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Habitat mapping and monitoring of allis shad on the River Tamar

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Habitat mapping and monitoring of Allis shad on the River Tamar

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Project details

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Project manager

Angela Gall

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Executive Summary

Allis shad (A*losa alosa*) is a migratory (anadromous) fish species of the herring family which matures in the sea and migrates to freshwater to spawn. Though once widespread around the UK, allis shad populations have declined significantly in recent decades and the River Tamar is now the only known spawning site in the UK for the species. The Tamar estuary is within the Plymouth Sound and Estuaries Special Area of Conservation (SAC), where allis shad is a designated species. Previous studies have shown that allis shad routinely spawn in the tidal reaches of the upper Tamar estuary, an observation unique to the Tamar. Spawning evidence from egg surveys has also been recorded on two previous occasions on the lower River Tamar. NE commissioned a survey of available allis shad spawning habitat on the Tamar and also monitoring of the timing and location of allis shad spawning. Mapping of available spawning habitat in the tidal reaches and lower River Tamar was completed in May 2019. Monitoring of allis shad spawning activity was undertaken between May and August 2019.

Allis shad spawning habitat is limited to approximately 0.6 ha in the tidal reach and 4.9 ha in the lower River Tamar between Gunnislake Weir and Horsebridge, approximately 11km upstream of the tidal limit; suitable spawning habitat almost certainly exists upstream of Horsebridge, but this was the upstream limit of this study, which focuses on the tidal reaches and lower River Tamar. Three significant migratory barriers identified in this survey probably limit access to allis shad spawning habitat upstream of the tidal limit. 1.3 ha of spawning habitat was identified in the River Tamar, upstream of the first barrier at Gunnislake Weir. The remaining 3.6 ha of potential spawning habitat was located upstream of a second significant barrier at Duchess Weir; the river substrate at all sites above Duchess Weir is generally coarser than allis shad spawning substrate described in the literature and it is not known if allis shad would utilise this habitat.

Allis shad spawned at five discrete spawning sites in 2019; two in the tidal reaches and three in the lower reaches of the River Tamar. Spawning in the tidal reaches took place between May and July, and in the river during June. Eggs were recorded on most sampling occasions (79%) from the tidal reaches but infrequently from surveys in the River Tamar (33%), suggesting that allis shad are not always able to access riverine spawning areas throughout the spawning season. Estimated spawning dates at riverine sites tended to coincide with spring tides, suggesting that allis shad may utilise spring tides to migrate upstream at Gunnislake Weir.

Allis shad eggs were mostly recorded from run habitat where the mean flow velocity was 0.43 m^{-s}. Eggs were recorded at water depths ranging from 15cm to 96cm and from channel widths between 14m and 35m, although sampling depth was limited to approximately one metre by the kick-sampling method and deeper habitat was not surveyed. The dominant substrate associated with egg presence was cobble, pebble or gravel, although this varied between spawning sites. Water temperature during May and much of June 2019 was probably too low for successful incubation; favourable temperatures for egg incubation did not prevail until late June and July 2019, suggesting that the most important spawning and incubation period on the Tamar is later than previously considered.

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Introduction

Allis shad (*Alosa alosa*) is a protected species and a qualifying feature of Plymouth Sound and Estuaries Special Area of Conservation (SAC). The Tamar is the only confirmed spawning site for allis shad in the UK.

In 2019, to provide further information on the management of this interest feature, Natural England (NE) funded the Environment Agency (EA) to;

1. Map the distribution of available allis shad spawning habitat in the tidal and lower River Tamar.

2. Investigate the timing and location of allis shad spawning.

Previous surveys of allis shad spawning distribution on the Tamar have reported spawning in the tidal freshwater reach downstream of Gunnislake Weir and in the lower River Tamar (Cotterell & Hillman, 2016).

Shad habitat spawning preference

Maitland & Hatton-Ellis (2003) proposed that allis shad may spawn anywhere along the river in fresh water, where the current is swift and the substrate is clean. Other authors describe allis shad showing a preference for spawning in swift currents at the end of pools where gravelly shallows begin (Le Clerc 1941; Hoestland 1958; Boisneau et al. 1990). They deposit their eggs over a substrate that can vary from sand (2µ - 2 mm) to pebbles (2 - 20 cm), in water depths of 0.5 - 3.0m, and where the current ranges from 0.5 - 1.5 m s-1 (Roule 1923; Ellison 1935; Le Clerc 1941; Dottrens 1952; Hoestlandt 1958; Cassou-Leins & Cassou-Leins 1981; Dautrey & Lartigue 1983; Boisneau et al. 1990; Belaud et al., 2001).

Gravel and pebble is the main substrate on the River Garonne allis shad spawning reserve at Agen, with little sand or silt (Maitland et al. 1995). Cassou-Leins & Cassou-Leins (1981) define the substrate there as pebbles of mean size 7–8 cm, with a range of 3–16 cm (Environment Agency River Habitat Survey Manual defines this as a mixture of pebble and cobble). On the River Dordogne, the majority of spawning took place over a substrate dominated by pebbles (and cobbles) ranging from 2–20 cm (Fatin & Dartiguelongue, 1995), whereas in contrast, the spawning site on the River Loire was dominated by sand followed by gravel (2–20 mm) (Boisneau et al. 1990).

Definition of shad spawning habitat

Shad spawning habitat is defined within this report as the area where spawning takes place and the eggs settle on the substrate (Caswell and Aprahamian, 2001). After spawning, the eggs lodge among the interstices of the gravel or are washed a short distance downstream (Maitland and Hatton-Ellis, 2003). At Agen on the River Garonne, Maitland et al. (1995) reported that the eggs drift up to a maximum of 100 m downstream. The sampling of egg abundance and distribution has been shown to provide a cost-effective method to gather semi-quantitative information on spawning activity and distribution (Thomas & Dyson 2012a, 2012b, Pinder et al. 2016a). Furthermore, the distribution of eggs also facilitates the detailed characterisation of habitat utilisation (Pinder et al. 2016b).

In very deep, tidal reaches of large rivers, or very turbulent river conditions, eggs have been reported as drifting long distances downstream from the spawning grounds. For example, Maitland et al. (1995) observed that at Lamajistere, River Garonne, the turbulent regime causes the eggs to drift up to 2km downstream. In the River Elbe, *A. fallax* spawns in very deep sections (up to 9.5m) of tidal fresh water where the eggs are maintained in the water column by the current (Hass, 1965; 1968; Thiel et al., 1996). Hass (1968) reported relatively large egg size on the Elbe and Aprahamian (pers. comm.) suggested that this might aid the buoyancy of eggs, which are stirred up and transported large distances by the tidal current.

On the Tamar, the lack of strong, very deep, tidal currents or very turbulent river conditions, and also the relatively small size of the Tamar compared to large European rivers inhabited by shad, suggests that egg distribution, as on most rivers, reflects spawning distribution.

Mapping spawning habitat

Method

Habitat surveys were undertaken over a 3-week period in May 2019 on the upper tidal Tamar and River Tamar between Impham Meadow (SX4373170502) and Horsebridge (SX4001274876), an 11.3km reach. Flow type, dominant substrate type, channel features and depth were recorded on survey maps, which were later digitised using ArcGIS.

Flow types were recorded according to the channel feature definitions described in the 2003 River Habitat Survey (RHS) Manual (Table 1 below, Environment Agency, 2018).

Table 1. RHS flow types and definitions (Environment Agency, 2018)

Flow Type	Associated Channel Feature
Free fall (FF)	Waterfall
Chute (CH)	Cascade
Broken Standing Wave (BW)	Rapids; a white water tumbling wave
Unbroken Standing Wave (UW)	Riffles; upstream facing wavelets
Chaotic Flow (CF)	Several faster flow types
Rippled (RP)	Runs. Small ripples only 1cm high
Upwelling (UP)	Boils
Smooth (SM)	Glides
No perceptible flow (NP)	Pools and impounded reaches; no net downstream flow

Shad spawning habitat was defined as described in Table 2.

Table 2. Definitions of habitat types for relevant life stages of shad

Life stage	Habitat definition	RHS features	Reference
Allis shad spawning	Depth below 1.5 m High flow velocity (0.5-1.5m/s) – Riffle or Run habitat Cobble, pebble, gravel or sand substrate	Unbroken standing wave or rippled flow Cobble, gravel, pebble and sand	(Roule 1923; Ellison 1935; Le Clerc 1941; Dottrens 1952; Hoestlandt 1958; Cassou-Leins & Cassou-Leins 1981; Dautrey & Lartigue 1983; Boisneau et al. 1990).
Allis shad larvae	Marginal dead water Low velocity Pools / areas of pools In close proximity to spawning habitat	Pools and slow moving water recorded as marginal deadwater, no perceptible flow, smooth flow	Cassou-Leins et al., 1988; Caswell & Aprahamian (2001)
Allis shad juveniles	Marginal dead water Low velocity Pools / areas of pools In close proximity to spawning habitat	Pools and slow moving water recorded as marginal deadwater, no perceptible flow, smooth flow	APEM (2014)

Results

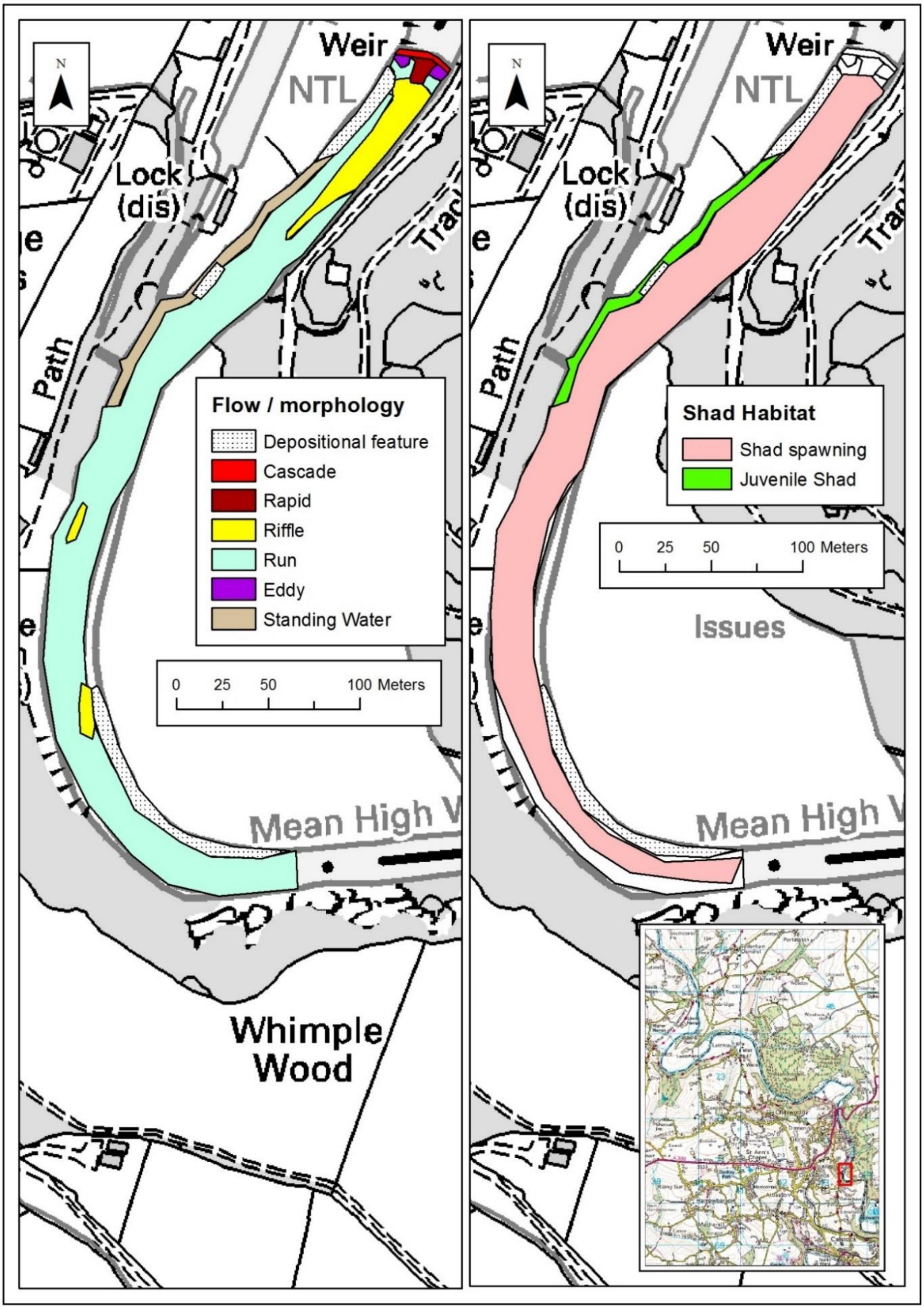

Figure 1. Map of flow type and allis shad habitat on the Upper Tamar Estuary, Impham Meadow meander bend to Cottage Run Weir

