Sampling also extended much further down the river at West Mud, but with fewer sites in the upper reaches. The otter trawl sampling in January and February 2016 caught smelt at Halton Quay (lower) and by March 2016 higher numbers of smelt were found around Halton Quay and many of these were in spawning condition. In total 40 fish species were sampled.

In summary, the status of the Tamar allis shad population is uncertain but there are several observations that give cause for concern, namely the sharp downturn in the number of allis shad seen migrating upstream via Gunnislake Fish Trap since 2011 and the apparent use of just one spawning site in the upper Tamar Estuary. The status of the Tamar smelt population is less clear as this is the first year of survey for the species and no spawning site was located, however the presence of a range of age classes suggests that in previous years spawning in the site was successful.

The report follows the 3 part structure set out in the proposal.

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Background to project

Allis shad (*Alosa alosa*) is a designated feature of the Plymouth Sound and Estuaries Special Area of Conservation (SAC). Cucumber smelt (*Osmerus eperlanus*) is a designated feature of the Tamar Estuary Sites Marine Conservation Zone (MCZ) which overlaps with the SAC. Both species are poorly researched within the site and as a result Natural England commissioned research into their condition and distribution to meet the following three areas of interest:

1. Monitoring of Allis shad within Plymouth Sound and Estuaries SAC.
2. Monitoring of smelt within Tamar Estuary Sites MCZ.
3. Survey/review of seasonal distribution of smelt and Allis shad within Plymouth Marine Protected Areas.

This report follows these three parts.

1 Part 1. Monitoring of allis shad within Plymouth Sound and Estuaries SAC. Juvenile density; the 2015 spawning distribution of allis shad in the Tamar and Lynher estuaries; and 2015 adult run size of allis shad at Gunnislake Weir

1.1 Introduction

Allis shad (*Alosa alosa*) are coastal in habit and occur throughout Europe, migrating into freshwater to spawn. In recent years their abundance has declined significantly throughout their geographical range primarily due to pollution, over-exploitation, habitat destruction/degradation or the construction of migratory barriers such as weirs or dams (Aprahamian *et al*., 2003; ICES, 2015). Allis shad are listed on Appendix III of the Bern Convention and Annexes II and V of the EC Habitats Directive. Allis shad is also protected under Schedule 5 of the Wildlife and Countryside Act (WCA) 1981.

The Tamar estuary and river represents the only known spawning location of allis shad in the UK (Hillman, 2003). Allis shad eggs were first recorded in the upper Tamar estuary in 2000 and have been recorded every year between 2000 and 2014 at a single spawning site in the upper Tamar Estuary and tend to spawn on the Tamar between May and July. In 2005 and 2006 allis shad eggs were recorded in the freshwater Tamar between Blanchdown and Gunnislake, but eggs have only been recorded twice from the freshwater River Tamar upstream of Gunnislake Weir (see Appendix 8.1 on page 98, below for a map of locations mentioned here). Between 2000 and 2014, allis shad have been recorded migrating upstream in relatively small numbers into the freshwater Tamar at Gunnislake Fish Pass and Trap, located at the tidal limit of the River Tamar with most records in May and June. Anglers and commercial netsmen regularly catch allis shad in the Tamar estuary and occasionally from the freshwater Tamar; catches are typically between May and July.

1.2 Objectives

A full survey of the Tamar and Lynher rivers was requested by NE to determine the spawning distribution of allis shad in 2015. Although allis shad have been proven to spawn every year at a site in the upper Tamar Estuary (Hillman, *pers. obs*.), the extent to which allis shad spawn in the freshwater Tamar or other rivers such as the Lynher is not known.

The juvenile density in the Tamar Estuary is unknown; NE requested monitoring of juvenile allis shad with the purpose of setting a catch per unit effort target for the site.

Also, to determine the adult run size based upon individuals recorded migrating upstream at Gunnislake Fish Trap and Fish Pass. This monitoring used bycatch data from EA monitoring of salmon and sea trout. Additional targeted monitoring of camera footage collected from Gunnislake Fish Pass was used to assess shad migration outside of trapping periods.

1.3 Methods

1.3.1 Trawling for larvae and juveniles

The Common Standards Monitoring Freshwater Fauna Guidance for Shad, based upon Hillman *et al*., (2003), describes micromesh seine netting as the preferred method for monitoring juvenile shad. However, due to difficulties gaining access from the river bank and a lack of information on the timing and location of juvenile shad within the estuary, and following advice from Paul Dando (*pers. comm.*) boat-towed plankton nets were the chosen sampling method. Sampling for larvae and juvenile shad took place on 24 Jul 2015 from EA's vessel SCATHROS, which was launched and recovered from the slipway at Cotehele House. The skipper was Alan Cole (EA) and the others on board were Rob Hillman and Paul Elsmere (EA) and Stephen Cotterell and Liam Faisey (MBA). Sampling commenced as far up the river as was practicable but away from the weirs at Cottage Run. The plankton net with 750µm cod end net was laced to a 1m diameter, circular, stainless steel net ring, towed on a 3-point bridle (length = 3m). A 5m polypropylene (floating) snag-line with a 15cm float was rigged to allow recovery if the net became fouled or the tow line parted. In order to keep the net vertical in the water, avoid it hitting the river bottom (contaminating the sample or damaging the net) a hard plastic trawl float with 15kg of lift was fitted to the top of the net ring. This was balanced by 5 or 10kg of chain fitted to the bottom of the net ring so that by paying out the tow line it was possible to tow the plankton net at or just below the surface, where most fish were expected. A flowmeter (General Oceanics INC, mechanical #2030R with standard rotors) was prepared and fitted according to manufacturer recommendations to the mouth of the net (Figure 1).

Figure 1. Plankton net laced to a 1m diameter circular, stainless steel net ring. Also shown are the 3 bridles, the top float (that would be situated outside the net), the lower weight and the mechanical flowmeter.

Two complete sets of plankton sampling nets were taken with the intention to operate using overlapping tows however, in practise it was safer and easier to stop, haul up the gear and log the necessary data; time, elapsed time, location (as National Grid Reference) environmental data (surface temperature and salinity and bottom values where the river was a little deeper, such that bottom values might yield different values, using a YSI Sonde), record flowmeter revolutions and approximate speed and average water depth. Next, the 750µm cod end was exchanged and the gear re-deployed for the next tow so that sample processing did not hinder fishing. As both wind and water speed due to tide or river flow were low repositioning the boat was rarely necessary and could be achieved from landmarks if required.

The tow line was paid out over the bow of SCATHROS and the vessel operated astern to avoid entanglement and because it is generally much easier to sample this way from small boats. Sampling was nominally for 10 minutes but natural breaks (for example obstructions or changes in river colour) were used as cues to begin a fresh sample.

Samples were rinsed into appropriately-sized containers before excess water was removed through a 500µm mesh. Sample preservation was by irrigation with 100% Industrial Methylated Spirit, which was replaced with fresh media the following day. All sampling work was carried out under licence L/2015/00003/3 of Wildlife and Countryside Act (1981) as amended.

No plankton sampling with MBA Sepia was undertaken.

1.3.2 Kick-sampling for eggs to assess spawning distribution

A water quality multi-parameter monitoring sonde, located at the tidal limit of the Tamar, was used to monitor water temperature in the river. When temperatures approached 15^{o}C (past experience on the Tamar indicates that this is when shad tend to spawn) egg surveys commenced, starting at the Cottage Run established spawning site in the tidal Tamar.

Other intended triggers that were used to determine the timing of the egg surveys were catching of adult allis shad in Gunnislake Fish Trap and catches by anglers and commercial netsmen; unfortunately no allis shad were recorded in Gunnislake Trap in 2015. Egg surveys were targeted during high pressure weather periods when flows were low and the river was not turbid: being able to see the river bed is part of the risk assessment for undertaking kick samples so turbid water conditions are avoided. Based upon experience of surveying for allis shad eggs on the River Tamar between 2000 and 2015, shad spawning appears to be triggered by warm conditions between mid-May and July (Hillman, pers. obs.). Once eggs were recorded at Cottage Run, surveys commenced in the freshwater Tamar and on the River Lynher.

The spawning distribution of allis shad was determined by kick-sampling for shad eggs, as recommended in the Common Standards Monitoring Guidance for Shad, based upon Hillman *et al*., (2003). A long-handled 800µn mesh kick-sampling net was used. 10 minute egg surveys (20 x 30 second kick samples) were undertaken by EA staff with support from NE staff and a student from Exeter University at weekly intervals at Cottage Run (more than this would disturb eggs to an unacceptable level), and other known spawning sites at Simon's Pool riffle and two sites at Blanchdown. Sampling was undertaken at a 90^{o} angle to the bank moving across the channel to survey a range of flow velocities; this is to ensure that all velocities are sampled as shad eggs can settle in a narrow band of 1-2m between marginal slack water and the faster current of the main channel.

Kick sampling was targeted downstream of suitable riffle spawning areas (Figure 2). Caswell and Aprahamian (2001) found that the spawning habitat of twaite shad was associated with fast-flowing shallow areas of unconsolidated gravel/pebble and/or cobble substrate. The River Habitat Survey (Raven *et al*., 1997) high energy flow types 'rippled flow' and 'unbroken standing waves' were significantly associated with the presence of eggs, and the absence of eggs was associated with the lower energy flow type 'smooth flow'. Table 2 describes the flow types at the Tamar and Lynher egg survey sites; the following definitions can be applied. Riffle features are characterised by predominantly unbroken standing wave flow type; rippled flow is mostly associated with runs; and smooth flow is mostly associated with glides (Anon, 2003).

Figure 2. Cottage Run Weir (foreground) and riffle downstream, adjacent to gravel bar.

A stopwatch was used during the kick sampling surveys to standardise the time spent sampling for eggs. This ensured that the time spent finding eggs within the net sample was not included in the kick-sampling effort time, as the sample processing time will vary between samplers depending upon past experience and samples, depending upon the size of the sample and the number of eggs found.

When surveying for shad eggs the priority on the freshwater Tamar was downstream of Duchess Weir, a significant weir at Lamerhooe. Egg surveys were undertaken on the Lynher at a representative selection of suitable habitat from the upper estuary into freshwater. It is likely that there is more spawning habitat available to shad on the Lynher, making potential sites spread out over a long stretch of river.

Using a standard recording form (see Figure 43, in Appendix 8.5 on page 105 below) the following was recorded; the number of nets used (usually one or two as more than this could cause an impact upon the spawning site), date, start and finish times, number of eggs recorded, condition of the eggs (fresh, developing larvae visible, opaque etc.), mean depth at location of egg presence, flow type at site of egg survey, flow type upstream, substrate at site of egg survey, substrate upstream at perceived spawning site, (see Table 1 and Table 2 for kick sample locations and their physical characteristics).

Table 1. The location of kick sampling sites visited in 2015.

Catchment	Survey site	Site number	Estuary / River	NGR
Tamar	Lower Cottage	T1	Estuary	SX4346070537
Tamar	Cottage Run	T2	Estuary	SX4354370832
Tamar	Riffle downstream Simon's Pool	T3	River	SX4362972640
Tamar	Blanchdown	T4	River	SX4364672765
Tamar	Blanchdown Fishing Croy	T5	River	SX4346972764
Lynher	Notter Bridge	L1	Estuary	SX3844460820
Lynher	Collapsed Weir Upstream Notter Bridge	L2	River	SX3834461353
Lynher	Pillaton Bridge	L3	River	SX3656963148
Lynher	Downstream of Clapper Weir	L4	River	SX3556264858
Lynher	Downstream Newbridge	L5	River	SX3473967926

Table 2. The physical characteristics of the survey sites.

Site number	Flow type at survey site	Flow type upstream	Substrate at survey site	Substrate upstream
T1	Run	Riffle	Cobble	Cobble
T2	Run/Riffle/Glide	Riffle	Gravel/Pebble	Cobble
T3	Run/Riffle	Riffle	Cobble	Cobble/Boulder
T4	Run/Riffle	Riffle	Gravel/Pebble	Pebble/Cobble
T5	Run/Glide	Run	Cobble	Cobble
L1	Run/Glide	Riffle	Gravel/Pebble	Pebble
L2	Riffle/Run	Riffle	Gravel/Pebble	Pebble/Cobble
L3	Run	Riffle	Bedrock/Gravel	Pebble/Cobble
L4	Run/Riffle	Riffle	Gravel/Pebble	Pebble/Cobble
L5	Run	Riffle	Gravel/Pebble	Pebble/Cobble

1.3.3 Review of Gunnislake Fish Pass camera footage to assess adult run size via upstream migration of allis shad into the River Tamar at the tidal limit

1.3.3.1 General method for review of fish counter camera footage

An overhead camera (3.6mm Aquacam, RF Concepts) mounted at a 60^{o} angle in the Cornwall Fish Pass at Gunnislake Weir, records footage of fish migrating (up and downstream) over the electrodes of the resistivity fish counter, which is located in the base of the fish pass. Camera footage is routinely collected during the main salmon and sea trout migration months of May to August inclusive. Infra-red lights (Bosch UFLED30-8BD, 850nm

LED IR illuminator) mounted above the fish pass enable footage to be collected during hours of darkness. The camera footage is stored on hardware located in the trapping hut (SuperDVR 4 channel video capture card (Voltek - PC based DVR system). The data is collected on a hard drive (FREECOM 1TB Toughdrive) and archived separately (diskAshur DT 2 TB iStorage).

The resistivity fish counter (Aquantic Logie C) records fish as they swim over the electrodes, generating a time record of each fish recorded. As the fish swim over the electrodes a deflection value is recorded; this is the degree to which the electrical field is disturbed and is generally proportional to the size of the fish (although species, flow, water temperature and depth in the water column relative to the electrodes also influence the deflection size). The fish counter compares the pattern of the disturbance to the electrical field to a pre-programmed algorithm and splits counts into upstream, downstream or event (uncertain). Associated with each count is a graph of the electronic trace, created as the fish swims over the electrodes; this trace data, which is used by the fish counter to determine if the count is upstream, downstream or uncertain (event), is also viewed by a monitoring officer to determine if the record is a fish or some other object such as debris washed downstream.

A proportion of the upstream counts are checked each month during the May to August period. A laptop or desktop PC with the Virtual Dub software programme installed is used to view the camera footage associated with individual electronic counts recorded by the fish counter. The camera footage is viewed at 15 frames per second, which speeds up viewing, whilst allowing fish to be seen on the screen. The viewer navigates to the camera footage corresponding to the time of the fish counter record; this may differ by a small interval due to differences between the fish counter clock and the camera clock. The size of each fish is measured on the screen. Because specific hardware is used to view the camera footage, the screen size itself remains constant. The image on the screen is always zoomed within the Virtual Dub software to 200%.

Depending upon the location of the fish on the electrodes when this measurement is taken (for example, between the top and middle electrode, lower and middle electrode or straddling the middle electrode) the length of the fish is calculated from the screen length by using conversion factors of the known distances between each electrode. Average distances are used from one side of the fish pass to the other.

Certain species are recognisable due to their body size and shape, and behaviour; sea lamprey for example, can swim upstream without stopping or attach onto the floor of the fish pass and move up in phases. Allis shad tend to be recognisable by their very thin body profile (when viewed from above) and deeply forked tail; however, sea trout and salmon can resemble allis shad but tend to be broader in profile.

In addition to checking the species and size of fish seen on camera footage by using the fish counter data, a proportion of the camera footage is also ‘blind watched’; this involves watching the camera footage without using the fish counter data to locate fish on the camera footage. Blind watching enables an assessment of the degree to which the fish counter fails to detect fish as they migrate over the electrodes. It provides assurance that the proportion of fish detected by the fish counter is within an acceptable limit. There is no formal target detection rate for fish counter monitoring but Gunnislake Fish Counter is operated with a target of 80% detection or above.

1.3.3.2 Method used to record allis shad on camera footage

Records of shad migrating upstream at Gunnislake Fish Pass and Trap generally span the period of late April to July. Within this period, blind watching and review of fish counter events was undertaken.

Shad were identified from the thin body profile, deeply-forked tail, difficulty in swimming upstream against the current (often resulting in a sinuous body shape when viewed from above) and body size (which was compared to the known size range in body length of allis shad caught in Gunnislake Trap during the period 2004-2013.

In addition to the routine camera footage reviewed in May, June, July and August (Table 3), additional effort was put into checking the fish counter camera footage in the period immediately after the sluice gate was fixed (1 July to 5 July 2015). This was done to check that the unusually low flows (due to the leaking sluice gate) had not prevented allis shad from migrating upstream, having observed a large number of eggs downstream of Gunnislake Weir on 1 July.

Table 3. The number of hours of camera footage reviewed and the number of fish counter counts checked for allis shad.

Period	Trace-validated fish counter counts (upstream counts and events) checked on camera. (Upstream only in brackets)	Hours of camera footage blind watched
28-30 Apr	108 (10)	3
1 May-31 May	2394 (405)	56
1 Jun-30 Jun	1810 (496)	22.5
1 Jul-31 Jul	4732 (398)	88.5
1 Aug- 31 Aug	6427 (333)	154.5

1.4 Results

1.4.1 Trawling for larvae and juveniles

25 plankton samples were taken on 24 Jul 2015. No allis shad larvae or juveniles were caught. However, some juvenile smelt were found in the samples. See Section 2.3.3.2 starting on page 34 and Table 16 in Appendix 8.3 on page 100, (below).

1.4.2 Kick-sampling for eggs to assess spawning distribution

Ten sites were surveyed for allis shad eggs between the 18 May and 3 July 2015 (Table 1). Eggs were found at one survey site in the upper Tamar estuary at Cottage Run, which is 250-350m downstream of Gunnislake Weir. No eggs were found at any of the sites on the River Lynher, upper Lynher estuary or freshwater Tamar in 2015, thus these sites have not been mapped separately using GIS though they are contained in the electronic appendix 'DASSHSE00000030_AS-01.xlsx'.

Allis shad eggs were found at depths of 25 to 50cm in a relatively narrow band at the edge of the main flow; it is presumed that the eggs came out of suspension and settled on the river bed (Table 4).

Figure 3 shows the catch per unit effort of shad eggs in relation to date, river flow and water temperature. Shad eggs were first found on 28 May, albeit in very low numbers. Higher numbers of eggs were found on the 8 and 17 June (24 and 14, or 1.2 and 0.7 eggs per sample, respectively). Spawning continued throughout June with low numbers of eggs found on the 26 June (Table 5). The main spawning event appeared to have taken place at the end of June; a survey on 1 July recorded 119 shad eggs, equivalent to 4.3 eggs per sample. The last date that allis shad eggs were found at Cottage Run was on the final survey date on 3 July.

Table 4. Water depth at site T2 in relation to CPUE on 18 June 2015.

Sample Number	Depth (m)	Number of eggs found
1	0.40	0
2	0.40	3
3	0.30	0
4	0.35	0
5	0.35	1
6	0.30	1
7	0.25	0
8	0.25	1
9	0.30	0
10	0.40	4
11	0.45	3
12	0.50	1
13	0.50	3
14	0.50	2
15	0.50	0
16	0.50	3
17	0.50	1
18	0.50	1
19	0.50	0
20	0.50	0

Table 5. The catch per unit effort (eggs per 30-second sample) of allis shad eggs at 10 survey sites on the Tamar and Lynher catchments.

Date	Mean CPUE (eggs per sample) at survey sites									
	T1	**T2**	**T3**	**T4**	**T5**	**L1**	**L2**	**L3**	**L4**	**L5**
18 May 2015		0								
28 May 2015		0.1								
8 Jun 2015		1.2								
9 Jun 2015			0	0	0					
17 Jun 2015	0	0.7	0	0						
18 Jun 2015						0	0	0	0	0
26 Jun 2015		0.2								
1 Jul 2015		4.3								
3 Jul 2015		0.3				0			0	0

Blank cells denote no survey on that date

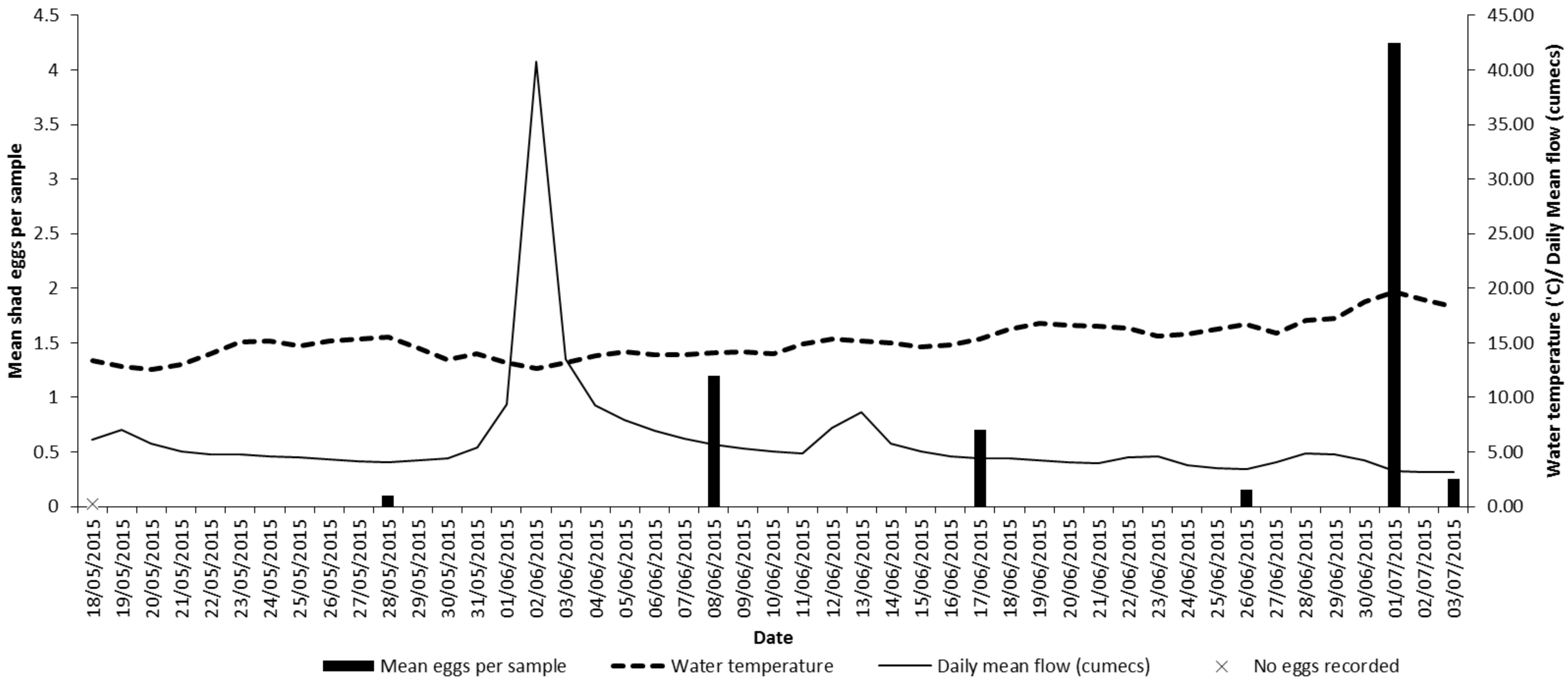

Figure 3. The catch per unit effort of shad eggs (eggs per 30-second sample) at Cottage Run (Site T2), in relation to river water temperature and daily mean river flow at Gunnislake Gauging Station. (Note: the flow through the fish pass and trap was considerably lower than that indicated on this graph due a failed sluice gate at Gunnislake Weir Canal. Almost all of the river flow went down this route during the allis shad spawning period in 2015).

1.4.3 Review of Gunnislake Fish Pass camera footage to assess upstream migration of allis shad into the River Tamar

No allis shad were seen migrating upstream at Gunnislake Fish Pass in 2015. Two fish were observed that resembled shad on the 3 and 4 July 2015. However, the total body length of these two fish was estimated at below 30cm which means that they were likely to be small sea trout (of which there are many migrating upstream at that time of year). The smallest allis shad recorded at Gunnislake Trap to date measured 37.0cm fork length (equivalent to 42.0cm total length). Therefore it is reasonable to expect any shad seen on camera footage to be at least 40cm or larger.

1.5 Discussion

1.5.1 Trawling for larvae and juveniles

The towed plankton net targeted a range of depths in the mid-channel across a range of water salinity, albeit on one sampling date. Future sampling could also target juvenile allis shad close to the banks (though river debris may prove to be a significant problem) and over a wider time period. During their period in the estuary juveniles tend to be found at the surface and close inshore (Taverny, 1991). Castelnaud *et al*., (2001), cited in Aprahamian *et al*., 2003) reported the juveniles to be ~ 10 times more abundant in the surface layers compared with samples taken 0.2 m above the bottom.

Lochet *et al.*, (2009) undertook monthly sampling of juvenile allis shad on the Gironde system at four transects in the mesohaline and oligohaline estuarine zones; each transect consisted of one station close to each bank and one in the middle axis of the estuary and recorded the peak arrival of allis shad juveniles in the estuary during August and September (aged 88 days). These shad stayed a relatively short time in the estuary (11 days) before exiting to the sea. Although the Tamar estuary (at ~30km) is relatively short compared to the Gironde estuary of ~70km the allis shad spawning grounds are many kilometres above the tidal limit so it seems reasonable to expect that young-of-the-year allis shad juveniles might be present in the upper and middle Tamar estuary at a similar time of year. Future monitoring could continue later into the year to ensure sampling of the whole seaward migration period.

Lochet *et al*., (2009) reported catching allis shad juveniles at low density on the Gironde system (at the peak month of arrival in the estuary 0.2 to 3.0 fish per 1000m^3 of water sampled). Lower juvenile densities might be expected on the Tamar, where fewer adult allis shad are reported compared to the Gironde, and future sampling might anticipate and be predicated on potentially low juvenile density.

Allis shad juveniles have not been recorded to date from the Tamar Estuary, making it difficult to determine the probable timing of their seaward migration and location within the estuary. Therefore, it is not possible to draw conclusions about the Tamar allis shad population from the lack of allis shad juveniles recorded in this study. Whilst future monitoring could target the estuary margins as well as the mid-channel and monitoring could be undertaken over a wider timescale at a range of locations within the estuary, samplers should be prepared to spend considerable time and resources undertaking sample analysis due to the high volume of non-target fauna in the estuary, most notably mysid shrimp.

1.5.2 Adult run and spawning distribution

The flows at Gunnislake Weir and Cornwall Fish Pass and Trap were significantly reduced in 2015 due to a leaking sluice gate at the downstream end of Gunnislake canal. Nearly all of the river flow in the River Tamar passed down the canal and under/through the sluice gates. However, this route was not accessible to fish migrating upstream. The river stopped flowing over Gunnislake Weir and lower than usual flows were running through Cornwall Fish Pass and Trap. The sluice gate was not repaired until 1 July 2015.

No shad were recorded all season migrating upstream via Gunnislake Fish Trap and no eggs were found in kick-sampling surveys at sites in the River Tamar. Furthermore, no shad were observed on camera footage from Gunnislake Fish Pass. Flows in the fish pass were very low in 2015 and it is likely that they were too low, either to attract shad or to enable shad to migrate upstream via the shallow flow in the fish pass. Therefore, the lack of adult shad recorded migrating upstream at Gunnislake Fish Trap (and lack of shad eggs recorded in freshwater) does not necessarily indicate a poor year for shad or a deterioration in adult shad numbers compared to previous years as shad may have spawned downstream of the weir.

River flows at Gunnislake Gauging Station from the beginning of May to the end of June 2015 were much lower than the average for this time of year. An analysis of the May and June flows on days when the trap was operating between 2004 and 2013 showed an average of 9.4 cumecs; the mean flow for the same period in 2015 was 5.8 cumecs but the flow going through the fish pass and over the weir was considerably less than this because most of the flow went under the leaking sluice gates in the bypass channel. For much of the May and June 2015 shad migration period Gunnislake Weir crest had no flow passing over it at all and the flow in the Cornwall fish pass was estimated to be less than one cumec. In conclusion, the low flows in the fish pass probably posed a migratory barrier to allis shad as the water was too shallow to permit upstream migration (either physically or behaviourally due to the lack of laminar flow preferred by shad).

The methods used worked well. Kick-sampling was successful at Cottage Run and the lack of eggs recorded at other survey sites reflects a lack of eggs rather than a shortfall of the method. Gunnislake Fish Trap has caught allis shad on many previous occasions and shad have been observed migrating upstream at Gunnislake Fish Pass. The methods for recording adult allis shad were not considered to be the reason for a lack of adult allis shad recorded in 2015; as discussed above, the most likely explanation for the lack of adults recorded was the low flows observed through the fish pass and trap.

1.5.3 Timing of spawning at Cottage Run

The timing of allis shad spawning in 2015 generally coincided with previous years observations; spawning began in late May and continued throughout June, with large numbers of eggs recorded relatively late in the season on 1 July. River temperatures in 2015 were above average (compared to 2000-2014) during May but cooler than average during

June; between 27 June and 1 July water temperatures rose rapidly from 15.9 to 19.7°C and remained warmer than average throughout July. This rapid rise in water temperature at the end of June/beginning of July appears to have triggered a significant spawning event; over 100 eggs were recorded at Cottage Run on the 1 July survey (refer to Figure 3).

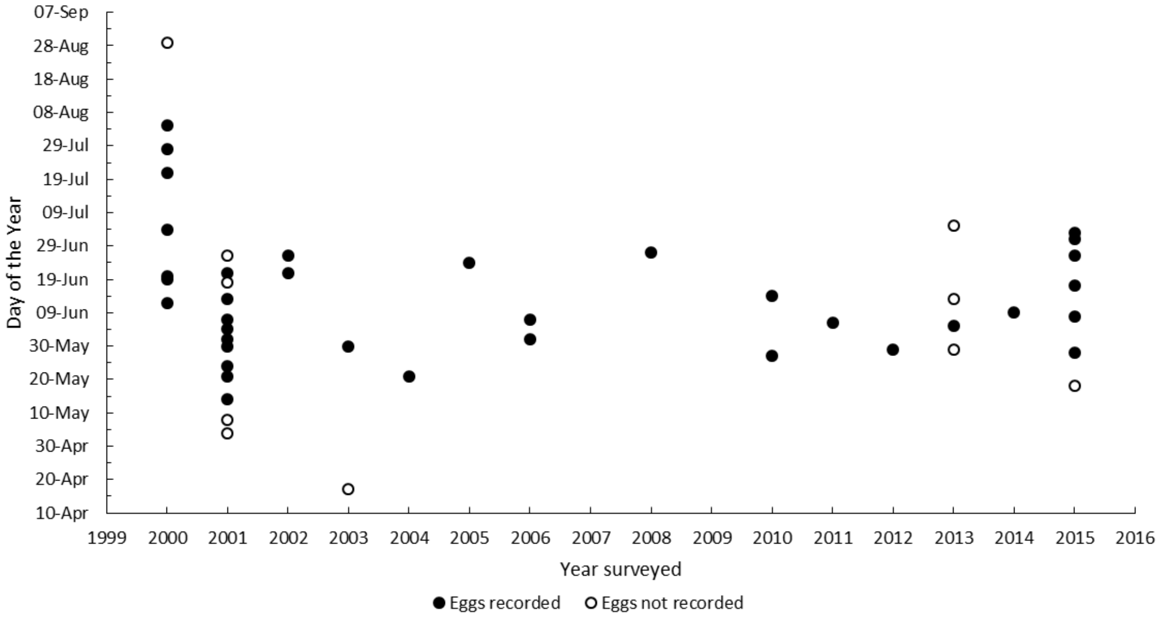

Figure 4. The timing of allis shad egg surveys at Cottage Run and the presence or absence of eggs.

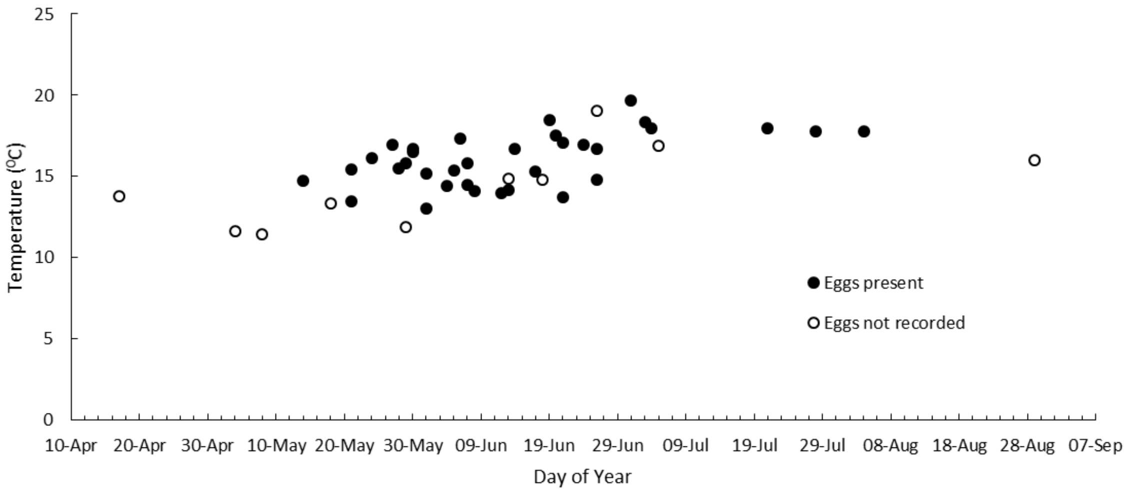

Figure 5. The presence or absence of allis shad eggs at Cottage Run between 2000 and 2015 in relation to day or year and water temperature.

Shad egg surveys have not routinely been carried out as late as July in previous years, with survey emphasis placed on confirming that allis shad have spawned within that year. 2000 was the only year in which egg surveys continued throughout July into August and eggs were recorded on 4 August 2000. It is possible that the allis shad spawning season on the

Tamar continues later into the year than Figure 4 and Figure 5 would suggest, as egg surveys undertaken between 2000 and 2015 have tended to cease before the eggs have disappeared from Cottage Run. As in 2015, a relatively cool June could delay the main spawning period until July or August.

Allis shad eggs have been recorded at Cottage Run when water temperature has been in the range 13.0 to 19.7^{o}C (Figure 5). As in late June 2015, a significant increase in water temperature appears to trigger allis shad spawning.

1.5.4 Water Quality

There appears to be a strong preference by allis shad for the River Tamar over other rivers draining to the same estuary. The Tavy estuary has a weir and fish pass at the tidal limit that is probably impassable to allis shad; also there is no apparent spawning habitat below this weir. Furthermore, the Tavy estuary is very short compared to the Tamar and Lynher with saline penetration right up to the weir. It is not possible to say with any degree of certainty whether shad would spawn further up the Tavy estuary if Lopwell Weir did not obstruct migratory access. However, given the similarity between the Lynher and Tavy catchments in that they are relatively steep gradient rivers draining acidic moorland habitat, it would be expected that the water chemistry and temperature of the Tavy to be more similar to the Lynher than the Tamar. The apparent lack of an allis shad run on the Lynher therefore suggests that the Tavy would not represent favourable habitat.

The Lynher offers free migratory access to allis shad and several kilometres of good spawning habitat, yet there is only one record of an allis shad being caught from the River Lynher. By comparison there are over 200 records of allis shad from the Tamar estuary and river, despite a series of challenging migratory barriers to allis shad on the River Tamar starting at Gunnislake Weir. Water quality differences between these two rivers may explain the disparity in allis shad spawning distribution between the Tamar and Lynher, although it is unclear which particular element of the River Lynher water quality that deters allis shad.

Table 6 summarises the water quality data for three sites on the lower River Tamar and two on the lower River Lynher. The Lynher, which drains from Bodmin Moor in the headwaters, is slightly more acidic than the Tamar with a lower conductivity and hardness than the Tamar. The water temperature of the two rivers also appears to differ, with the mean May-July Tamar temperature 1.4^{o}C warmer than the Lynher. This may be a key factor for allis shad as warm water temperatures are favourable for successful incubation of eggs and rapid development of larvae.

Interestingly, the mining legacy of the lower River Tamar causes elevated concentrations of certain metals; copper concentrations on the lower River Tamar for example are slightly higher than on the lower River Lynher. Perhaps because the adults spend little time in freshwater during the spawning run, this is not cause enough to deter allis shad.

Table 6. Water quality (January 2000 to August 2015) in the River Tamar and River Lynher.

Site	Mean pH	Mean conductivity	Mean May-July temperature	Mean hardness (mg/l CaCO3)	Mean Cu (µg/l) filtered (max)	Mean Zn (µg/l) (max)	Ortho-phosphate (mg/l)
Tamar, Gunnislake Bridge	7.6	188.5 (129-234)	15.2 (10.4-20.1)	60.5 (38.7-77.8)	10.8 (30.2)	17.6 (107.0)	0.06 (0.02-0.18)
Tamar, Gunnislake Gauging Station	7.6	-	-	70.0 (39.5-72.1)	8.1 (46.9)	14.7 (44.7)	0.06 (0.02-0.13)
Tamar, Horsebridge	7.6	-	-	60.2 (38.6-72.7)	2.1 (3.4)	13.2 (74.3)	0.06 (0.02-0.14)
Lynher, Notter Bridge	7.5	149.9 (84-184)	13.8 (9.7-18.1)	46.1 (31.5-54.8)	6.9 (11.7)	31.3 (80.3)	0.06 (0.01-0.34)
Lynher, Pillaton Bridge	7.5	-	-	42.1 (29.3-48.1)	7.9 (20.9)	38.2 (81.2)	0.07 (0.02-0.47)

2 Part 2. Monitoring of smelt within the Tamar Estuary MCZ

2.1 Introduction

Smelt (*Osmerus eperlanus)*, also known as sparling, is a euryhaline fish species mainly found in estuaries. They migrate into the freshwater upper-reaches of rivers in large shoals during the early spring; usually just upstream of the zone of saline influence (Colclough and Coates, 2013). Smelt are an interest feature of the Tamar Estuary Sites Marine Conservation Zone though the status of this geographically isolated UK population is largely unknown and has not been studied since the 1970s. The nearest known smelt populations are the Poole Harbour/Frome/Piddle complex to the east and to the north, the Rivers Nyfer (Nevern) and Conwy in north-west Wales (Colclough and Coates, 2013). Smelt generally appear to be more abundant in rivers of eastern England, north Wales and Scotland. Little is known of the location of spawning sites, the spawning stock and the timing of the spawning migration on the Tamar.

Paul Dando studied Tamar smelt populations in the 1970s and has advised the authors on likely timing and location of smelt spawning and appropriate survey methods. More recently, Hillman (2016) sampled smelt on the middle Tamar Estuary by seine netting in February 2015; although 31 individual smelt were caught during this monitoring, the size range based upon Power and Attrill (2007) suggests that they were less than a year old and therefore not part of the spawning stock. Six smelt measuring 71-170mm were caught on 29 October 2003 in beam trawls at Warren Point in the lower Tamar Estuary; based upon Power and Attrill (2007) these fish are likely to be from the 0+ and 1+ age classes. Boom boat electric fishing surveys undertaken on 12 December 2012 at South Hooe and 21 November 2013 at North Hooe each produced a single smelt measuring 250mm and 150mm respectively; these fish are likely to belong to the 2+/3+ and 1+ age classes, respectively.

In the winter months leading up to and prior to spawning, smelt are reported to accumulate in the middle and upper estuary (Maitland, 2003). Lyle and Maitland, (1997) report that on the River Cree (Dumfries and Galloway, Scotland), smelt first appear in the lower river near the spawning grounds during January and the estimated spawning period for smelt, based upon other populations is February/March, depending upon water temperature. On the River Cree, the spawning runs have started in early March when the water temperature exceeds 5^{o}C (Hutchinson and Mills, 1987). Also, that the spawning period lasts for around one week. Colclough and Coates, (2013) observed spawning to take place on the Thames at 10^{o}C and that the temperature threshold for the smelt spawning appears to vary from estuary to estuary. Spawning usually takes place at night with the eggs adhering to gravel, stone and soft vegetation such as *Fontinalis*, as available (Colclough and Coates, 2013).

The smelt was adopted under the UK Biodiversity Action Plan (UK BAP) as a Priority Species in 2007.

2.2 Objectives

- To monitor smelt within the Tamar Estuary Sites MCZ to allow Natural England to develop an understanding of the condition of this species within the area.
- To initiate and develop a monitoring programme for smelt including spawning distribution, juvenile density and distribution and adult population size.

2.3 Smelt spawning sites and timing of spawning

The monitoring described here was undertaken by the Environment Agency in collaboration with the MBA. The objective of the monitoring was to identify spawning sites in the Tamar Estuary MCZ, identify the timing of spawning and pioneer fyke netting as a method of collecting information on the spawning stock. The survey locations and methods were chosen following discussions with and advice from Paul Dando (*pers. comm.*).

2.3.1.1 Survey location

Based upon advice from Paul Dando (*pers. comm.*) who monitored smelt on the Tamar in the 1970s the spawning grounds of smelt were thought to be in the upper Tamar Estuary downstream of Gunnislake Weir. Dando recorded smelt eggs in the 1970s at two spawning sites in the vicinity of Cottage Run, downstream of a weir at the head of Cottage Run. Smelt are known to spawn in the upper estuary but can also utilise freshwater for spawning in large clean rivers (Etheridge, 2010). Etheridge (2010) reported smelt on the River Cree spawning in freshwater; however, since smelt have never been recorded in Gunnislake Fish Trap in 10 years of monitoring, it is concluded that the spawning grounds are probably downstream of the tidal limit.

The focus of monitoring for smelt eggs was therefore the upper Tamar Estuary downstream of Gunnislake Weir to Impham Meadows, in shallow, fast-flowing water over boulder/cobble substrate. Downstream of Impham the estuary is deep and muddy and offers very limited access for surveys on foot. Egg surveys were undertaken at all sites with gravel/cobble/boulder substrate in the channel margins between Impham and Gunnislake Weir, although suitable spawning sites were limited to just three sites, of which only two were accessible on smaller tides due to a weir at the head of Cottage Run.

One of these sites immediately downstream of the weir at the head of Cottage Run is where Dando recorded smelt spawning in the 1970s. Sampling was not possible at a second survey site where Dando recorded smelt eggs, as during the survey window this was inaccessible due to deep water; it was not considered to be suitable for smelt spawning in 2016 due to water depth and a silty substrate.

Two sites were surveyed for eggs on the Lynher Estuary at and immediately above the tidal limit. The Lynher Estuary was surveyed after eggs had been found on the Tamar.

Fyke netting was undertaken on the inside of a meander bend at Impham Meadows (SX4346770546). This site was downstream of the two spawning sites identified by Dando in the 1970s.

2.3.2 Methods

2.3.2.1 Egg surveys

Using river water temperature, as measured at Gunnislake Weir by a continuous water quality monitoring probe, egg surveys commenced when water temperatures exceeded 6^{o}C and continued at a rate of approximately one visit per week; Maitland and Lyle (2001) did not observe smelt spawning on the River Cree at river temperatures below 6^{o}C.

To identify the location and timing of smelt distribution, surveys for smelt eggs were undertaken along 50m sections of the shoreline of the upper estuary, or as long as possible where less than 50m of suitable habitat was available. Sampling for eggs involved a visual inspection of marginal wetted pebbles/cobbles/boulders at each site by lifting them out of water and making a thorough examination. Particular attention was given to substrate with attached vegetation as smelt eggs tend to adhere to vegetation. At least one cobble per 5m of riverbank was examined and the number of eggs on each stone was recorded. This provided a catch per unit effort of eggs per stone examined.

Egg surveys were always undertaken at low water. An inspection of vegetation and boulders above the waterline was also made at survey sites with observations of dead eggs recorded.

Two people undertook egg surveys along the wetted margin of the estuary, ensuring they surveyed together so as not to double-count the same pieces of substrate.

Eggs were identified on the basis of their size, colour, the presence of oil globules and the parachute-like structure that attaches the egg to the channel substrate.

Eggs found on the 18 March and 6 April were collected and photographed in the laboratory using a camera-mounted microscope. This was to confirm identification and identify the development stage and therefore likely spawning date of the eggs. The development stage of the smelt eggs was estimated by EA staff (Rob Hillman) and confirmed by Paul Dando (MBA) using a guide (Gorodilov *et al*, 2006). Based upon the water temperature, we were able to estimate the likely spawning date based upon the egg development stage.

Surveyors looked out for spent smelt carcasses which could be collected for genetics and age estimation from scale-reading. Observations of predators would have been noted as per Etheridge (2011), although on the Tamar none were seen.

2.3.2.2 Trawling for larvae and juveniles

The survey methods used to trawl for larval and juvenile smelt are presented in Section 1.3.1 (starting on page 14, above) because the same trawl surveys targeted allis shad and smelt.

2.3.2.3 Fyke netting

We used a pair of 5m fyke nets joined with a central leader section of 10m in length (Figure 6). One fyke net fished the flood tide and the other fished during the ebb. The net aperture was a D-shaped frame, 1m deep and 1m along the straight (bottom) edge. The fyke net mesh size was 20mm with 10mm mesh in the cod-end. Nets were fitted with otter guards and EA contact details. The nets were set at an angle of approximately twenty degrees to the Devon bank with the upstream end at the edge of the wetted channel and the downstream end further out in the channel.

Fyke nets were set in late afternoon or early evening at low water with the aim of fishing the flood tide overnight or during darkness hours. The fykes were set at the margin of the upper estuary out of the main flow. High flow conditions were avoided for health and safety reasons, ease of anchoring the equipment and expected avoidance behaviour of smelt. The flow was noted during an initial visit to the proposed fyke-netting site on 25 January 2016 at which point the river level was deemed safe to survey; we ensured that the flow did not exceed this level when the fyke netting took place. The nets were recovered either late in the evening or at first light to process the catch. Care was taken to set the nets in water deep enough to ensure that the catch was kept submerged at low water.

Figure 6. Fyke nets deployed at Impham Meadow 25 February 2016.

To prevent the net from rolling with the tide/flow, heavy metal weights were used to weigh down the entrance to the fyke. Stones were also used to add additional weight and also to secure the central section to the bed and prevent fish from swimming underneath this section. A heavy anchor was used at each cod-end of the fyke net to secure the fyke to the river bed and a grapnel-style anchor was used at the downstream end to provide good anchorage in the higher flow of the channel. Ropes were used to ensure that in the event of the fyke net anchors being washed out, the fyke net remained at the survey site and could be recovered at low water.

The fyke netting site was accessed via the Devon Bank Forestry track from Gunnislake Bridge and was set by wading from the bank in late afternoon or early evening in the estuary margins.

After a long period of high flows in February, the first fyke netting date of 25 February was selected, based upon water temperature meeting threshold and flows having dropped to approximately 21 cumecs. Subsequently, we used the presence of eggs in the upper Tamar Estuary to initiate fyke netting.

All smelt caught were measured, weighed, sexed, a scale sample taken (to enable the fish to be aged) and then released. Sex was determined by applying gentle pressure to the abdomen, with males identified from the release of milt and females from the release of eggs. Smelt were processed without anaesthesia. Prior to release, fish were allowed to recover in fresh river water (an aerator and bin were on hand in the event of large catches). Other fish species caught in the fykes were identified and a fork length measurement taken.

We did not catch smelt in large numbers in 2016 but in the event of large catches we had planned to release fish as soon as possible to avoid mortalities. Sub-sampling would have taken place to collect data on only a small proportion of the catch.

2.3.3 Results

2.3.3.1 Egg surveys

Eggs were not found on the Lynher Estuary. On the Tamar a small number of smelt eggs were located at Cottage Run (Site T2) and one egg found at Impham Meadow (T1) (Table 7).

Table 7. Location, timing and results of smelt egg surveys on the Lynher and Tamar Estuaries

Estuary	Site	NGR	Date range (2016)	Number of surveys	Surveys eggs found	Number of live eggs
Lynher	L1. Notter Bridge	SX3847260856	18 Mar	1	0	0
Lynher	L2. Hales Wood	SX3841861219	18 Mar	1	0	0
Tamar	T1. Impham Meadow	SX4347770546	5 Feb - 21 Apr	8	1	1
Tamar	T2. Cottage Run	SX4361470935	5 Feb - 21 Apr	7	3	11
Tamar	T3. Gunnislake Island	SX4366371033	18 Mar	1	0	0
Tamar	T4. First Run	SX4378571097	5 Feb - 18 Mar	4	0	0

Table 8 shows the timing of surveys and the catch rate of live smelt eggs at Cottage Run.

Table 8. Results from egg surveys at Cottage Run, Tamar Estuary.

Date	Cobbles examined	Live eggs found	CPUE (Eggs per cobble)	Comment
05 Feb 2016	15	0	0.00	
10 Feb 2016	15	0	0.00	
23 Feb 2016	15	0	0.00	
07 Mar 2016	15	0	0.00	5 dead eggs found above the waterline
16 Mar 2016	15	2	0.13	~25 dead eggs above waterline
18 Mar 2016	50	7	0.14	~25 dead eggs above waterline
06 Apr 2016	33	1	0.03	5 dead eggs found above the waterline
14 Apr 2016	48	0	0.00	4 dead eggs found on river substrate
21 Apr 2016	35	0	0.00	

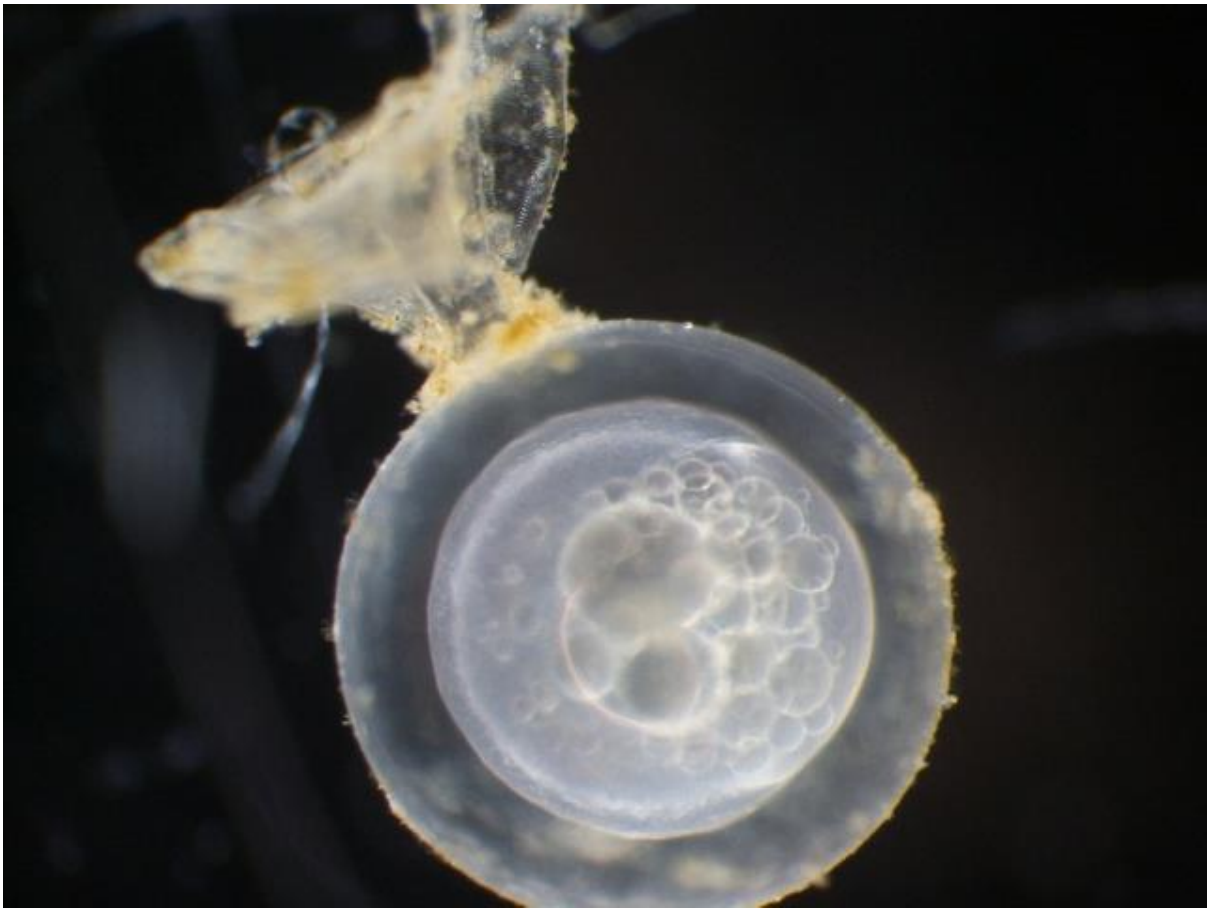

Figure 7. Photograph of a smelt egg collected from Cottage Run in 2016 showing oil globules and attachment structure.

2.3.3.2 Trawling for larvae and juveniles

25 plankton samples were taken on 24 Jul 2015. The catch data is shown in Table 16, Appendix 8.3 on page 100 (below). Probably owing to an error in communication there is a

mistake in the NGR positions for haul 03. There is also a slight projection offset in this raster chart segment (Ch0871 part2) however, it is probably rarely used for navigation and did not affect positional accuracy here.

The upper reaches of the river were clear and dark in colour; containing freshwater. Smelt first appeared at haul station 19 around Okeltor Boathouse, upstream of Calstock, (Figure 8). Numbers gradually increased in the stretch past Calstock and Cotehele (Figure 9) and salinity values were also increasing however, sampling had to stop as the tide was by now ebbing quickly and the bottom of the slipway was becoming exposed necessitating the recovery of the boat.

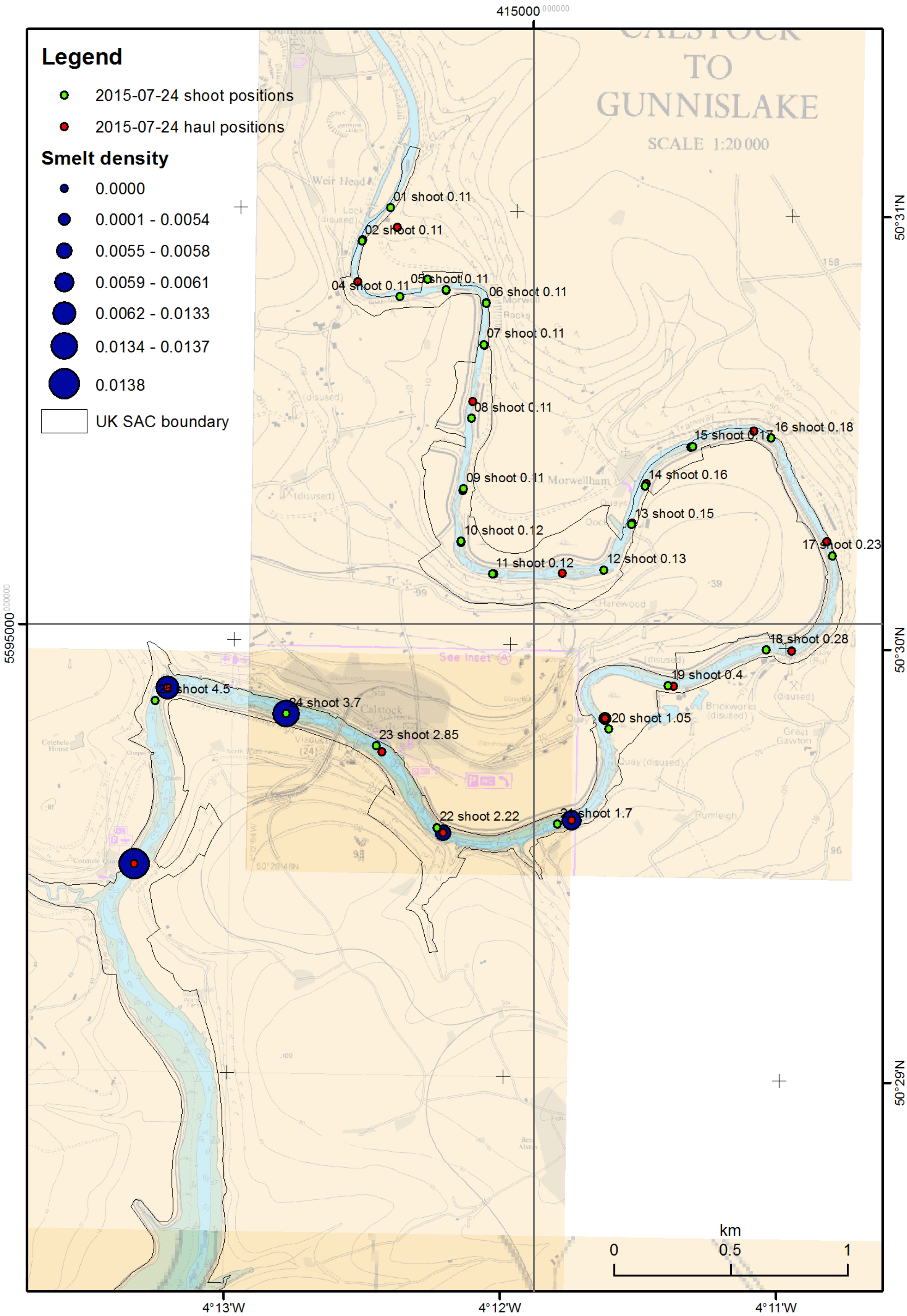

Figure 8. Shoot and haul positions from P01 plankton trawl trip 01 on 24 Jul 2015. Also shown is the density of juvenile smelt (number per m^3) at relevant haul locations. The shoot labels also show surface salinity.

Figure 9. Example of relatively large plankton sample from near Calstock on 24 Jul 2015 (left) and a juvenile smelt (right) amid smaller fish and other plankton.

2.3.3.3 Fyke netting

Table 9 shows the catch of smelt from fyke netting. Five smelt were caught from two fyke netting surveys in spawning condition (Table 10 and Figure 10).

Table 9. The results from three fyke-netting surveys at Impham Meadow, Tamar Estuary.

Date fyke net set	Start netting time	End netting time	Hrs:mins fished	HW time (Cargreen)	Smelt caught	Upstream fyke	Down-stream fyke	Comments
25 Feb 2016	16:40	22:30	04:50	19:35	0	0	0	
15 Mar 2016	16:30	06:45	14:15	22:40	3	2	1	
16 Mar 2016	18:00	07:50	13:50	23:50	2	1	1	One sea lamprey caught

Table 10. The biological measurements from 5 smelt in spawning condition caught in a fyke net at Impham Meadow, Tamar Estuary.

Survey date	Fork length (mm)	Total length (mm)	Weight (g)	Sex
15 Mar 2016	200	214	68	M
15 Mar 2016	195	210	66	F
15 Mar 2016	188	204	48	M
16 Mar 2016	184	202	60	F
16 Mar 2016	174	187	40	F

Figure 10. Smelt in spawning condition caught fyke netting on 15 March 2016.

2.3.4 Discussion

2.3.4.1 Location of spawning sites

On the Tamar eggs were recorded at Cottage Run, although very small numbers of eggs were found here compared with observations of 400 eggs per square metre by Paul Dando in 1975 (Dando, *pers. comm*.). Furthermore, when examined under a microscope, the development stage of eggs found on each egg survey varied suggesting multiple spawning dates. We did not record large numbers of smelt eggs at any of the survey sites, on any of the survey dates; had smelt spawned at a site within the three weeks prior to the survey, large numbers of eggs would have been expected. This suggests that either the main spawning run did not occur within the egg survey window of 5 February to 21 April 2016, or more probably, that spawning occurred further down the estuary, possibly due to high flows recorded during most of February.

P. Dando (*pers. comm*.) observed eggs being transported on the tide and it is possible that the small number of eggs found below the weir at Cottage Run (and the single egg found at Impham Meadow) were deposited by the flooding tide. However, the catch of 5 adult smelt in spawning condition over two consecutive nights on the 15 and 16 March 2016 tends to suggest that smelt migrated into the upper estuary to spawn somewhere in the vicinity of

Impham Meadow. Alternatively, these fish were searching for a suitable spawning site but did not spawn in the area.

2.3.4.2 Timing of spawning migration

Based upon egg surveys between 5 February and 21 April 2016 and fyke netting on three occasions during February and March 2016 we were able to estimate spawning dates of smelt using the egg development stage (Gorodilov *et al.*, 2006). Based upon egg surveys up to 6 April 2016, the observed egg development stages suggests that spawning occurred at or around 7-10 March, 14-16 March, 25-27 March and 2 April 2016. The spawning in early March is likely to have been on or before the 7 March rather than the 8-10 March, as there was a large spate on 8 March and flows exceeded 76 cumecs. Furthermore, the times of high water on the 9 and 10 March did not offer a spawning opportunity under cover of darkness and as such were probably unsuitable. Dead smelt eggs were found in vegetation above the waterline immediately below the Cottage Run Weir on 7 March, which also suggests spawning in the preceding days.

It is possible that a significant smelt spawning event occurred between egg surveys on 18 March and 6 April 2016. A small number of eggs were found on 18 March (estimated to be from a range of spawning dates), after which a spate on 27 March 2016 could have washed out any eggs that were deposited. However, the period between 23 and 26 March may have been unsuitable for smelt spawning as the time of morning and evening high water fell during daylight hours. This would have left a relatively small window between 18 and 23 March 2016, and it is unlikely that smelt would have spawned in the upper Tamar only during that period.

Observations suggest that spawning occurred over a period of weeks during March and at least early April; there is no evidence from egg or fyke-netting surveys of spawning having taken place during February 2016, although a small number of dead eggs were found on 6 and 14 April. No eggs at all were found on the 21 April. During late March and throughout April 2016, a film of diatom growth developed on the river substrate at sites in the upper Tamar Estuary. By 21 April this growth was significant. It is possible that during late March and April smelt were deterred from spawning in the upper estuary where diatom growth was significant, due to the smothering impact this would have on developing smelt eggs.

Numerous smelt caught on otter-trawling surveys at Braunder Wood and Halton Quay on 14 March 2016, were observed to have red marks around the vent which further suggests that recent spawning had occurred.

2.3.4.3 Environmental conditions associated with smelt spawning

Figure 13 (page 42, below) shows the flow, water temperature, lunar phase and timing of high water with respect to darkness hours. The flow during February 2016 almost certainly prevented smelt spawning in the upper reaches of the Tamar Estuary until the end of the month; flow remained above 20 cumecs until the 27 February 2016 when it remained so for a 3 day period before increasing again. Water temperature was relatively cool (mean 6.4^{o}C) during the period of 27-29 February and this was not long after the full moon, so either water temperature or light conditions may have been unfavourable for spawning at the end of February.

The exact limit of flow for smelt to be able to spawn in the upper Tamar Estuary is unknown, but P. Dando reported the mean flow range for smelt over 5 spawning events in the 1970s to be between 11.3 and 18.8 cumecs (Dando, *pers. comm*.). During March 2016 the flow dropped below 20 cumecs on the 3 March, 5 to 8 March and 12 to 26 March. This roughly corresponds to the estimated spawning dates, extrapolated from the development stages of eggs recorded at Cottage Run (see Table 7). Therefore, flow seems to have been the limiting factor for smelt spawning in 2016 (see Figure 11).

Figure 11. The weir at the head of Cottage Run is a migratory barrier to smelt except at high water on spring tides.

It is unclear why smelt did not spawn in March in any great numbers (based upon the small number of eggs recorded) in the upper Tamar Estuary between Impham Meadow and Cottage Run, after the flows had dropped to low levels. It is possible that spawning had already happened somewhere further down the estuary by the time that flows had reached an acceptable level in early to mid-March. However, the red-vent fish state observed during otter-trawling and fyke-netting observations tend to suggest that spawning had occurred during early to mid-March 2016. For most of March 2016 flows were below 20 cumecs and appeared to offer smelt spawning opportunities in the upper Tamar Estuary. The flow was 16.6 and 15.2 cumecs on 15 and 16 March 2016, when smelt were caught in a fyke net at Impham Meadow, which confirms that smelt could physically access the upper Tamar Estuary at these flow rates. Water temperature during March ranged from 6.0^{o}C to 9.0^{o}C (Mean 7.7^{o}C) which is within the reported range for smelt spawning. It is also unlikely that lunar phase, darkness of nights or tidal height would prevent spawning in the upper Tamar Estuary over such a wide time range.

P. Dando (*pers. comm*.) inspected the Cottage Run former smelt spawning site on 14 April 2016 and observed that the substrate had become coarser than during the 1970s, when the site substrate was predominantly gravel, pebble and cobble. Now, the substrate below the weir at Cottage Run is dominated by boulders, except for a discrete patch of gravel/pebble near the Cornwall Bank, downstream of Cottage Run Weir (Figure 12). This spawning area may now be less attractive to smelt than in the 1970s due to a lack of suitable spawning substrate. The reasons for this apparent change in river substrate are unclear; dredging of channel material upstream or a change in flow regime since the 1970s could be contributing factors. P. Dando also confirmed that the substrate in the estuary at Impham Meadow looked ideal for smelt spawning but numerous egg surveys at this site failed to detect more than a single smelt egg.

Figure 12. Apparently former smelt spawning site downstream of Cottage Run Weir.

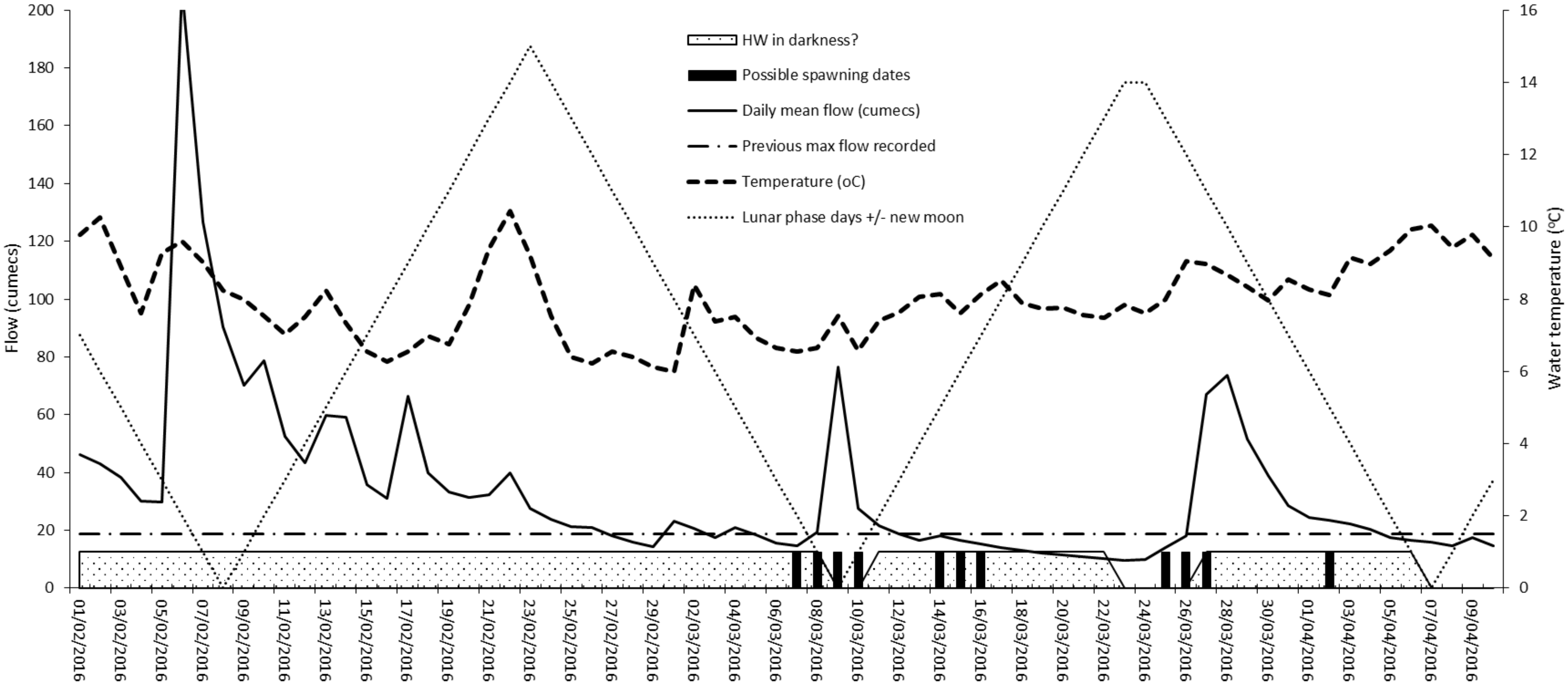

Figure 13. Environmental conditions between 1 February 2016 and 10 April 2016.