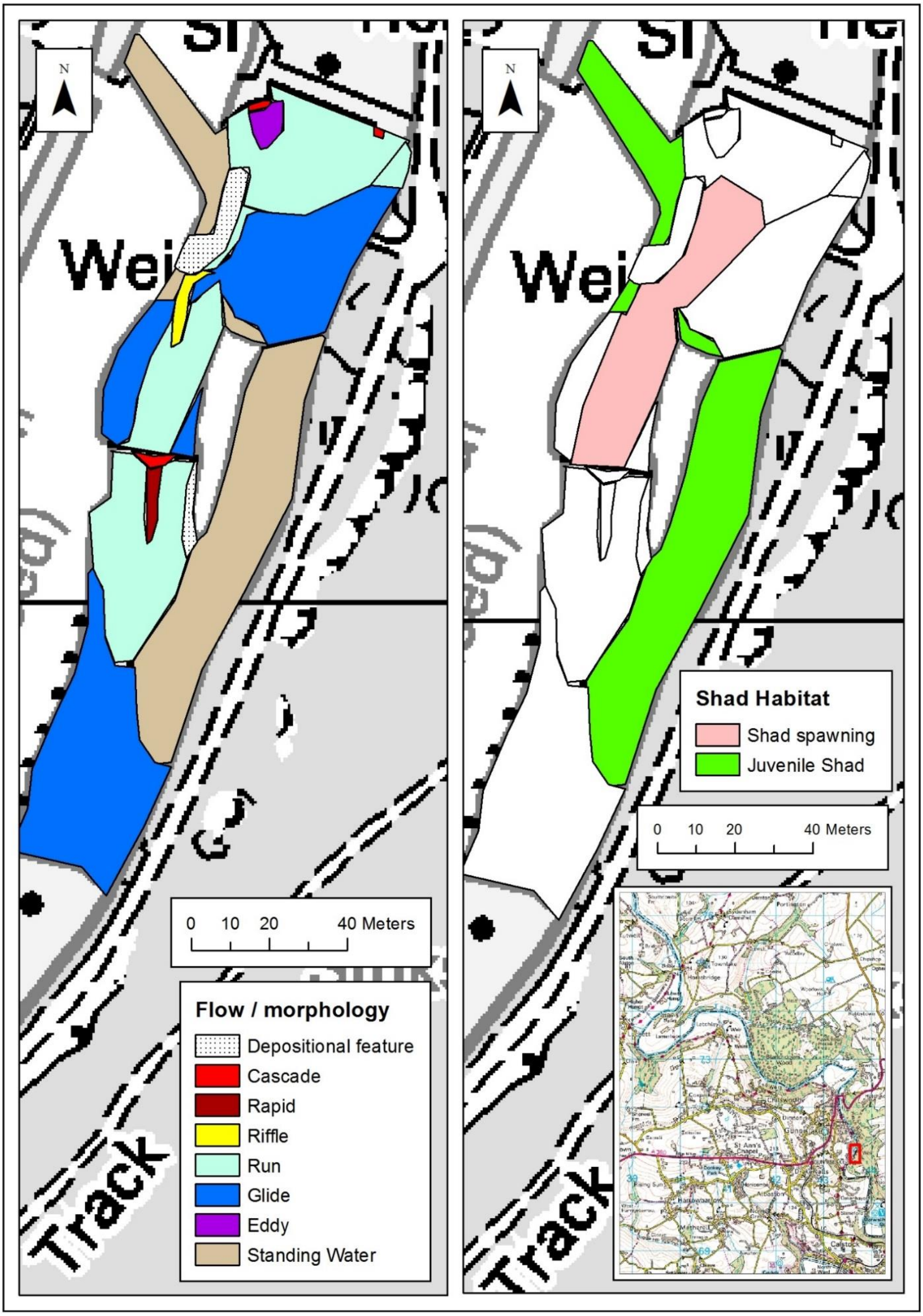

Figure 2. Map of flow type and allis shad habitat on the Upper Tamar Estuary, Cottage Run Weir to Gunnislake Weir

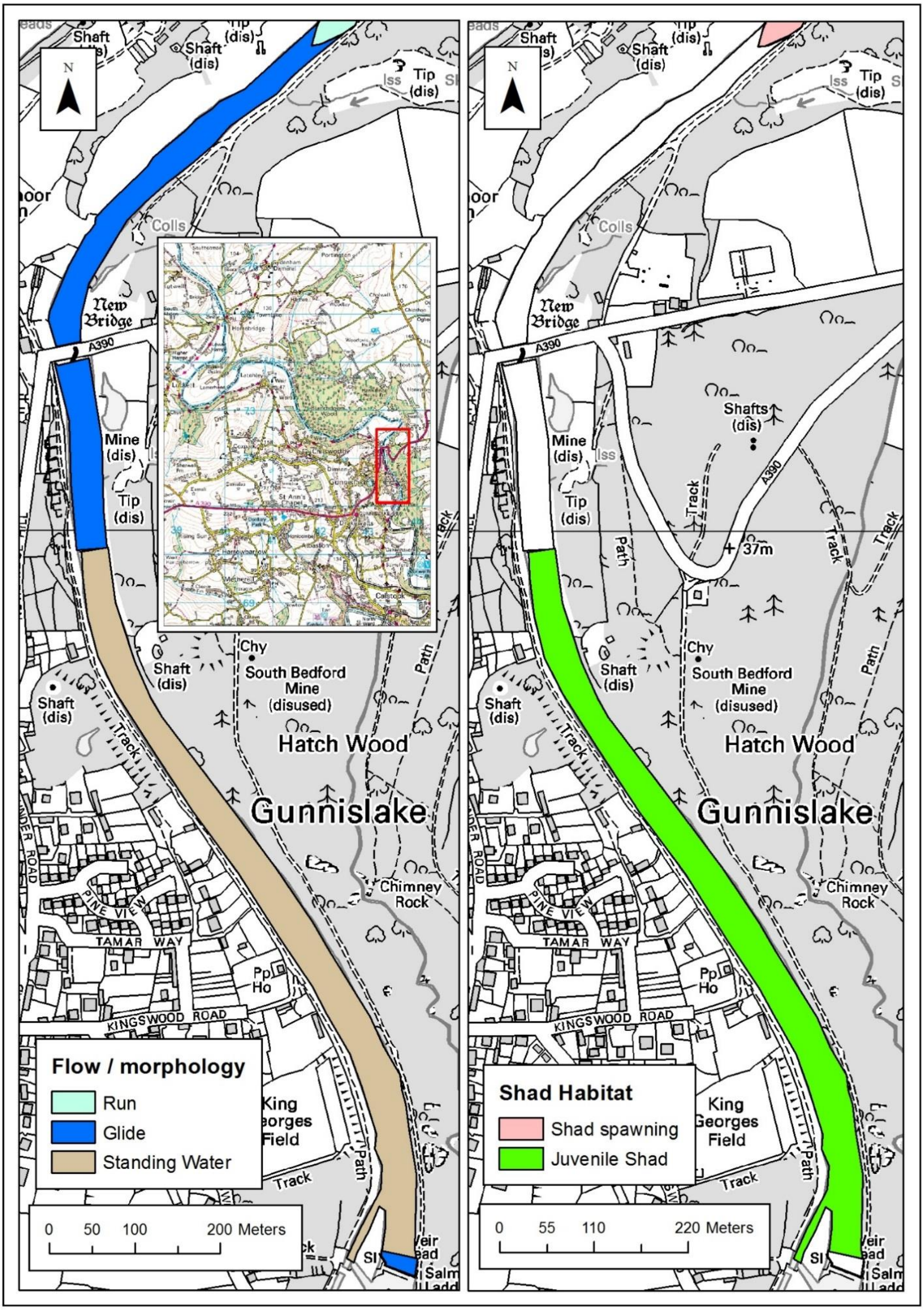

Figure 3. Map of flow type and allis shad habitat on the River Tamar, Gunnislake Weir to Hawkmoor Mine

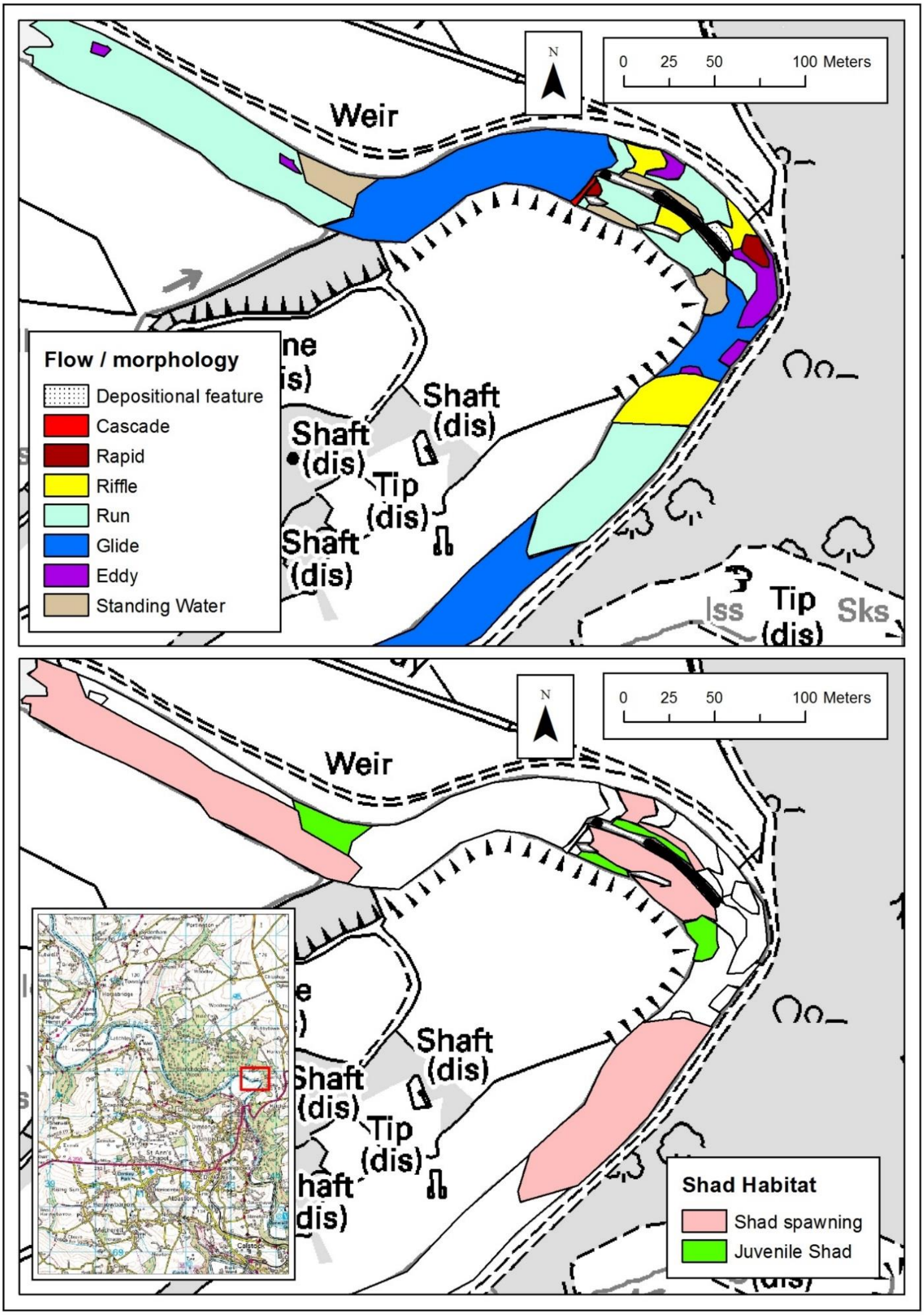

Figure 4. Map of flow type and allis shad habitat on the River Tamar, Hawkmoor Mine to Ochre

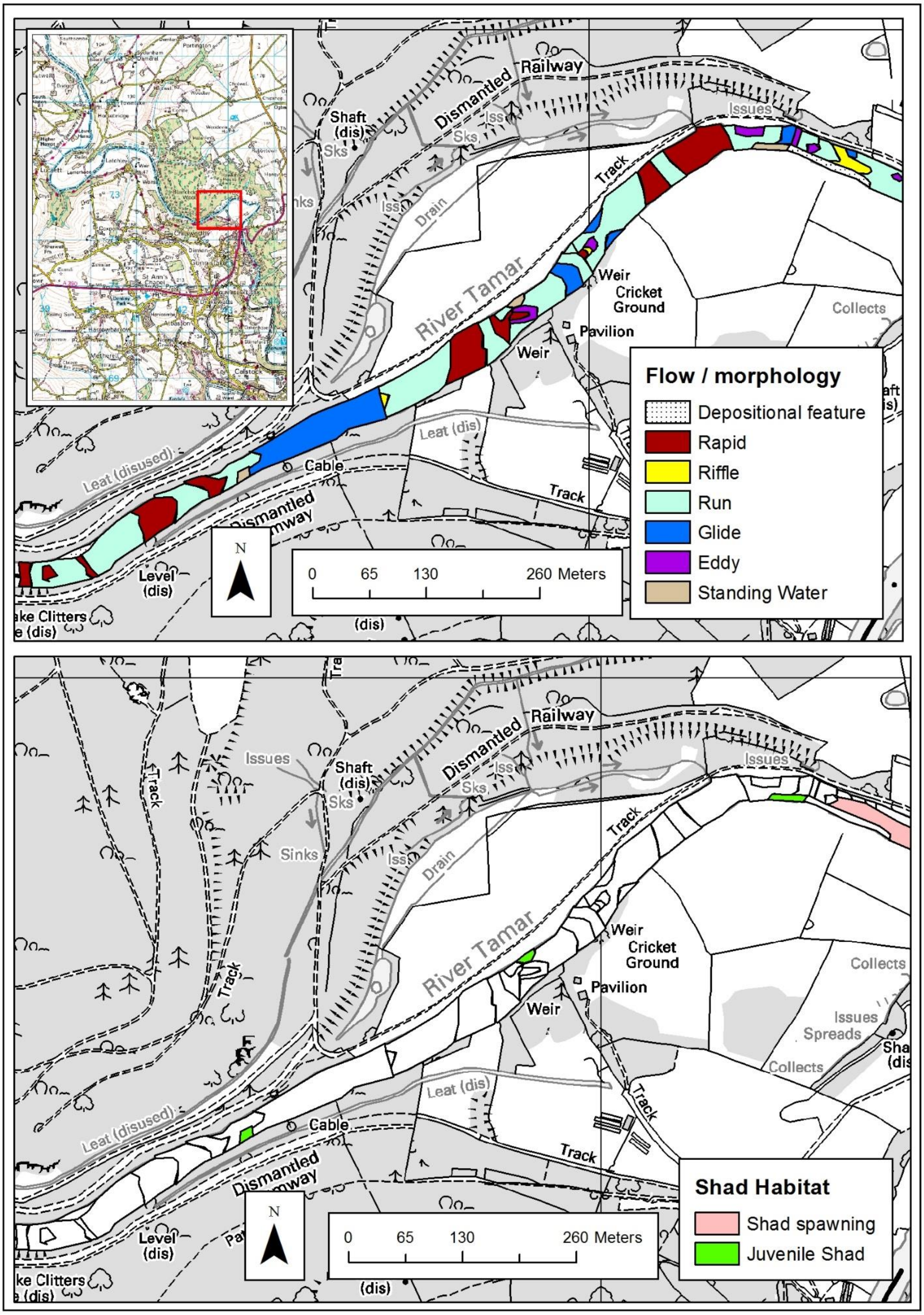

Figure 5. Map of flow type and allis shad habitat on the River Tamar, Ochre to Gunnislake Clitters Mine