Note: the dot dash line shows the maximum flow (18.8 cumecs) recorded by Paul Dando (*pers.comm.*) on 5 previous spawning dates in the 1970s. The shaded area represents periods when at least one HW was in darkness; the gaps represent periods when the morning and evening were during daylight hours. The dotted line represents the number of days (0-15) from the new moon. The bars represent possible spawning dates in 2016 based upon fyke netting results and the development stage of eggs collected on 18 March and 6 April which was correlated to likely spawning date based upon the prevailing water temperature.

2.4 Seasonal distribution of adult smelt within the estuary

2.4.1 Introduction

The survey work described here was undertaken by the Marine Biological Association with the assistance of the Environment Agency and personnel from Natural England. The objective was to understand where and when smelt were found and the associated environmental conditions with the available resources. Sampling methods were discussed with Paul Dando (*pers. comm.*) and the seagoing group at the MBA, especially Roger Pawley (SPEIA's skipper) and Aisling Smith (SEPIA's, manager).

2.4.2 Methods

Beam and otter trawl surveys were carried out from RV MBA SEPIA, which is a multipurpose 15.4m research vessel that is well suited to operating throughout the navigable areas of the Tamar due to her shallow draft (1.35m) and ability to operate a variety of sampling gears. Chosen for this work were:

- 4m light **beam** trawl with 90/50 diamond mesh, a 20mm cod end mesh and an inner cod end of 5mm mesh (Figure 14, top). This gear has the advantages that it could be deployed in the much narrower and more restrictive upper parts of the river and deployed and recovered quickly. This beam trawl is towed from two points (using two warps) so with little warp out it is manageable, remains close to the towing boat and has a light footprint and it remains a light fishing gear even in deeper water when more warp is paid out on deployment. Also, if this gear becomes snagged (on an underwater obstruction for example) it can normally be repaired quite quickly. Its disadvantages include a limited headline height (approximately 0.7m) that means it is less likely to catch target species where these are off the substrate and up in the water column, which is possible for the species of interest. It is also a small fishing gear and therefore less-suited to locations where the river is large or deep.
- 8 fathom light demersal '**otter**' trawl (Figure 14, bottom) with 114/90/60/40mm net meshes and a 20mm mesh cod end without a fine cover. This gear is a smaller version of the MBA's 'inshore' trawl and has the advantage of a much higher headline height (approximately 2m), which could be increased further with additional flotation to target better the particular species of interest, though this may result in insufficient ground contact. Compared to the beam trawl, this otter trawl has a much larger width; thus it will filter a greater volume of water and it is therefore better in locations where it can be used. To minimise river bed disturbance the ground gear was roller discs on a single chain and light trawl doors were used. This gear is more time consuming to deploy (shoot) and recover (haul) than the beam trawl as many more steps are involved. It also requires more space as the towing vessel has to be moving forward before shooting and after hauling. It also works best when used in a straight line; changes of course due to the other vessels, moorings/obstructions or river meanders lead to sub-optimal sampling. These factors limit the area of operation of this gear to the lower reaches of the river and into the estuary.

Given the time and logistics required to change between these gears on board it was not possible to use both on a single day of sampling. Also, no plankton sampling for larvae or juveniles was undertaken although some smelt were sampled in the plankton tows (P01) on 24 Jul 2015; see Section 1.3.1 starting on page 14 and Section 1.4.1 starting on page 20.

Figure 14. Example fishing gear arrangements on RV MBA SEPIA. Top, rigged with the 4m beam trawl just before deployment. Bottom, hauling the 8 fathom otter trawl with the floats on the surface. Both show two sample processing stations, the top of the SVP pole arrangement and various tubs (see text for details).

Sets of trawls were run from the upper reaches of the Tamar towards the sea with each tow generally against the prevailing flow (where river or tidal influence was the strongest). As there were expectations that smelt may aggregate around the saltwater wedge of the estuary (Dando, *pers. comm.*), where salinity values change quickly over a relatively short distance, SEPIA proceeded above this with observations to note the colour of the river water and *ad hoc* dips for salinity until freshwater was reached. Earlier sets of trawls (e.g. T01 and T02) in the upper reaches of the Tamar (starting at Morwellham Quay) were conducted during spring high tides with later runs over neap high tides as it was preferable to complete sampling of the lower sections of the river (around West Mud) rather than to sample the highest reaches. The large flow of tidal water during spring tides made sampling lower stations more difficult and early morning daylight was limited, which made it difficult to get to the upper reaches of the river before the spring tides had begun to ebb.

Tow duration was nominally 10 minutes though on occasions ‘hitches’ where the gear came fast to underwater obstruction meant these were shorter. Some tows were longer where conditions allowed or where previous tows had yielded few fish.

An electronic log of tow number, time and positions of gear deployment (shooting) and retrieval (hauling) was maintained in the wheelhouse for later analysis.

At the end of each tow the catches from both normal and fine (where fitted) cod ends were emptied into separate water-filled tubs. The catch was then further divided into separate species and groups as appropriate in additional tubs. This process also removed debris such as leaves and twigs. SEPIA is fitted with an ambient water flow arrangement on port and starboard sides of the deck to refresh tubs and this system was used to maintain the divided catch in its best condition before and after sampling for length, weight etc. Generally starting with the largest fish, those of most interest or those known to be sensitive to handling, all fish were measured for total length (to the mm below) then returned to tubs with refreshed water. Some fish weights (to the gram below) were taken by calibrated spring balances, however, weighing small fish at sea or where there is a breeze generally leads to imprecise measurements and was not routine except for examples of particular interest. Some scale samples from smelt were taken for potential, later analysis. In order for the sampling to be as non-destructive as possible caught fish were returned to the river as soon after processing as possible, but not so they would be re-caught by the sampling gear. Also, fishes were not routinely sexed.

Salinity was calculated from measurements of speed of sound through water, pressure (depth) and water temperature, taken at 1 Hz using a Sound Velocity Profiler (Valeport Monitor, SVP) with internal data logging (also visualised on a PC running Valeport DataLog Express). The SVP was fitted to a survey pole (GeoAcoustics Ltd) with its probes submerged at a depth as close to 1m below the surface as possible; to be consistent across surveys and to minimise possible equipment damage. The SVP and PC clocks were set to GPS time with daylight saving where appropriate. Positional data for the SVP was derived from a handheld GPS (Garmin GPS76 in WAAS mode, also on local time), which was placed on Sepia’s deck winches for good satellite cover. This GPS was set to log every 10s.

The survey pole and SVP were swung into position when on station and strapped fore and aft to stay in place. It was raised during some transits (e.g. between Kingsmill Lake and West Mud) to allow a faster vessel speeds to be achieved.

Date-time strings of SVP data were downloaded on completion of each day's work as was data from the handheld GPS for *post hoc* analyses. Additional, salinity measurements were taken using a dipping probe (YSI Sonde) when time permitted and the vessel was stationary. Salinity values reported here are ratio values and are therefore dimensionless.

Due to the limited memory in the handheld GPS, on some occasions portions of the upper trawls were not available however, the salinity and water temperature data for these portions was reconstructed from the time interval between the gear deployment and recovery on the electronic wheelhouse log coupled with the same time section of the SVP data.

Positions of gear deployment (green) and recovery (red), vessel track (blue) and water temperature and derived salinity data from the SVP were plotted in ArcMap 10.3. For convenience and to show as much detail as practicable a colour ramp of seven colours was used for both temperature (blue = low to red = high) and salinity (green = low to red = high). The data were plotted using natural breaks and without normalisation. Both temperature and salinity were resolved at 2 decimal places.

Few length (L) to weight (W) conversions factors (for $W = aL^b$) for smelt could be found however two, Arkhiptseva (1956) and Berg (1962) are cited by FishBase (Frose and Pauly, 2015). Both are very similar; Arkhiptseva (1956) generated a = 0.00420 and b = 3.163 and Berg (1962) reports a = 0.00420 and b = 3.163 both with $r^2 = 0.998$. As slightly more metadata from Arkhiptseva (1956) is available these values were used. Both Arkhiptseva (1956) and Berg (1962) used fork length measurements while total length was gathered here so a conversion factor (based on morphometrics) of 0.914 was applied.

2.4.3 Results

2.4.3.1 Trawl samples with environmental data

Six separate fishing trips were completed (Table 11) comprising 55 tows; 32 with the beam trawl and 23 using the otter trawl occupying 47 people-days of fieldwork (see Table 15 in Appendix 8.2 on page 99 (below) for personnel). The first three of these trips were with the beam trawl on 06 Aug 2015 (T01, 11 contiguous hauls, Table 17 (Appendix 8.4, page 101), Figure 15 and Figure 16) and 03 Nov 2015 (T02, 11 contiguous hauls, Table 18 (Appendix 8.4, page 102), Figure 17 and Figure 18) between Morwellham Quay at the limit of navigable water and Pentillie Quay where the river opens out. After further discussions with the client the next sampling on 12 Jan 2016 (T03, 10 stratified replicate hauls, Table 19 (Appendix 8.4, page 103), Figure 19 and Figure 20) was between Halton Quay (lower area) and West Mud. The consecutive days of 12 and 13 Jan 2016 were used to test the efficacy of the two gears. Andrew Stanger from NE assisted on 12 Jan 2016 and was involved in the discussions following the next day's sampling, which led to a preference for the otter trawl to be used for the remainder of the sampling.

It had been hoped that this test could have been run during the December 2015 sampling period and SEPIA was booked and prepared for beam trawl sampling on 03 Dec 2015 and otter trawl sampling on 04 Dec 2015. However, on these days the river was closed for naval shipping movements and sampling was not possible.

Instead, the remainder of the sampling comprised three further trips using the otter trawl on 13 Jan 2016 (T04, 6 hauls, Table 20 (Appendix 8.4, page 103), Figure 21 and Figure 22), 16 Feb 2016 (T05, 9 hauls, Table 21 (Appendix 8.4, page 104), Figure 23 and Figure 24) and 14 Mar 2016 (T06, 8 hauls, Table 22 (Appendix 8.4, page 104), Figure 25 and Figure 26). These trips were all of stratified replicate sampling design making the best use of available time and tide between Halton Quay (lower) and West Mud. On 16 Feb 2016 (T05) some modifications in float arrangement were made to the trawl to attempt to minimise the volume of leaf and twig debris at some stations and on 14 Mar 2016 (T06) the first two tows were on the short straight north/south section of the river, north of the bend above Halton Quay, called HQ (upper).

Table 11. Fishing dates using MBA SEPIA including, trip numbers, gear, number of tows and start and finish locations. See Table 15 in Appendix 8.2 on page 99 (below) for personnel on board SEPIA).

Date	Trip	Gear	Number of tows	Start location	Finish location
06 Aug 2015	T01	Beam	11	Morwellham Quay	Pentillie Quay
03 Nov 2015	T02	Beam	11	Morwellham Quay	Pentillie Quay
12 Jan 2016	T03	Beam	10	Halton Quay (lower)	West Mud
13 Jan 2016	T04	Otter	6	Halton Quay (lower)	West Mud
16 Feb 2016	T05	Otter	9	Halton Quay (lower)	West Mud
14 Mar 2016	T06	Otter	8	Halton Quay (upper)	West Mud

Across the 55 tows (with a total time of 09:35:39 or 575.65 minutes) 3,132 individual fish were caught (and measured) from across 40 species (Table 12).

While no allis shad were found in any of these tows, 247 smelt were caught and measured for length and of these 101 were weighed across a range of sizes (see below). Smelt were present in all trips except T03 on 12 Jan 2016 and only 1 smelt was caught during T05 (on 16 Feb 2016) (Table 12). The greatest number (n=127) were caught during T06 on 14 Mar 2016.

When smelt were found they were always in the upper reaches of the Tamar; Figure 15, Figure 17, Figure 19, Figure 21, Figure 23 and Figure 25 for abundance (numbers per minute and temperature); Figure 16, Figure 18, Figure 20, Figure 22, Figure 24 and Figure 26 for cpue (catch per unit effort as weight (g) per minute) and salinity (dimensionless).

Table 12. Numbers and totals of individual fish by species (in alphabetical order by genus) and common name measured during the six trips along with tow durations; *Osmerus eperlanus* (smelt) is highlighted.

Trip		**T01**	**T02**	**T03**	**T04**	**T05**	**T06**	
Gear		**Beam trawl**			**Otter trawl**			
Date		**03 Aug 2015**	**03 Nov 2015**	**12 Jan 2016**	**13 Jan 2016**	**16 Feb 2016**	**14 Mar 2016**	**Totals**
Number of tows		**11**	**11**	**10**	**6**	**9**	**8**	
Total duration of tows	**(hh:mm:ss)**	**01:44:19**	**01:45:13**	**01:40:56**	**01:38:32**	**01:25:41**	**01:20:58**	**09:35:39**
	(mm:mm)	**104.32**	**105.22**	**100.93**	**98.53**	**85.68**	**80.97**	**575.65**
Species name	**Common name**							
Agonus cataphractus	pogge						3	3
Anguilla anguilla	eel	10	6				3	19
Atherina presbyter	sand smelt				11	8	47	66
Blicca bjoerkna	silver bream		1				1	2
Callionymus lyra	common dragonet			1	2		1	4
Chelon labrosus	thick-lipped mullet	1					3	4
Ciliata mustela	five-bearded rockling						1	1
Clupea harengus	herring			1	43	20	60	124
Dicentrachus labrax	bass	10	12	46	333	8	1,027	1,436
Gasterosteus aculeatus	three-spined stickleback	1						1
Gobius niger	black goby				1	3	3	7
Leuciscus leuciscus	dace		8					8
Limanda limanda	dab				1		2	3
Liza aurata	golden grey mullet						2	2
Liza ramada	thin-lipped grey mullet		1		3	1	25	30
Merlangius merlangus	whiting				5	18	12	35
Mullus surmuletus	red mullet				8	1	2	11
Osmerus eperlanus	**smelt**	**38**	**3**		**27**	**1**	**178**	**247**
Pagrus pagrus	Couch's bream				1			1
Petromyzon marinus	sea lamprey					1		1
Platichthys flesus	flounder	27	54	19	45	45	297	487
Pleuronectes platessa	plaice			10	12	3	18	43
Pollachius pollachius	pollock			1	4	1	7	13
Pomastoschistus microps	common goby		131	2	7	18	3	161
Pomastoschistus minutus	sand goby		12	2	25	1	2	42
Raja clavata	thornback ray			6	9	1	3	19
Rutilus rutilus	roach		2				3	5
Salmo salar	salmon		1					1
Salmo trutta	brown trout					1		1
Scophthalmus rhombus	brill						1	1
Scyliorhinus canicula	dogfish					1		1
Solea solea	sole	55		15	14	3	21	108
Sparus aurata	gilthead bream			1				1
Spondyliosoma cantharus	black seabream						4	4
Sprattus sprattus	sprat	3			89	58		150
Syngnathus acus	greater pipefish					1	1	2
Syngnathus typhle	deep-snouted pipefish				1			1
Trigla lucerna	tub gurnard				3			3
Trisopterus luscus	bib			1	6		1	8
Trisopterus minutus	poor cod			5	55	11	5	76
Total number		145	231	110	705	205	1,736	3,132

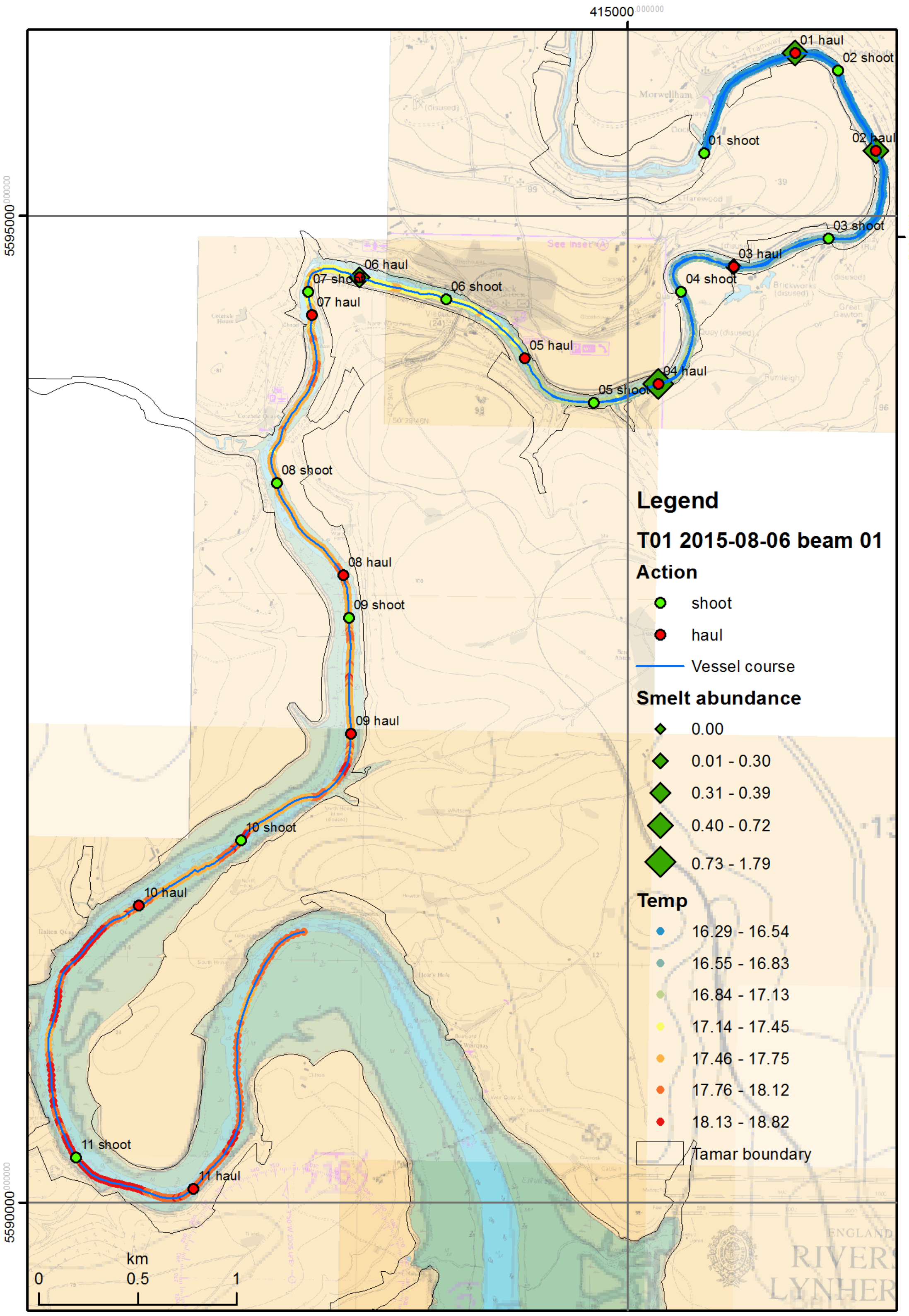

Figure 15. Shoot and haul positions and vessel track from T01 beam trawl trip 01 on 06 Aug 2015. Also shown are smelt abundances (number per minute, at haul position) and along track water temperature (from SVP).

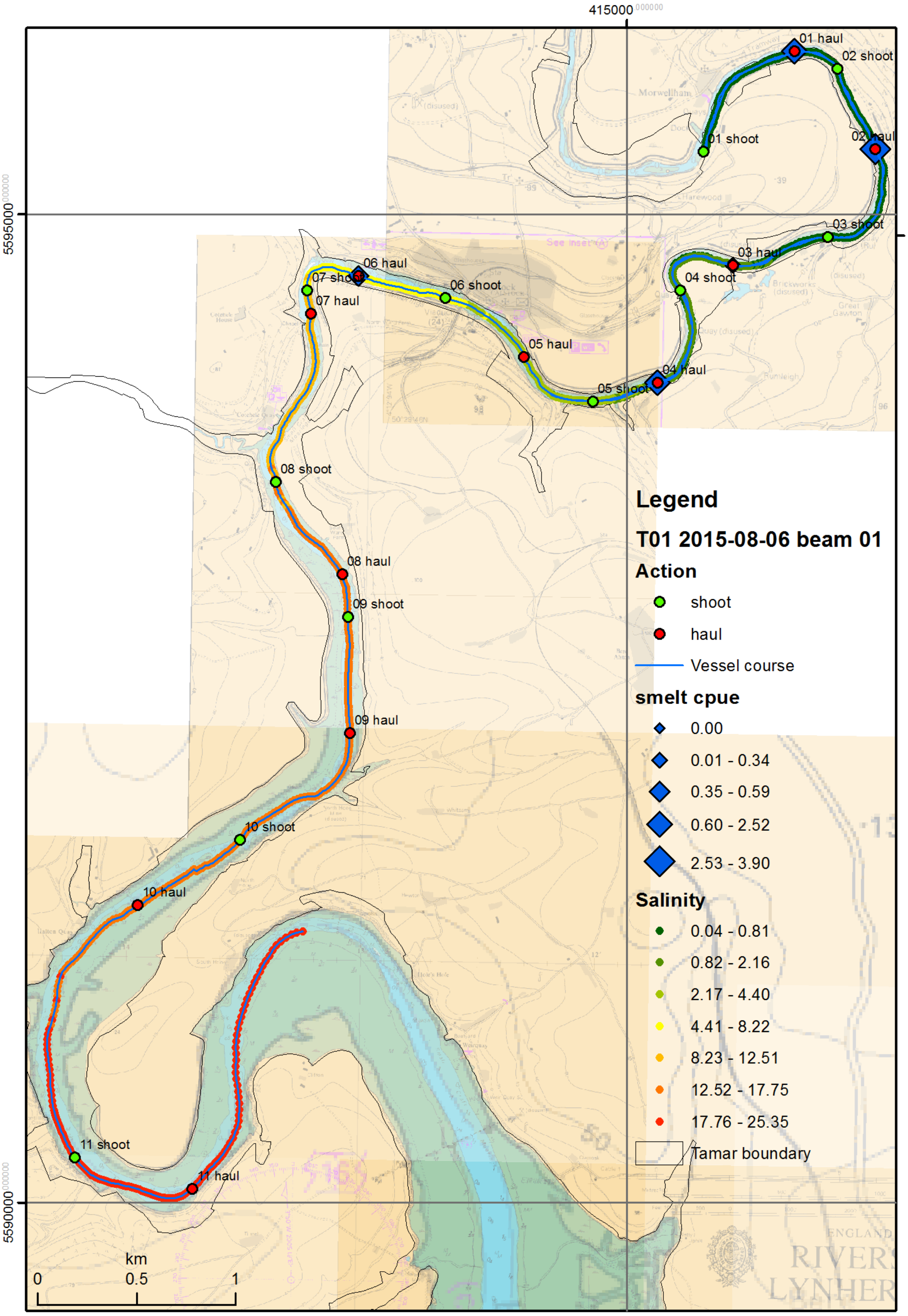

Figure 16. Shoot and haul positions and vessel track from T01 beam trawl trip 01 on 06 Aug 2015. Also shown are smelt cpue (weight (g) per minute, at haul position) and along track salinity (from SVP).

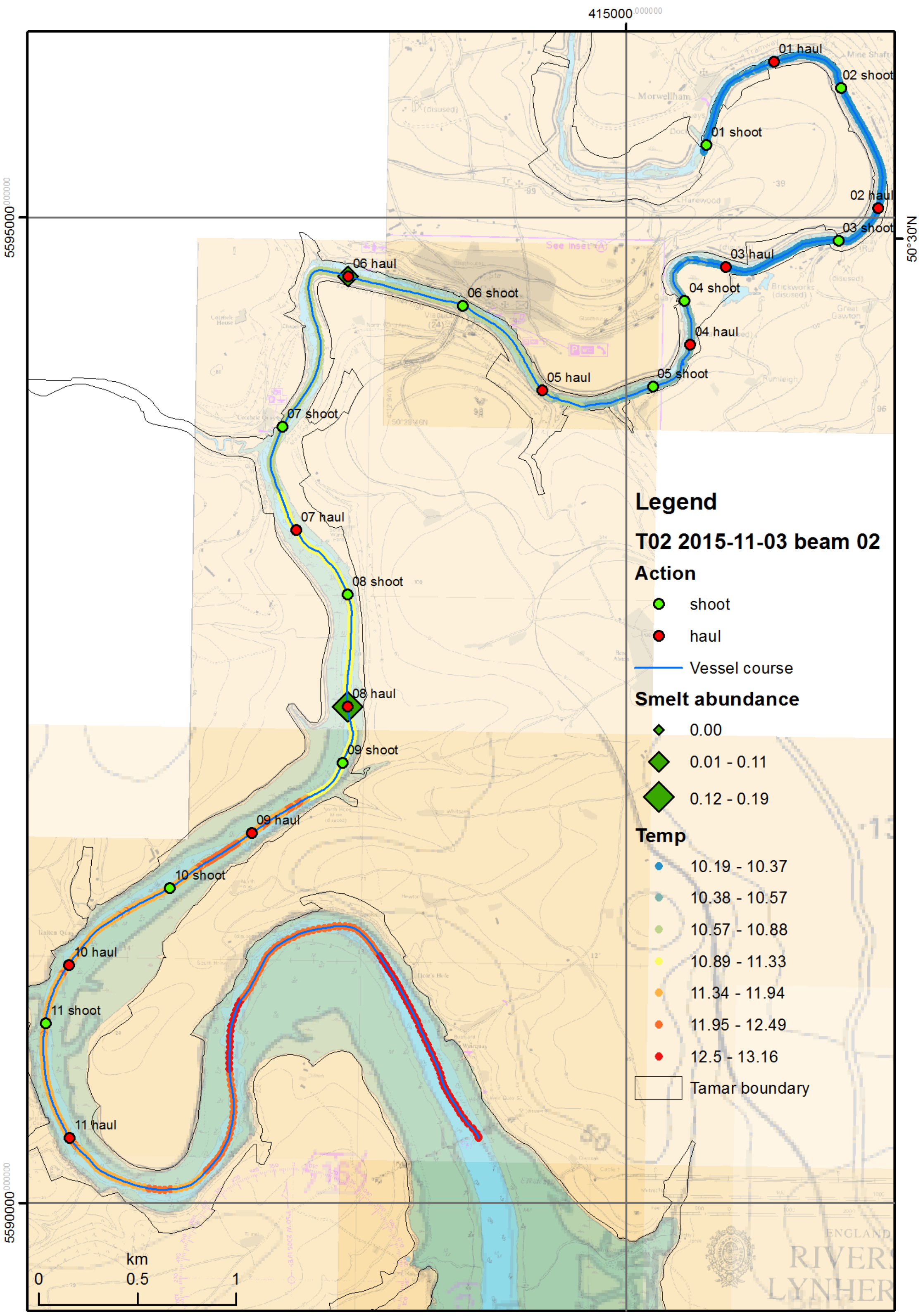

Figure 17. Shoot and haul positions and vessel track from T02 beam trawl trip 02 on 03 Nov 2015. Also shown are smelt abundances (number per minute, at haul position) and along track water temperature (from SVP).

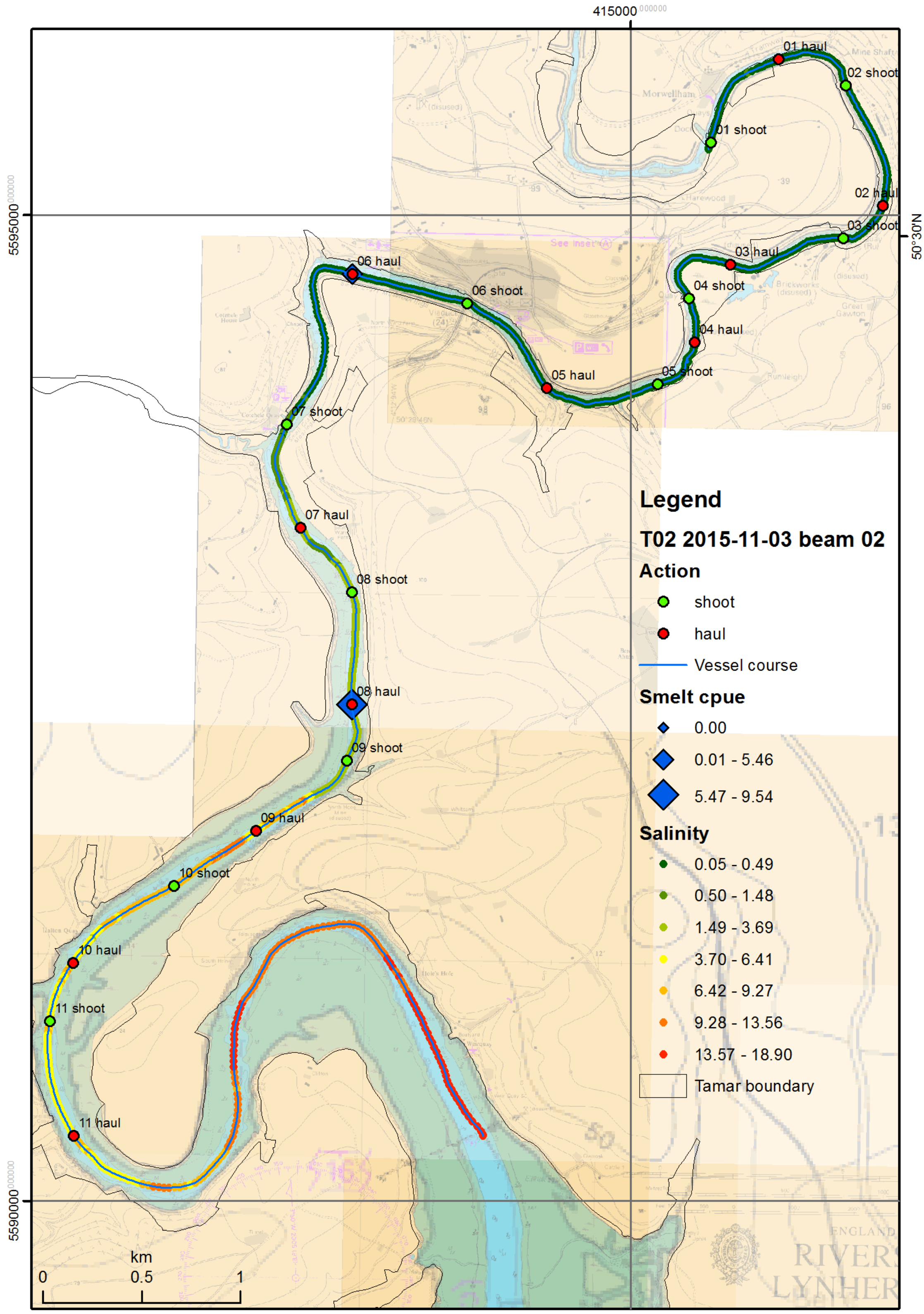

Figure 18. Shoot and haul positions and vessel track from T02 beam trawl trip 02 on 03 Nov 2015. Also shown are smelt cpue (weight (g) per minute, at haul position) and along track salinity (from SVP).

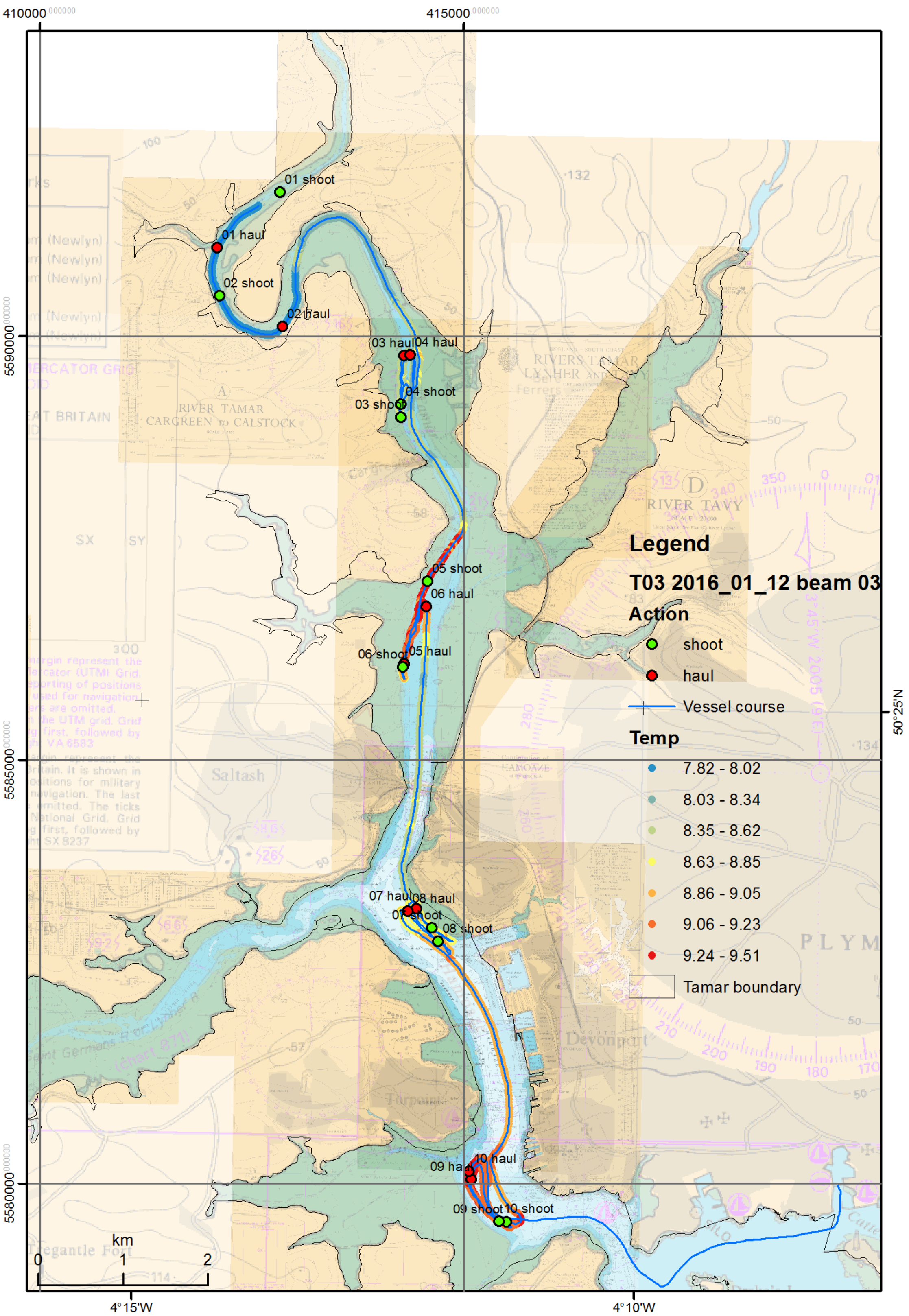

Figure 19. Shoot and haul positions and vessel track from T03 beam trawl trip 03 on 12 Jan 2016. Also shown are smelt abundances (number per minute, at haul position) and along track water temperature (from SVP).

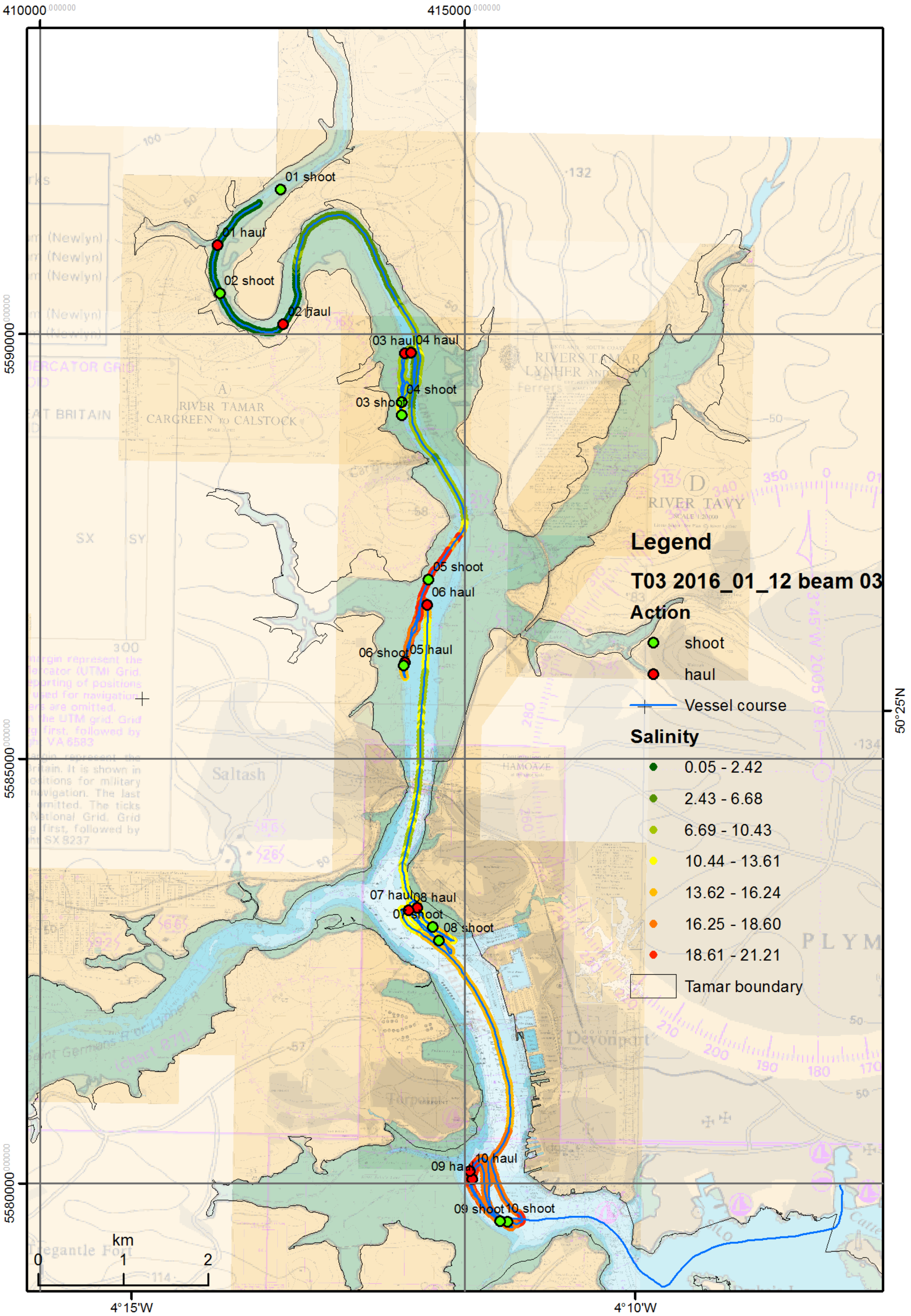

Figure 20. Shoot and haul positions and vessel track from T03 beam trawl trip 03 on 12 Jan 2016. Also shown are smelt abundances (weight (g) per minute, at haul position) and along track salinity (from SVP).

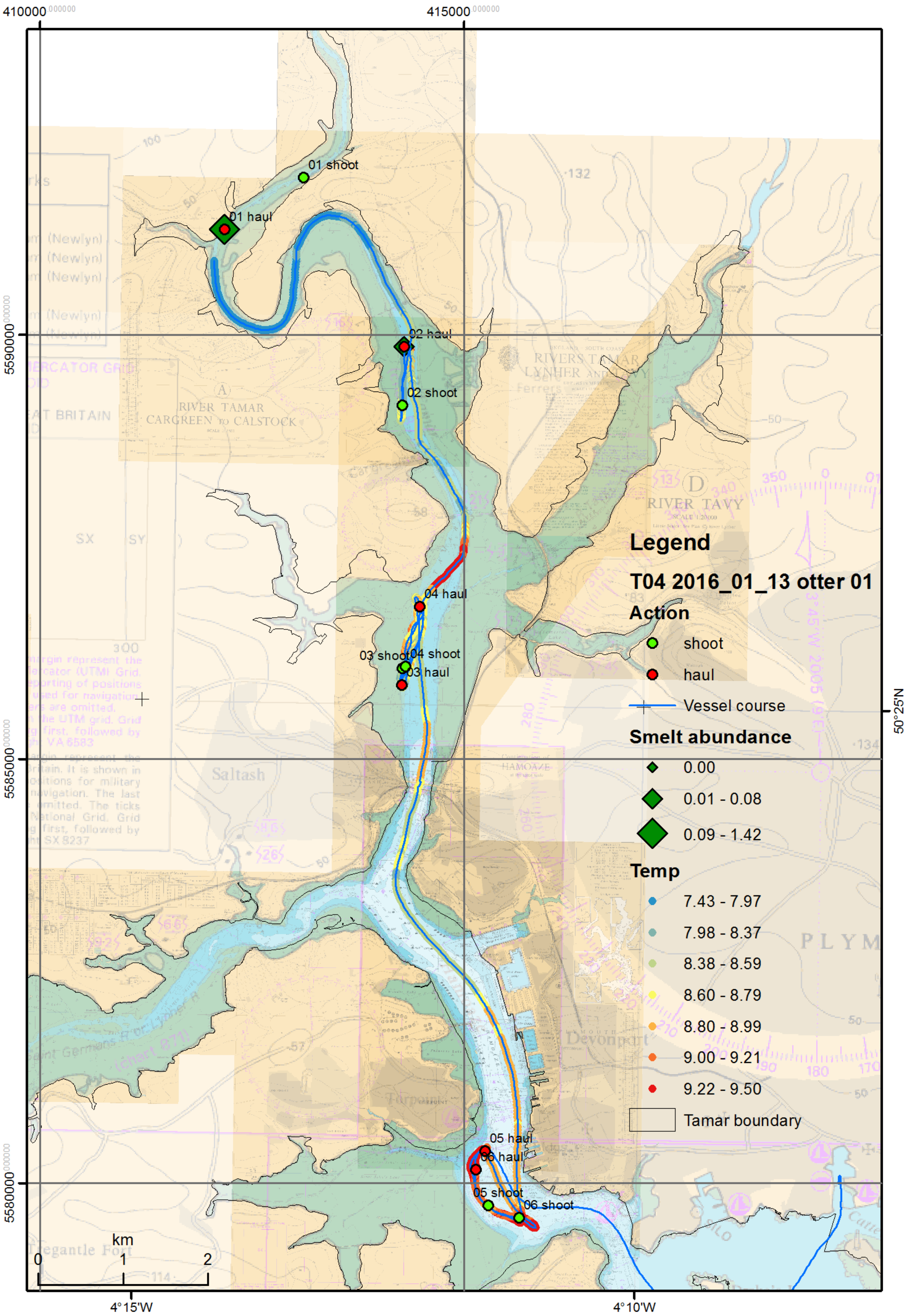

Figure 21. Shoot and haul positions and vessel track from T04 otter trawl trip 01 on 13 Jan 2016. Also shown are smelt abundances (number per minute, at haul position) and along track water temperature (from SVP).

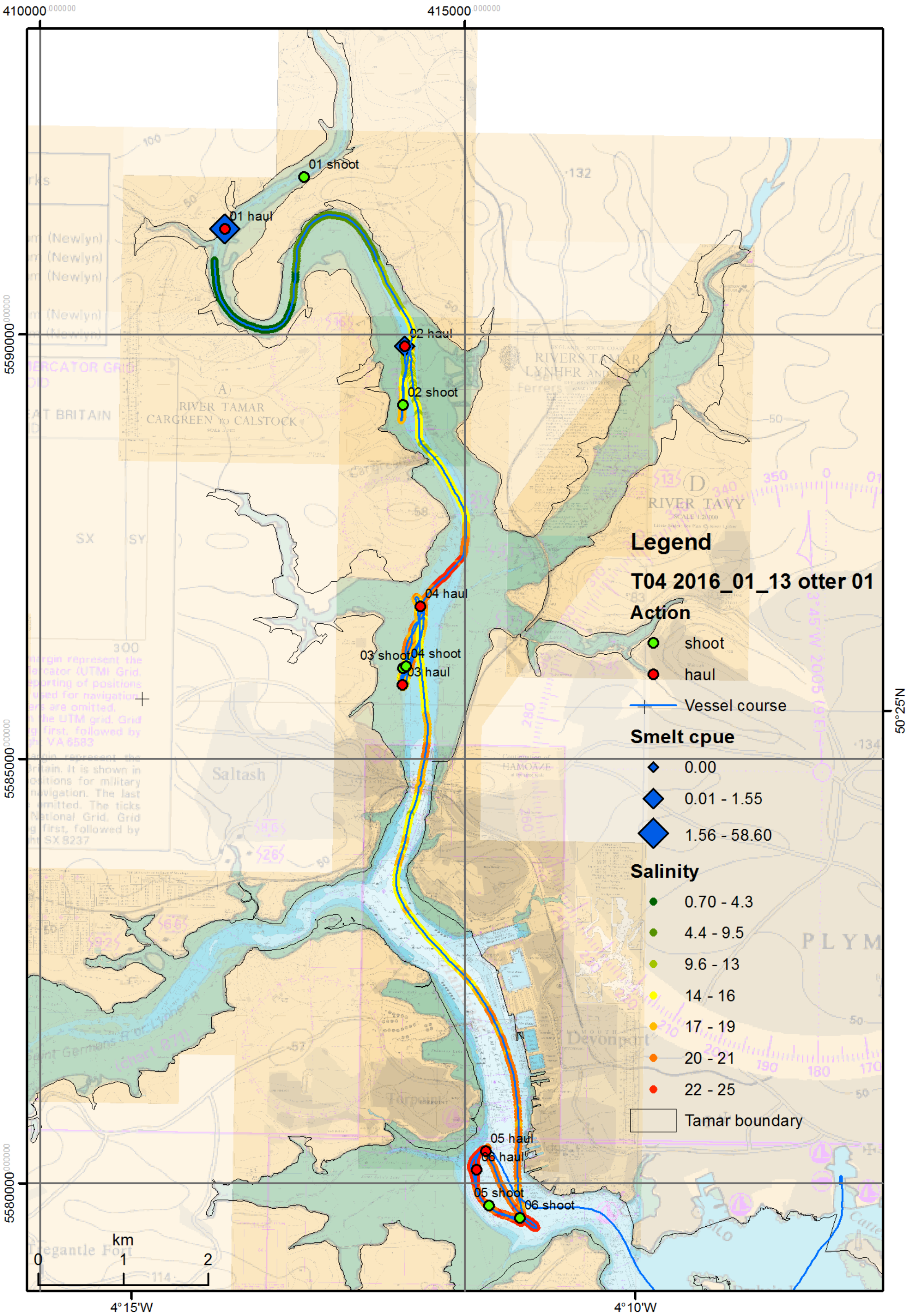

Figure 22. Shoot and haul positions and vessel track from T04 otter trawl trip 01 on 13 Jan 2016. Also shown are smelt cpue (weight (g) per minute, at haul position) and along track salinity (from SVP).

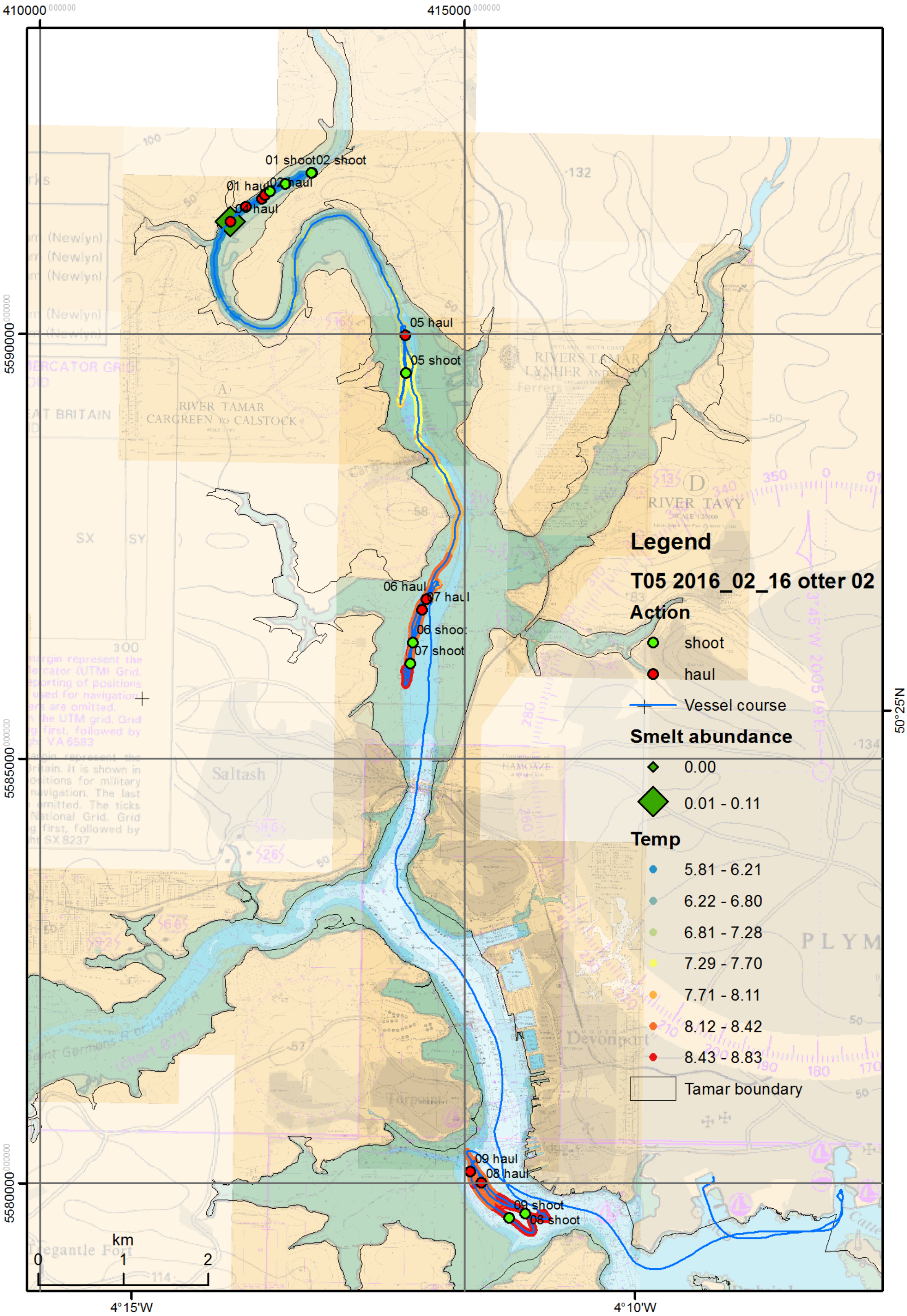

Figure 23. Shoot and haul positions and vessel track from T05 beam trawl trip 02 on 16 Jan 2016. Also shown are smelt abundances (number per minute, at haul position) and along track water temperature (from SVP).

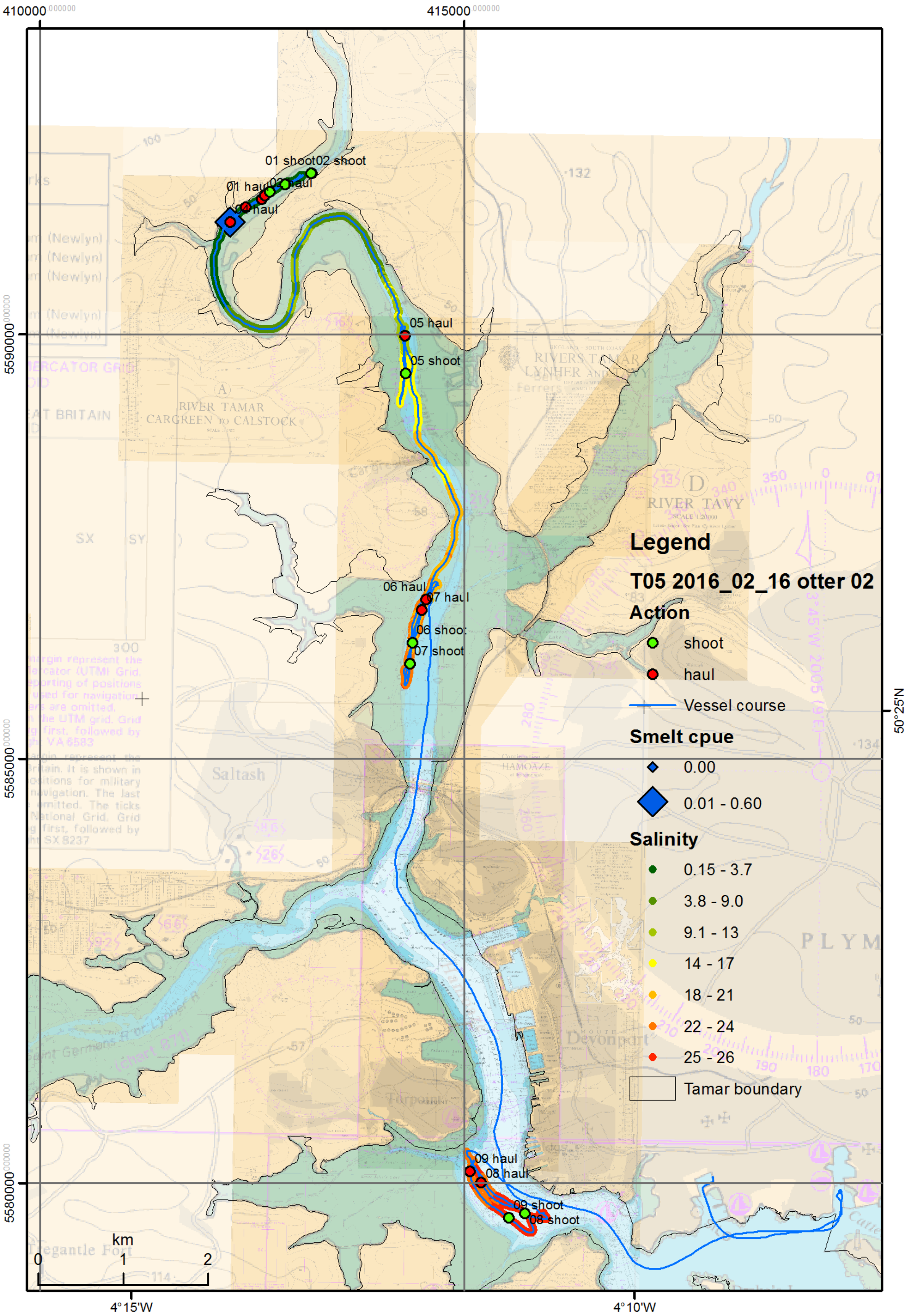

Figure 24. Shoot and haul positions and vessel track from T05 beam trawl trip 02 on 16 Feb 2016. Also shown are smelt cpue (weight (g) per minute, at haul position) and along track salinity (from SVP).

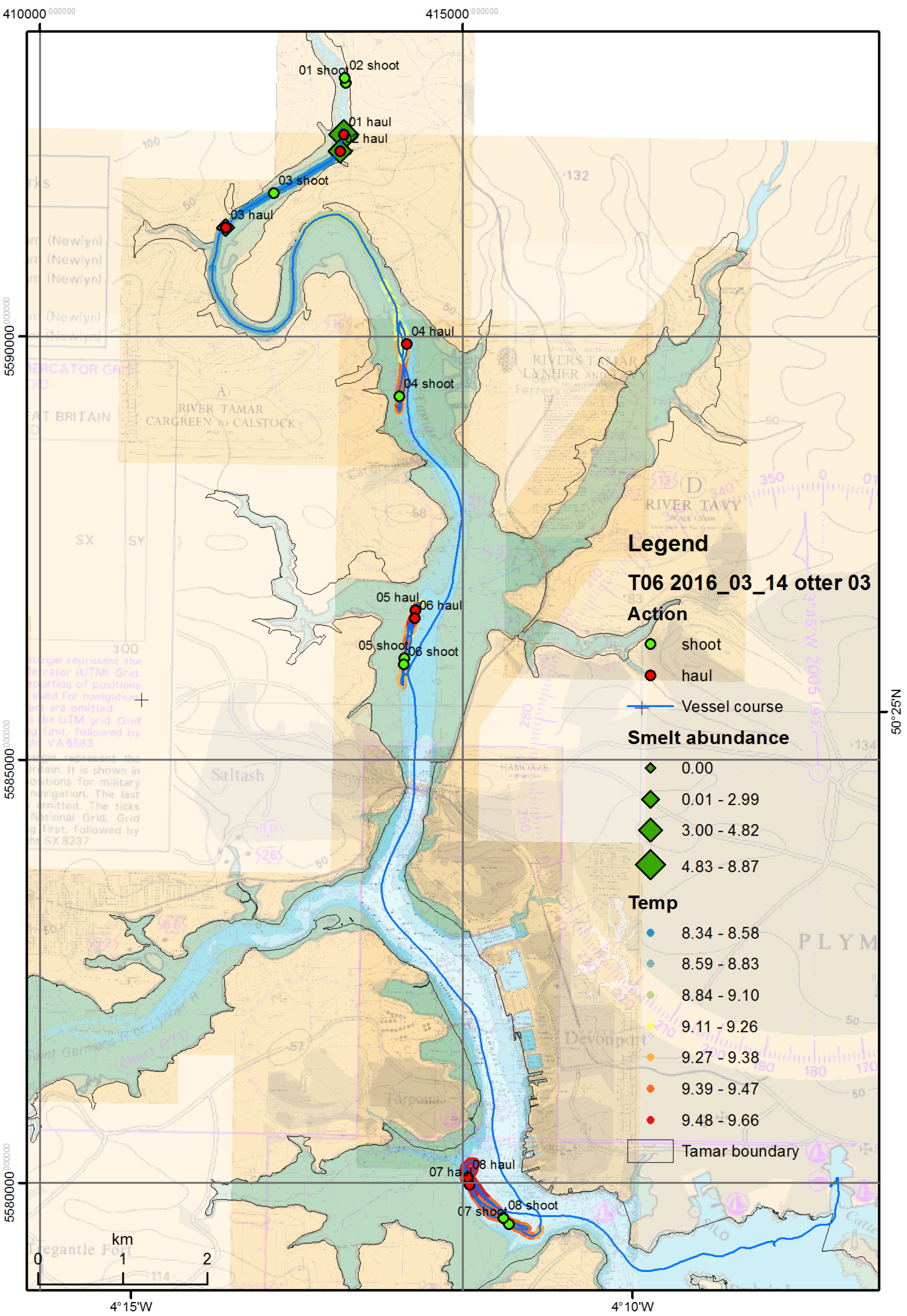

Figure 25. Shoot and haul positions and vessel track from T06 otter trawl trip 03 on 14 Mar 2016. Also shown are smelt abundances (number per minute, at haul position) and along track water temperature (from SVP).

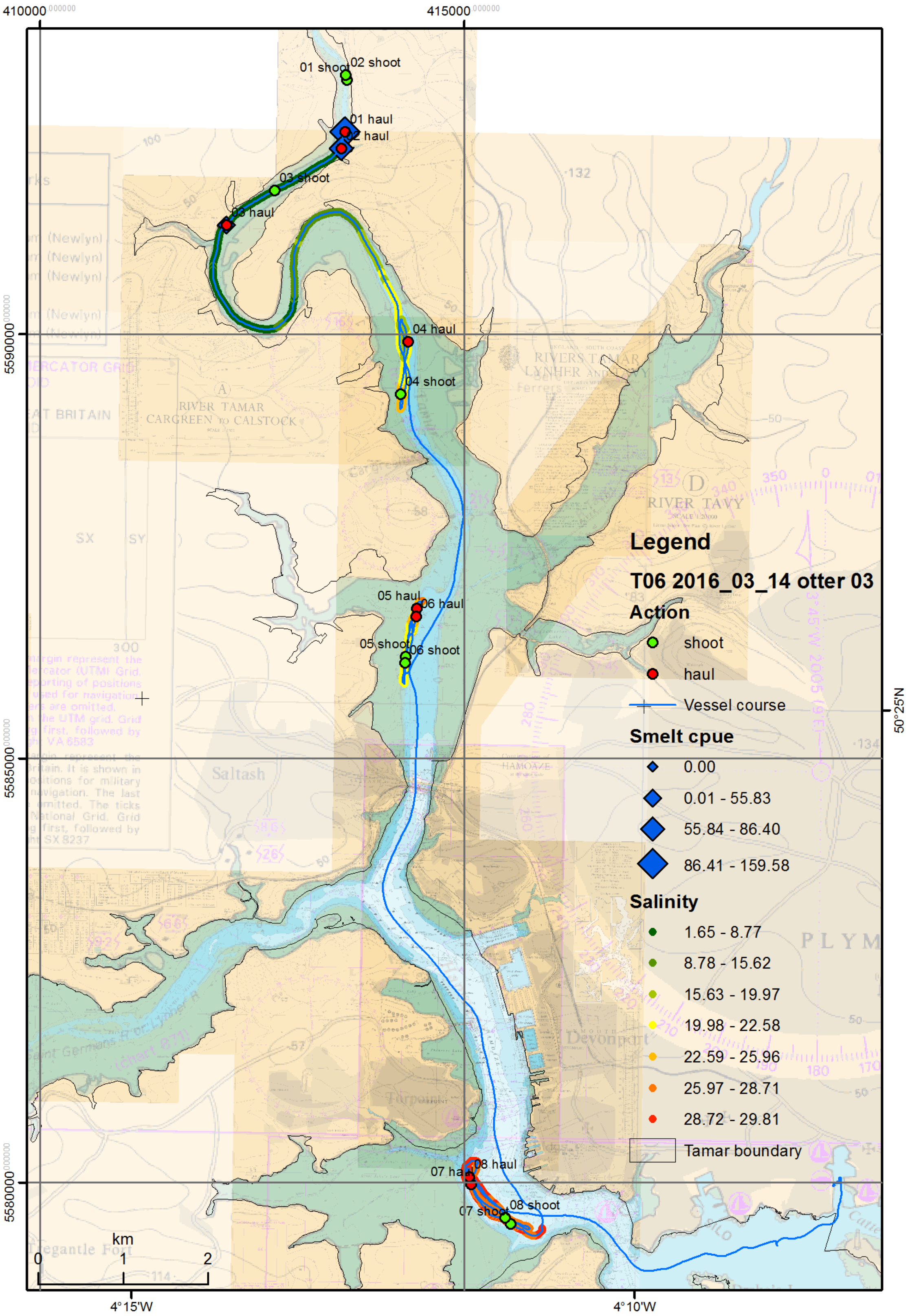

Figure 26. Shoot and haul positions and vessel track from T06 otter trawl trip 03 on 14 Mar 2016. Also shown are smelt cpue (weight (g) per minute, at haul position) and along track salinity (from SVP).

During the summer of 2015 (T01, 06 Aug 2015) the greatest abundance and catch per unit effort (cpue) of beam trawl caught smelt was around Okeltor Boathouse (T01_04, upstream of Calstock), although smelt were also caught in T01_01 from Morwellham Quay to T01_06 Calstock (lower). These tows had an average water temperature of 16.72°C and salinity of 1.75 (Table 13). Tows without smelt were generally below Cotehele (with sampling during T01 down to Pentillie Quay). The average temperature and salinity of these tows were 17.62°C and 12.53, respectively. The higher salinity in lower parts of the river is to be expected and it is interesting to note the higher temperature of the freshwater. See Table 17 for complete temperature and salinity values during T01.

Table 13. Average water temperature (°C) and SVP derived salinity during tows based on whether *Osmerus eperlanus* (smelt) was present. Also shown is smelt abundance (numbers per minute).

Trip	Gear	Smelt present?	Smelt abundance (n min^{-1})	Average water temp (°C)	Average salinity
T01	Beam	Y	7.60	16.72	1.75
		N	0.00	17.63	12.53
T02	Beam	Y	1.50	10.86	0.99
		N	0.00	10.87	2.16
T03	Beam	Y	n/a	n/a	n/a
		N	0.00	8.68	11.49
T04	Otter	Y	13.50	7.89	6.45
		N	0.00	8.95	19.88
T05	Otter	Y	1.00	5.94	0.60
		N	0.00	7.29	13.10
T06	Otter	Y	59.33	8.42	4.03
		N	0.00	9.39	24.64

Only 3 smelt were caught by beam trawl during T02 on 03 Nov 2015 (Table 12) n=2 at Halton Quay (upper) and one at Calstock (lower). By November the water temperature where the smelt were found (average = 10.86°C) was very similar to the average where they were not (average = 10.87°C). The average salinity where smelt were found was lower (0.99) than it had been in the summer however the salinity was also much lower in the lower reaches of the river (also down to Pentillie Quay) so T02 can be directly compared to T01. See Table 18 for complete temperature and salinity values during T02.

As mentioned above no smelt were found in the beam trawl samples during T03 on 12 Jan 2016 when sampling was between Halton Quay (lower) and West Mud. The average water temperature throughout the samples had decreased from the November average (10.86°C) to 8.68°C. The periods of high flow in late 2015 may have affected expected smelt locations as in order to sample down to West Mud the beam trawl sampling began at Halton Quay (lower). Nevertheless the salinity at the first two sites (T03_01, Halton Quay (lower) and

T03_02, Pentillie Quay was 0.14 and 0.57 respectively (Table 19 and Figure 20). After these tows (Cargreen onwards) the average salinity was 14.28 and was already 9.05 at Cargreen. See Table 19 for complete temperature and salinity values during T03.

T04 on 13 Jan 2016 was the first of the otter trawl samples (Table 11). Smelt were caught (*n*=26) at Halton Quay (lower) with a further *n*=1 at Cargreen. The averages of temperature and salinity at both these sites were 7.89°C and 6.45, respectively (Table 13). At Halton Quay (lower) where the vast majority of the smelt were found the average temperature was 7.51°C, which had increased to 8.27°C at Cargreen. The salinity at Halton Quay was 0.51 and this had risen to 12.38 at Cargreen, (Table 20, which also shows the complete temperature and salinity values during T04).

That smelt were caught during T04 where none were caught the previous day during T03 might be due to fish movements. More likely however, is that this was due to them being higher off the river bottom than could be caught by the beam trawl.

Only 1 smelt was caught by otter trawl during T05 on 16 Feb 2016, in haul T05_04 at Halton Quay (lower). There is a marked difference in both temperature and salinity in the samples where smelt were caught or not (see T05 samples in Table 13) but there is also consistency in these values for 4 trawls at Halton Quay (lower) averages = 5.87°C (stdev = 0.06) and 0.41 (stdev = 0.15). At the next sampling station at Cargreen the temperature and salinity values had risen to 7.32°C and 13.13, respectively. See Table 21 for complete temperature and salinity values during T05.

The final otter trawl samples (T06) on 14 Mar 2016 caught 178 smelt (Table 12) across the first three hauls (T06_01 *n*=84; T06_02 *n*=64 and T06_03 *n*=30, Figure 25 (abundance) and Figure 26 (cpue). For T06_01 and T06_02 (both at Halton Quay (upper) the average temperature and salinity were 8.33 then 8.40°C and 2.62 then 2.60, respectively. These had risen to 8.73°C and 6.87 respectively at T06_03. By Cargreen, the first site where no smelt were caught the water average water temperature was 9.39°C and the salinity had risen to 21.93. For all sites and at all locations where smelt were not found see Table 13 and Table 22 for the complete temperature and salinity values during T06.

2.4.3.2 Smelt length weight

All smelt were measured to the mm below for length (*n*=247) across the six trawls and a representative sample (*n*=101) were weighed.

After correction from total length to fork length (TL = FL * 0.914) wet weights (g) were plotted against fork lengths for the sampled fish (Figure 27). The power curve trend-line for the sample that were weighed is a good fit over the calculated length to weight values (*n*=247) although there are two or three measured weight values that were probably overestimated.