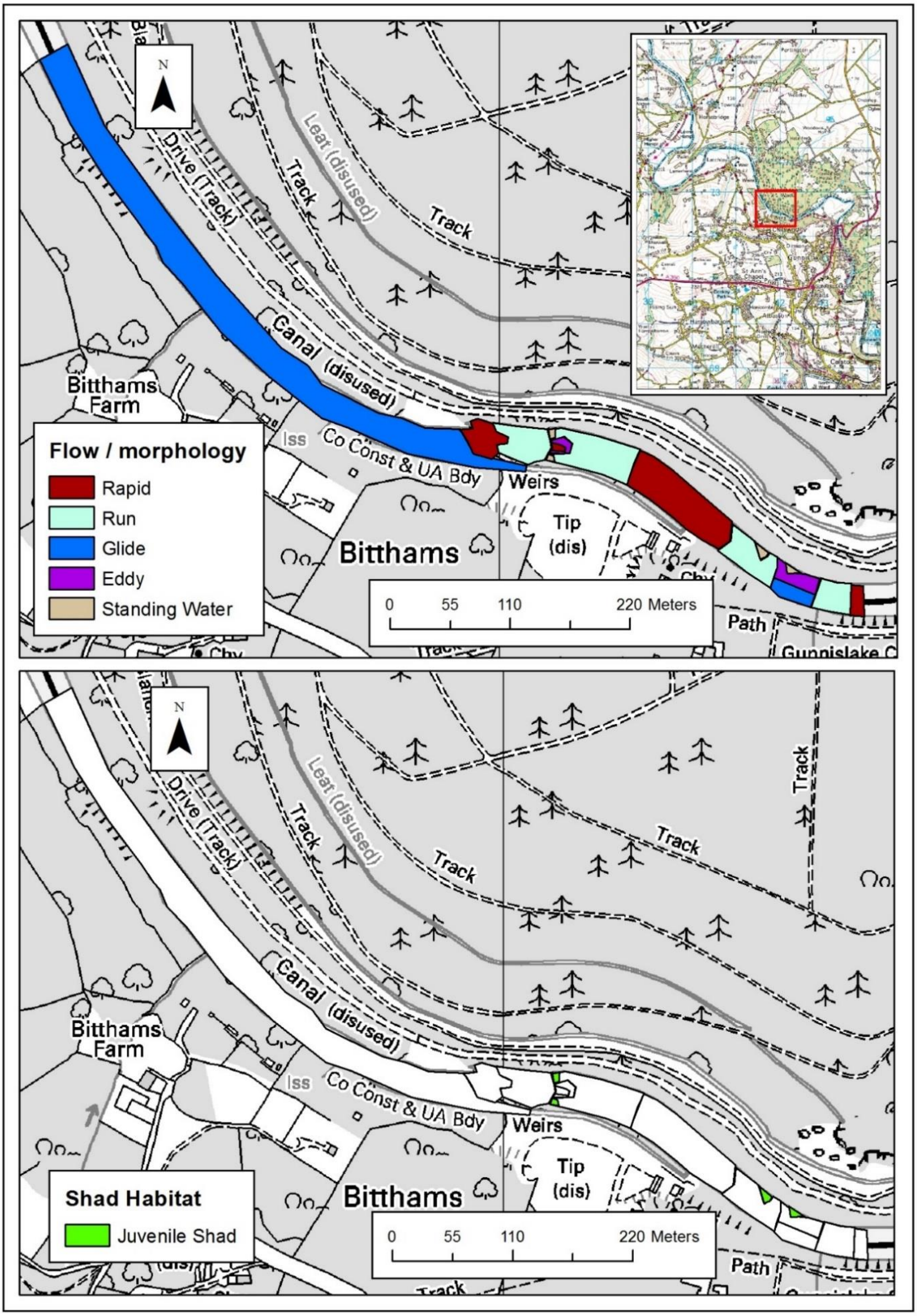

Figure 6. Map of flow type and allis shad habitat on the River Tamar, Gunnislake Clitters Mine to West Devon Consols Mine

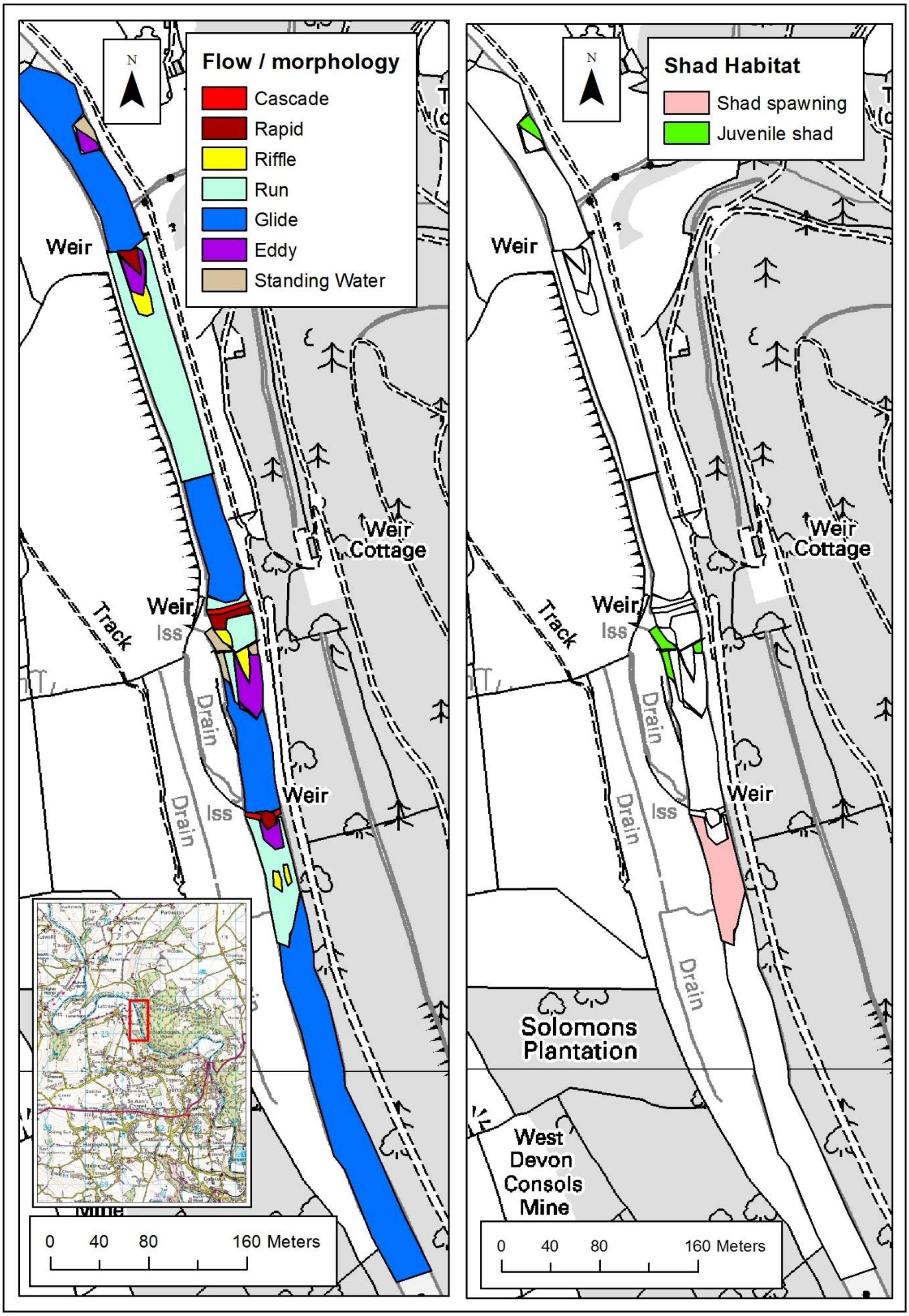

Figure 7. Map of flow type and allis shad habitat on the River Tamar, West Devon Consols Mine to Devon Great United Mine

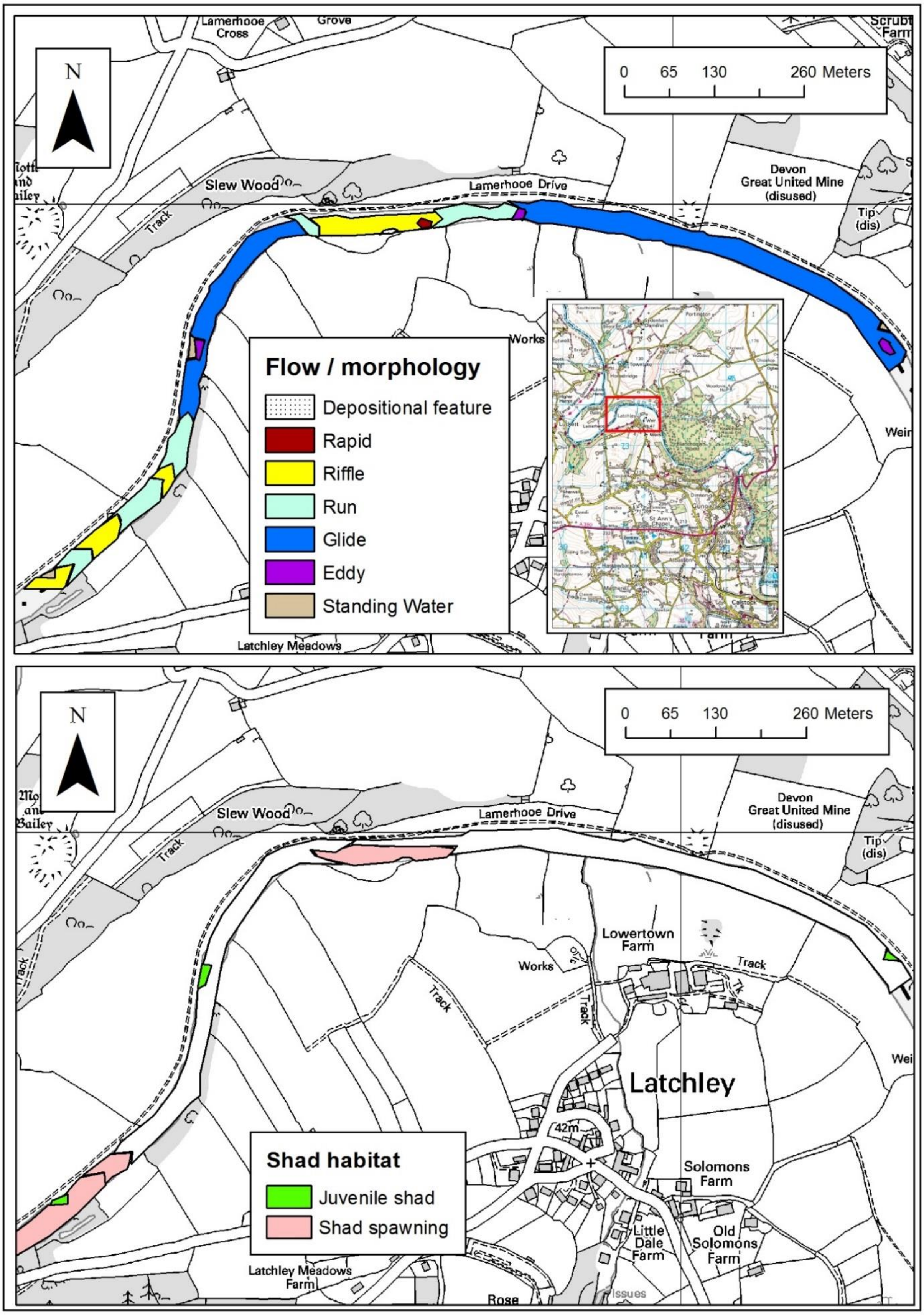

Figure 8. Map of flow type and allis shad habitat on the River Tamar, Devon Great United Mine to downstream of Lamerhooe Ford

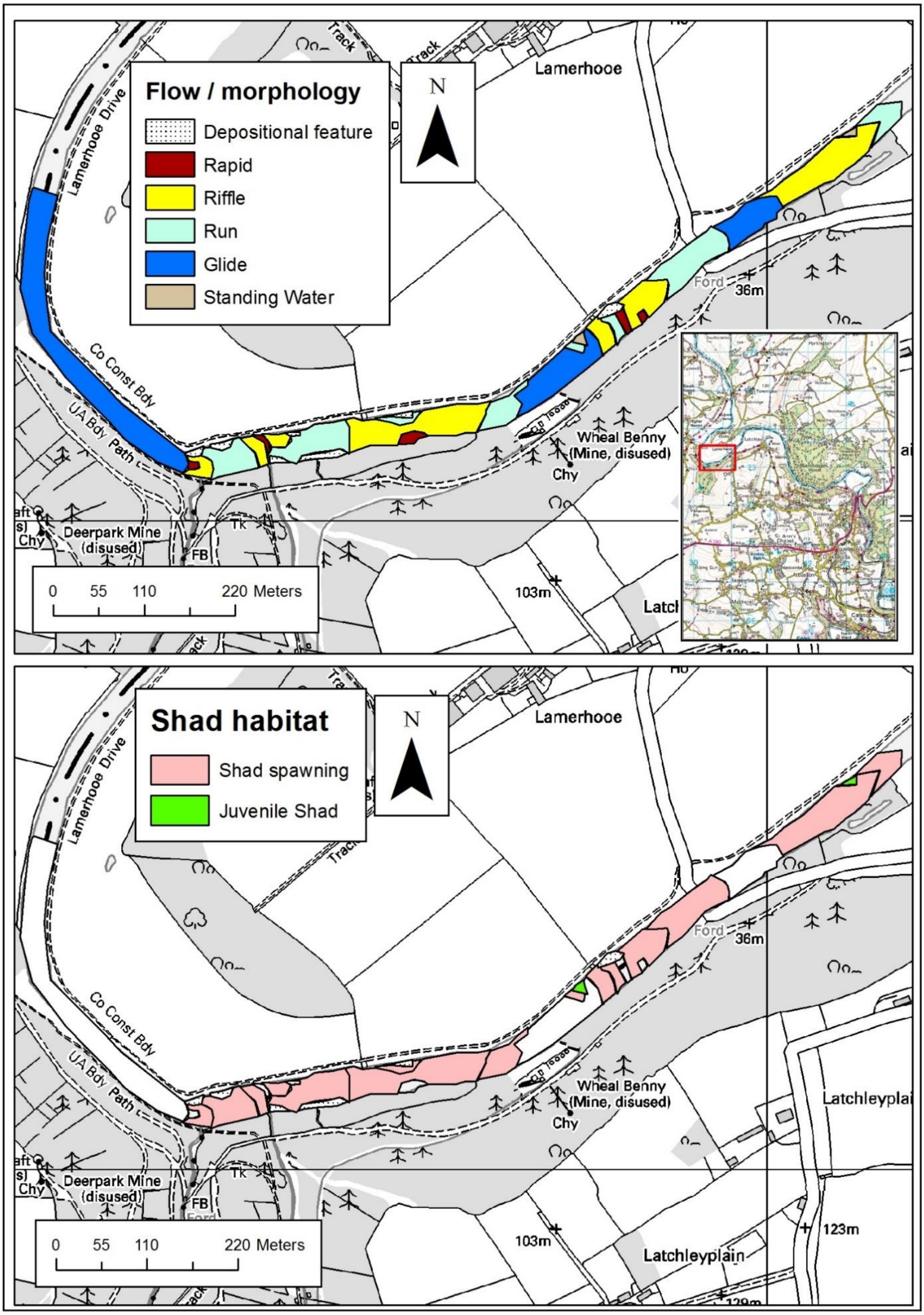

Figure 9. Map of flow type and allis shad habitat on the River Tamar, downstream of Lamerhooe ford to Greenscombe Farm