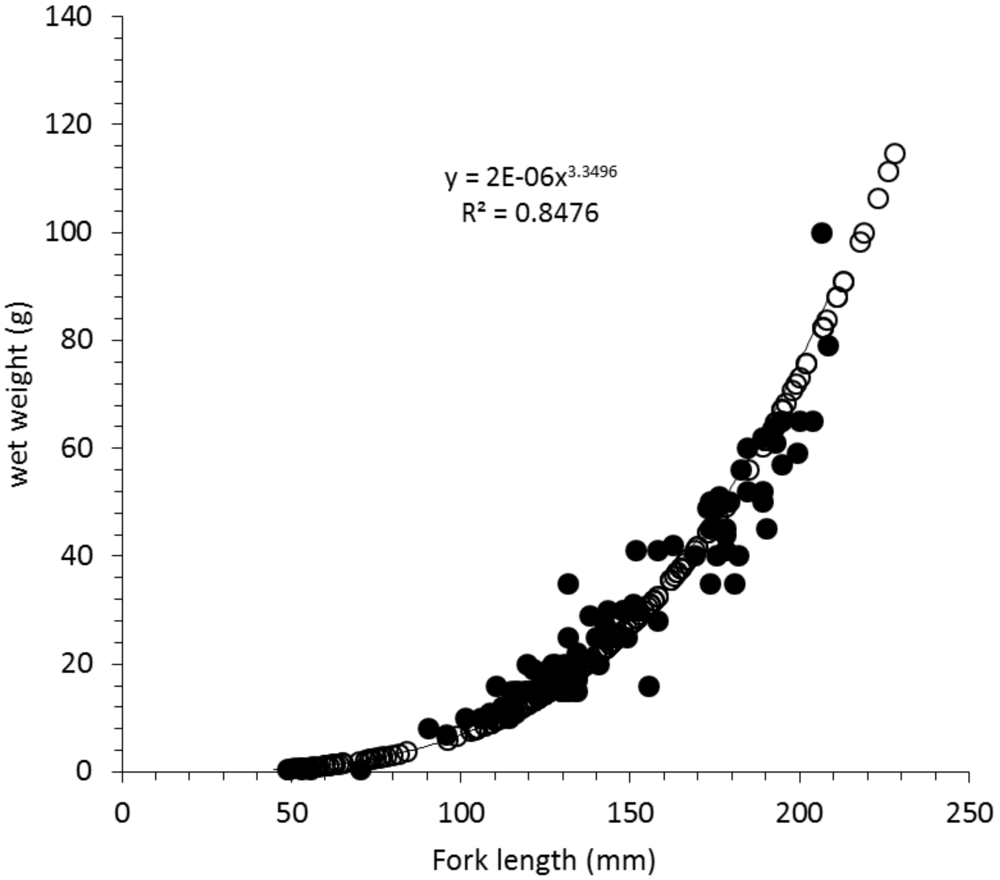

Figure 27. *Osmerus eperlanus* (smelt) measured weight (g) against fork length (mm) (derived for measured total length (mm)), (closed circles, *n*=101) and calculated weight (g) against fork length (mm) derived for measured total length (mm), (*n*=247, open circles). Trend-line is measured weight (g) against fork length (mm) (derived for measured total length (mm) based on *n*=101 observations).

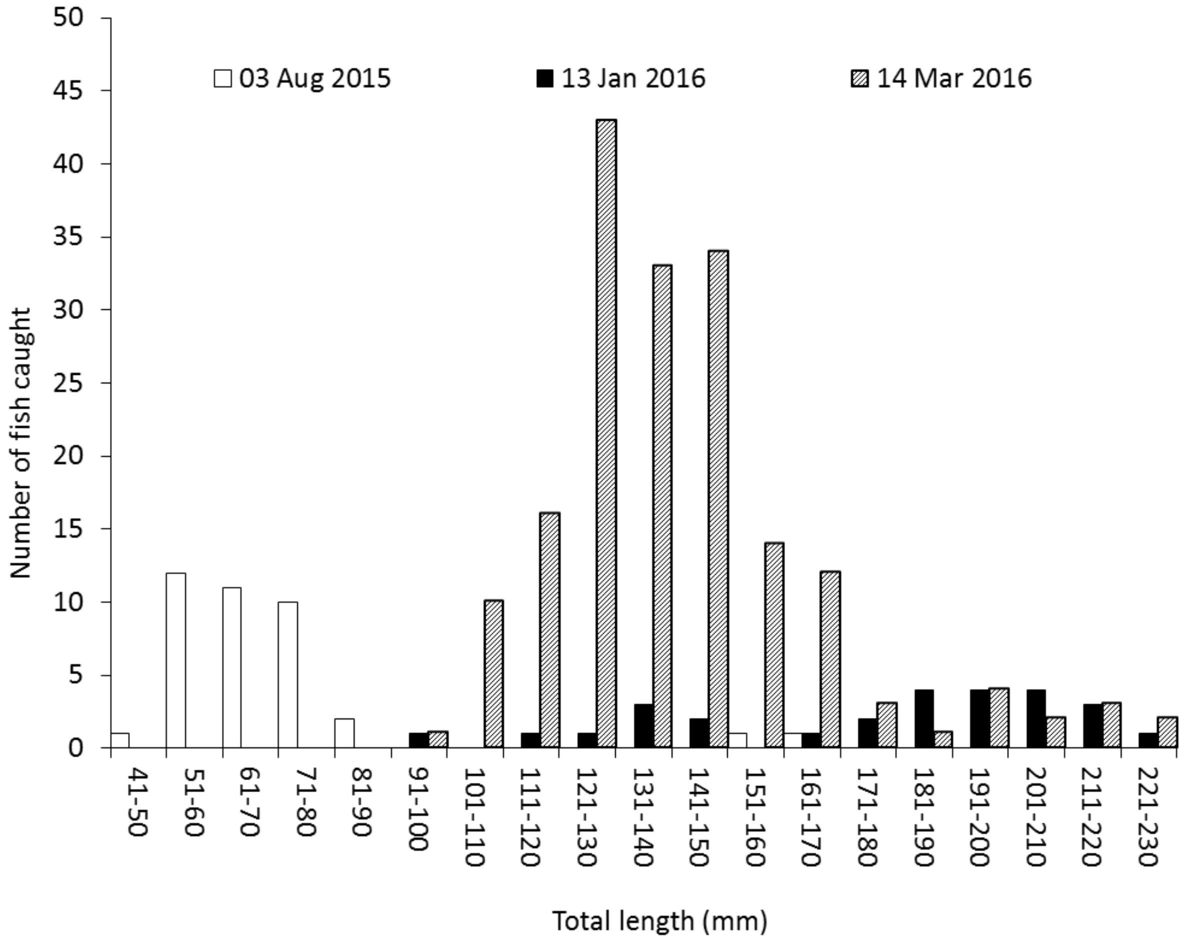

Figure 28. Histogram of number of smelt caught at various size classes across different sampling events.

It is possible to see several probable year classes in Figure 27 and Figure 28. The first in the data covers the smallest <50mm fish to ~84mm TL, (~76mm FL). The next year class is around ~96mm TL (~88mm FL) to between ~150 to 160 mm TL (~138 to 145mm FL). There are probably two or three year classes (Dando *pers. comm.*) in the larger sizes from >170mm TL (or >155mmFL) to the largest smelt caught during these trawls (at 228mm TL, 208mmFL, which weighed 79g on 13 Jan 2016. There were two smelt slightly smaller (223 and 226 mm TL respectively) that weighed 65g and 100 g on 14 Mar 2016, both of which showed evidence of spawning (redness at the genital opening, Figure 29), which was common on several of the smelt caught on 14 Mar 2016 and which had not been seen during any trawls before this date.

Figure 29. *Osmerus eperlanus* (smelt) showing redness at the genital vent.

In August, nearly all of the catch was composed of fish aged less than one year with only two adult smelt caught; however, these surveys started in the upper estuary at Morwellham, whereas surveys over the winter months started in the middle estuary downstream of Cotehele. In November, only three smelt were caught but these were adult fish 192-199mm in length. The 27 smelt caught in January 2016 and 178 caught on 14 March were of a range of age classes, including adults up to 226mm. This suggests that adult smelt are present in the middle Tamar estuary from November to March; it would be useful to determine smelt presence within the estuary between April and August.

2.4.4 Discussion

Both beam and otter trawling were used in catching smelt and the Tamar Estuary has a diverse range of fishes. Although no allis shad were caught during these trawls in addition to smelt, 39 other fish species were present.

Smelt were only found in the upper reaches of the Tamar Estuary. During summer 2015 they appeared to be restricted to low salinity (and cooler) water above Cotehele, and mostly above Calstock but were found up as far as was navigable by SEPIA at Morwellham Quay using the beam trawl. By November 2015 the river water was cooler than the sea and the few smelt that were caught in the beam trawl were in the stretch between Calstock down to Halton Quay (upper) despite fishing from Morwellham Quay to Pentillie Quay. Expanding the surveying down to include West Mud restricted the number of tows in the upper reaches and in January 2016 no smelt were caught by beam trawling at all sites between Halton Quay and West Mud.

Smelt were caught at both Halton Quay and Cargreen, using the otter trawl in January 2016. At this time however, there was not much difference in temperature between the upper and lower parts of the river, although most of the smelt were found where the salinity was very low. Very few smelt were found during February 2016; only at Halton Quay (lower) though most (72%) of the entire catch was found in the tows in the upper reaches during March 2016 where the salinity was 0.57. Most of these smelt were at Halton Quay (upper), which was difficult to sample with the otter trawl owing to limited space and it was sampled in an attempt to push the otter trawling up as far as possible on the last sampling event; this yielded good results on this occasion.

In all the trawling surveys undertaken, smelt were caught within the salinity range 0.1 to 6.9, although most smelt were caught at the lower end of this range typically at salinities less than 3.0.

The otter trawl, which has a wider opening and a higher headline height was seemingly better at catching smelt (that were probably off the river bottom) than the beam trawl. The otter trawl was much more restricted in where it could operate, was more difficult to operate (especially where there is flow in the river and submerged obstructions), and more fragile and time-consuming to repair if damaged. Here though it caught smelt in the same place where the beam trawl had proved unsuccessful the previous day. Gear selection is not easy to target smelt in their environment.

Debris mainly comprising leaves and twigs was a constant feature of much of the estuary. Samples from Cargreen generally contained very large amounts, which was probably due to this area being the first where the river really opens out resulting in reduced flows. This widening is probably the cause for the 'spike' in salinity values apparent in Figure 20, Figure 22 and Figure 24 where the SVP was not lifted in the region. On some occasions the volume of leaves and twigs was so great that the net did not sample properly and could also be damaged. This applied to both the otter and beam trawls. There were also larger pieces of debris, particularly branches and other waterlogged pieces of wood.

After converting from total to fork length, the 'a' and 'b' values for deriving weight from measured length generated seemingly reliable values of weight for the group of smelt where these measurements were not taken.

2.5 General discussion on smelt monitoring

There is no clear evidence that smelt spawned at any of the egg survey sites in the upper Tamar (or Lynher) Estuary, during February, March or April 2016. The small number of eggs found downstream of Cottage Run Weir, which were at a range of development stages, were probably deposited by tidal movement rather than spawned at the site. Had there been significant smelt spawning, many more smelt eggs would have been expected than were found in 2016.

The location of smelt spawning in 2016 is unknown and the reasons for the apparent lack of spawning in the upper Tamar Estuary during March 2016 are unclear. Paul Dando (*pers. comm.*) concluded that spawning had probably occurred further down the Tamar Estuary. The apparent lack of suitable spawning substrate on the riverbed downstream of Impham Meadow, suggests that spawning may have occurred on marginal structures and plant material. The Tamar Estuary warrants investigation for potential spawning sites downstream of Impham Meadow.

The dates when live eggs were found on smelt egg surveys at Cottage Run suggests that peak spawning occurred during March 2016, with some spawning during early April. The red vent state of smelt caught on otter trawls on 14 March further suggests that spawning occurred during March 2016. High flows during February 2016 probably prevented spawning in the upper Tamar estuary.

Smelt distribution within the Tamar Estuary appeared to favour the middle and upper estuary during August and over the winter months between November and March, with greatest catches in March 2016 in the vicinity of Halton Quay. This apparent aggregation in the middle/upper estuary suggests pre-spawning behaviour as described by Maitland (2003). It is unclear why the February 2016 surveys yielded such low smelt catches; high flows may have driven smelt further down the estuary or the smelt population may have been further upstream from the trawl start location at Halton Quay. Hillman (2016) sampled smelt in the Tamar Estuary by seine netting in February 2015; although reasonable smelt catches were made at Cotehele Quay and Braunder Wood in early February the individuals caught (64 to 96mm fork length) were not of spawning age (probably 2014 year class). Only one adult smelt (138mm FL) in early February 2015 (Hillman, 2016), suggesting that the pre-spawning aggregation of smelt had not yet begun. Hillman (2016) also found that under high river flows in late February 2015, no smelt were recorded; a similar situation of high freshwater flows in February 2016 may account for the poor catch of smelt.

3 Part 3. Review of Tamar allis shad distribution and observations on the spawning migration

This section focuses on allis shad, where there is considerable data available from monitoring by the EA in the Upper Tamar Estuary. Section 2.1 summarises existing information on smelt within the Tamar Estuary.

3.1 Seasonal timing of the Tamar allis shad run

Figure 30 shows the timing of 195 allis shad records for the River Tamar and Tamar Estuary; these includes some records of shad (species unconfirmed) from the estuary netsmen and rod anglers and observations on the camera footage at Gunnislake Fish Pass. More specifically, Figure 30 shows the timing of 91 records of allis shad caught at Gunnislake Fish Trap (2004-2013), 23 records of shad (assumed to be allis) seen migrating upstream at Gunnislake Fish Pass (1999-2009), 23 catches from rod anglers from the upper Tamar Estuary and River Tamar (1997-2015), 43 catches by estuary salmon netsmen (1998-2015) and 15 allis shad found dead in the River Tamar and Upper Estuary (2004-2013).

Allis shad have been recorded at Gunnislake Trap between 24 April and 26 August, with one outlier on 30 September (not shown on Figure 30). Most allis shad were recorded in Gunnislake Trap during May and June, with a few records in July and early August. Shad are not routinely identified from camera footage at Gunnislake Fish Counter so counter records are sporadic; of the few records of allis shad identified on camera footage, most are from May and June.

Anglers tend to catch shad on fly or spinner as a bycatch of salmon or sea trout. Records are from the River Tamar or freshwater part of the tidal Tamar from Impham Meadow to Gunnislake Weir. Angler records date from May to August.

Estuary shad catches are exclusively from salmon and sea trout netsmen operating in the middle Tamar estuary between Cotehele and Weir Quay. Because the netting season has been restricted to late June to the end of August, records from the estuary are not representative of May and June. Most records of netted shad are from late June to the end of July. Contrary to trap records, estuary records tend to suggest that shad are still present in the estuary during July. Estuary netting ceased altogether between 2004 and 2013 during a 10-year net-limitation order. As such, estuary records of shad are from two periods; 1998-2003 and 2014-2015.

Occasionally, spent shad carcasses are found on the upstream side of the trap bar screen, having floated downstream. Allis shad are occasionally found in the margins of the river or upper estuary on gravel bars. Most records of spent shad are from late June to late July, which tends to suggest that the spawning period typically continues until this time. Dead shad have also been found in the freshwater Tamar in a condition that suggests they have not spawned.

These records have been collated and are contained in the electronic appendix ‘DASSHSE00000030_AS-01.xlsx’ and a shapefile included in the ArcGIS map package. Due to the nature of this dataset complex symbology has not been applied.

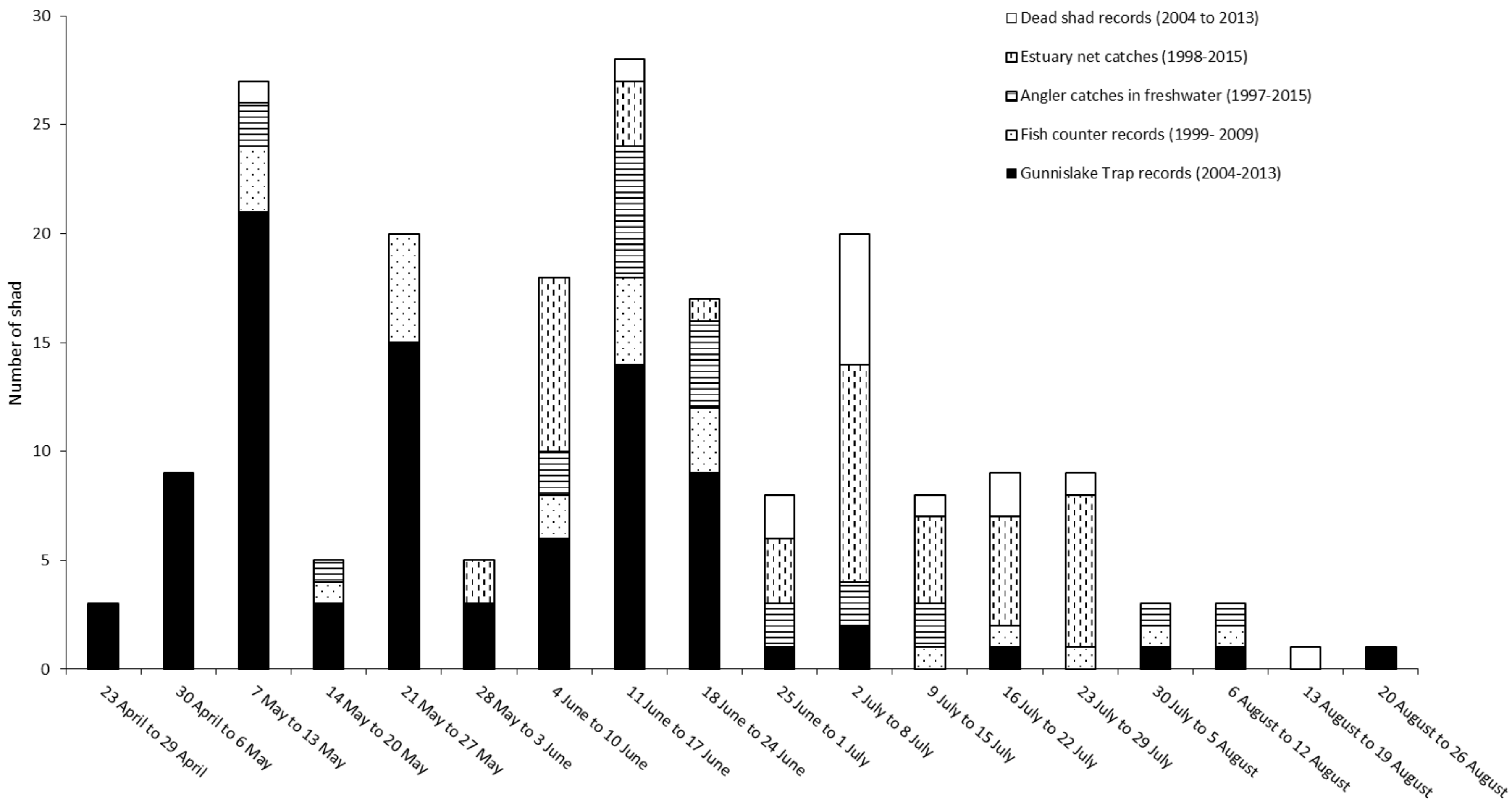

Figure 30. Allis shad records from the River Tamar and Tamar Estuary (1997 to 2015).

3.2 Kick-sampling records at Cottage Run

Kick-sampling for allis shad eggs at Cottage Run (SX4354770860) has been undertaken at least once every year between 2000 and 2015 inclusive, with the exception of 2007 and 2009 (see Figure 4 on page 26, above). This site downstream of Gunnislake Weir has consistently produced shad eggs and appears to be the preferred spawning site on the Tamar. Out of 46 sampling occasions at Cottage Run over the 16-year sampling period, shad eggs were found on 36 occasions between 14 May and 4 August. Shad eggs were usually present at this site when sampled in May, June and July (see Figure 5 on page 26, above). Only twice has this site been surveyed in August, both of which in 2000; eggs were present on the 4 August 2000 but not on the 29 August 2000. This tends to suggest that the shad spawning period can extend well into July if not August in some years.

Of the ten unsuccessful sampling occasions at Cottage Run, one was in April and four in May when water temperatures were between 11.4 and 13.8°C. One of the sample occasions was very late in the season on 29 August, which was probably after shad spawning had finished.

3.3 Location of other kick-sampling surveys

3.3.1 Downstream Gunnislake Weir

Kick-sampling surveys were undertaken in the upper Tamar Estuary on 14 June 2000 at Morwell Wood and 17 June 2015 at Lower Cottage Run. Eggs were not found at either location.

Under low-flow conditions a shallow riffle (albeit tidal) exists immediately downstream of Cottage Run (SX4350470793). Eggs have been found in low numbers here in 2011 and 2013; it is unclear if the eggs found here have drifted downstream from the riffle upstream of Cottage Run or if this is a discrete spawning site.

In 2010, a gravel bar existed immediately downstream of Gunnislake Weir at SX4367171123 and a larger riffle in First Run at SX4366671093 (both of which have since been removed). Eggs were found at this location on 27 May 2010 and a single egg on 14 June 2010. Eggs were not found at these locations on 29 May 2012. First Run and the nearby smaller riffle below the weir represent the second known spawning site downstream of Gunnislake Weir.

3.3.2 Upstream Gunnislake Weir

Several locations upstream of Gunnislake Weir have been surveyed for shad eggs between 2000 and 2015 between Gunnislake Weir and Lamerhooe. Shad eggs have only been found on two occasions; at Blanchdown (SX4348472747) on 28 June 2005 and at the riffle downstream of Simon’s Pool (SX4366972617) on 7 June 2006. This represents a further two spawning sites upstream of Gunnislake Weir, giving a total of four known shad spawning sites on the Tamar.

3.4 Diurnal timing of shad migration

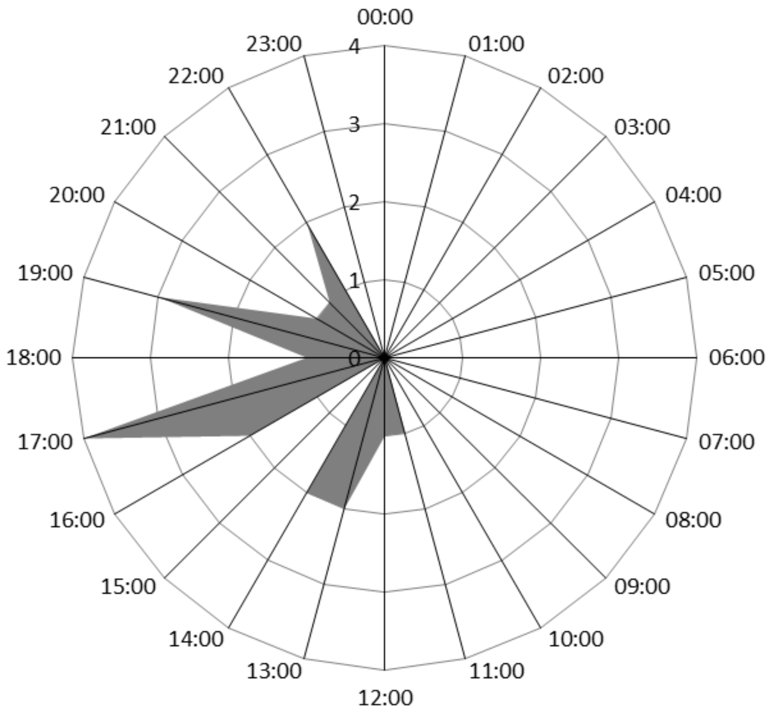

Figure 31. The timing of upstream shad migration at Gunnislake Fish Counter, based upon 23 fish counter records between 1999 and 2006.

Although only based upon 23 Gunnislake Fish Counter records, there appears to be a preference for migration during daylight hours. 21 of the 23 fish counter records were between 09.00 and 23.00 (Figure 31).

The records from Gunnislake Trap appear to support the observation that shad tend to migrate upstream during daylight hours. During the period 2004 to 2013 the trap was typically fishing overnight from 19.00 to 07.00 and fishing during the day between 08.00 and 16.00. 44 shad were caught in the trap following overnight trapping, compared to 49 caught after daylight trapping. Although apparently similar, the overnight sessions were typically 12-hour, whereas the daytime sessions were typically of 8-hour duration. When expressed as shad records per hour of trapping time, the average number of shad caught per hour during overnight trapping sessions was 3.7, compared to 6.1 shad per hour during daylight trapping sessions. The overnight trapping sessions typically included a few hours of daylight at the end of the day between 19.00 and 23.00 so shad caught in overnight trapping sessions did not necessarily migrate into the trap during darkness hours.

3.5 Annual run size at Gunnislake Fish Trap (2004-2015)

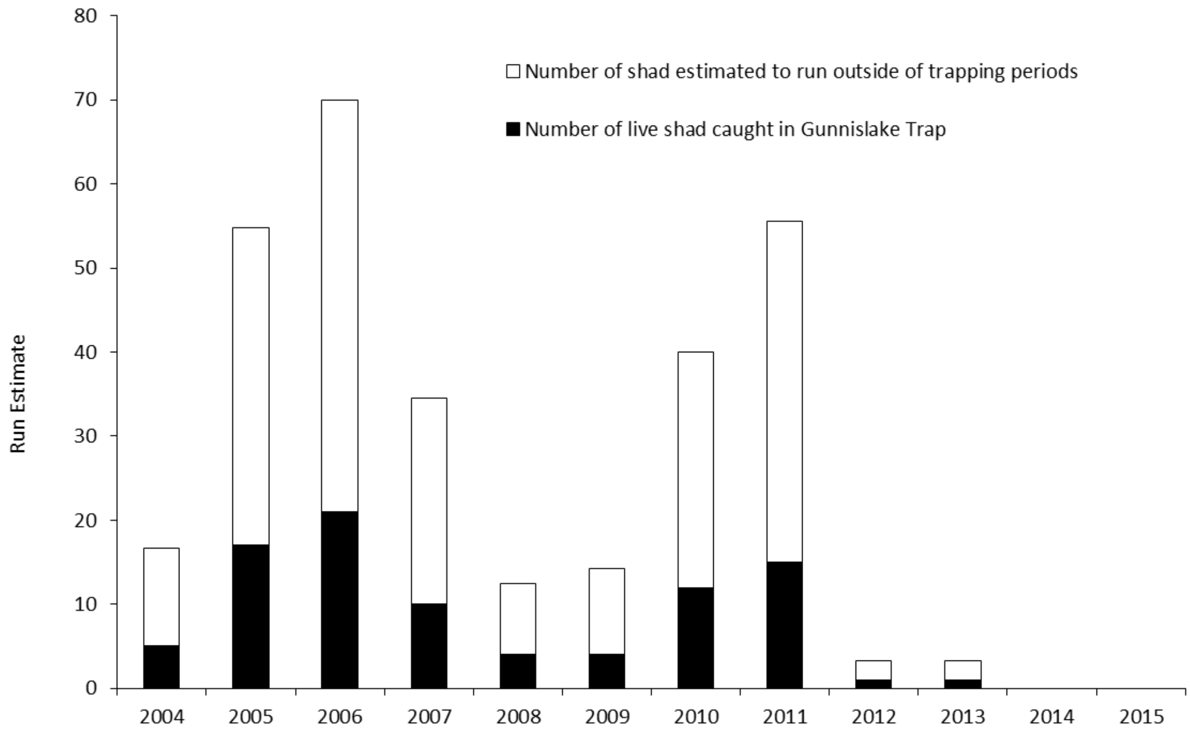

Figure 32. The number of allis shad recorded at Gunnislake Fish Trap and total number estimated to have migrated upstream into freshwater between 2004 and 2015 (Note; no trapping in 2014).

Trapping was not undertaken during 2014. Trapping resumed in 2015, albeit at reduced effort compared to previous years. The trap was operational for 445 hours between May and July in 2015 but no shad were caught, suggesting that shad did not migrate into the River Tamar in 2015. The leaking sluice gates and associated low flows could have impacted the ability of shad to successfully migrate upstream in 2015. Despite considerable effort spent reviewing camera footage of the fish pass in May, June and July 2015, no shad were seen migrating upstream at Gunnislake Fish Pass, either before or after the sluice gate was repaired on 1 July.

If the trap records are representative of the spawning run, Figure 32 suggests cyclical variation in population size with good and bad years. Aprahamian (*pers. comm.*) made similar observations in other European shad populations. The trap records also suggest that between 2004 and 2011, there were reasonable shad numbers migrating upstream at Gunnislake Weir, with allis shad catches typically on 4 or 5 occasions per season. From 2012 onwards only two allis shad have been observed at Gunnislake Fish Trap (Figure 32); one in 2012 and another in 2013. Flows in 2012 between mid-April and the end of June were very high compared to the 2004 to 2011 period, which may explain the lack of allis shad recorded at Gunnislake Trap. However, flows in 2013 were low yet allis shad were all but absent from the trap records in this year. 2015 was an unusual year with respect to the very low flows seen through the fish pass and trap due to the leaking sluice gates; this may explain why allis shad were not seen migrating upstream in this year.

Although we can speculate that unfavourable flow conditions were the cause of an almost complete absence of allis shad seen in the trap since 2011, it is possible that there has been a step change in the Tamar shad population between 2011 and 2012. Additional monitoring at Gunnislake Fish Trap in 2016 should provide further data to address this possibility.

3.6 Environmental conditions associated with shad migration

Gunnislake Trap has been operated for 12 months of the year between 2004 and 2009 and approximately 10 months of the year from 2010 to 2013. On average trapping took place on 3 days (2 sessions per day) out of 7, with slightly greater emphasis during the main migration months (June-August) than the winter months. In 2015, trapping targeted only the main salmon and sea trout migration months between May and October, with greater effort between June and September.

Throughout all of these trapping sessions, 91 allis shad were caught on 43 occasions. Amongst these 43 occasions, the number of allis shad caught per occasion ranged from one to 11 fish, but on average 2.1 allis shad were caught at a time. On 26 of the 43 occasions when allis shad were caught in Gunnislake Fish Trap, a single individual was caught.

In order to investigate the environmental conditions under which allis shad were caught migrating into Gunnislake Fish Trap, environmental data was collected and statistical analyses were performed on the data set with the following conditions.

1. <u>Time of year</u>; allis shad have been caught in the trap between 24 April and 26 August, with an outlier on 30 September. Therefore, environmental data was collated from all trapping sessions between 14 April 2004 and 31 August 2015 (excluding 2014 when the trap was not operational). Arguably, the data analyses could have used a smaller time range which, for example, included the period when 90% of allis shad catches were made. This would have narrowed the analysis period to between late April and early August.
2. <u>Water temperature</u>; the mean 24-hour daily water temperature was used. Where the trap was set in the evening and the catch was processed the following morning, the mean temperature was used on the day that the trap was set. Where the trap was set in the morning and attended on the afternoon or early evening of the same day, then the mean temperature of that day was used. Data predominantly came from a Tiny Tag data logger located in Gunnislake Fish Trap. In the latter years of the survey period, a YSI data monitoring sonde was used to collect the data, again located at Gunnislake Trap. Gaps were filled using available data from temperature taken during trapping sessions. It is important to note that river water temperature was used, rather than the temperature of the estuary, where the fish were migrating from.
3. <u>River flow</u>; the 24-hour daily mean flow (cumecs) was used, adopting the same principals as water temperature, depending upon the day that the trap started fishing. Flow data from Gunnislake Gauging Station was used. Note that in 2015, the

sluice gates in the canal at Gunnislake Weir were leaking badly to the extent that most of the water in the river was flowing through the canal and under the sluice gates, rather than the usual route over the weir and down the fish pass and through the fish trap. Therefore, the flows recorded in 2015 up to 1 July at Gunnislake Gauging Station were considerably higher than the actual flow through the fish pass; the weir face itself was completely dry.

4. <u>Maximum tidal height;</u> tidal data from Devonport tide logger (UK Coastal Monitoring and Forecasting Service Plymouth Class A Tidal Gauge) was used to calculate the maximum tidal height during trap sessions. This was by no means ideal, due to the tidal lag between Devonport and Gunnislake but it gave an indication of whether allis shad preferentially migrated upstream on larger tides and if tidal height was significant.

3.6.1 Logistic regression of environmental factors associated with allis shad migration

Logistic regression (see Appendix 8.6 on page 106, below) was used to divide the data set up into bands and create a model that would predict the presence or absence of allis shad being caught at Gunnislake Fish Trap (i.e. a binary classifier). Maximum tidal height within the trapping session did not feature as an explanatory variable within the best fitting model. It is possible that tide is important to allis shad in other ways that could not be measured in these analyses; for example on very high spring tides allis shad might be able to migrate directly over the face of Gunnislake Weir, providing flows were not too high. Similarly, tidal state and relative height could be an important variable in determining the timing of migration upstream to Gunnislake Weir or the timing of spawning below the weir at Cottage Run, but that is outside the scope of these analyses.

The bands used were as follows;

- Day; April and May, June (reference band in the model), July and August (3 bands)
- Water temperature (^{o}C); <14.5 (reference band), 14.5-16.99, >=17.0 (3 bands)
- Flow (cumecs); <4 (reference band), 4-9.99, 10-19.99, >20 (4 bands)

This model was then tested and the ROC (Receiver Operating Curve) was 0.822 indicating a good fit. The ROC is a curve generated by plotting the true positive rate against the false positive rate; ideally we would like our curve to get as close to the top left hand corner (x=0, y=1) as possible. The AUC is the area under the ROC curve; a model with good predictive ability should have an AUC closer to 1 than to 0.5. Each of the factors (e.g. low temperature) within the respective categories used in the model relate to the reference category (indicated in the bullet points above). So for instance the April & May factor for the day category (referred to in Appendix 8.6) as daybandAprilMay) relates to the June factor. Therefore, from this relationship, it is possible to assess how much more / less likely shad records are to relate to environmental conditions.