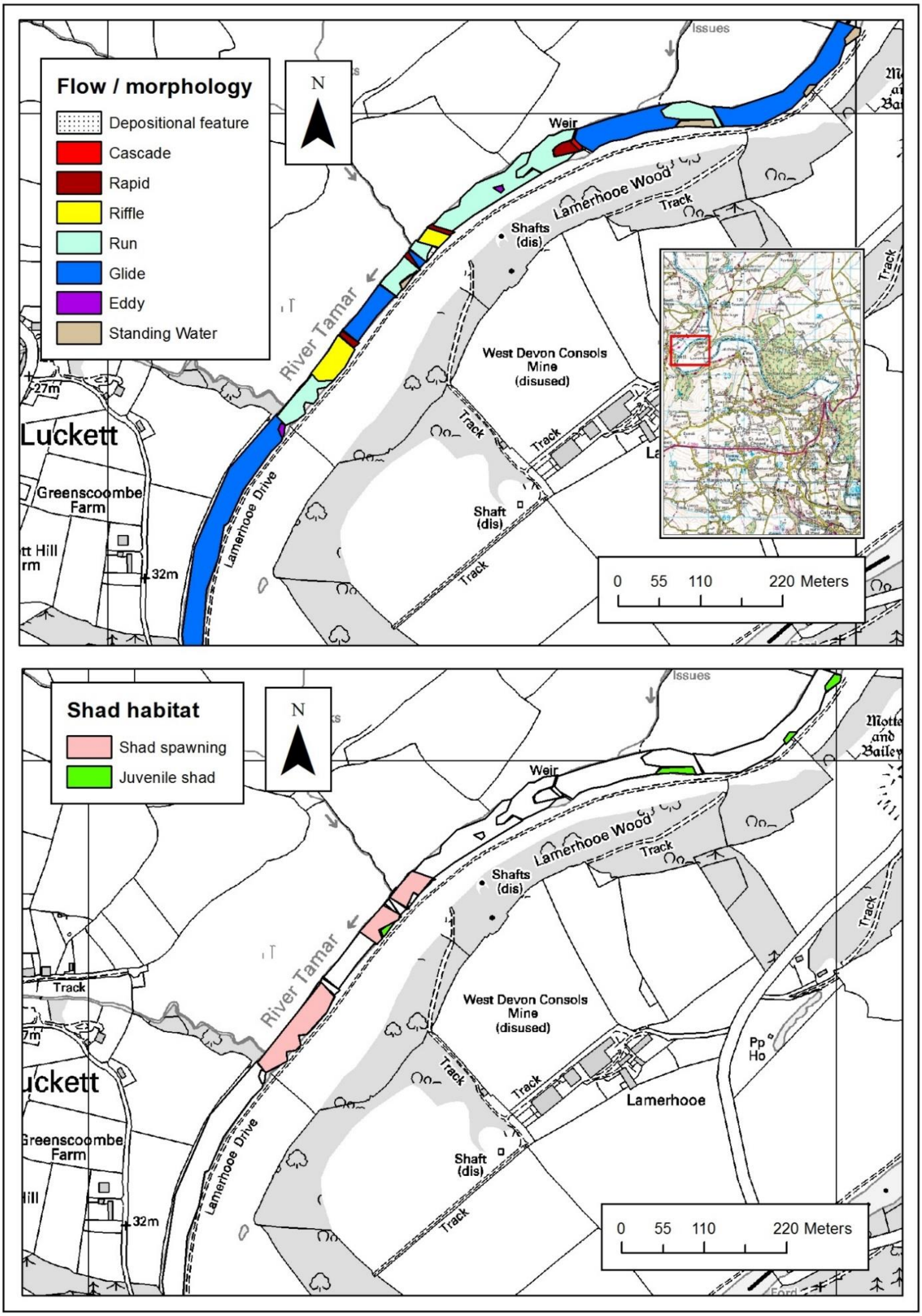

Figure 10. Map of flow type and allis shad habitat on the River Tamar, Greenscombe Farm to upstream Lamerhooe horse shoe meander

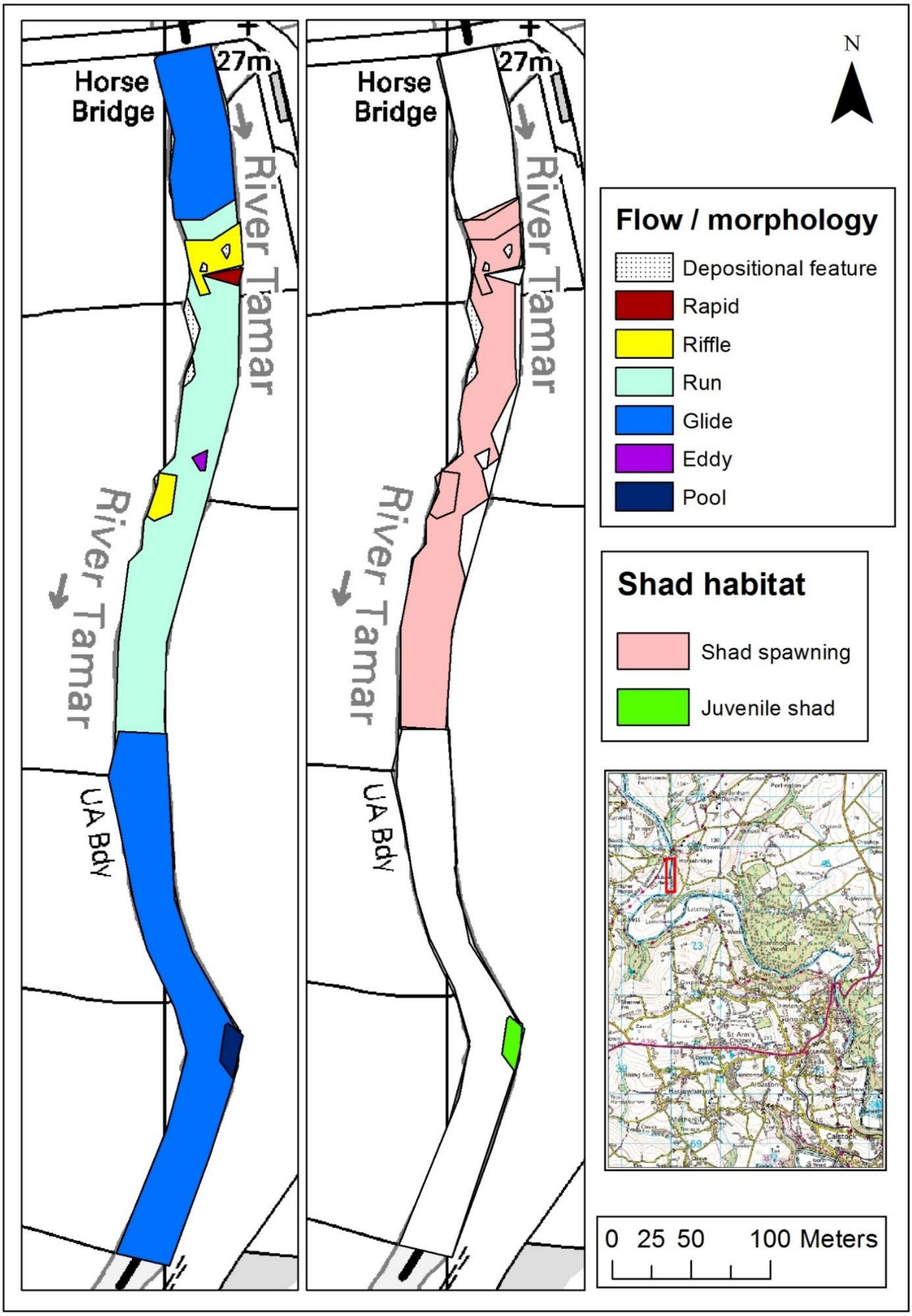

Figure 11. Map of flow type and allis shad habitat on the River Tamar, upstream Lamerhooe horse-shoe meander to Horsebridge

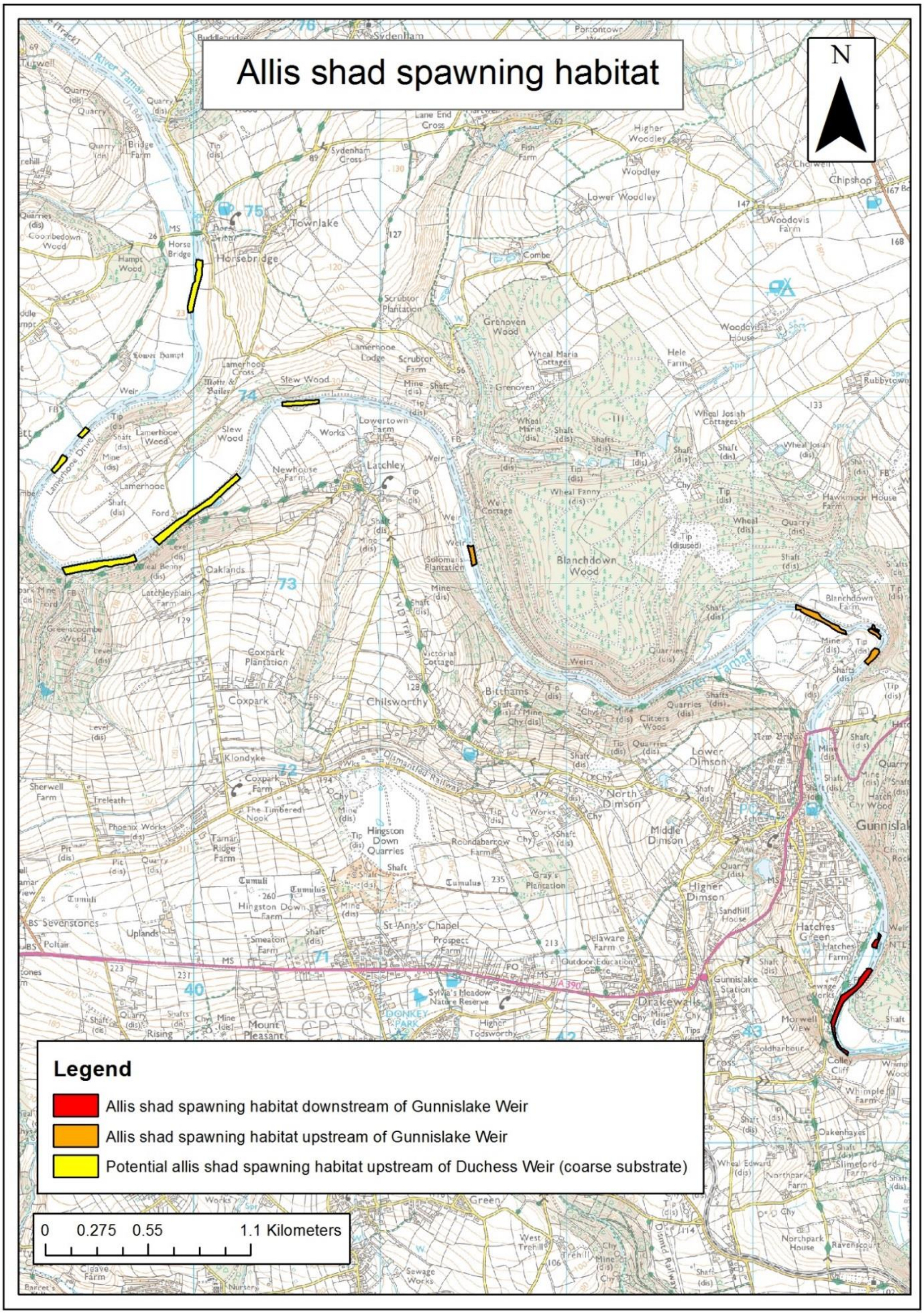

Figure 12. Summary map of suitable allis shad spawning habitat on the River Tamar and Upper Tamar Estuary

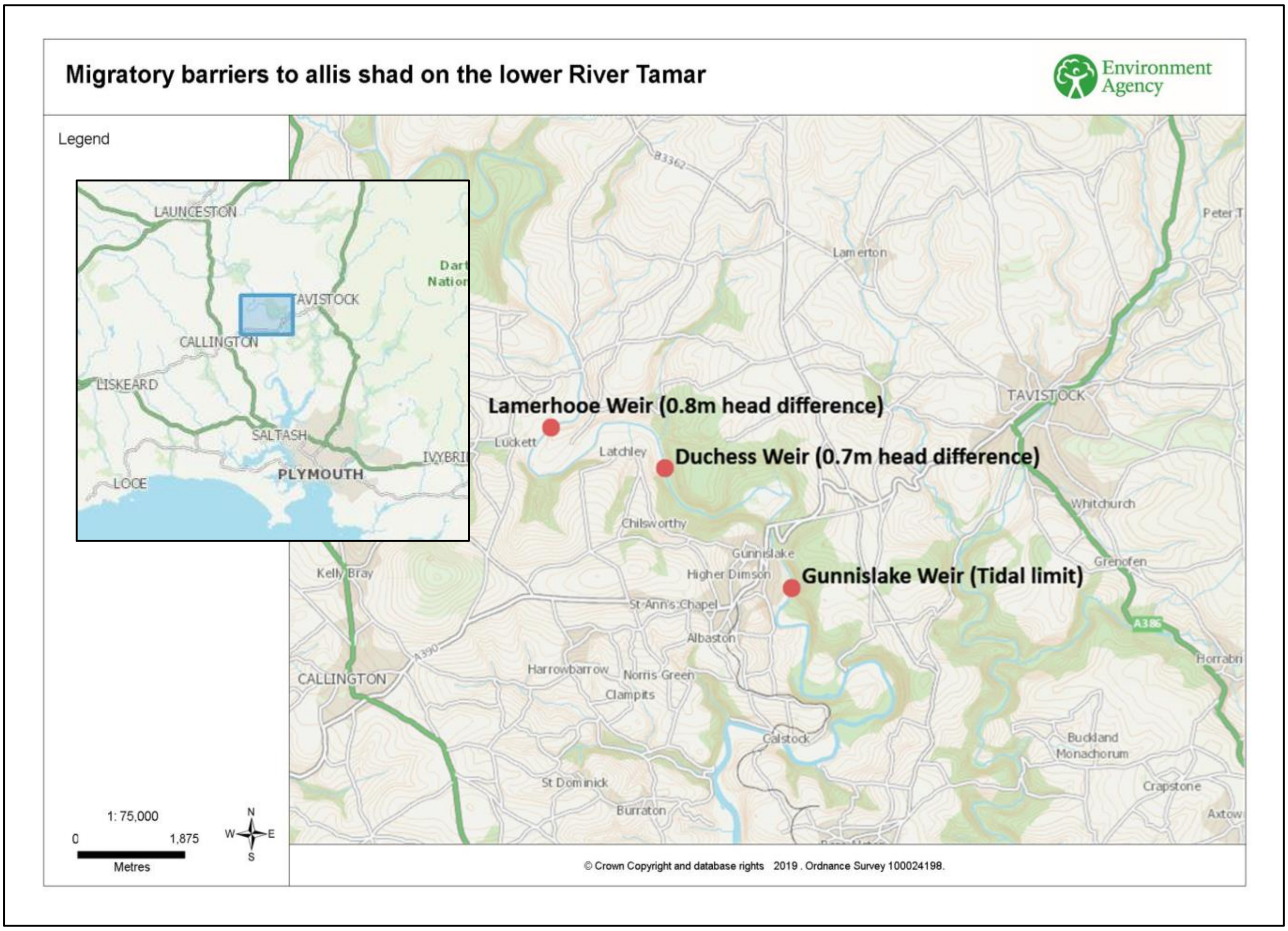

Figure 13. Map of migratory barriers to allis shad on the lower River Tamar and Upper Tamar Estuary