This model was fitted using data from April 2004 to August 2011, and includes only 40 sightings of Allis Shad (or a 4.5% probability of seeing allis shad).

3.6.1.1 Conclusions from the logistic regression model

- The model suggests encounters of allis shad in April & May are twice as likely than in June though the confidence is much less certain – with anything from a 32% decrease to a 6.6 times increase between these two periods (see Appendix 1- likelihood odds). The model is able to consider periods of different lengths (for example comparing June to April & May) and in future, when further records of allis shad catches at Gunnislake Weir become available, the model could be refitted splitting April, May and June into separate months. However, for now the low number of occasions when allis shad have been recorded at Gunnislake Trap prevent further splitting into separate months without compromising the fit of the model.
- It is expected to encounter significantly fewer allis shad in July & August than in June (between 36% and 93% less – even though this is a longer period).
- It is expected that more allis shad will be encountered where temperatures are between 14.5ºC and 16.99ºC than in low temperatures (<14.5ºC; between 41% and 15 times more); and even more so in high temperatures (>=17ºC).
- More allis shad are likely to be encountered in medium flows (4-9.99 cumecs) than in low flows (<4 cumecs). More allis shad in high flows (10-19.99) than in low flows is unlikely (see below).

3.6.2 River flow

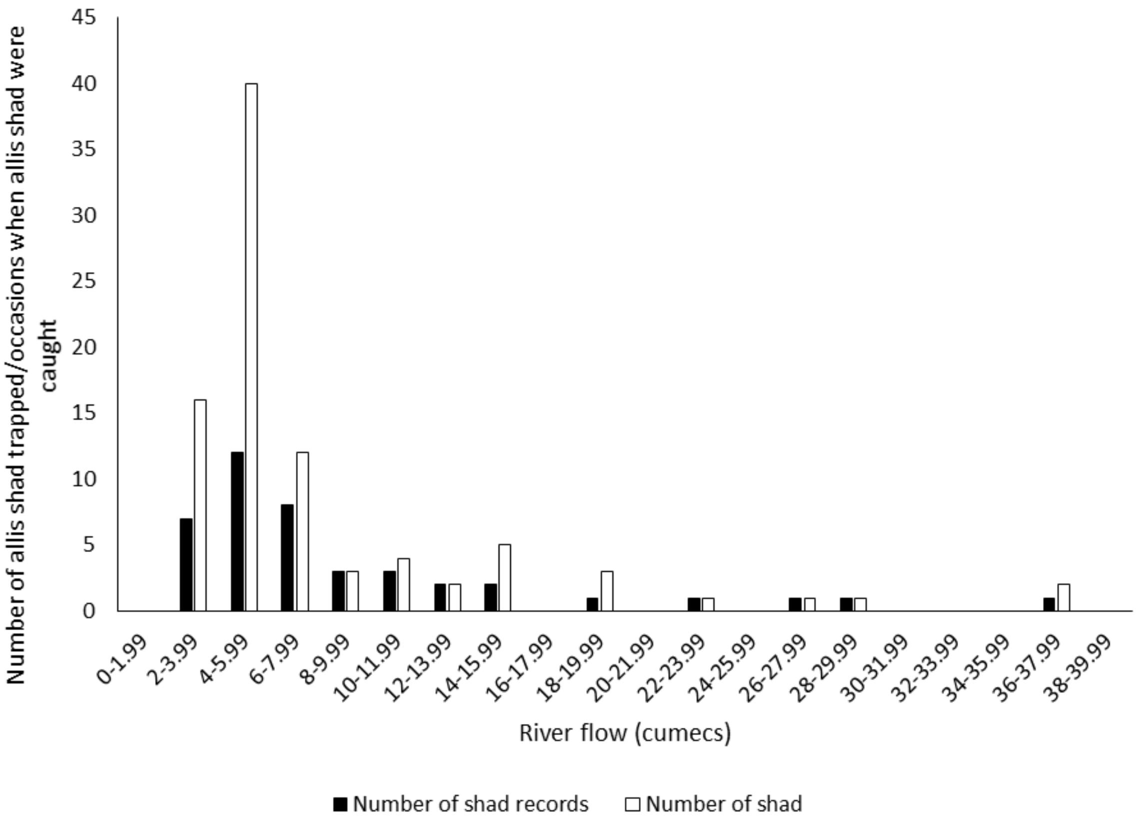

Figure 33. The number of allis shad upstream migration events and number of allis shad caught at Gunnislake Trap under different flow conditions, 2004-2013.

Allis shad were observed migrating upstream at Gunnislake Trap under a wide range of flow conditions, from 2.36 to 37.88 cumecs (Figure 33). The mean flow on 42 occasions when allis shad were caught in the trap was 9.05 cumecs; factoring in the number of allis shad caught on these occasions, the mean flow volume of 90 allis shad catches in the trap was 7.87 cumecs. Most allis shad (31 out of 42 occasions; 72 out of 90 fish) were observed migrating upstream at flows of between 2.36 and 9.99 cumecs (74% of occasions when shad were recorded in the trap and 80% of individual shad recorded in Gunnislake Trap). Of the remaining 11 occasions when allis shad were caught in the trap in flows greater than 10 cumecs, 8 catches were made during April and May; this equates to 15 of the 18 allis shad observed migrating under higher flows.

Figure 34 shows the relationship between the available flows and the flows under which allis shad were caught (by occasion and number of individuals caught). It shows an apparent avoidance of very low flows and high flows, whilst flows in the 4 to 8 cumec range were used at a higher frequency than the availability of these flows.

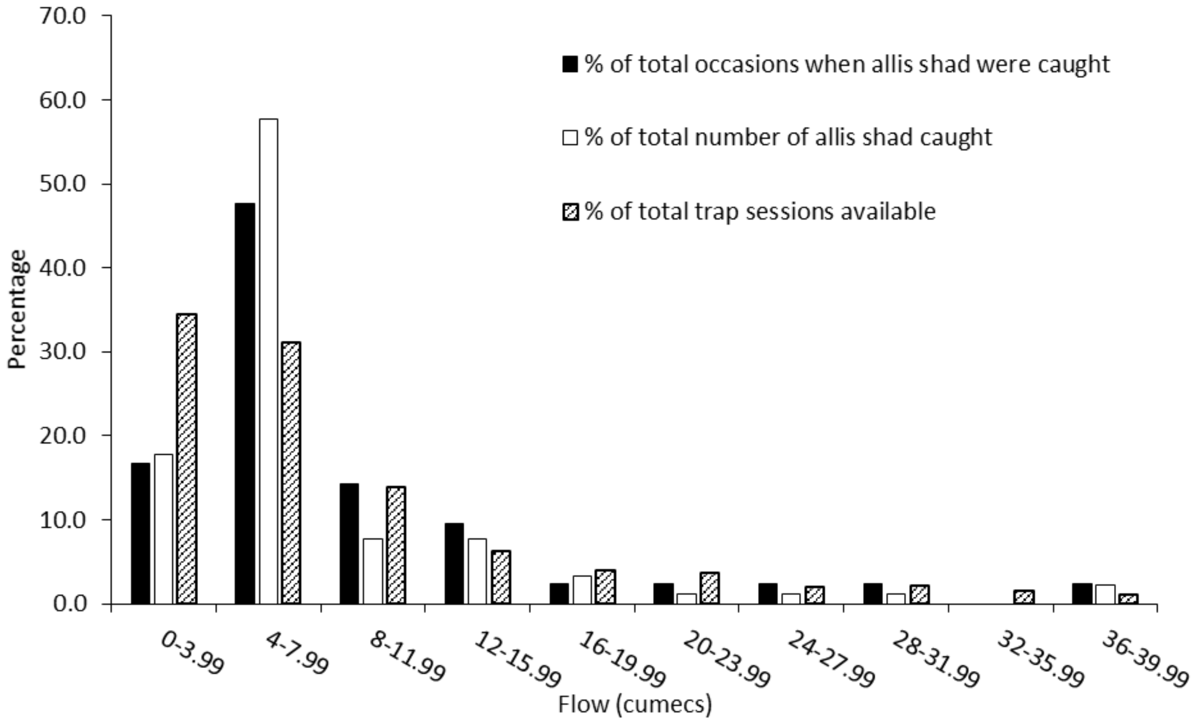

Figure 34. Percentage of flows in each band when allis shad were observed (by occasion and number of individuals), compared to the percentage of available flows among trap sessions between mid-April and the end of August 2004-2015.

Generally, male allis shad will arrive in the river about 2 weeks before female allis shad. It may be speculated that many of these records of allis shad migrating upstream under flows of greater than 10 cumecs in April and May could be males. From 9 dead allis shad recovered from the River Tamar between 2000 and 2007, 8 were male. This suggests that male allis shad are more able to cope with upstream migration at Gunnislake Weir, assuming that the post-spawning mortality rate is equal between the two sexes.

Allis shad were not observed migrating upstream at Gunnislake Weir at flows of below 2.36 cumecs, although between 2004 and 2013, river flows were only recorded below this during the May-July period during 2011 and briefly during 2010.

3.6.3 Water temperature

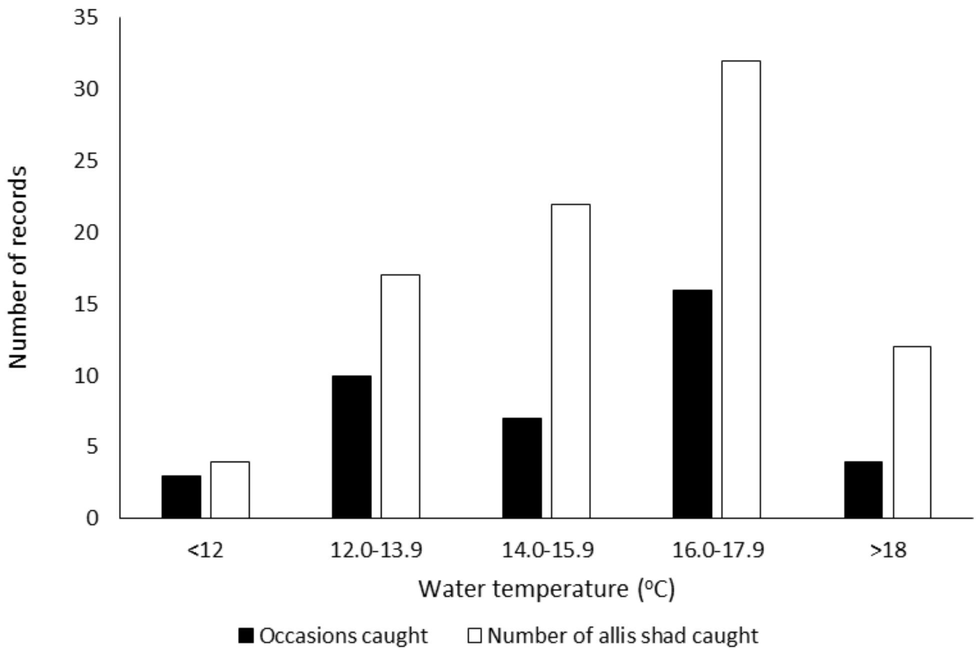

Figure 35. The number of allis shad upstream migration events and number of allis shad caught at Gunnislake Trap under different water temperature bands, 2004-2013.

As indicated by the Logistic Regression analysis, warm water temperature is a significant factor in allis shad upstream migration at Gunnislake Weir (and certainly spawning, since water temperature will determine the speed at which the resulting eggs develop and hatch). The greater the water temperature, the more likely we appear to be to observe allis shad at Gunnislake Trap.

Allis shad have been caught in Gunnislake Trap at water temperatures as low as 11.21°C, but more allis shad are seen at warmer water temperatures (Figure 35). Figure 36 shows that allis shad tend to actively target higher water temperature (16 to 17.9°C) but are infrequently caught at lower water temperatures (<12°C). The mean water temperature on 40 occasions when allis shad were caught at Gunnislake Trap was 15.37°C; when the number of allis shad on these occasions is accounted for, the mean water temperature of 87 allis shad catches was 15.49°C.

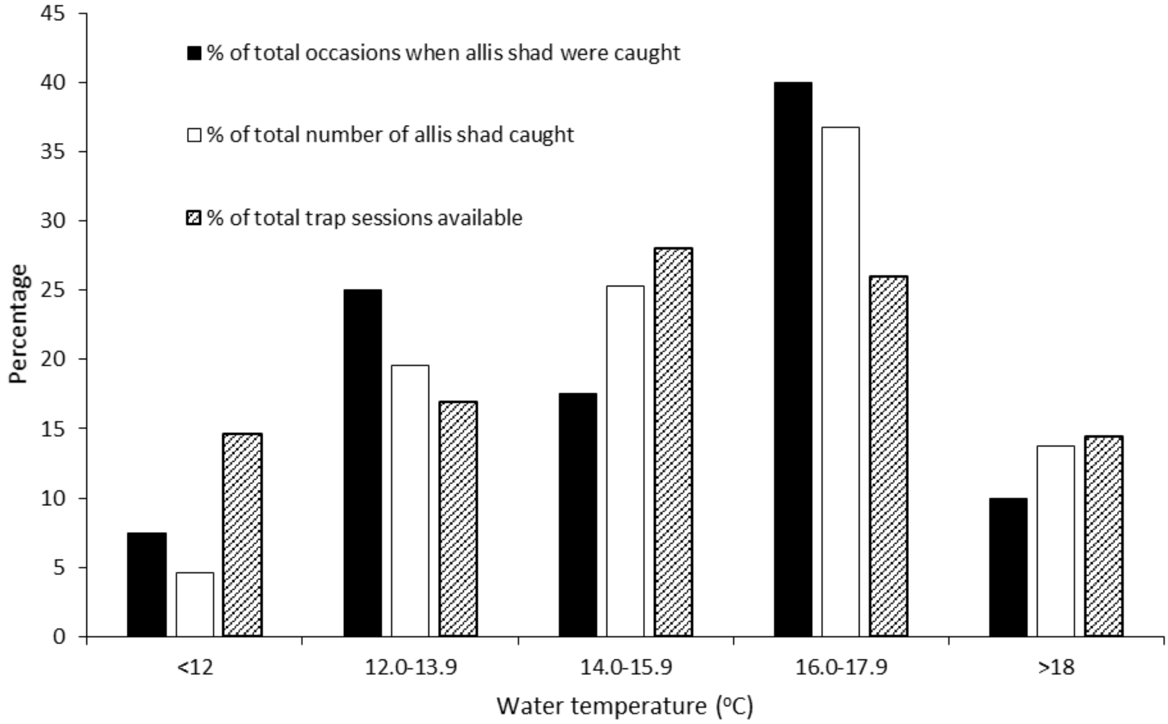

Figure 36. The percentage of allis shad trap catches and percentage of the number of allis shad caught at Gunnislake Trap, compared to the available water temperature in mid-April to end August 2004-2013 and 2015.

3.6.4 Maximum tidal height during trapping session

Maximum tidal height was not found to be a significant factor in determining the presence of allis shad in Gunnislake Fish Trap (Logistic Regression analysis). Figure 37 shows that the maximum tidal height observed during 1,152 available trap sessions between mid-April and the end of August between 2004 and 2013, and 2015, was very similar to the maximum tidal height on trap sessions when trap were caught. In other words (and as the Logistic Regression analysis suggests), allis shad do not appear to be actively targeting tides of a particular size when migrating into Gunnislake Trap; the percentage availability of tides appears to mirror the tidal heights under which shad were observed, both in terms of occasions trapped and the number of individual allis shad caught.

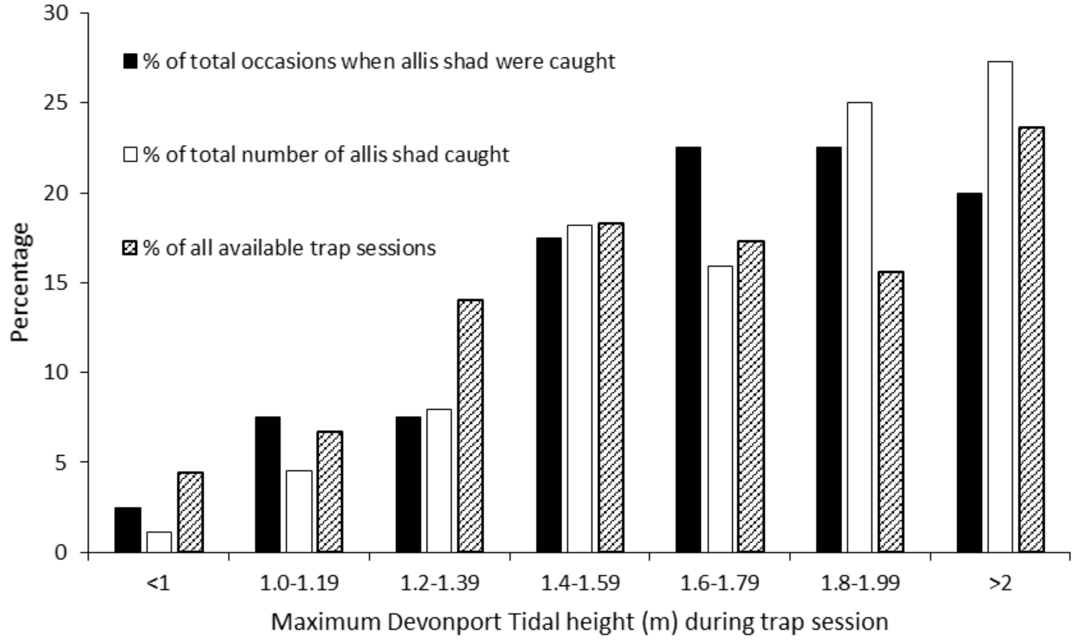

Figure 37. The percentage of total occasions when allis shad were observed in Gunnislake Trap and the percentage of total allis shad caught within each maximum tidal height band, compared to the percentage availability of each maximum tidal height band.

3.7 Environmental conditions associated with shad spawning

3.7.1 Timing of spawning

Allis shad eggs have been recorded at Cottage Run every year between 2000 and 2015, although no surveys were undertaken in 2007 and 2009. The timing of spawning varies from year to year (depending upon the prevailing environmental conditions of flow and water temperature) but the recorded range is from 15 May (in 2001) to 4 August (in 2000). The mean annual date of egg presence at Cottage Run (based upon 14 seasons of egg surveys) is 11 June (see Figure 4 on page 26, above). However, the survey driver in most years was only to confirm that allis shad had spawned, rather than to monitor the extent of the spawning period, so the true mid-point of the spawning period is likely to be later than this.

Eggs have been recorded upstream of Gunnislake Weir on only two occasions; once on 28 June 2005 and once on 7 June 2006.

3.7.2 Water temperature

Allis shad eggs have been recorded at Cottage Run at water temperatures ranging from 13.0 to 19.7°C (based upon 33 successful egg surveys between 2000 and 2015) (see Figure 5 on page 26, above). The mean water temperature when eggs have been recorded at Cottage Run was 16.0°C.

On the two occasions when allis shad eggs were recorded upstream of Gunnislake Weir, the water temperature was 20.5°C on 28 June 2005 and 15.8°C on 7 June 2006.

3.7.3 River flow

The river flow on the two occasions when allis shad eggs were recorded upstream of Gunnislake Weir was 3.6 cumecs in 2005 and 7.5 cumecs in 2006. In 2005, flows in the week preceding the egg survey were between 3.5 and 5.0 cumecs. In 2006, flows in the week leading up to the egg survey flows ranged from 15.0 on the 31 May 2006 to 8.0 cumecs on 6 June 2006, reducing all the time over this week.

River flow on days when allis shad eggs were recorded at Cottage Run (based upon 35 occasions between 2000 and 2015), ranged from 1.91 to 13.12 cumecs; the mean flow was 5.34 cumecs.

3.8 Description of Tamar shad population

Between 2000 and 2015, the EA has collected records of Tamar Estuary and River-caught shad from a number of sources, including allis shad caught at Gunnislake Fish Trap, rod anglers fishing in the tidal and freshwater Tamar, records of shad seen on cameras in the fish pass at Gunnislake Weir, sightings of shad, bycatch records from estuary salmon netsmen and dead allis shad found in the River Tamar and upper Tamar Estuary. Wherever records have enabled the physical examination of a specimen to confirm species as allis shad, measurements of length and weight were recorded and a fish has been aged from scale-reading, these fish have been included in subsequent analyses of the length, weight, age structure and spawning history of allis shad on the Tamar.

Scale-reading was undertaken using the methods proposed in Bagliniere *et al*., (2001). A scale sample was aged from 112 allis shad for this review; where scales had been read on a previous occasion they were re-read to ensure a consistent approach to age estimation.

The number of annuli was recorded and any additional growth on the scale edge. Where scales showed a clear spawning mark (reabsorption of scale material in the anterior and lateral scale) this was recorded along with the age at which the fish first spawned. Based upon 14 years of egg surveys at Cottage Run between 2000 and 2015, the mean date of egg presence was 10 June. However, in some years the driver for surveying was to determine if allis shad had spawned, rather than to continue to survey throughout the spawning season. Therefore, the true mean date of spawning is probably slightly later on the Tamar. Allowing for egg development and hatching, the anniversary date is assumed to be 1 July (as applied to allis shad in France (Bagliniere *et al.*, 2001). The total age of allis shad was determined by adding the total number of annuli and spawning marks on the scales and adding one for the scale edge. If a fish had an obvious spawning mark and was caught after the anniversary date, a year was not added for the scale edge as there was no plus growth after the spawning mark. Likewise, for a fish at the start of the freshwater phase of their spawning migration the edge of the scale is considered as and annulus, even if not visible (Bagliniere *et al*., 2001).

Many fish examined showed signs of reabsorption at the scale edge, as would be expected on a spawning migration. Also observed in many individuals, was the partial reabsorption of the scale material in the year or years before they were caught. An explanation for this might be that these individuals migrated into freshwater but did not successfully spawn.

Figure 38 shows the weight and fork length of allis shad of different ages. The fork length of Tamar allis shad (caught in the trap, recovered dead, caught by anglers or caught in estuary nets), ranged from 370 to 574mm (mean=476.8mm; *n*=114). Based upon the fork length: total length relationship in 25 fish, the fork length as a proportion of total length is 0.88. The weight of allis shad ranged from 680 to 2,230g (mean=1,367.2g; *n*=66).

Table 14 shows the mean fork length and weight of Tamar allis shad caught during the freshwater migration period.

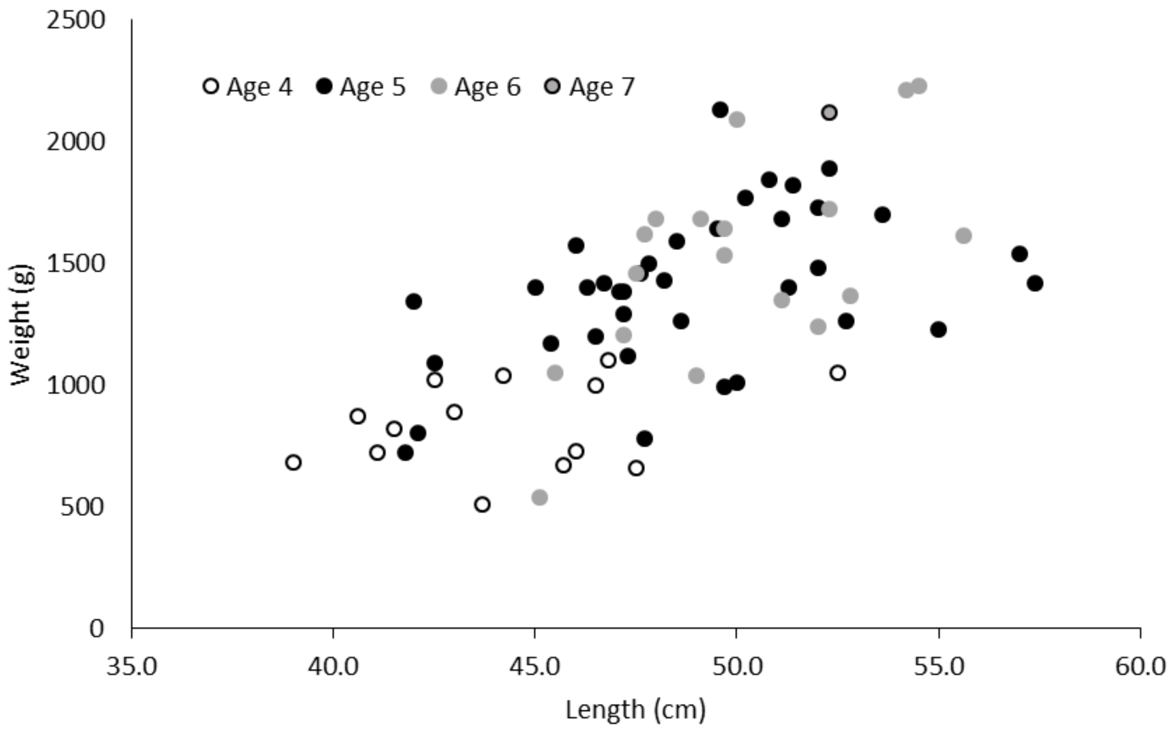

Figure 38. Fork length, weight and age of allis shad caught in the Tamar estuary and river, 2000 to 2015 (*n*=70).

Table 14. Mean weight and length of allis shad by month.

Month	*n*	Mean fork length (mm)	SD fork length	*n*	Mean weight (g)	SD weight
Apr	3	472.0	36.4	2	1580	325.2
May	49	468.8	39.2	31	1387	425.1
Jun	40	485.8	38.7	32	1348	374.0
Jul	16	491.7	49.1	13	1010	390.4

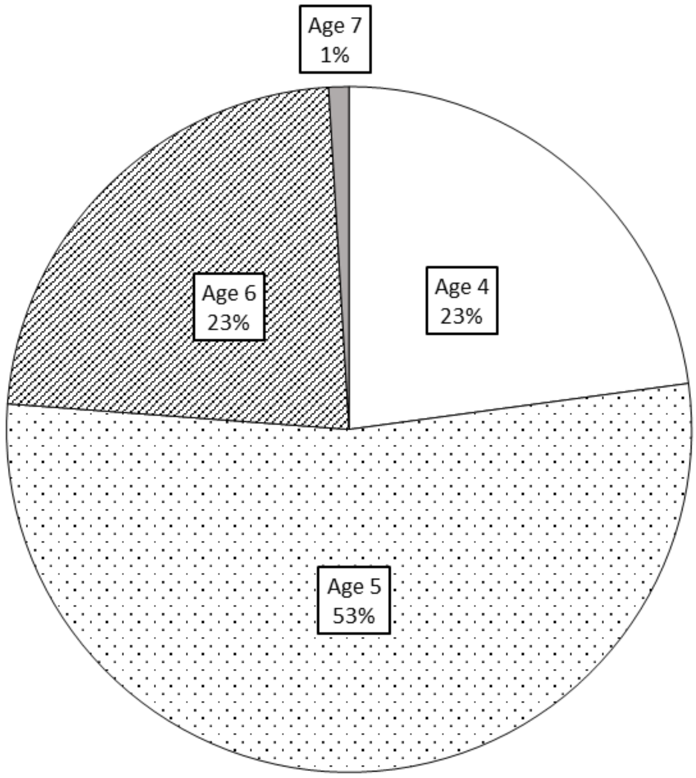

Figure 39. Age structure of Tamar allis shad population based upon 106 allis shad, aged from reading scales, from the Tamar Estuary and River, 2000-2015.

Of 106, successfully scale-aged allis shad (a further 6 individuals either had unreadable scales or too few scales to permit an age estimate), the spawning population spanned four age classes from 4 to 7 years old (Refer to Figure 39). However, one of the of the 4 year-old fish examined had a spawning mark on its scales at Age 3, which suggests that the spawning population spans five year classes. Most fish examined (53%) spawned at the age of 5, with an equal split between 4 and 6 year old fish (23% each); one seven year old fish was recorded.

Nine of the 106 allis shad examined (8.5%) had spawned on at least one previous occasion; the remaining 91.5% were on their first spawning migration (Figure 40). Two individuals examined (1.9%) had spawned twice previously and 7 fish had spawned on one previous migration (6.6%). Assuming that these two individuals successfully spawned in the year of capture they would have spawned three times in total.

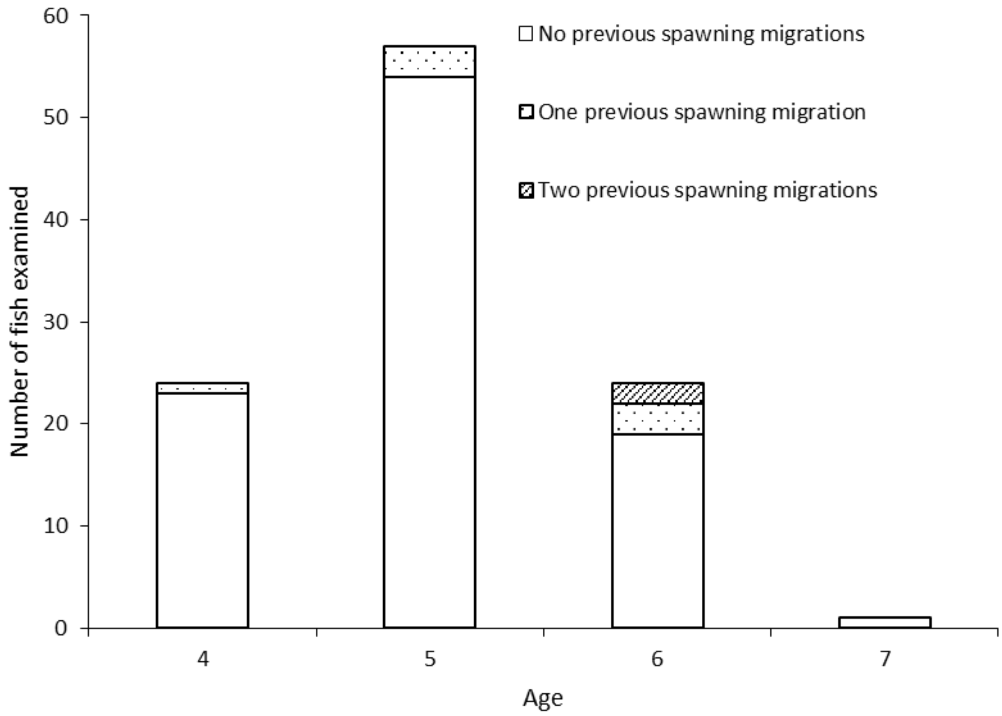

Figure 40. The number of previous spawning migrations made by allis shad caught in the Tamar estuary and river, 2000-2015 (*n*=106).

The age at first spawning ranged from 3 to 7 (Figure 41). Most fish (53%) spawned for the first time at the age of 5, with 27% first spawning at the age of 4, 18% at age 6 and approximately 1% at the ages of 3 and 7.

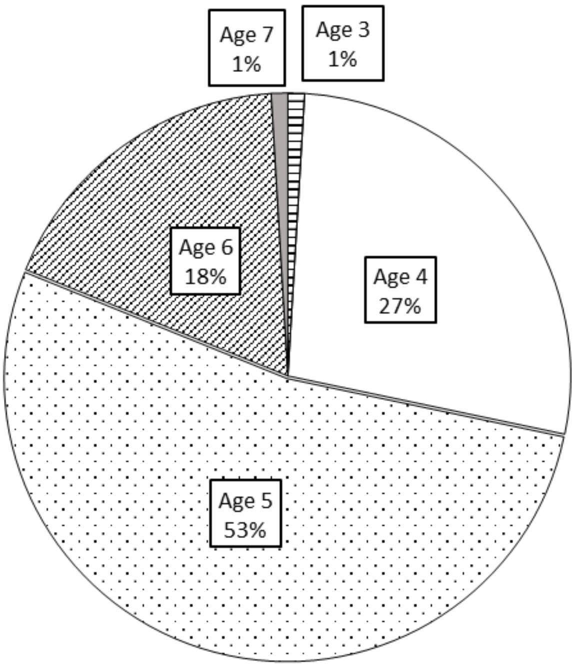

Figure 41. Age at first spawning of 106 allis shad caught on the River Tamar and Tamar Estuary.

3.9 Sex Ratio

Between 2000 and 2015, the sex has been determined by examining 16 dead allis shad. Seven females and 9 males were examined. Although allis shad eggs have been recorded upstream of Gunnislake Weir in some years, no female allis shad have been recovered from the freshwater Tamar, with the exception of one fish on 7 July 2006 which was found dead on the upstream side of Gunnislake Trap screen. By comparison, 5 dead males have been recorded from the freshwater Tamar with a further 2 fish caught migrating upstream at Gunnislake Trap, where sex was determined by recording the release of milt by males. This tends to suggest that males are more likely to successfully migrate upstream at Gunnislake Trap than females.

The mean age of females (*n*=7) was 5.4, compared to 4.8 in males (*n*=9). Two of these females and one male had spawned at least once previously. The mean fork length of females was 498mm, compared to 450mm in males. Females were considerably heavier weighing 1,174g on average (*n*=7), compared to 774g among males (*n*=6). However, the gonadosomatic index (GSI) of females was higher on average (9.83%, *n*=6) than that of males (3.15%, *n*=5). Therefore, the differences in size could be attributed to age and spawning condition, rather than true differences between the sexes; a larger sample size is needed to accurately compare the morphology of the two sexes.

3.10 Distribution of shad and allis shad records in the River Tamar and Tamar Estuary

Records of allis shad and shad from Gunnislake Trap, Gunnislake Fish Pass, rod anglers, estuary netsmen, sightings, dead specimens recovered from the river and kick-sampling surveys have also been collated and mapped (see electronic appendix 'EC18234_ShadAndSmelt_01.mpk').

3.10.1 Allis shad records from nearby estuaries

There are records of shad from almost all the estuaries along the south coast of Devon and Cornwall. In terms of allis shad and records of fish in spawning condition, there is only one confirmed record of a male from the Fowey Estuary in August 2000. There are anecdotal records of shad in the 4-5lb weight range caught near Topsham in the upper Exe Estuary which suggests a spawning migration. Scales from one shad specimen caught at Topsham in 2000 were examined by R. Hillman; this fish was 6 years old and on its third spawning migration. At the time, the species was thought to be twaite shad due to the number of spawning migrations, but evidence from the Tamar population presented in this review suggests that this individual may have been an allis shad. However, an allis shad in spawning condition has yet to be confirmed from the Exe Estuary.

4 Review of Monitoring Methods

4.1 Trawling for larval and juvenile allis shad and smelt

4.1.1 Allis shad

This method was successful in catching 0-group smelt but was not successful in catching allis shad larvae or juveniles. It is unclear why juvenile allis shad were not caught (this is discussed in Section 1.5.1). Other studies such as Maitland and Lyle (2001) used frame net traps and ichthyoplankton nets on the Cree Estuary, Scotland, to sample allis shad, but neither method successfully captured juvenile allis shad. On the Gironde Estuary system, France, Lochet *et al.*, (2009) reported catching allis shad juveniles at low density even during the peak month of arrival in the estuary.

In terms of future sampling of allis shad larvae and juveniles, sampling could be undertaken close to the banks (accepting that fallen tree debris may pose a significant problem), at the water surface and over a wider time period (Refer to Section 1.5.1). However, it is possible that the Tamar allis shad population is relatively small which will present challenges locating allis shad larvae in the Tamar Estuary, especially given uncertainties in the timing of downstream migration and transition time within the estuary.

4.1.2 Smelt

In terms of future improvements, surveys for smelt could focus at, and immediately downstream of the saline wedge rather than start near the tidal limit; smelt first appeared in the samples at a surface salinity of 0.40 (See Appendix 5.3, Table 16). On the day the surveys were undertaken juvenile smelt were recorded between Okeltor Works and Cotehele Quay, although the downstream extent of juvenile smelt distribution was not located as the surveys did not continue past Cotehele Quay. Braunder Wood was the furthest downstream site where juvenile smelt (0-group) were recorded in EA seine netting surveys in February 2015.

In future it would be useful to continue sampling until the downstream extent of juvenile smelt distribution was identified. If the start location for trawling was further down the estuary from Gunnislake it should be possible to trawl for juvenile smelt in one sampling occasion across the range of their distribution, before the tide begins to flood though access, operating, and egress is challenging during low water.

Future smelt surveys would benefit from accurately recording bottom salinity; we experienced difficulty keeping the salinity probe near the bed due to the tidal and downstream currents. Increased weight on the cable probe might resolve this issue.

4.2 Kick-sampling for allis shad eggs to assess spawning distribution

This method worked very well. Future surveys would benefit from continuing later into July and even early August to determine the temporal extent of allis shad spawning. It would also be useful in future to collect specific information on the flow velocity at locations where shad eggs were collected; this might help to locate appropriate survey areas when monitoring at different survey sites. Three people are recommended when monitoring the flow velocity associated with egg presence; one to survey for shad eggs, one person to operate the flow velocity recording equipment and a third person to record the data.

4.3 Use of Gunnislake Fish Trap bycatch and review of Gunnislake Fish Pass camera footage to assess upstream migration of allis shad into the River Tamar

In 2015, no allis shad were caught in Gunnislake Fish Trap or seen migrating upstream at Gunnislake Fish Pass. Using these two methods in combination is an effective method for assessing the extent of upstream allis shad migration at Gunnislake Weir (even though it was apparently zero in 2015). Gunnislake Fish Trap is operated between May and October so there is potential each year to catch allis shad as they migrate upstream. However, the trap is only operated twice per week in May, rising to five times per week in June. In future, if Gunnislake Fish Trap is to be used as a method of monitoring upstream allis shad migration the effort in May should be increased.

The review of camera footage at Gunnislake Fish Pass is very labour intensive and does not always enable an absolute identification between allis shad and other species, such as sea trout, depending upon the angle and position of the fish in the image frames available to view. However, camera footage is reviewed for salmonids between June and August so looking out for allis shad, provided appropriate training is given, is possible.

In future it might be advisable to focus on monitoring the number of allis shad caught as a bycatch at Gunnislake Fish Trap and make an adjustment for the time that the trap was non-operational to estimate the number of individuals migrating upstream.

4.4 Smelt egg surveys

The physical examination of pebbles and cobbles to search for smelt eggs was successful in that live smelt eggs were found (even though the smelt spawning sites were not identified). However, there are a number of potential sampling changes that could be made in future; firstly, sampling for smelt eggs was targeted on the upper Tamar Estuary at historic spawning sites (Dando, *pers. comm.*) and nearby sites with shallow, fast flowing water over gravel/pebble/cobble substrate. On the Lynher Estuary, sampling was focused at and around the tidal limit. Smelt eggs were not found in abundance in any of the egg surveys, leading to the conclusion that the spawning location on the Tamar Estuary was further down the estuary than the lowest egg survey site. Future egg sampling should extend from the tidal limit at Gunnislake further down the estuary to Calstock. Pedestrian access to the estuary foreshore becomes almost impossible downstream of Impham Meadow. A small, shallow-drafted boat is probably the best means of undertaking egg surveys at high or mid-tide. It is likely, given the muddy nature of the estuary downstream of Impham Meadow that smelt spawn on marginal vegetation so egg surveys should focus upon the estuary margins around and below the high water mark. Maitland (2003) reported that at Limerick on the River Shannon, Ireland, where the river is deep, smelt spawn alongside thick growths of *Fontinalis* moss growing on vertical man-made stone walls.

To support the physical search for eggs at the spawning site, it is advisable to also sample for eggs in the current using a plankton net held against the current in the estuary margins. The specification of the plankton net is described in Section 1.3.1. This would provide a relative indication of the number of smelt eggs drifting on the tide (dislodged from the spawning site); examination of these eggs to determine the development stage would provide information on the timing of spawning events. If large numbers of free-floating, early-development-stage eggs are found, this is a good indication that there should be eggs attached to the channel/marginal substrate somewhere in the upper estuary.

Kick-sampling for smelt eggs has been used on the Thames Estuary in conjunction with a visual substrate inspection at low tide (Smelt Citizen Science Guide). However, access to the Upper Tamar Estuary at low tide is more difficult than the Thames. Attempts to kick-sample for smelt eggs in the Upper Tamar Estuary were unsuccessful, primarily due to an apparent lack of smelt spawning in the upper estuary, but in hindsight there is limited access to spawning sites in the upper estuary. The Thames in contrast has several km of potential smelt spawning habitat upstream of the kick-sampling locations between Hammersmith and Greenwich.

It is possible that smelt egg sampling will span two financial years as it continues through March into early April; future sampling will need to address this. Greater emphasis should also be placed on continuous egg sampling at weekly intervals. Rather than pausing egg sampling during periods of high flow (as happened in spring 2016 due to the expectation that smelt would spawn in the upper estuary, upstream of Impham Meadow), future sampling should continue (as long as it is safe to do so), albeit focusing further down the estuary.

In 2016 significant diatom growth was observed in late March and early April, making it unlikely that smelt would choose to spawn on the channel substrate. Future egg sampling at these times should focus more upon (or at least include) marginal vegetation further down the estuary, due to the apparent unsuitability of the channel substrate once diatom growth is established. In terms of the start date for egg sampling, this should be driven by water temperature but based upon observation on the Cree (Maitland & Lyle, 2001) spawning could take place in mid-February in some years.

4.5 Fyke netting for smelt

This method was successful, given that on two of the three sampling occasions smelt were caught, albeit in small numbers. It did provide a useful insight into the distribution of adult smelt in spawning condition, especially since the capture of ripe adult smelt in the upper estuary contrasted to a failure to find a spawning site in the area.

If this method were to be used again in future the use of additional pairs of fyke nets would provide higher catches. Also, less emphasis should be given to the high spring tides; Maitland and Lyle (2001) concluded that tide level is probably less important in rivers where passage to the spawning grounds is more freely achieved. The Tamar Estuary downstream of Cottage Run Weir is accessible on smaller tides, whereas larger tides are required to enable smelt to access areas up to the tidal limit at Gunnislake Weir.

On the two occasions smelt were caught in the fykes, the nets were operational from early evening to the following morning. Where possible this is recommended (rather than netting in the evening only) as smelt are known to migrate into the upper estuary around midnight (Dando, *pers.com.*).

In this study, fyke netting was undertaken by way of a trial to determine how successful it is as a viable method for catching smelt on a spawning run. If used in future, more sampling occasions would provide greater catches and better information on the timing of smelt migration into the Upper Tamar Estuary. Unfortunately, suitable fyke netting sites were difficult to find and fyke netting further downstream from Impham Meadow would not be at all easy, given the muddy substrate, poor access and relatively deep water.

We found that the fyke netting location on the inside of a meander bend worked well, enabling the fyke net to be set within the channel but out of the main flow of the current. In future, emphasis should be placed on preventing the rolling of the fyke net at high water; we found anchors and heavy weights on the mouth of each fyke net worked very well.

4.6 Beam and otter trawling for adult smelt

Adult smelt were caught in both beam and otter trawls, although it was not possible to use both sampling methods on the same day to compare smelt catches. Ten surveys using the beam trawl on 12 January 2016 did not catch smelt, whereas 6 surveys using the otter trawl the following day on 13 January 2016 captured 27 smelt in total. However, the beam trawl successfully caught 38 smelt, although predominantly 0-group, on 3 August 2015.

After comparison with the beam trawl, the otter trawl was used from 13 January 2016 onwards; this generated excellent catches of smelt, particularly in March 2016. Some hauls by both gears included very large volumes of leaf litter.

Although the beam trawl could be used further up the Tamar Estuary as far as Morwellham, the otter trawl was certainly successful in the reach from Braunder Wood to Halton Quay. If future sampling is required upstream of Braunder Wood, then beam trawling is suitable; downstream of Braunder Wood otter trawling is possible and is the recommended method based upon the results of this monitoring. A detailed description of the beam and otter trawling results is given in Section 2.4.3.1.

5 Overall Conclusion

5.1 Health of population

5.1.1 Allis shad

There is no evidence, either as eggs or observations of migrating fish, that allis shad entered the non-tidal freshwater Tamar in 2015. Evidence suggests that in 2015, allis shad spawned at just one location downstream of Gunnislake Weir at Cottage Run in the Upper Tamar Estuary. That is not to say that allis shad eggs have not been found in the past at sites in the freshwater Tamar above the tidal limit. No allis shad were caught at Gunnislake Fish Trap in 2015, nor were any shad seen migrating upstream on camera footage at Gunnislake Fish Pass. Indeed, 2011 was the last year that more than one allis shad was caught in Gunnislake Fish Trap (Figure 32, Section 3.5). Although allis shad eggs have been found at the Cottage Run spawning site in the Upper Tamar Estuary every year since 2011, there is little evidence that allis shad are utilizing the freshwater Tamar to spawn and care should be taken when treating the results of this survey as a baseline against which to compare future surveys, due to the unusually low flows in Gunnislake Fish Pass in 2015, caused by the leaking sluice gate.

In 2015, two allis shad were caught by anglers downstream of Gunnislake Weir and three allis shad were caught by estuary salmon netsmen in two hauls at Cotehele and Hole's Hole. In addition, anglers reported catching shad from Plymouth Sound and a shad was seen on an underwater webcam in Plymouth Sound. All of these records confirm that allis shad are continuing to return to the Tamar Estuary.

The size of the Tamar adult spawning allis shad population is unknown, so it is not possible to determine population health with respect to the size of the breeding population. King and Stevens (2015) undertook a genetic analysis of Tamar allis shad samples from 2004 to 2013 and concluded that there was a single, freely-interbreeding population with genetic profiles stable over the 10-year sampling period. However, there appears to have been a sharp downturn in the number of allis shad observed migrating upstream at Gunnislake Fish Trap since 2011 and most of the samples in this analysis pre-date this observation.

The spawning population of allis shad on the Tamar is predominantly from three year classes (4, 5 and 6-year old fish) with more than half the spawning population from the 5-year age class. There is a low incidence of repeat-spawning in the Tamar allis shad population; the spawning population, although typical of other European stocks (Aprahamian *et al.*, 2003), is composed of relatively few age classes, which depending upon year-class strength may account for the relatively large annual fluctuation in numbers seen at Gunnislake Fish Trap.

The absence of allis shad larvae and juveniles from plankton netting, beam and otter trawl surveys mirror findings in other studies (e.g. Maitland and Lyle, 2001). The rapid estuary transition time of juvenile allis shad described by Lochet *et al.*, (2009) makes this a very difficult life stage to study due to temporal and spatial sampling uncertainty.

In summary, the status of the Tamar allis shad population is uncertain but there are several observations that give cause for concern, namely the sharp downturn in the number of allis shad seen migrating upstream via Gunnislake Fish Trap since 2011 and the apparent use of just one spawning site in the upper Tamar Estuary (and apparent lack of spawning in other estuaries in the SAC such as the Lynher). However, recent catches of allis shad by anglers and netsmen in the tidal Tamar and the presence of allis shad eggs every year in the upper estuary since 2011 shows that allis shad are continuing to spawn at the site. Future research should focus upon the adult spawning population in the upper estuary to provide a size estimate of the spawning allis shad population.

5.1.2 Smelt

Otter trawl catches of adult smelt in the Tamar estuary in spring 2016 suggest that the adult spawning stock is composed of a range of age classes (based upon the size range), which is indicative of a healthy population. However, there is no way of making a quantitative estimate of smelt population size based upon available data.

Smelt did not utilize the historic spawning site at Cottage Run in spring 2016 and although a few ripe adult smelt were caught in the upper estuary in fyke nets at Impham Meadow, no spawning site was found. It is unclear why smelt did not spawn at the historic spawning site; neither is the location of the current smelt spawning site known. There is no evidence that smelt use other estuaries in the Tamar MCZ, apart from the Tamar itself.

5.2 Distribution within the Tamar Estuaries

5.2.1 Allis shad

No adult allis shad were caught or seen at Gunnislake Fish Trap or Fish Pass. No eggs were found at any of the sampling sites in the freshwater Tamar (or Lynher). This suggests that allis shad did not migrate into the freshwater River Tamar in 2015. Spawning appears to be limited to a single site at Cottage Run in the Upper Tamar Estuary, where shad spawn in a riffle downstream of Cottage Run Weir.

No larval, juvenile or adult allis shad were caught in the Tamar Estuary by any of the sampling methods in 2015. A small number of records were reported by anglers and netsmen from the tidal Tamar in 2015. Records of allis shad in the estuary are almost exclusively from either salmon and sea trout rod anglers or netsmen and the distribution of allis shad records reflects the distribution of these two fisheries. Angler records are most numerous between Gunnislake Weir Pool and Lower Cottage Run which are upstream and downstream of the spawning site, respectively. Most allis shad caught in the net fishery are caught at the netting stations at Hole’s Hole, Cotehele and Calstock.

5.2.2 Smelt

In August 2015 beam trawling showed that adult smelt were present in the upper estuary, with two individuals caught at Morwellham. However, most of the smelt caught in August between Morwellham and Calstock were 0-group year class. Catches were made at five sites between Morwellham Quay and Calstock, suggesting that the 0-group was distributed throughout this reach on the day of the survey. Beam trawls in November 2015 recorded 3 adult smelt; one from Calstock and two from Halton Quay.

Adult smelt tended to congregate in spring 2016 between January and March in the middle Tamar Estuary between Halton Quay and Braunder Wood. In January, 25 adult smelt were caught at Halton Quay (Lower) and one adult smelt at Cargreen; one of the smelt caught at Halton Quay (Lower) was possibly 0-group. Only one smelt was caught in February otter trawls; a probable 0-group fish at Halton Quay (Lower). Most of the 178 individuals caught in March were adult smelt at Halton Quay; approximately 12 of these fish are suspected to be 0-group based upon the size of the fish. EA seine netting surveys in February 2015 found that 0-group smelt were present at Cotehele and Braunder Wood but not at sites lower down the Tamar estuary; one adult smelt was caught at Cotehele.

In summary, juvenile (0-group) smelt were caught between Morwellham and Calstock in August but present as far downstream as Halton Quay in spring months. Adult smelt were present in the upper estuary in August, with catches between Calstock and Cargreen between November and March, with most catches of adult smelt at Halton Quay. There was a notable lack of smelt in the lower estuary in the spring months. The distribution of adult smelt in the middle and lower Tamar estuary between April and October requires further investigation.

6 Recommendations

6.1 Allis shad

Future research should prioritise determining adult spawning population size on the Tamar, downstream of Gunnislake Weir. The size of the adult allis shad run on the Tamar is unknown, because it is not known how large a proportion of the overall spawning run might ascend Gunnislake Weir via the monitoring facility at Gunnislake Fish Pass and Trap. One way of assessing population size would be to study spawning adults on the spawning site; Aprahamian *et al.*, (2003) give a good description of the nocturnal spawning behavior of allis shad. Cameras with infra-red lights and microphones could be set up at the spawning site to record the number of matings (fish swim in a swirl at the surface with vigorous splashing of the water) and this could be used to infer the number of spawning individuals. This should be feasible at the spawning site if equipment was set up on the Devon Bank where the riverbank rises several metres above the water height, offering a good vantage point for setting up cameras above the surface of the water.

Although technically challenging, it might be possible to set up a temporary array of underwater cameras to capture images of allis shad migrating upstream at an upper estuary location such as Impham Meadow. However, a light source would be needed to record the migration of allis shad from daytime holding areas to the spawning site at night; a power source would obviously be required. Hately and Gregory (2005) found that twaite shad tended to avoid multi-beam sonar system equipment (DIDSON), rendering this unsuitable as a method of monitoring upstream allis shad migration on the Tamar.

It may be possible to use the genetic diversity among eggs sampled throughout a spawning season to calculate the size of the parent stock. However, this would involve considerable sampling of eggs, many of which would be from the same spawning adults. This could also be potentially damaging to the allis shad population if all spawning is limited to one location.

Although it would be advantageous to understand the distribution of larval and juvenile allis shad in the Tamar Estuary, this is a very difficult life stage to sample. Considerable sampling effort could be spent looking for juvenile allis shad in the Tamar Estuary, but with such temporal and spatial sampling uncertainty and a relatively large search area, there is a relatively low chance of success. Future efforts to locate and capture juvenile allis shad in the Tamar Estuary should target surface layers, close to the banks during the period July to September inclusive; sampling intervals should be monthly, preferably fortnightly. Netting could be done on foot by holding a plankton net against the current of an ebbing tide in the estuary margins. Provision would need to be made for significant sample analysis time. However, monitoring resources would be better focused upon the adult spawning migration and egg distribution.

Kick-sampling for eggs should continue as the principle method for determining spawning distribution. Annual monitoring is recommended at Cottage Run, as as potentially this site represents the entire Tamar spawning stock. Egg surveys should begin in May when water temperature reaches around 15^{o}C, and continue later than in previous years with particular emphasis on the latter end of the allis shad spawning season; does it extend into July and August in most years or was 2000 an unusual year?

Monitoring of allis shad caught at Gunnislake Fish Trap and seen (opportunistically) on camera footage from the fish pass should continue, especially given that there have been no significant allis shad catches since 2011. Continued recording of allis shad catches by rod anglers and estuary netsmen is recommended. Records of shad catches should also be collected from anglers, netsmen and other sources such as commercial fishermen and IFCAs. Some estuaries in south-west England deserve future investigation with respect to potential allis shad spawning populations; based upon reports of shad catches in the Topsham area there may be a spawning population of allis shad in the Exe Estuary. There have also been several catches of allis shad by salmon netsmen in the Torridge Estuary and rod anglers on the River Torridge downstream of Beam Weir which might suggest a spawning run.

6.2 Smelt

Future research should prioritise locating the smelt spawning site(s) in the Tamar Estuary, given that smelt did not spawn at the historic spawning sites in the upper Tamar Estuary between Impham Meadows and Gunnislake Weir in 2016. Suggested methods for doing so are included in Section 4.4. Upstream of Impham Meadow the egg survey methods used in 2016, involving a visual inspection of channel substrate for smelt eggs, worked very well and should be repeated in future monitoring. However, egg surveys should also be undertaken further down the estuary. Downstream of Impham Meadow the River Tamar is characterised by steep muddy banks. Access on foot is difficult and in any case spawning in the channel is unlikely on the silty substrate. If spawning occurs in the estuary downstream of Impham Meadow (and the lack of spawning observed in the upper Tamar Estuary in 2016 suggests that it does), egg surveys could be done either on foot looking at marginal vegetation for eggs or by boat at high water, again targeting marginal structures to see where spawning has taken place. It should be obvious where smelt have spawned due to a high density of eggs adhering to marginal structures and vegetation. It is possible that Morwellham Island represents suitable spawning substrate and this requires investigation.

To support investigations on the timing and location of spawning a tow-net survey is recommended further down the estuary when looking for eggs; this would show when (if not exactly where) spawning had taken place. Alternatively larvae and post-larvae could be surveyed on foot using a plankton-net held against the tidal flow near the margins of the estuary. This would give an indicating of the timing of smelt spawning from the development stage of the larvae and post-larvae caught. Egg traps could be considered downstream of Impham Meadow as a means of determining the timing of spawning and narrowing down the spawning location by relative egg abundance in the water column; they could be inspected at low water by pulling to the bank without having to enter the muddy channel, or at high water by boat.

Planning for smelt egg surveys should anticipate that monitoring will bridge two financial years (i.e. end of March and beginning of April); this should help to avoid long gaps between egg survey dates in future. Frequent egg surveys are recommended, with no more than weekly intervals between survey dates.

Other significant knowledge gaps include the distribution of adult smelt outside of the spawning period; do smelt disperse throughout the Tamar Estuary or migrate out of the estuary to coastal waters? A tracking study is probably the best way of determining the post-spawning estuarine and coastal distribution between April and November. If adult fish were otter trawled, tagged and released in March at Halton Quay, this should provide a good sample size allowing for post-spawning mortality. It should also reveal where smelt are congregating to spawn in the upper estuary, assuming that not all the population have spawned by March. If tagging stock are to be collected it is advisable to attempt collecting individuals to tag in February in case spawning occurs earlier than expected. Ensure that otter/beam trawling is undertaken as far upstream as possible (between Cotehele and Halton Quay ideally).

Fyke netting was successful at catching adult smelt in spawning condition and should be considered as a viable method for future monitoring of smelt on the spawning run; it provides data on the size, sex ratio and relative abundance of spawners. The low number of smelt caught in the fyke net in 2016 may be due to smelt apparently not spawning in the upper Tamar Estuary above the fyke netting site, rather than the method failing to catch smelt. Section 4.5 provides some suggested changes to fyke netting that might improve catches in future.

Trawling for adult smelt has proven to be a good catch method but gear selection is important to consider. Due to depth restrictions only beam trawling can be used when smelt are up as far as Morwellham Quay however, as soon as it is possible (in deeper water and where width permits) otter trawling yields potentially greater catches. This raises significant challenges for survey design and consistency.

The upper navigable areas (around Morwellham Quay) can only be sampled by towed gear on spring tides. Even during the last days of these tides there is insufficient time to transit up the river in the winter (due to daylight limits) for full-river sampling to be undertaken as by the lower reaches the tide is in full ebb. The situation is better on neap tides but on these the upper areas cannot be reached. This point with the one above implies that sampling needs to be stratified by gear and area. This will increase the number of days required for a full river survey though more replicates could then be undertaken.

In future, some changes should be applied when collecting data from smelt caught whilst trawling. Where possible all smelt in spawning condition should be sexed as this proved to be relatively straightforward and might be useful for determining better length and weight characteristics, plus sex ratio, however, this may have implications for the survival of individuals. When catches allow it is probably desirable to laboratory weigh some specimens. Weighing small specimens at sea is difficult and can sometime be imprecise for smaller individuals. Scale samples were taken from a number of adult smelt; these have been retained and could be aged in a laboratory to provide more detailed information on the age structure and growth rate of the Tamar smelt stock. It may also be possible to submit these samples for chemical analysis to determine relative time spent in low salinity estuarine environments versus marine environments (for example from the Calcium to Strontium ratio in different parts of the scale).

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8 Appendix

8.1 Map of locations

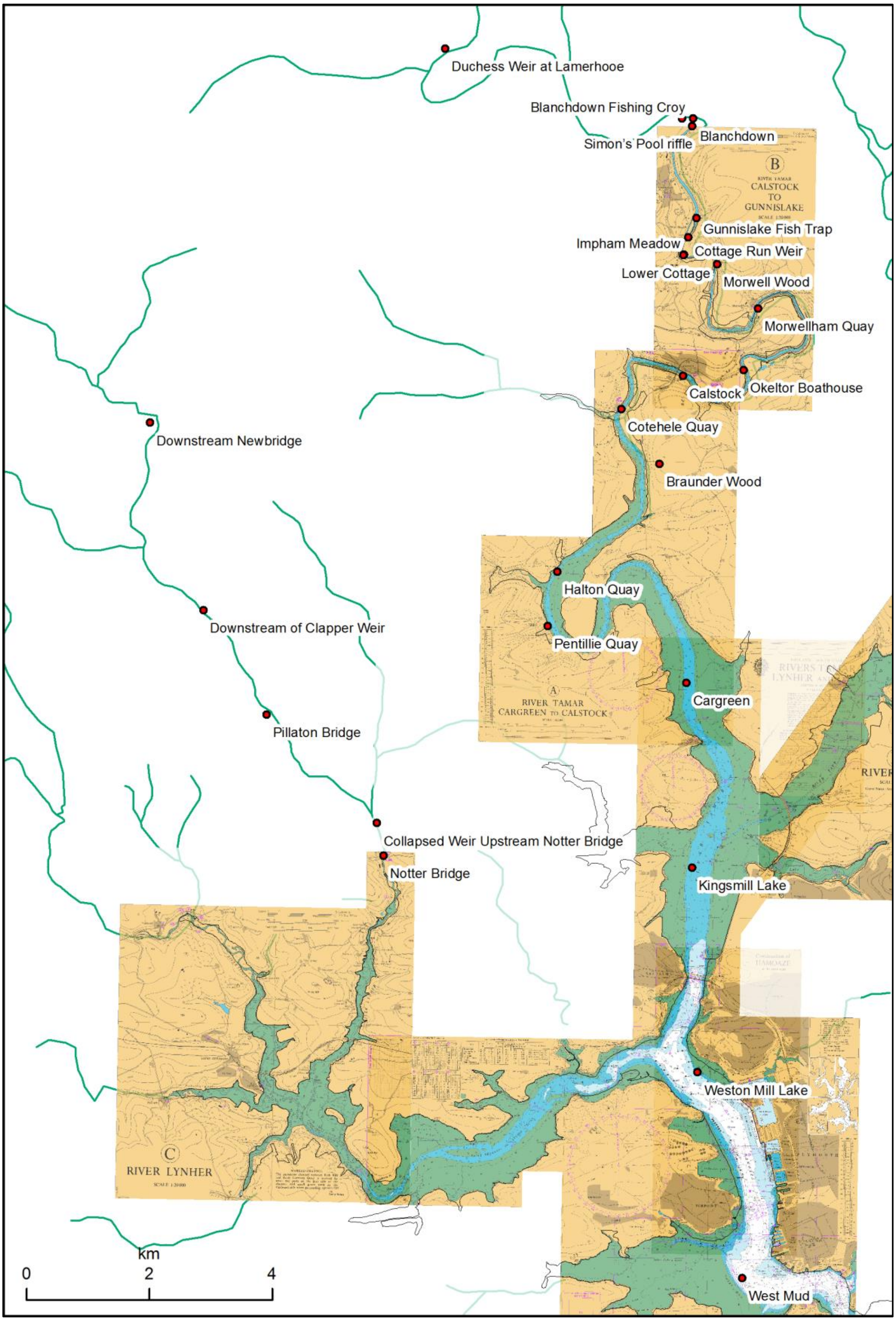

Figure 42. Map of locations.

8.2 Fishing trips including personnel

Table 15. Fishing dates, trip numbers, number of tows, start and finish locations and personnel on board SEPIA.

Date	06 Aug 2015	03 Nov 2015	12 Jan 2016	13 Jan 2016	16 Feb 2016	14 Mar 2016
Trip	T01	T02	T03	T04	T05	T06
Gear	Beam	Beam	Beam	Otter	Otter	Otter
Number of tows	11	11	10	6	9	8
Start location	Morwellham Quay	Morwellham Quay	Halton Quay (lower)	Halton Quay (lower)	Halton Quay (lower)	Halton Quay (upper)
Finish location	Pentillie Quay	Pentillie Quay	West Mud	West Mud	West Mud	West Mud
Skipper	Roger Pawley, MBA	Roger Pawley, MBA	Roger Pawley, MBA	Roger Pawley, MBA	Roger Pawley, MBA	Roger Pawley, MBA
Personnel	Sean McTierney, MBA	Sean McTierney, MBA	Sean McTierney, MBA	Sean McTierney, MBA	Sean McTierney, MBA	Andrew Pawley, MBA
	Andrew Pawley, MBA	Sophie Banham, MBA	Pete Rendle, MBA	Pete Rendle, MBA	Pete Rendle, MBA	Aisling Smith, MBA
	Stephen Cotterell, MBA	Aisling Smith, MBA	Sophie Banham, MBA	Andrew Pawley, MBA	Aisling Smith, MBA	Sophie Banham, MBA
	Liam Faisey, MBA	Stephen Cotterell, MBA	Stephen Cotterell, MBA	Sophie Banham, MBA	Sophie Banham, MBA	Stephen Cotterell, MBA
	Rob Hillman, EA	Pete Rendle, MBA	Rob Hillman, EA	Stephen Cotterell, MBA	Stephen Cotterell, MBA	Liam Faisey, MBA
		Rob Hillman, EA	Andrew Stanger, NE	Jack Dickenson, MBA	Rob Hillman, EA	Rob Hillman, EA
		Paul Elsmere - EA			Paul Elsmere, EA	Paul Elsmere, EA
					Trudy Russell, NE	Annie Jenkin, NE
						Zoe Gonvett, NE

8.3 Details of smelt plankton sampling

Table 16. Start, end (duration) and position (NGR and decimal degrees) of plankton tows on 24 Jul 2015 that targeted shad. Also given are: approximate distances along track (and sampled volume based on mechanical flowmeter readings), surface and where possible bottom salinity measurements, water temperature and counts (and derived density values) for juvenile smelt.

Sample number	Time Start	End	Duration (hh:mm)	(s)	Recorded position (NGR) Start	End	Action	Derived position (start) Latitude	Longitude	Action	Derived position (end) Latitude	Longitude	Approx. distance along river (m)	Surface Salinity start	Surface Salinity end	Bottom Salinity start	Bottom Salinity end	Av. trawl speed (kt)	Av water depth (m)	Flowmeter Start	End	Count	Distance (m)	volume sampled	Comments	Count of smelt juveniles	Smelt density (n m^3)
1	10:11	10:18	00:07	420	SX4358770877	SX4346870741	01 shoot	50.516727	-4.207629	01 haul	50.515473	-4.209249	180	0.11	0.11			1.5	1.2	0	4971	4971	134	105	T = 16.2	0	0.000
2	10:20	10:27	00:07	420	SX4346570737	SX4344570562	02 shoot	50.515437	-4.209289	02 haul	50.513859	-4.209498	176	0.11	0.11			1.0	1.4	4971	11386	6415	172	135		0	0.000
3	10:29	10:35	00:06	360	SX4374370568	SX4361670794	03 shoot	50.513992	-4.205300	03 haul	50.515989	-4.207185	140	0.11	0.11			1.3	2.2	11386	17011	5625	151	119		0	0.000
4	10:36	10:42	00:06	360	SX4362370496	SX4382170521	04 shoot	50.513313	-4.206961	04 haul	50.513591	-4.204181	200	0.11	0.11			1.0	2.3	17011	21060	4049	109	85		0	0.000
5	10:45	10:52	00:07	420	SX4382270522	SX4399370466	05 shoot	50.513600	-4.204168	05 haul	50.513142	-4.201734	180	0.11	0.11			1.0	2.3	21060	26026	4966	133	105		0	0.000
6	10:54	11:02	00:08	480	SX4399370463	SX4398270283	06 shoot	50.513115	-4.201733	06 haul	50.511495	-4.201813	177	0.11	0.11			0.9	1.8	26026	34590	8564	230	181	T = 16.1	0	0.000
7	11:04	11:12	00:08	480	SX4398070286	SX4392970043	07 shoot	50.511521	-4.201842	07 haul	50.509324	-4.202459	248	0.11	0.11			1.2	2.1	34590	41462	6872	185	145		0	0.000
8	11:16	11:28	00:12	720	SX4392269970	SX4388169663	08 shoot	50.508666	-4.202527	08 haul	50.505896	-4.202977	309	0.11	0.11			0.9	2.0	41462	48753	7291	196	154		0	0.000
9	11:29	11:37	00:08	480	SX4388569670	SX4387169440	09 shoot	50.505960	-4.202923	09 haul	50.503890	-4.203024	242	0.11	0.11			1.0	2.2	48753	56173	7420	199	157		0	0.000
10	11:39	11:46	00:07	420	SX4387269444	SX4400869302	10 shoot	50.503926	-4.203012	10 haul	50.502686	-4.201036	229	0.12	0.12			0.9	2.2	56173	61596	5423	146	114		0	0.000
11	11:47	11:59	00:12	720	SX4400469302	SX4430469301	11 shoot	50.502685	-4.201093	11 haul	50.502756	-4.196865	300	0.12	0.13			0.9	2.3	61596	72153	10557	284	223	Upstream M. I. T = 17.2	0	0.000
12	12:04	12:13	00:09	540	SX4448169313	SX4460569513	12 shoot	50.502911	-4.194376	12 haul	50.504741	-4.192712	235	0.13	0.15			0.9	2.5	72153	80318	8165	219	172	Downstream M. I.	0	0.000
13	12:15	12:24	00:09	540	SX4460369506	SX4466869681	13 shoot	50.504678	-4.192738	13 haul	50.506268	-4.191894	186	0.15	0.16			0.9	2.8	80318	87654	7336	197	155		0	0.000
14	12:26	12:36	00:10	600	SX4466369671	SX4486069833	14 shoot	50.506176	-4.191961	14 haul	50.507684	-4.189252	146	0.16	0.17			0.9	2.8	87654	96050	8396	226	177		0	0.000
15	12:38	12:44	00:06	360	SX4486969837	SX4513269898	15 shoot	50.507723	-4.189127	15 haul	50.508341	-4.185446	271	0.17	0.18			1.2	2.7	96050	102480	6430	173	136	T = 17.2. Ebb tide noticeable	0	0.000
16	12:47	12:57	00:10	600	SX4520469869	SX4543869420	16 shoot	50.508099	-4.184420	16 haul	50.504126	-4.180936	506	0.18	0.22			1.5	3.1	102480	112170	9690	260	204		0	0.000
17	13:00	13:09	00:09	540	SX4546069361	SX4527968955	17 shoot	50.503602	-4.180602	17 haul	50.499905	-4.182984	479	0.23	0.28			2.0	3.3	112170	120800	8630	232	182	T = 17.4	0	0.000
18	13:17	13:25	00:08	480	SX4517168961	SX4477268811	18 shoot	50.499931	-4.184508	18 haul	50.498477	-4.190067	426	0.28	0.37			1.9	3.1	120800	128810	8010	215	169	T = 17.3	0	0.000
19	13:28	13:37	00:09	540	SX4474868813	SX4447868677	19 shoot	50.498489	-4.190406	19 haul	50.497195	-4.194154	548	0.40	0.98		2.94	2.1	3.2	128810	137617	8807	237	186		1	0.005
20	13:39	13:48	00:09	540	SX4449368632	SX4432868243	20 shoot	50.496794	-4.193923	20 haul	50.493255	-4.196086	451	1.05	1.96	2.94	6.84	1.9	3.9	137617	145443	7826	210	165	T = 17.6	1	0.006
21	13:50	13:58	00:08	480	SX4426668227	SX4377768196	21 shoot	50.493094	-4.196953	21 haul	50.492686	-4.203828	512	1.70	2.04	6.84	6.00	2.1	3.8	145443	153568	8125	218	171		1	0.006
22	14:02	14:09	00:07	420	SX4375268219	SX4352068548	22 shoot	50.492886	-4.204190	22 haul	50.495780	-4.207596	402	2.22	3.30	6.00	8.50	2.1	3.6	153568	160243	6675	179	141	Much of sample lost while fixing.	0	0.000
23	14:12	14:21	00:09	540	SX4349668573	SX4311268716	23 shoot	50.495998	-4.207945	23 haul	50.497181	-4.213415	409	2.85	3.80	8.50	9.40	2.2	3.0	160243	167150	6907	186	146		2	0.014
24	14:24	14:34	00:10	600	SX4311268716	SX4260468835	24 shoot	50.497181	-4.213415	24 haul	50.498114	-4.220622	521	3.70	4.11	9.40		1.9	3.1	167150	177860	10710	288	226	Flow prevented B sal read. T= 17.9	3	0.013
25	14:37	14:50	00:13	780	SX4255268781	SX4245368083	25 shoot	50.497614	-4.221332	25 haul	50.491315	-4.222432	738	4.50	5.64		12.04	1.9	2.9	177860	191612	13752	370	290	T = 18.0	4	0.014

8.4 Details of smelt beam and otter trawl sampling

Table 17. Details of T01 on 06 Aug 2015 detailing gear, stations, times, duration and position of shoot and hauling along with sound velocity profile derived water temperature and salinity.