Discussion

There are no other known allis shad spawning populations in the UK (Maitland & Hatton-Ellis, 2003), but we can look to studies of populations in mainland Europe to determine their spawning habitat requirements. Spawning habitat is characterized by an area of coarse substrate limited upstream by a pool and downstream by shallow water with fast-moving currents (Bagliniere et al., 2003). The spawning substrate varies from sand (2µ - 2mm) to pebble/cobble (2 - 20cm). Eggs are deposited in water 0.5 to 3.0m deep where the current ranges from 0.5 to 1.5m/s (Roule 1923; Ellison 1935; Le Clerc 1941; Dottrens 1952; Hoestlandt 1958; Cassou-Leins & Cassou-Leins 1981; Dautrey & Lartigue 1983; Boisneau et al. 1990; Belaud et al., 2001). Allis shad spawning sites have been reported from channel widths between 15m and 200m (Aprahamian et al., 2003).

Although this habitat mapping study has been undertaken with these definitions in mind, it is inherently difficult to identify all available allis shad spawning habitat with absolute confidence, particularly where potential spawning habitat may exist in small, isolated pockets or certain characteristics (for example, substrate type) are marginally suitable compared to other studies.

This mapping exercise was undertaken from the river bank and channel, but where the water depth was too deep to permit wading, the river substrate was inferred from visible sections of the channel up and downstream. Habitat mapping was undertaken from the tidal reaches to

Horsebridge because the focus was on the lower reaches of the River Tamar, but suitable spawning habitat almost certainly exists upstream of Horsebridge.

Tidal freshwater Tamar

Allis shad have not been reported spawning in tidal sections of other rivers, but allis shad have been recorded spawning in the tidal Tamar since eggs were first found in 2000 (Cotterell and Hillman, 2016). Hass (1968) and Thiel et al. (1996) reported twaite shad spawning in the upper reaches of the Elbe estuary where the salinity was in the region of 0.3 parts per thousand, which suggests that allis shad could also utilise tidal spawning habitat, provided the salinity was low enough.

Suitable allis shad spawning habitat was identified downstream of Gunnislake Weir at two locations; Gunnislake Weir Pool and First Run (SX4367171093), and Cottage Run (SX4355970844). Allis shad eggs have been recorded at both of these sites prior to the habitat assessment (Cotterell and Hillman, 2016); on gravels at the head of First Run in 2010 and at Cottage Run on many occasions since 2000.

A tidal weir at the head of Cottage Run plunges into a pool, below which is an extensive riffle, adjacent to a large depositional side-bar of boulders and cobbles. This gives way to run and glide habitat in the middle and lower part of Cottage Run near Lock Cottage. Under low flows, there is a second area of riffle habitat towards the Cornwall-bank (SX4350470793), immediately downstream of Lock Cottage; however at the time of this habitat survey the water depth had flooded the riffle. Eggs were found on this riffle in the lower part of Cottage Run in 2011 and 2013, but it is not known if the eggs found here had drifted downstream from the riffle upstream or if this is a discrete spawning site.

The river substrate in Cottage Run is clean boulder/cobble in the upper reaches, transitioning to cobble/pebble/gravel in the run habitat. Downstream of Cottage Run as far as Impham Meadow meander bend, run and glide habitat prevails (with two small patches of riffle habitat) over a substrate of clean gravel/pebble/cobbles. However, this reach is tidal and previous egg surveys in 2015 at Lower Cottage Run, immediately upstream of Impham meander (SX4346070537), failed to detect allis shad eggs. It is unclear if the salinity here precludes allis shad spawning, or if allis shad preferentially spawn further up the Tamar system in the uppermost tidal reaches or in the river. A juvenile smelt survey in 2015 recorded salinity below 0.3 parts per thousand downstream as far as Morwellham Quay (Cotterell & Hillman, 2016), which suggests that salinity itself is not a limiting factor in the tidal reach downstream of Cottage Run, if the salinity tolerance of allis shad is similar to that recorded on the Elbe (Hass 1968; Thiel et al. 1996).

At Gunnislake Weir Pool, the tidal limit, there is a deep pool below the weir which flows over a small riffle into run habitat in First Run on the Cornwall-bank side of a mid-channel island. The river substrate in the weir pool is gravel and coarse sand, whereas in First Run gravel/pebble substrate predominated. At the head of First Run, near the Cornwall-bank of the weir pool, there is a depositional channel bar composed primarily of sand and gravel, with more silt at the upstream end and pebbles at the downstream end. Adjacent to First Run is a mid-channel island. A croy is present at the downstream end of First Run. Most of the flow from the weir pool passes to the Cornwall-side of the island (via First Run); at the time of survey, there was very little flow on the Devon-side of the island. Furthermore a croy downstream of the weir pool probably deters spawning on the Devon-side of the island, whereas on the Cornwall-side there is suitable riffle-run spawning habitat over gravel/pebble substrate.

Gunnislake Weir to Duchess Weir

The River Tamar is impounded by Gunnislake Weir for approximately 1.7km, with no suitable allis shad spawning habitat within this reach. The first available spawning habitat upstream of Gunnislake Weir is at Downstream Symon's Pool (SX4366972617). The substrate here is very clean and dominated by cobbles, with boulder, pebble and gravel also present. A deep pool (Symon's Pool) flows into an extensive bank-to-bank riffle, which sequences into run and glide habitat downstream. Allis shad eggs were found in a 2006 survey at this site.

Upstream of Symon's Pool at Blanchdown, there is possible allis shad spawning habitat either side of a mid-channel island. Towards the Cornwall-bank the substrate is dominated by cobbles with a small croy at the upstream end of the island. Immediately upstream of Blanchdown Island is an extensive deep glide known as Blanchdown Pool. The habitat is shallow, fast-flowing cobble-dominated habitat adjacent to Blanchdown Island is potentially suitable for allis shad spawning in the lower reaches of Blanchdown Pool. However, the croy on the Cornwall-bank side of the island prevents natural transition into faster flows downstream, which might deter spawning here. There is a small amount of potential spawning habitat to the Devon-bank side of Blanchdown Island.

Upstream of Blanchdown Pool there is an extensive area of run habitat over clean cobble-dominated substrate, varying in depth between 30 and 60cm. At the lower end of Blanchdown run a large fishing croy extends from the Devon bank with 5 concrete platforms in the channel downstream, at the head of the pool (SX4348472747); allis shad eggs were recorded at this location in 2005. Towards the Devon-bank the channel depth increases and there are numerous, large mid-channel boulders, but the habitat towards the Cornwall-bank is cobble-dominated, with boulder, pebble and gravels. Blanchdown Pool offers an ideal holding pool for allis shad, albeit with the suitable spawning habitat located upstream of the pool within Blanchdown Run.

At the upstream end of this reach is Ochre Pool on the Devon-side of the channel (SX4326072864) - a potential holding pool for allis shad. An extensive cobble point-bar fringes the channel on the Cornwall bank, adjacent to Ochre Pool. The reach from Blanchdown Pool to Ochre Pool looks suitable for allis shad spawning.

The river upstream of Blanchdown changes in character to a series of turbulent rapids, interspersed with a mosaic of rippled-flow and lower energy flow types. The river here is dominated by coarse substrate- predominantly large cobbles and boulders, which would probably deter shad spawning. At Bitthams, a weir impounds the river upstream almost as far as Duchess Weir, rendering this slow-flowing reach unsuitable for spawning.

Immediately downstream of Duchess Weir the substrate is dominated by very clean gravel, pebble and cobbles. Run habitat prevails for approximately 100m before transitioning to glide and the impounded reach downstream. This site looks suitable for allis shad spawning, albeit there is no pool at the head of the reach. The river at Duchess Weir is channelled through the central section of the weir, making the plunge pool fast flowing and turbulent. It's possible that allis shad could utilise the deeper habitat either side of the weir flume, downstream of the weir, and spawn within the run.

Duchess Weir to Lamerhooe Weir

Immediately upstream of Duchess Weir lies a second weir, smaller than Duchess Weir. Beyond this, the river is a slow-flowing glide, impounded for approximately 400m, with a series of fishing croys. A riffle-run-glide sequence north-west of Latchley offers potential shad spawning habitat, but the river here and at sites upstream is dominated by very coarse cobble and boulder substrate, which may deter spawning by allis shad. There are no reports of allis shad utilising a river substrate coarser than 20cm to spawn and it is unknown whether allis shad will tolerate coarser substrates for spawning.

The southern side of Lamerhooe horse-shoe meander offers almost a kilometre of riffle-run-glide sequences that look suitable for allis shad spawning, albeit over relatively coarse river substrate dominated by cobbles and boulders. At the upstream limit of this sequence, the river becomes impounded; it is possible that allis shad would use this site as a pool, which flows into riffle and run habitat downstream. A male allis shad in spawning condition was recovered dead from the riverbank at Greenscombe in 2007; although this individual had not spawned, it shows that some allis shad penetrate this far upstream on their spawning migration and suggests that allis shad are prospecting for potential spawning sites in this area.

Upstream, at the Luckett-end of the Lamerhooe horse-shoe meander, the river is impounded for approximately 500m. There are two further areas of potential shad spawning habitat between 200m and 400m downstream of Lamerhooe Weir, albeit over a coarse cobble/boulder substrate.

Lamerhooe Weir to Horsebridge

Approximately 100m downstream of Horsebridge is a 300m section of riffle-run habitat which could be suitable for allis shad spawning, albeit over a coarse cobble substrate. Downstream of this the river is dominated by glide habitat until it becomes impounded upstream of the Lamerhooe Weir.

Although Horsebridge was selected as the upstream limit for this study, there is almost certainly suitable shad spawning habitat upstream of Horsebridge. Despite the numerous migratory barriers in the lower Tamar, an allis shad has been recorded from upstream of Lamerhooe Weir. In 2000, a male allis shad in spawning condition was caught by a rod angler at Greystone Bridge, some 12km further upstream than Horsebridge.

Conclusion

Allis shad spawning habitat on the River Tamar and tidal freshwater reach is limited to relatively few locations, based upon the availability of habitat features, flow type and substrate required. Two locations in the tidal reach were identified as suitable for allis shad spawning, where spawning has been recorded previously; Cottage Run and Gunnislake Weir Pool/First Run. Approximately 1.2 ha of potential allis shad spawning habitat was identified downstream of Gunnislake Weir. However, if allis shad avoid spawning in all but the uppermost tidal reaches, as is likely, the useable spawning habitat in the tidal reach is approximately 0.6 ha.

Upstream of Gunnislake Weir, a partial migratory barrier to allis shad, the Blanchdown area is important and offers multiple suitable spawning locations for allis shad. Potential spawning habitat was also identified immediately downstream of Duchess Weir. Migratory barriers at Duchess Weir and Lamerhooe Weir limit access to potential shad spawning areas upstream. The spawning habitat available to allis shad between Gunnislake Weir and Duchess Weir amounts to approximately 1.3 ha.

Generally, the river substrate upstream of Duchess Weir is dominated by either large cobbles or small boulders- a coarser substrate than has been described in literature as being used by allis shad. It is not known if allis shad would utilise such coarse substrate for spawning. Between Duchess Weir and Horsebridge approximately 3.6 ha of potential allis shad spawning habitat exists, if the coarse substrate was tolerable to allis shad.

Recommendations

1. Survey the substrate size at sites upstream of Duchess Weir to provide comparability to other literature on known allis shad spawning substrate. This would help identify whether allis shad could utilise potential spawning habitat in this area.
2. The route of upstream migration at Gunnislake Weir remains unclear, although this study suggests that migration into the river takes place around spring tides. Monitoring at the weir face and base of the fish passes using cameras at spring tides would help identify the migration used by allis shad at Gunnislake Weir.
3. This study mapped potential allis shad spawning habitat upstream to Horsebridge; future studies could continue to map potential spawning habitat further upstream.

Monitoring spawning distribution

Method

Egg surveys

Potential allis shad spawning sites were selected where suitable habitat features were identified during the field mapping in May 2019. Some of these sites had been surveyed in previous years (Cotterell & Hillman, 2016).

On arrival at each site, an initial walkover survey was conducted to identify the patches of previously identified spawning habitat and to update dynamic risk assessments including the scoping of safe points for access and egress to the river.

Spawning by allis shad was determined by the presence of eggs, utilising the kick-sampling method (Caswell & Aprahamian 2001; Thomas & Dyson 2012a & b; Garrett et al. 2014; Pinder et al. 2016a). Surveying areas of suitable habitat in a downstream to upstream direction, samples were semi-randomly distributed (ignoring small patches of sand, silt etc.) across the full width of river, unless habitat features were restricted to a specific part of the channel. Kick sampling was carried out using a standard 250 µm macroinvertebrate hand net (width = 200mm, height = 250mm). The net was held vertically and the substrate upstream of the net was dislodged by for 30 seconds. The net was held close enough to the area being disturbed so that the eggs flowed into the net with the current. The contents of the net were then checked for the presence of shad eggs. At least 10 kick-samples were taken at each survey site, with additional kick-samples undertaken at sites with more suitable spawning habitat.

Habitat surveys at egg survey sites

Regardless of the presence/absence of eggs, each sampling location was georeferenced using a handheld GPS unit (Garmin) and the following physical habitat characteristics recorded: river depth (cm), river width (m), distance to bank (m), flow velocity at mid-depth (cm/s - Sontek Flow Tracker), flow type (RHS) and substrate composition (% boulder (>256mm), % cobble (64-246mm), pebble (32-64mm), gravel (2-32mm), sand (0.063-2mm), silt (<0.063m)). Channel position was also recorded as a ratio of total river width, where a channel position of 0.5 would represent mid channel width. Where sampling points were adjacent to mid-channel islands or depositional side bars, the width and channel position was recorded to the island/bar, rather than the true bank.

Where necessary, the georeferenced sample point location was retrospectively corrected using sampler notes and physical characteristics such as river width, distance to river bank and channel position. This was necessary where poor signal strength to the GPS unit resulted in inaccurate sample point locations.

At each sampling site a single suite of the following physicochemical parameters was also recorded using a YSI Pro+ handheld multi-probe: dissolved oxygen (% and mg/l), conductivity (µS), temperature (°C) and pH. Digital photographs were also captured to record general site characteristics at each of the five sampling sites.

As a proxy for spatial egg abundance, Catch-Per-Unit-Effort (CPUE) was calculated as a ratio of the number of shad eggs to the number of samples collected at each survey site.

Survey sites

Two sites were surveyed downstream of Gunnislake Weir (A and B), in the tidal reach. In the River Tamar three sites were surveyed (Sites C, D and E) (Figure 14). During the habitat survey, a significant migratory barrier was identified at Duchess Weir (SX4148573207); survey sites were restricted to suitable habitat downstream of this barrier. The river substrate at sites upstream of Duchess Weir was coarser than that known to have been utilised by allis shad populations elsewhere, which was a secondary factor in determining the upstream limit for egg survey sites.

Surveys were undertaken between 17 May and 23 August 2019, with most survey effort focussed on May and June, when eggs have been recorded in the past. A period of increased flow and high turbidity from 7 June to 17 June prevented surveying for eggs.

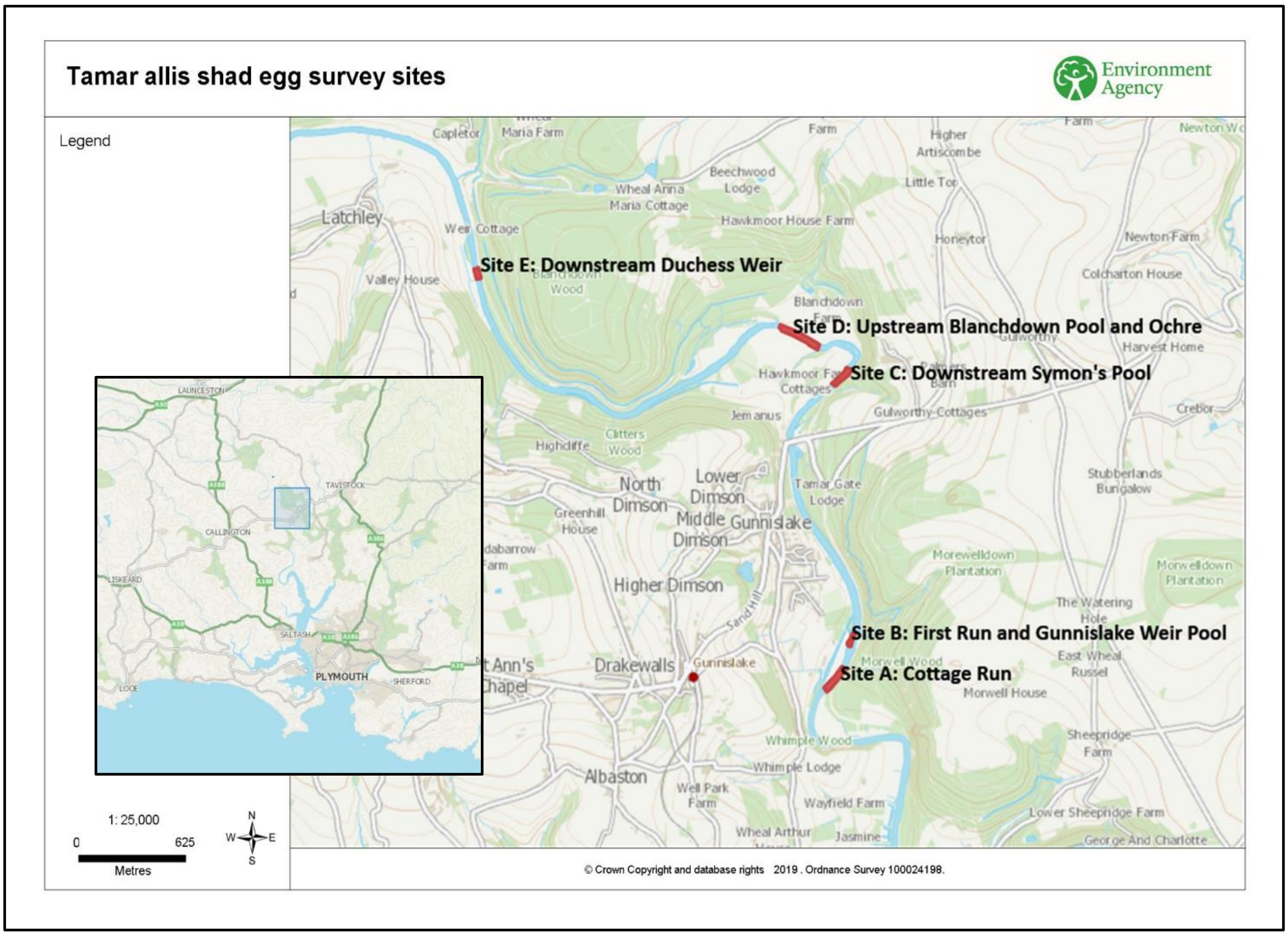

Figure 14. Map of allis shad egg survey sites

Tidal Freshwater Tamar

Site A: Cottage Run (SX4354970835)

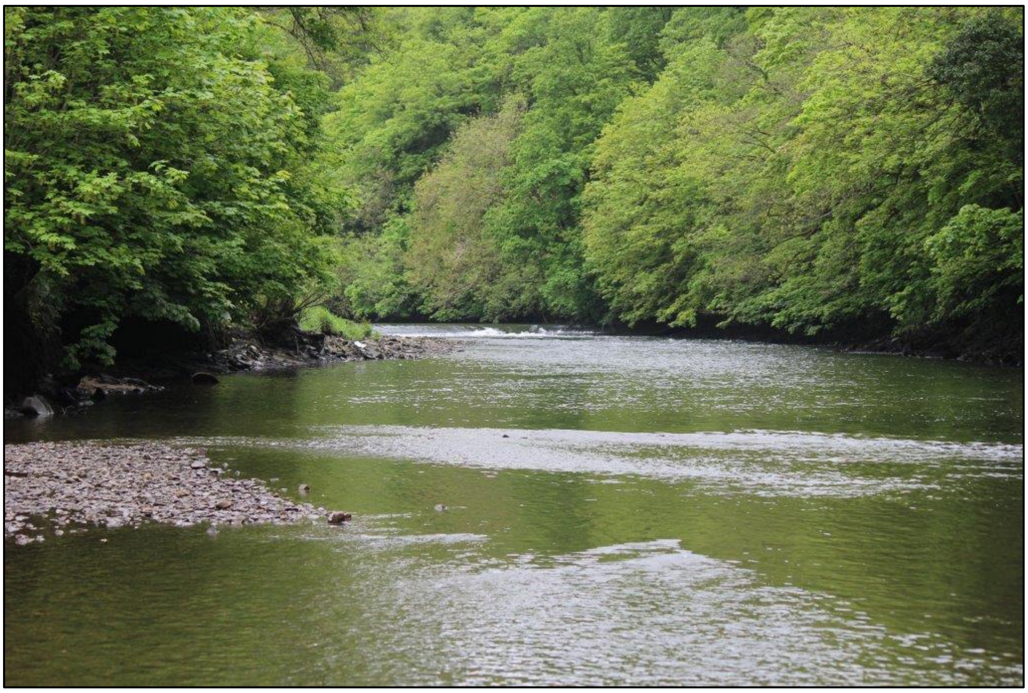

Figure 15. Site A, Cottage Run, looking upstream to Cottage Weir, viewed from the channel

Site A is located approximately 300m downstream of the tidal limit at Gunnislake Weir. Allis shad have regularly spawned at this site between 2000 and 2019; eggs were found at Site A in all 17 previous years between 2000 and 2019 inclusive, when egg surveys have been undertaken (2000-2006, 2008, 2010-2017, 2019). Eggs have been found in previous surveys downstream of a weir at the head of Cottage Run (hereafter referred to as Cottage Weir (SX4363070931)) and throughout the riffle and run habitat up to ~150m downstream of this weir (Figure 15).

There is a small pool immediately downstream of Cottage Weir, giving way to riffle, run and eventually glide habitat downstream. The predominant flow type was run habitat, characterised by rippled flow. The substrate was dominated by cobble, pebble and gravel (Table 3). The survey site extent was approximately 4,250m².

Table 3. Site characteristics of sample points at Site A

Site A	Depth (cm)	Flow velocity (cm/s)	Width (m)	Channel position
Mean	56.3	47.4	21.2	0.5
SD	17.3	14.6	3.4	0.2
Min	12.0	19.0	15.0	0.1
Max	90.0	78.0	27.0	0.9
N	80	40	80	80

Table 4. Substrate characteristics of sample points at Site A

Site A	Substrate (% cover)					
	Boulder (>256mm)	Cobble (64-256mm)	Pebble (16-64mm)	Gravel (2-16mm)	Sand (0.06-2mm)	Silt (<0.06mm)
Mean	6.5	31.2	35.6	17.6	7.0	1.5
SD	9.7	18.4	15.5	10.5	4.4	2.1
Min	0	0	5	2	0	0
Max	50	60	70	45	20	5
N	60	60	60	60	60	60

Table 5. Flow type at Site A sample points

Site A	Flow type sampled		
	Unbroken Wave	Rippled	Smooth
N	7	60	3
%	10	85.7	4.3

Table 6. Physicochemical water parameters at Site A sample points

Site A	Physicochemical parameters				
	Dissolved oxygen (%)	Dissolved oxygen (mg/l)	Conductivity (µS)	Water temperature (°C)	pH
Mean	100.4	10.0	259.1	15.6	7.9
SD	2.7	0.5	29.6	2.5	0.1
Min	95.5	9.2	193.8	13.0	7.8
Max	104.1	10.7	307.2	19.4	8.1
N	10	10	10	10	10

Site B: First Run and Gunnislake Weir Pool (SX4366671088)

Figure 16. Site B, Gunnislake Weir Pool viewed from right-hand bank

Figure 17. Site B, First Run viewed from right-hand bank

Site B is located immediately downstream of the tidal limit at Gunnislake Weir, from the downstream edge of the weir pool (SX4367871112) to the croy at the downstream end of First Run (SX4365071040). Sampling was undertaken on the right-hand side of the channel (nearest the Cornwall Bank) within the lower, right-hand side of Gunnislake Weir Pool (Figure 16) and in First Run (Figure 17). Sampling was limited to the right-hand channel, adjacent to the mid-channel island at First Run. At the time of sampling, a gravel bar was present at the edge of the weir pool, at the head of First Run.

Eggs have been found at this site in the past when suitable substrate and flows were present. Previous egg surveys recorded eggs in May and June 2010, but not in May 2012 or May 2017 (Suitable spawning habitat was very limited in 2017 due to recent deepening and dredging of gravels).

Sampling was undertaken within an area of approximately 1,400m². Gunnislake Weir Pool, located upstream of Site B, is both large and deep, at ~1,700m² and >1m deep.

The predominant flow type sampled was run habitat, characterised by rippled flow, although glide habitat at the tail end of Gunnislake Weir Pool was also sampled (Table 9). The substrate was gravel and sand in Gunnislake Weir Pool and pebble/gravel in First Run (Table 8).

Table 7. Site characteristics of sample points at Site B

Site B	Depth (cm)	Flow velocity (cm/s)	Width (m)	Channel position
Mean	59.9	39.9	25.9	0.7
SD	20.6	22.0	8.5	0.2
Min	7.0	10.0	8.0	0.2
Max	100.0	121.4	50.0	1.0
N	86	42	86	86

Table 8. Substrate characteristics of sample points at Site B

Site B	Substrate (% cover)					
	Boulder (>256mm)	**Cobble (64-256mm)**	**Pebble (16-64mm)**	**Gravel (2-16mm)**	**Sand (0.06-2mm)**	**Silt (<0.06mm)**
Mean	2.2	8.1	27.5	40.9	18.5	2.9
SD	5.6	13.1	15.7	14.2	14.4	2.7
Min	0	0	5	5	3	0
Max	20	50	60	70	70	10
N	52	52	52	52	52	52

Table 9. Flow type at Site B sample points

Site B	Flow type sampled		
	Unbroken Wave	**Rippled**	**Smooth**
N	0	58	18
%	0	76.3	23.7

Table 10. Physicochemical water parameters at Site B sample points

Site B	Physicochemical parameters				
	Dissolved oxygen (%)	**Dissolved oxygen (mg/l)**	**Conductivity (µS)**	**Water temperature (°C)**	**pH**
Mean	97.6	9.7	259.4	16.2	7.8
SD	4.4	0.5	28.1	1.5	0.1
Min	90.0	8.9	203.4	14.4	7.7
Max	106.0	10.4	291.0	18.4	8.2
N	9	9	9	9	9

River Tamar

Site C: Downstream Symon's Pool (SX4362872606)

Site C is located approximately 1.5km upstream of the tidal limit, upstream of a 1.5km reach impounded by Gunnislake Weir. The site is approximately 2,500m².

The site is approximately 50m downstream of a deep pool (Symon's Pool). The site consists of a wide riffle, giving way to run and glide habitat (Figures 18 and 19). The substrate here was dominated by boulder, cobble and pebble (Table 12).

Eggs have previously been found at this site on one out of seven previous surveys. Eggs were recorded in June 2006, but not in June 2000, June 2008, May 2010, June 2015 (2 survey dates) or May 2017.