						Duration		Position (DD, WGS84)						SVP water temperature (°C)					SVP water salinity						
Trip	Gear	Station	Action	Haul code	DateTime	(mm:ss)	(mm.mm)	Latitude	Longitude	Distance (m)	Speed over ground (kt)	Course over ground (°M)	Cumulative distance (nm)	n	min	mean	max	stdev	n	min	mean	max	stdev	Bottom salinity	Comments
T01	Beam	Morwellham Quay	01 shoot		06/08/2015 09:38:41			50.503705	-4.193187	n/a	0.7	198	0.0											T 0.23; B 0.18	
T01	Beam	Morwellham Quay	01 haul	T01_01	06/08/2015 09:49:20	10:39	10.65	50.508318	-4.186787	685	2.5	081	0.3	639	16.31	16.34	16.41	0.02	639	0.11	0.18	0.34	0.03	T 0.33; B 0.33	
T01	Beam	New Quay straight	02 shoot		06/08/2015 09:53:25			50.507547	-4.183715	234	2.2	155	0.5											T 0.33; B 0.33	
T01	Beam	New Quay straight	02 haul	T01_02	06/08/2015 10:03:11	09:46	9.77	50.503935	-4.180943	447	1.4	163	0.7	586	16.42	16.46	16.55	0.02	586	0.24	0.33	0.48	0.04	T 0.48; B 0.49	
T01	Beam	Brickworks	03 shoot		06/08/2015 10:12:45			50.499913	-4.184207	504	2.4	271	1.0											T 0.60; B -	
T01	Beam	Brickworks	03 haul	T01_03	06/08/2015 10:22:48	10:03	10.05	50.498542	-4.190920	500	1.5	281	1.2	603	16.54	16.65	16.94	0.07	603	0.47	0.73	1.64	0.14	T 0.94; B 1.21	
T01	Beam	Okeltor Boathouse	04 shoot		06/08/2015 10:30:02			50.497372	-4.194677	297	1.9	143	1.4											T 1.28; B -	
T01	Beam	Okeltor Boathouse	04 haul	T01_04	06/08/2015 10:40:06	10:04	10.07	50.493158	-4.196158	480	1.9	254	1.7	604	16.75	16.83	17.07	0.06	604	1.20	1.61	2.12	0.23	T 2.24; B 3.30	
T01	Beam	Calstock (upper)	05 shoot		06/08/2015 10:46:33			50.492247	-4.200750	341	2.2	267	1.8											T -; B -	
T01	Beam	Calstock (upper)	05 haul	T01_05	06/08/2015 10:56:11	09:38	9.63	50.494215	-4.205720	415	0.7	333	2.1	578	16.96	17.04	17.15	0.03	578	2.28	3.02	3.64	0.44	T 6.50; B 8.50	
T01	Beam	Calstock (lower)	06 shoot		06/08/2015 11:04:40			50.496850	-4.211408	499	1.5	287	2.3											T 6.20; B 11.20	
T01	Beam	Calstock (lower)	06 haul	T01_06	06/08/2015 11:14:49	10:09	10.15	50.497793	-4.217585	451	1.5	288	2.6	609	17.18	17.31	17.73	0.10	609	4.79	5.88	7.49	0.67	T 7.1; B 10.2	
T01	Beam	Cotehele Quay	07 shoot		06/08/2015 11:22:07			50.497107	-4.221242	271	1.9	184	2.7											T -; B -	
T01	Beam	Cotehele Quay	07 haul	T01_07	06/08/2015 11:24:40	02:33	2.55	50.496042	-4.220942	120	1.9	177	2.8	153	17.39	17.46	17.54	0.03	153	8.17	9.00	9.89	0.32	T 11.8; B 14.2	short tow - net damaged
T01	Beam	Halton Quay (upper)	08 shoot		06/08/2015 11:39:24			50.488360	-4.223277	871	1.9	175	3.3											T 13.1; B 16.3	
T01	Beam	Halton Quay (upper)	08 haul	T01_08	06/08/2015 11:49:32	10:08	10.13	50.484203	-4.218428	576	2.1	160	3.6	608	17.48	17.59	17.79	0.09	608	12.38	12.96	13.62	0.31	T 13.1; B 16.3	
T01	Beam	Halton Quay (lower)	09 shoot		06/08/2015 11:52:49			50.482282	-4.217975	216	3.6	179	3.7											T 13.5; B 16.7	
T01	Beam	Halton Quay (lower)	09 haul	T01_09	06/08/2015 12:02:53	10:04	10.07	50.476992	-4.217692	589	1.8	183	4.0	604	17.49	17.66	18.18	0.14	604	13.21	13.96	14.32	0.25	T 15.6; B 19.2	
T01	Beam	Halton Quay (lower)	10 shoot		06/08/2015 12:13:41			50.472055	-4.225412	776	2.2	222	4.4											T 16.4; B 22.2	
T01	Beam	Halton Quay (lower)	10 haul	T01_10	06/08/2015 12:24:18	10:37	10.62	50.469018	-4.232597	612	1.9	244	4.8	637	17.58	17.78	18.33	0.20	637	14.51	16.29	17.07	0.57	T 16.8; B 24.77	
T01	Beam	Pentillie Quay	11 shoot		06/08/2015 12:38:14			50.457505	-4.236800	710	3.1	145	5.5											T 21.9; B 22.4	
T01	Beam	Pentillie Quay	11 haul	T01_11	06/08/2015 12:48:52	10:38	10.63	50.456163	-4.228382	616	2.2	052	5.8	638	17.72	18.23	18.82	0.28	638	18.46	19.97	22.07	1.01	T -; B -	

Table 18. Details of T02 on 03 Nov 2015 detailing gear, stations, times, duration and position of shoot and hauling along with sound velocity profile derived water temperature and salinity.

						Duration		Position (DD, WGS84)						SVP water temperature (°C)					SVP water salinity						
Trip	Gear	Station	Action	Haul code	DateTime	(mm:ss)	(mm.mm)	Latitude	Longitude	Distance (m)	Speed over ground (kt)	Course over ground (°M)	Cumulative distance (nm)	n	min	mean	max	stdev	n	min	mean	max	stdev	Bottom salinity	Comments
T02	Beam	Morwellham Quay	01 shoot		03/11/2015 09:02:33			50.504167	-4.192910	n/a	2.2	017	0												
T02	Beam	Morwellham Quay	01 haul	T02_01	03/11/2015 09:12:17	09:44	9.73	50.507988	-4.188173	542	1.8	069	0.29	584	10.20	10.31	10.65	0.07	584	0.00	0.15	0.66	0.06	0.1	
T02	Beam	New Quay straight	02 shoot		03/11/2015 09:18:50			50.506853	-4.183350	365	3.2	159	0.49												
T02	Beam	New Quay straight	02 haul	T02_02	03/11/2015 09:28:47	09:57	9.95	50.501408	-4.180567	637	1.9	202	0.83	597	10.26	10.28	10.31	0.01	597	0.11	0.20	0.27	0.03	0.1	
T02	Beam	Brickworks	03 shoot		03/11/2015 09:34:40			50.499882	-4.183370	262	3	273	0.98												
T02	Beam	Brickworks	03 haul	T02_03	03/11/2015 09:45:07	10:27	10.45	50.498608	-4.191393	587	1.4	289	1.29	627	10.30	10.33	10.37	0.02	627	0.09	0.21	0.30	0.03	0.1	
T02	Beam	Okeltor Boathouse	04 shoot		03/11/2015 09:51:20			50.497042	-4.194313	271	2.5	158	1.44												
T02	Beam	Okeltor Boathouse	04 haul	T02_04	03/11/2015 09:55:15	03:55	3.92	50.495022	-4.193822	227	3.1	190	1.56	235	10.39	10.41	10.46	0.01	235	0.09	0.21	0.35	0.06	0.1	short tow due to snapped beam
T02	Beam	Calstock (upper)	05 shoot		03/11/2015 10:17:09			50.493100	-4.196457	284	3	249	1.72												
T02	Beam	Calstock (upper)	05 haul	T02_05	03/11/2015 10:27:18	10:09	10.15	50.492837	-4.204355	561	1.7	315	2.02	609	10.46	10.55	10.62	0.04	609	0.04	0.12	0.30	0.03	0.1	
T02	Beam	Calstock (lower)	06 shoot		03/11/2015 10:37:42			50.496643	-4.210153	591	2.9	294	2.34												
T02	Beam	Calstock (lower)	06 haul	T02_06	03/11/2015 10:46:43	09:01	9.02	50.497885	-4.218340	597	1.9	289	2.66	541	10.64	10.67	10.71	0.02	541	0.07	0.13	0.21	0.02	0.15	
T02	Beam	Cotehele Quay	07 shoot		03/11/2015 10:57:21			50.490980	-4.222873	833	3	209	3.11												
T02	Beam	Cotehele Quay	07 haul	T02_07	03/11/2015 11:07:33	10:12	10.20	50.486282	-4.221780	528	1.8	148	3.39	612	10.78	10.91	11.09	0.10	612	0.44	1.18	2.71	0.63	5.9	Taken mid-tow
T02	Beam	Halton Quay (upper)	08 shoot		03/11/2015 11:13:43			50.483405	-4.218025	417	3.7	156	3.62												
T02	Beam	Halton Quay (upper)	08 haul	T02_08	03/11/2015 11:24:09	10:26	10.43	50.478275	-4.217898	571	2	178	3.93	626	11.00	11.05	11.12	0.03	626	1.52	1.84	2.45	0.17	7	
T02	Beam	Halton Quay (lower)	09 shoot		03/11/2015 11:29:11			50.475708	-4.218175	286	3.5	204	4.08												
T02	Beam	Halton Quay (lower)	09 haul	T02_09	03/11/2015 11:39:36	10:25	10.42	50.472432	-4.224602	584	1.6	238	4.4	625	11.13	11.63	12.21	0.33	625	2.15	5.69	10.54	2.46	14.8	
T02	Beam	Halton Quay (lower)	10 shoot		03/11/2015 11:48:15			50.469880	-4.230392	500	3.7	242	4.67												
T02	Beam	Halton Quay (lower)	10 haul	T02_10	03/11/2015 11:58:19	10:04	10.07	50.466277	-4.237500	645	2.5	219	5.02	604	11.43	11.73	11.96	0.15	604	3.58	6.26	8.30	1.29	14.5	
T02	Beam	Pentillie Quay	11 shoot		03/11/2015 12:05:20			50.463622	-4.239097	316	2.9	189	5.19												
T02	Beam	Pentillie Quay	11 haul	T02_11	03/11/2015 12:16:13	10:53	10.88	50.458405	-4.237242	595	0.9	152	5.51	653	11.52	11.66	12.21	0.13	653	3.62	5.39	10.73	1.22	13.8	

Table 19. Details of T03 on 12 Jan 2015 detailing gear, stations, times, duration and position of shoot and hauling along with sound velocity profile derived water temperature and salinity.

						Duration		Position (DD, WGS84)						SVP water temperature (°C)					SVP water salinity						
Trip	Gear	Station	Action	Haul code	DateTime	(mm:ss)	(mm.mm)	Latitude	Longitude	Distance (m)	Speed over ground (kt)	Course over ground (°M)	Cumulative distance (nm)	n	min	mean	max	stdev	n	min	mean	max	stdev	Bottom salinity	Comments
T03	Beam	Halton Quay (lower)	01 shoot		12/01/2016 08:33:17			50.470838	-4.228388	n/a	4.2	238	0.00											0.09	
T03	Beam	Halton Quay (lower)	01 haul	T03_01	12/01/2016 08:43:37	10:20	10.33	50.464847	-4.238677	989	3.3	208	0.54	620	7.85	7.88	7.91	0.01	620	0.00	0.14	0.24	0.03	0.13	
T03	Beam	Pentillie Quay	02 shoot		12/01/2016 08:48:24			50.459768	-4.238173	566	4.7	157	0.84												
T03	Beam	Pentillie Quay	02 haul	T03_02	12/01/2016 08:58:03	09:39	9.65	50.456547	-4.227627	830	3.0	041	1.29	579	7.82	7.87	7.94	0.02	579	0.05	0.57	1.62	0.31	1.05	
T03	Beam	Cargreen	03 shoot		12/01/2016 09:41:39			50.447183	-4.207650	2130	0.7	119	2.81												
T03	Beam	Cargreen	03 haul	T03_03	12/01/2016 09:51:31	09:52	9.87	50.453735	-4.207308	729	2.0	025	3.20	592	8.32	8.48	8.91	0.10	592	6.27	9.05	13.41	1.63		
T03	Beam	Cargreen	04 shoot		12/01/2016 10:01:28			50.448538	-4.207670	579	1.8	008	3.52												
T03	Beam	Cargreen	04 haul	T03_04	12/01/2016 10:13:01	11:33	11.55	50.453822	-4.206288	596	1.1	135	3.84	693	8.17	8.39	8.68	0.10	693	4.78	7.39	10.58	1.32		
T03	Beam	Kingsmill Lake	05 shoot		12/01/2016 10:26:54			50.429827	-4.202832	2682	3.5	210	5.29												
T03	Beam	Kingsmill Lake	05 haul	T03_05	12/01/2016 10:36:09	09:15	9.25	50.421023	-4.206525	1015	3.9	196	5.83	555	8.75	9.10	9.38	0.15	555	12.75	17.18	20.52	1.77		
T03	Beam	Kingsmill Lake	06 shoot		12/01/2016 10:39:59			50.420680	-4.206682	40	2.6	013	5.85												
T03	Beam	Kingsmill Lake	06 haul	T03_06	12/01/2016 10:53:39	13:40	13.67	50.427150	-4.202998	766	4.2	165	6.27	820	8.78	9.19	9.55	0.16	820	11.90	17.90	20.78	2.05		
T03	Beam	Weston Mill Lake	07 shoot		12/01/2016 11:17:16			50.393067	-4.201173	3795	1.3	329	8.32												
T03	Beam	Weston Mill Lake	07 haul	T03_07	12/01/2016 11:23:01	05:45	5.75	50.395063	-4.203788	290	2.0	339	8.47	345	8.56	8.66	8.78	0.05	345	10.45	12.07	13.92	0.75	20.3	
T03	Beam	Weston Mill Lake	08 shoot		12/01/2016 11:35:59			50.391605	-4.200153	464	1.3	313	8.72												
T03	Beam	Weston Mill Lake	08 haul	T03_08	12/01/2016 11:46:26	10:27	10.45	50.394800	-4.205260	508	1.9	314	9.00	627	8.73	8.80	9.04	0.04	627	12.45	13.10	16.03	0.51		
T03	Beam	West Mud	09 shoot		12/01/2016 12:13:05			50.361950	-4.188030	3854	2.2	298	11.08												
T03	Beam	West Mud	09 haul	T03_09	12/01/2016 12:23:15	10:10	10.17	50.366395	-4.193985	651	2.6	006	11.43	610	9.05	9.25	9.41	0.09	610	16.76	19.05	20.87	1.12		
T03	Beam	West Mud	10 shoot		12/01/2016 12:35:04			50.362040	-4.189260	590	2.2	290	11.75												
T03	Beam	West Mud	10 haul	T03_10	12/01/2016 12:45:19	10:15	10.25	50.367255	-4.194433	687	2.8	009	12.12	615	9.08	9.21	9.35	0.07	615	16.98	18.49	20.21	0.88		

Table 20. Details of T04 on 04 Jan 2016 detailing gear, stations, times, duration and position of shoot and hauling along with sound velocity profile derived water temperature and salinity.

						Duration		Position (DD, WGS84)						SVP water temperature (°C)					SVP water salinity						
Trip	Gear	Station	Action	Haul code	DateTime	(mm:ss)	(mm.mm)	Latitude	Longitude	Distance (m)	Speed over ground (kt)	Course over ground (°M)	Cumulative distance (nm)	n	min	mean	max	stdev	n	min	mean	max	stdev	Bottom salinity	Comments
T04	Otter	Halton Quay (lower)	01 shoot		13/01/2016 08:45:49			50.472227	-4.224473	n/a	2.4	241	0.00												
T04	Otter	Halton Quay (lower)	01 haul	T04_01	13/01/2016 09:04:11	18:22	18.37	50.466593	-4.237465	1115	2.6	215	0.60	1102	7.32	7.51	7.55	0.03	1102	0.00	0.51	1.01	0.10		Tow along full stretch
T04	Otter	Cargreen	02 shoot		13/01/2016 09:50:40			50.448270	-4.207472	2948	2.1	008	2.19												
T04	Otter	Cargreen	02 haul	T04_02	13/01/2016 10:03:01	12:21	12.35	50.454513	-4.207302	695	1.6	003	2.57	741	8.08	8.27	8.43	0.06	741	9.39	12.38	15.23	1.51		
T04	Otter	Kingsmill Lake	03 shoot		13/01/2016 11:01:55			50.420397	-4.206750	3797	1.3	347	4.62												
T04	Otter	Kingsmill Lake	03 haul	T04_03	13/01/2016 11:24:40	22:45	22.75	50.418643	-4.206850	195	1.8	006	4.72	1365	8.17	8.66	9.10	0.20	1365	13.27	17.87	20.75	1.30		
T04	Otter	Kingsmill Lake	04 shoot		13/01/2016 11:28:13			50.420602	-4.206315	221	2.0	010	4.84												
T04	Otter	Kingsmill Lake	04 haul	T04_04	13/01/2016 11:45:51	17:38	17.63	50.427008	-4.204130	730	2.2	177	5.24	1058	8.16	8.77	9.24	0.18	1058	13.31	17.86	20.91	1.24		
T04	Otter	West Mud	05 shoot		13/01/2016 12:27:39			50.363618	-4.191147	7114	2.4	314	9.08												
T04	Otter	West Mud	05 haul	T04_05	13/01/2016 12:42:10	14:31	14.52	50.369388	-4.191758	643	1.3	111	9.42	871	8.90	9.26	9.44	0.14	871	18.98	22.68	24.37	1.39		
T04	Otter	West Mud	06 shoot		13/01/2016 12:53:01			50.362405	-4.185977	879	2.0	293	9.90												
T04	Otter	West Mud	06 haul	T04_06	13/01/2016 13:05:56	12:55	12.92	50.367385	-4.193303	761	2.2	000	10.31	775	8.90	9.11	9.28	0.11	775	18.65	21.12	23.01	1.22		

Table 21. Details of T05 on 16 Feb 2016 detailing gear, stations, times, duration and position of shoot and hauling along with sound velocity profile derived water temperature and salinity.

						Duration		Position (DD, WGS84)						SVP water temperature (°C)					SVP water salinity						
Trip	Gear	Station	Action	Haul code	DateTime	(mm:ss)	(mm.mm)	Latitude	Longitude	Distance (m)	Speed over ground (kt)	Course over ground (°M)	Cumulative distance (nm)	n	min	mean	max	stdev	n	min	mean	max	stdev	Bottom salinity	Comments
T05	Otter	Halton Quay (lower)	01 shoot		16/02/2016 09:48:38			50.472652	-4.223177	n/a	2.1	241	0.00											0.11	d 4m, t 216 0.8kt, wire 10m
T05	Otter	Halton Quay (lower)	01 haul	T05_01	16/02/2016 09:58:09	09:31	9.52	50.469812	-4.231413	665	2.4	236	0.30	571	5.77	5.81	5.85	0.01	571	0.13	0.31	0.69	0.12		no fish
T05	Otter	Halton Quay (lower)	02 shoot		16/02/2016 10:18:46			50.472653	-4.223328	655	2.3	238	0.70											0.11	5.6 dC; d 3.4m, w 20m, t221 0.7 kt
T05	Otter	Halton Quay (lower)	02 haul	T05_02	16/02/2016 10:28:26	09:40	9.67	50.470203	-4.230882	602	1.1	238	1.00	580	5.78	5.85	5.91	0.03	580	0.16	0.28	0.58	0.09	2.85	5.9 dC, only sea lamprey caught
T05	Otter	Halton Quay (lower)	03 shoot		16/02/2016 10:45:53			50.471457	-4.227542	275	2.4	254	1.20												w 20m, d 3.3m, t 224 0.5kt
T05	Otter	Halton Quay (lower)	03 haul	T05_03	16/02/2016 10:55:38	09:45	9.75	50.468913	-4.234040	541	1.0	244	1.50	585	5.84	5.88	5.93	0.02	585	0.19	0.46	0.82	0.14	3.7	6.0 dC
T05	Otter	Halton Quay (lower)	04 shoot		16/02/2016 11:13:57			50.470598	-4.230055	339	2.6	231	1.60												w 20m d 3.4m, t 222 0.2kt
T05	Otter	Halton Quay (lower)	04 haul	T05_04	16/02/2016 11:23:22	09:25	9.42	50.467338	-4.236553	587	1.9	221	2.00	565	5.89	5.94	6.00	0.03	565	0.32	0.60	0.98	0.13		
T05	Otter	Cargreen	05 shoot		16/02/2016 12:19:43			50.451607	-4.207092	2728	2.6	007	3.40												w 20m, d 3.5m, t 167 0.2kt
T05	Otter	Cargreen	05 haul	T05_05	16/02/2016 12:26:47	07:04	7.07	50.455605	-4.207315	445	1.6	000	3.70	424	7.07	7.32	7.54	0.17	424	11.33	13.13	15.40	1.12	16.75	7.5dC
T05	Otter	Kingsmill Lake	06 shoot		16/02/2016 13:07:34			50.423095	-4.205262	3621	2.5	021	5.60												w 30m, d 5.4m, t 205 0.4kt
T05	Otter	Kingsmill Lake	06 haul	T05_06	16/02/2016 13:17:06	09:32	9.53	50.427685	-4.203038	535	1.8	029	5.90	572	8.22	8.35	8.49	0.05	572	20.57	21.80	22.98	0.47	22	8.2 dC
T05	Otter	Kingsmill Lake	07 shoot		16/02/2016 13:36:20			50.420877	-4.205615	779	2.2	001	6.30												w 25m, d 6m, t 211 0.5kt
T05	Otter	Kingsmill Lake	07 haul	T05_07	16/02/2016 13:46:46	10:26	10.43	50.426617	-4.203735	652	2.0	023	6.70	626	8.10	8.24	8.49	0.10	626	19.62	20.69	22.65	0.83		
T05	Otter	West Mud	08 shoot		16/02/2016 14:31:13			50.362867	-4.185050	7215	2.1	306	10.60											28	9.6 dC; w 60m, d 21m, t 110 1.4kt
T05	Otter	West Mud	08 haul	T05_08	16/02/2016 14:41:41	10:28	10.47	50.366047	-4.192423	633	2.6	332	10.90	628	8.22	8.43	8.61	0.11	628	23.18	24.22	25.45	0.71	18.9	7.9 dC
T05	Otter	West Mud	09 shoot		16/02/2016 15:00:15			50.362345	-4.187683	532	2.6	306	11.20												R float, w 60m, d 25m, t116 1.5kt
T05	Otter	West Mud	09 haul	T05_09	16/02/2016 15:10:05	09:50	9.83	50.367180	-4.194232	712	2.5	359	11.60	590	8.20	8.42	8.62	0.10	590	22.55	23.92	25.72	0.81		

Table 22. Details of T06 on 14 Mar 2016 detailing gear, stations, times, duration and position of shoot and hauling along with sound velocity profile derived water temperature and salinity.

						Duration		Position (DD, WGS84)						SVP water temperature (°C)					SVP water salinity						
Trip	Gear	Station	Action	Haul code	DateTime	(mm:ss)	(mm.mm)	Latitude	Longitude	Distance (m)	Speed over ground (kt)	Course over ground (°M)	Cumulative distance (nm)	n	min	mean	max	stdev	n	min	mean	max	stdev	Bottom salinity	Comments
T06	Otter	Halton Quay (upper)	01 shoot		14/03/2016 09:16:39			50.482593	-4.217643	n/a	2.1	180	0.00												Gear back to original floats etc
T06	Otter	Halton Quay (upper)	01 haul	T06_01	14/03/2016 09:26:07	09:28	9.47	50.477112	-4.217783	610	2.1	181	0.32	568	8.20	8.33	8.39	0.04	568	1.83	2.62	3.70	0.57	2.6	
T06	Otter	Halton Quay (upper)	02 shoot		14/03/2016 09:46:03			50.483138	-4.217808	671	2.8	169	0.69												
T06	Otter	Halton Quay (upper)	02 haul	T06_02	14/03/2016 09:59:19	13:16	13.27	50.475312	-4.218380	872	3.3	215	1.16	796	8.31	8.40	8.46	0.03	796	1.65	2.60	3.44	0.58	6.57	
T06	Otter	Halton Quay (lower)	03 shoot		14/03/2016 10:42:15			50.470782	-4.229257	922	3.3	243	1.66												
T06	Otter	Halton Quay (lower)	03 haul	T06_03	14/03/2016 10:52:18	10:03	10.05	50.467032	-4.237240	704	2.2	223	2.04	603	8.47	8.54	8.73	0.09	603	4.20	6.87	8.78	1.23		
T06	Otter	Cargreen	04 shoot		14/03/2016 11:39:20			50.449360	-4.207823	2869	2.5	002	3.58											10.94	
T06	Otter	Cargreen	04 haul	T06_04	14/03/2016 11:49:22	10:02	10.03	50.454980	-4.206743	630	2.0	356	3.92	602	9.29	9.39	9.44	0.04	602	20.58	21.93	23.17	0.64	19.4	
T06	Otter	Kingsmill Lake	05 shoot		14/03/2016 12:20:14			50.421615	-4.206310	3711	1.8	015	5.93												
T06	Otter	Kingsmill Lake	05 haul	T06_05	14/03/2016 12:30:01	09:47	9.78	50.426692	-4.204588	578	2.1	034	6.24	391	9.00	9.27	9.39	0.10	391	20.18	22.05	24.93	0.78	25.5	
T06	Otter	Kingsmill Lake	06 shoot		14/03/2016 12:46:32			50.420908	-4.206343	655	1.6	016	6.60												
T06	Otter	Kingsmill Lake	06 haul	T06_06	14/03/2016 12:56:50	10:18	10.30	50.425895	-4.204642	568	0.2	014	6.90	618	9.18	9.40	9.68	0.11	618	20.11	22.08	25.24	1.35		
T06	Otter	West Mud	07 shoot		14/03/2016 13:36:23			50.361620	-4.187407	7256	2.3	293	10.82												
T06	Otter	West Mud	07 haul	T06_07	14/03/2016 13:45:37	09:14	9.23	50.365760	-4.194005	658	2.1	335	11.17	554	9.39	9.44	9.48	0.02	554	27.70	28.66	29.13	0.26		Caught debris (mattress)
T06	Otter	West Mud	08 shoot		14/03/2016 14:04:38			50.362262	-4.188358	559	2.9	312	11.48												
T06	Otter	West Mud	08 haul	T06_08	14/03/2016 14:13:28	08:50	8.83	50.366563	-4.194413	644	2.4	346	11.82	530	9.41	9.46	9.53	0.03	530	27.88	28.47	28.79	0.17		

8.5 Environment Agency – River Tamar shad egg survey form

Environment Agency - River Tamar shad egg survey

Site Name: ______________________________

Site No: ______________________________

NGR: ______________________________

Kick sample record

Sample No:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Sampler(s)
Date:																										
Other SAC species:																										
Date:																										
Other SAC species:																										
Date:																										
Other SAC species:																										
Date:																										
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Date:																										
Other SAC species:																										

Notes / Comments:

Figure 43. Environment Agency – River Tamar shad egg survey form.

8.6 Logistic regression model for predicting presence/absence of allis shad

```
Call:
glm(formula = Presence ~ dayband + tempband + flowband, family = binomial(link =
"logit"),
    data = data.train)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-0.6858  -0.3384  -0.2469  -0.1992   3.0859

Coefficients:
                  Estimate Std. Error z value Pr(>|z|)
(Intercept)        -4.7794     0.8415  -5.680 1.35e-08 ***
daybandAprilMay     0.7412     0.5778   1.283  0.19956
daybandJulyAugust  -1.5035     0.5542  -2.713  0.00667 **
tempbandhigh        2.3732     0.7721   3.074  0.00211 **
tempbandmedium      1.5302     0.6062   2.524  0.01159 *
flowbandextreme     0.8803     0.8816   0.999  0.31799
flowbandhigh        1.2770     0.7061   1.809  0.07052 .
flowbandmedium      1.0785     0.5091   2.118  0.03416 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

(Dispersion parameter for binomial family taken to be 1)

    Null deviance: 251.46  on 673  degrees of freedom
Residual deviance: 231.19  on 666  degrees of freedom
AIC: 247.19

Number of Fisher Scoring iterations: 6
```

Note; Negative estimate values (for example, 0.742 for daybandAprilMay) are less likely, positive values are more likely.

<u>Likelihood odds of seeing allis shad or not in the trap for each variable, relative to the reference factor.</u>

```
                  2.5 % 97.5 %
(Intercept)       0.001  0.040
daybandAprilMay   0.680  6.610
daybandJulyAugust 0.071  0.642 between 97% and 63 % less likely to see allsi
shad.
tempbandhigh      2.406 49.967
tempbandmedium    1.412 15.384
flowbandextreme   0.323 12.057
flowbandhigh      0.860 14.222
flowbandmedium    1.110  8.320
```

9 List of electronic appendices

The following electronic appendices are included:

'EC18234_MonitoringOfAllisShadAndSmeltInTamarEstuaries.docx' is this report in Word format.

'EC18234_MonitoringOfAllisShadAndSmeltInTamarEstuaries.pdf' is this report in pdf format.

'GIS' folder

- 'EC18234_ShadAndSmelt_01.mpk' is archive of ArcGIS files in document format and contains separate shapefiles of the data.

'Metadata' folder

- 'ec18234_2015_mba_and_ea_tamar_estuary_southwest_england_plankton_trawl_ec18234_f12d99e8599a93451ded5019abe1d69a.xml' covers the plankton sampling metadata
- 'ec18234_2015_mba_and_ea_tamar_estuary_south_west_england_smelt_and_shad_fish_survey_885be58729.xml' covers the smelt beam and otter trawling metadata
- 'ec18234_1990_2015_ea_tamar_and_lynher_rivers_and_estuaries_shad_surveys_and_records_d16a4432331f935ac456ceed2a03a3ed.xml' covers the historical shad records

'Records' folder

- 'DASSHSE00000030_AS-01.xlsx' describes the historical shad records.
- 'DASSHDT00000277-AS01.xlsx' describes the smelt beam and otter trawling records.
- 'DASSHDT00000278_AS01.xlsx' describes the shad/smelt plankton-net sampling.
- 'EC18234_MR_database_May2016.mdb' contains the sample data in Marine Recorder format.

'Pictures' folder

- Stills images contained in this report. Also previously supplied are 3 videos of various trawling.

Further information

Natural England evidence can be downloaded from our **Access to Evidence Catalogue**. For more information about Natural England and our work see **Gov.UK**. For any queries contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk** .

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