Figure 18. Site C, Downstream Symon's Pool viewed from channel looking downstream

Figure 19. Site C, Downstream Symon's Pool upstream view from channel

Table 11. Site characteristics of sample points at Site C

Site C	Depth (cm)	Flow velocity (cm/s)	Width (m)	Channel position
Mean	63.3	40.6	27.3	0.4
SD	20.8	13.5	3.6	0.2
Min	20.0	10.6	22.0	0.3
Max	95.0	65.8	32.0	0.8
N	30	30	30	30

Table 12. Substrate characteristics of sample points at Site C

Site C	Substrate (% cover)					
	Boulder (>256mm)	**Cobble (64-256mm)**	**Pebble (16-64mm)**	**Gravel (2-16mm)**	**Sand (0.06-2mm)**	**Silt (<0.06mm)**
Mean	23.8	36.9	16.9	15.4	7.2	0.1
SD	15.5	11.9	12.8	6.4	4.6	0.6
Min	0	10	5	5	0	0
Max	50	50	60	30	20	3
N	29	29	29	29	29	29

Table 13. Flow type at Site C sample points

Site C	Flow type sampled		
	Unbroken Wave	**Rippled**	**Smooth**
N	1	27	2
%	3.3	90.0	6.7

Table 14. Physicochemical water parameters at Site C sample points

Site C	Physicochemical parameters				
	Dissolved oxygen (%)	**Dissolved oxygen (mg/l)**	**Conductivity (µS)**	**Water temperature (°C)**	**pH**
Mean	99.6	10.0	253.2	16.0	8.0
SD	2.7	0.4	39.2	1.6	0.1
Min	96.5	9.7	208.0	14.5	7.9
Max	101.4	10.4	278.6	17.7	8.1
N	3	3	3	3	3

Site D: Upstream Blanchdown Pool (SX4348172739) and Ochre (SX4325472862)

Site D is an extensive area of riffle and run habitat upstream of a very large and deep pool, Blanchdown Pool. A fishing croy and five concrete platforms marks the lower extent of the site where the run gives way to glide and pool (Figure 20); the water depth at the head of Blanchdown Pool, downstream of the sampled run habitat (Figure 21), made sampling unfeasible. At the upstream end of the site is a pool, below which is a marginal gravel bar (Figures 22 and 23). This area is known by anglers as Ochre.

The substrate at Site D was dominated by cobbles and pebbles (Table 16).

The site covers approximately 6,500m^2.

Eggs have been found here on one of four previous surveys; eggs were present in June 2005 but were not recorded in June 2006, May 2010 or June 2015. Ochre was surveyed once previously in 2006, but no eggs were found.

Table 15. Site characteristics of sample points at Site D

Site D	Depth (cm)	Flow velocity (cm/s)	Width (m)	Channel position
Mean	56.7	57.3	27.7	0.7
SD	20.2	14.2	5.1	0.1
Min	25.0	18.8	18.0	0.3
Max	110.0	99.4	35.0	1.0
N	60	60	60	60

Figures 20 to 23. Site D, Clockwise from top left, **Figure 20.** Upstream Blanchdown Pool, downstream view towards pool from croy on left-hand bank; **Figure 21.** Upstream Blanchdown Pool, upstream view from croy on left-hand bank; **Figure 22.** Ochre, upstream view from gravel bar on right-hand bank; **Figure 23.** Ochre, downstream view from left-hand bank.

Table 16. Site characteristics of sample points at Site D

Site D	Depth (cm)	Flow velocity (cm/s)	Width (m)	Channel position
Mean	56.7	57.3	27.7	0.7
SD	20.2	14.2	5.1	0.1
Min	25.0	18.8	18.0	0.3
Max	110.0	99.4	35.0	1.0
N	60	60	60	60

Table 17. Substrate characteristics of sample points at Site D

Site D	Substrate (% cover)					
	Boulder (>256mm)	**Cobble (64-256mm)**	**Pebble (16-64mm)**	**Gravel (2-16mm)**	**Sand (0.06-2mm)**	**Silt (<0.06mm)**
Mean	13.1	37.7	25.3	17.1	5.8	0.9
SD	9.9	9.9	8.6	6.0	2.0	1.9
Min	0	10	10	5	5	0
Max	50	60	50	30	15	5
N	60	60	60	60	60	60

Table 18. Flow type at Site D sample points

Site D	Flow type sampled		
	Unbroken Wave	**Rippled**	**Smooth**
N	0	60	0
%	0	100	0

Table 19. Physicochemical water parameters at Site D sample points

Site D	Physicochemical parameters				
	Dissolved oxygen (%)	**Dissolved oxygen (mg/l)**	**Conductivity (µS)**	**Water temperature (°C)**	**pH**
Mean	102.3	10.2	257.4	15.6	8.0
SD	3.8	0.2	26.2	1.5	0.1
Min	97.7	10.0	212.1	14.3	7.9
Max	107.4	10.5	277.6	18.0	8.2
N	5	5	5	5	5

Site E: Downstream Duchess Weir (SX4149973145)

Site E is a large area of very clean gravel, pebble and cobble dominated substrate (Table 20) immediately downstream of Duchess Weir (Figure 24). This site represents approximately 2000m^2 of allis shad spawning habitat. Downstream of this site the river becomes slow-flowing and impounded by another small weir downstream.

Site E had never been surveyed for allis shad eggs, prior to 2019.

Figure 24. Site E, Downstream Duchess Weir, viewed from the channel looking upstream

Table 20. Site characteristics of sample points at Site E

Site E	Depth (cm)	Flow velocity (cm/s)	Width (m)	Channel position
Mean	51.6	40.3	25.0	0.5
SD	18.5	11.2	0.0	0.1
Min	25.0	16.0	25.0	0.2
Max	85.0	57.0	25.0	0.7
N	10	10	10	10

Table 21. Substrate characteristics of sample points at Site E

Site E	Substrate (% cover)					
	Boulder (>256mm)	Cobble (64-256mm)	Pebble (16-64mm)	Gravel (2-16mm)	Sand (0.06-2mm)	Silt (<0.06mm)
Mean	9.0	26.5	34.5	22.0	8.0	0.0
SD	9.7	14.3	12.6	9.8	3.5	0.0
Min	0	5	20	5	5	0
Max	30	40	60	35	15	0
N	10	10	10	10	10	10

Table 22. Flow type at Site E sample points

Site E	Flow type sampled		
	Unbroken Wave	**Rippled**	**Smooth**
N	0	10	0
%	0	100	0

Table 23. Physicochemical water parameters at Site E sample points

Site E	Physicochemical parameters				
	Dissolved oxygen (%)	**Dissolved oxygen (mg/l)**	**Conductivity (µS)**	**Water temperature (°C)**	**pH**
Mean	104.2	10.3	259.7	14.2	8.1
SD	0.0	0.0	0.0	0.0	0.0
Min	n/a	n/a	n/a	n/a	n/a
Max	n/a	n/a	n/a	n/a	n/a
N	1	1	1	1	1

Results

Spawning distribution and timing

In total, 24 egg surveys were completed on the freshwater and tidal Tamar in 2019, comprising 266 30-second kick samples. These surveys spanned 5 sites between 17 May and 23 August 2019. Two periods of elevated turbidity and increased river flow prevented sampling between 8 and 16 June and 15 and 19 August 2019. 15 surveys were carried out at two sites downstream of the tidal limit (Sites A and B); the remaining 9 surveys were carried out at 3 sites (Sites C, D and E) upstream of Gunnislake Weir in the River Tamar.

Eggs were present on 11 of the 15 surveys (73%) undertaken at sites downstream of Gunnislake Weir. However, one of these surveys on 23 August was undertaken to confirm spawning had finished so, excluding this survey, eggs were present on 79% of surveys undertaken in the tidal reach. At sites upstream of Gunnislake Weir eggs were present on 3 of the 9 surveys (33%). Figure 25 shows the mean number of eggs per kick sample found on each survey.

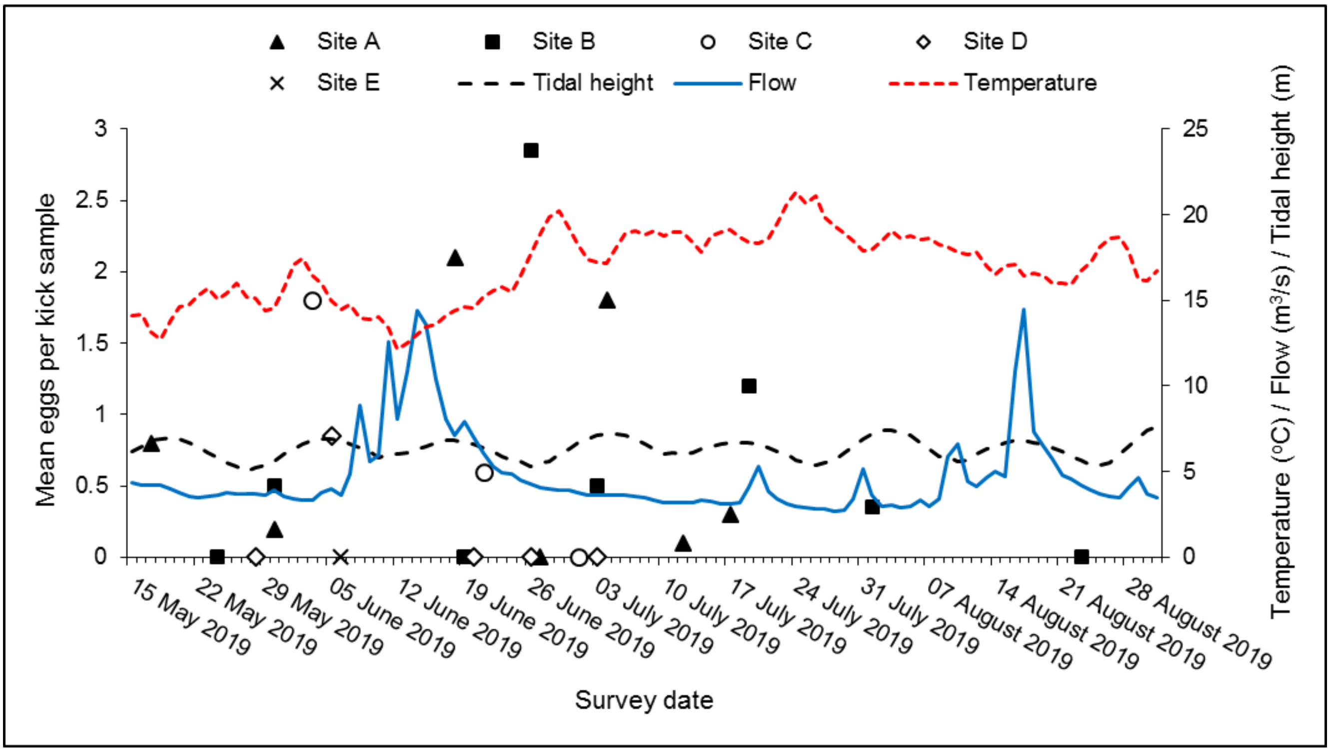

Figure 25. Mean number of allis shad eggs per kick sample recorded from each survey site (tidal sites A & B shaded symbols; river sites C, D & E unshaded symbols), plotted against prevailing water temperature, flow and tidal height.

Site A: Cottage Run

Cottage Run was surveyed 7 times in 2019 and allis shad eggs were present on 6 occasions (86%). Eggs were present throughout May, June and July, except on one survey in late June. Peak catch per unit effort was in mid-June and early July.

Table 24. Site A egg survey results

Date	Water temperature (°C)	Eggs	Samples	CPUE (Mean eggs per kick)
17 May 2019	13.1	12	15	0.8
30 May 2019	14.5	3	15	0.2
18 June 2019	14.4	21	10	2.1
27 June 2019	18.2	0	10	0.0
04 July 2019	16.5	18	10	1.8
12 July 2019	19.2	1	10	0.1
17 July 2019	19.4	3	10	0.3

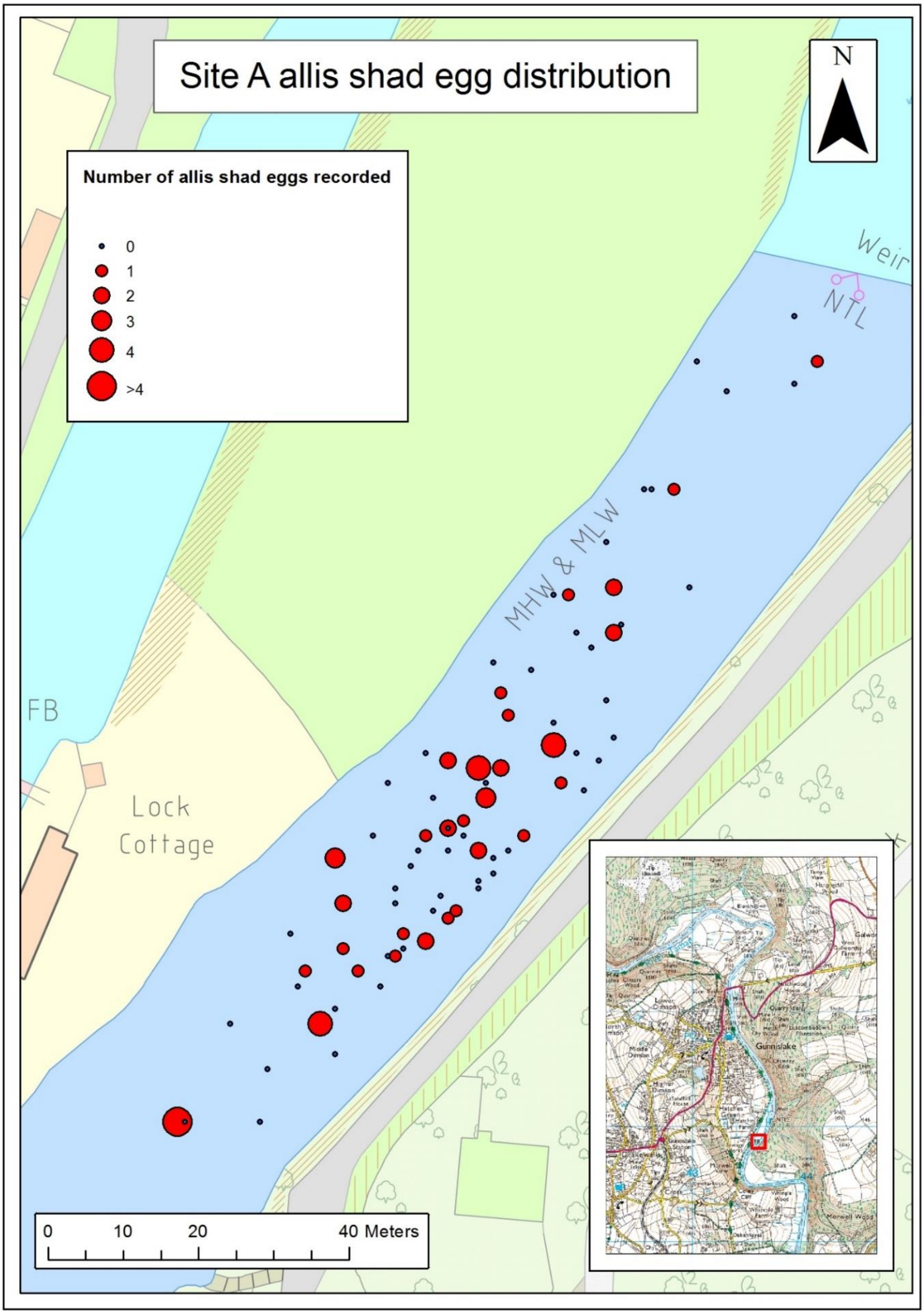

Figure 26. Allis shad egg distribution and relative abundance from all 2019 surveys at Site A (Cottage Run)

Allis shad eggs were found throughout Cottage Run in 2019, with most eggs found in the run and riffle habitat just upstream of Lock Cottage (Figure 26). Smaller numbers of eggs were found at the upstream end of Cottage Run.

The eggs recorded on 17 May and 18 June 2019 were fresh indicating recent spawning. The eggs recorded on 4 July were in various stages of development from fresh to early stages of development (no embryo was visible, albeit examination took place in the field). On 12 July only one egg was found containing a well-developed allis shad embryo, moving in the egg. At the water temperature of approximately 19.2°C, as recorded on 12 July, the incubation time for allis shad is between 96 and 168 hrs (4-7 days) (Aprahamian et al., 2003). This suggests that the egg recorded on 12 July was spawned sometime during the period 5-8 July 2019.

Site B: First Run and Gunnislake Weir Pool

Gunnislake Weir Pool and First Run was surveyed 8 times in 2019; allis shad eggs were present on 5 sampling occasions (63%). Eggs were present from late May until early August, with peak catch per unit-effort in late June and mid-July (Table 24).

Table 25. Site B egg survey results

Date	Water temperature (°C)	Eggs	Samples	CPUE (Mean eggs per kick)
24 May 2019	15.0	0	10	0.0
30 May 2019	14.7	5	10	0.5
19 June 2019	14.4	0	9	0.0
26 June 2019	17.2	37	13	2.8
03 July 2019	17.3	5	10	0.5
19 July 2019	18.4	12	10	1.2
01 August 2019	17.8	5	14	0.4
23 August 2019	15.9	0	10	0.0

Allis shad eggs were recorded at the edge of the weir pool, adjacent to a depositional bar near the Cornwall-bank side of the channel (Figure 27). Eggs were recorded at sampling depths of 45 to 96cm in the weir pool- it was not possible to sample depths greater than 96cm. Very high egg density was recorded in a shallow back-eddy immediately downstream of the depositional bar at the Cornwall-side of the weir pool. On 26 June 2019, two 30-second kick samples recorded 10 and 12 allis shad eggs respectively from this back-eddy. The water depth in the back eddy was very shallow at 15 and 16cm for the two kick-samples described above.

Allis shad eggs were also present in First Run in run habitat. Eggs were typically found in the rippled flow in areas of reduced current velocity, on the edge of the faster flow. One such area was at the mid-channel island side of First Run, where the flow velocity was lower than the centre of the channel.

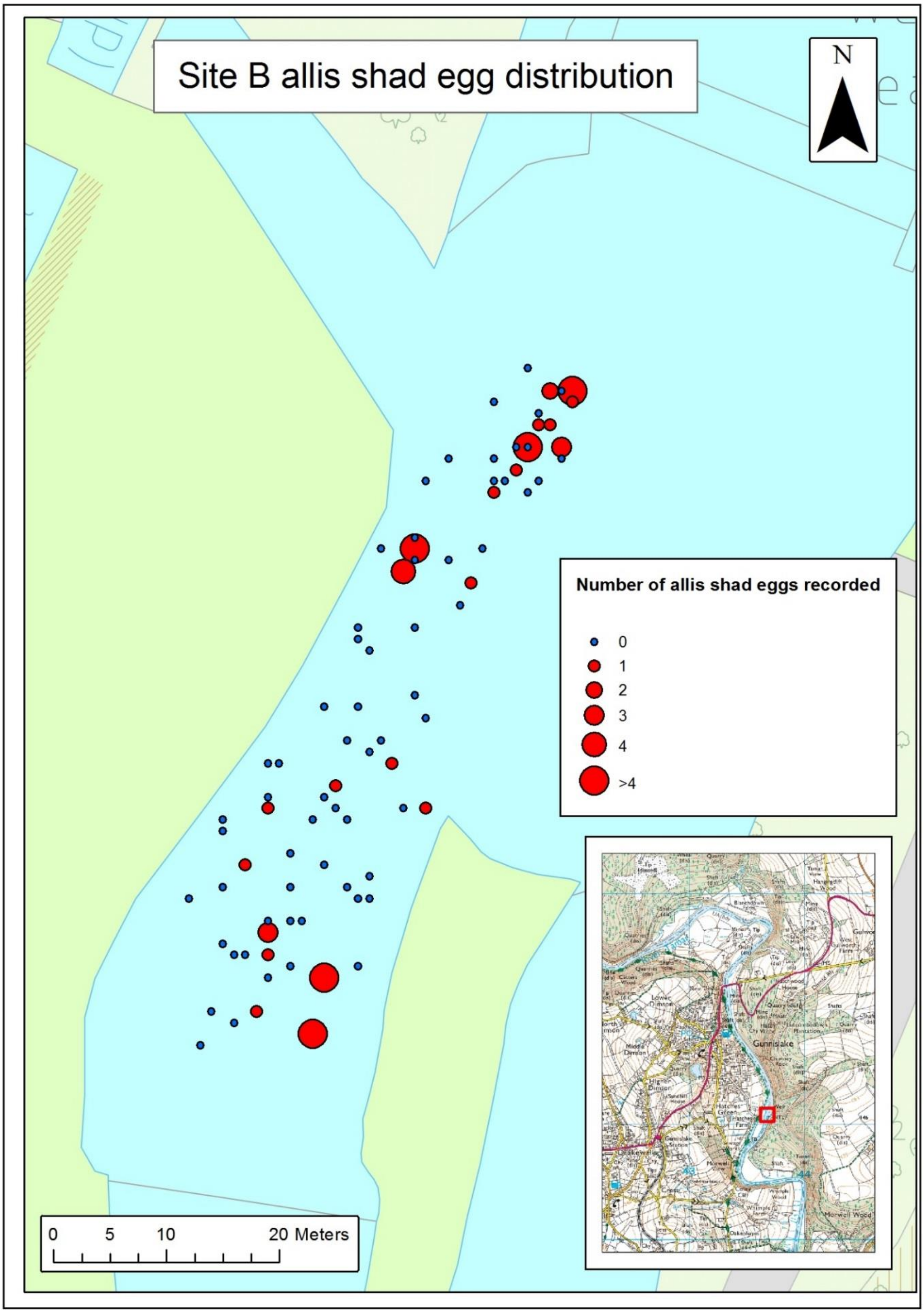

Figure 27. Allis shad egg distribution and relative abundance from all 2019 surveys at Site B (Gunnislake Weir Pool and First Run)

The eggs recorded in Gunnislake Weir Pool were recorded where the flow type was either smooth or rippled, whereas eggs adjacent to the depositional bar and in First Run were recorded in rippled flow.

Sampling was limited to the Cornwall-side of Gunnislake Weir Pool and First Run, because at the time of sampling there was very little flow on the Devon-bank side of the island.

Egg development stage was not recorded on 30 May. On 26 June the eggs recorded all appeared to be fresh, none contained well-developed embryos. This indicates spawning in the days immediately prior to the survey.

On 3 July, 3 of the eggs were in the early stages of development and two contained well-developed embryos. At prevailing water temperatures, these eggs would have most likely been spawned within the 7 days prior to the survey, during the period 26 June to 2 July.

Egg recorded on 19 July appeared to be fresh indicating recent spawning.

4 of the 5 eggs recorded on the 1 August were in the pigmented-eye embryo, final development stage. Based upon prevailing water temperature at the time, this suggests that spawning took place 4 to 7 days prior to sampling (25-28 July).

<u>Site C: Downstream Symon's Pool</u>

Downstream Symon's Pool was surveyed 3 times in 2019; eggs were present on two occasions in June, with greatest numbers of eggs in early June (Table 25).

Table 26. Site C egg survey results

Date	Water temperature (°C)	Eggs	Samples	CPUE (Mean eggs per kick)
03 June 2019	15.8	18	10	1.8
21 June 2019	14.5	6	10	0.6
01 July 2019	17.7	0	10	0.0

Allis shad eggs were distributed throughout the run habitat below a riffle (Figure 28). Most eggs were recorded in the deeper water (70-95cm) in the lower site, whilst a few were recorded in shallower faster flowing water further upstream.

Egg development stage was not recorded on 3 June; spawning would have occurred within the previous 7 days based upon the prevailing water temperature at the time (ref). None of the eggs recorded on 21 June contained well-developed embryos, indicating that spawning had occurred within the previous 7 days. This suggests that allis shad spawned sometime between 28 May and 2 June and between 15 and 20 June.

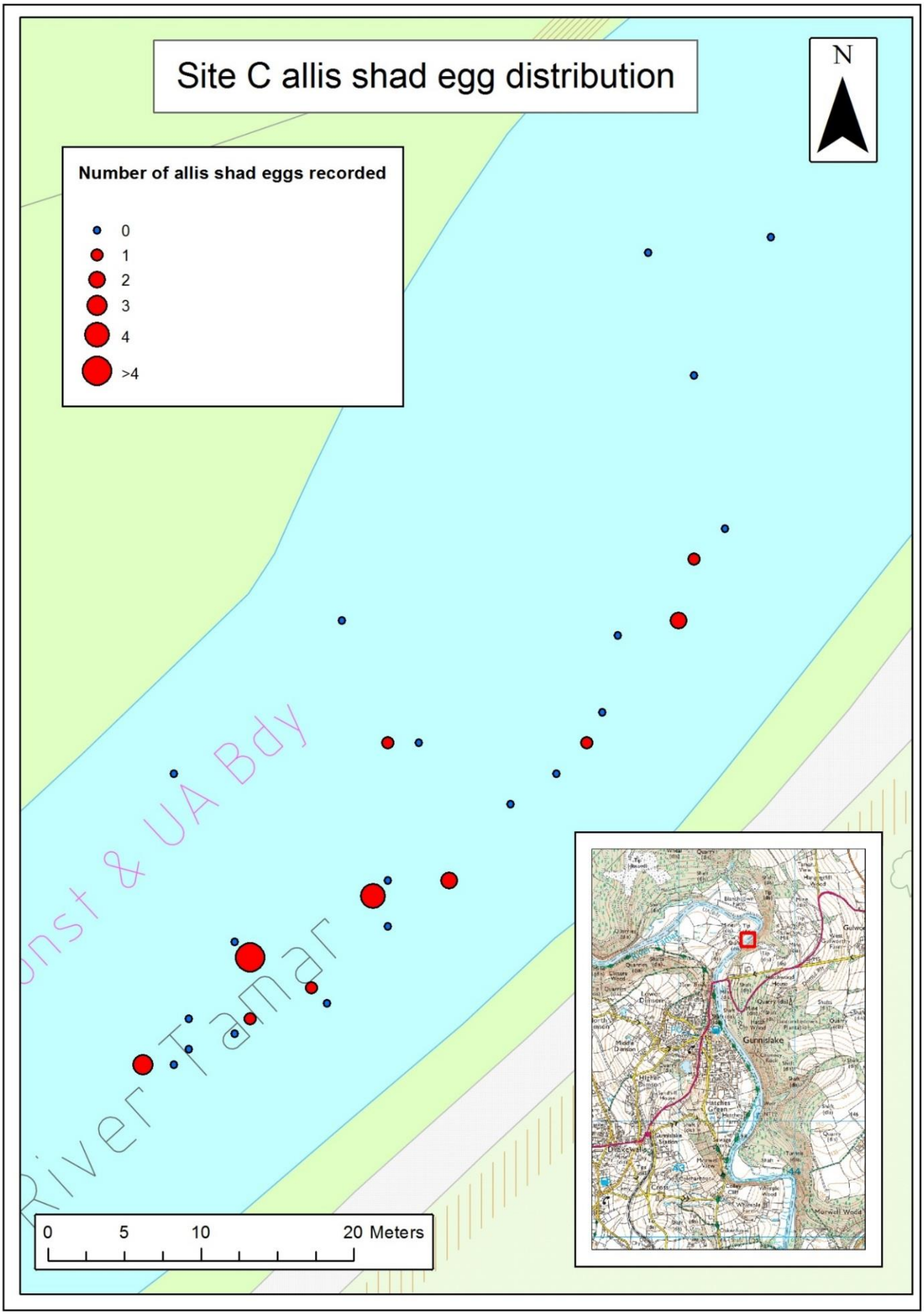

Figure 28. Allis shad egg distribution and relative abundance from all 2019 surveys at Site C (Downstream Symon's Pool)

Site D: Upstream Blanchdown Pool and Ochre

Upstream Blanchdown Pool and Ochre was surveyed 5 times from late May until early July 2019; eggs were only recorded on one sampling occasion on 5 June 2019 (Table 26).

Table 27. Site D egg survey results

Date	Water temperature (°C)	Eggs	Samples	CPUE (Mean eggs per kick)
28 May 2019	15.0	0	10	0.0
05 June 2019	14.3	17	20	0.9
20 June 2019	14.5	0	10	0.0
26 June 2019	18.0	0	10	0.0
03 July 2019	16.2	0	10	0.0

Allis shad eggs were recorded in two discrete areas; the area in the lower site immediately upstream of Blanchdown Pool (subsequently referred to as D1) and the upper part of the site at Ochre (subsequently referred to as D2) (Figure 29). This is the first time that allis shad eggs have been recorded at Ochre.

Sampling effort at Site D was initially distributed evenly throughout the site, but following the survey on 5 June in which allis shad eggs were recorded in two discrete areas within Site D, further sampling effort was divided (albeit unequally) between D1 and D2. D1 was surveyed on 5 occasions (45 kick samples in total) and D2 on 4 occasions (15 kick samples in total).

In summary maps (Figures 31-33), Site D is split into D1 and D2 in terms of the total eggs recorded (Figure 31), CPUE (Figure 32) and number of occasions surveyed verses eggs recorded (Figure 33).

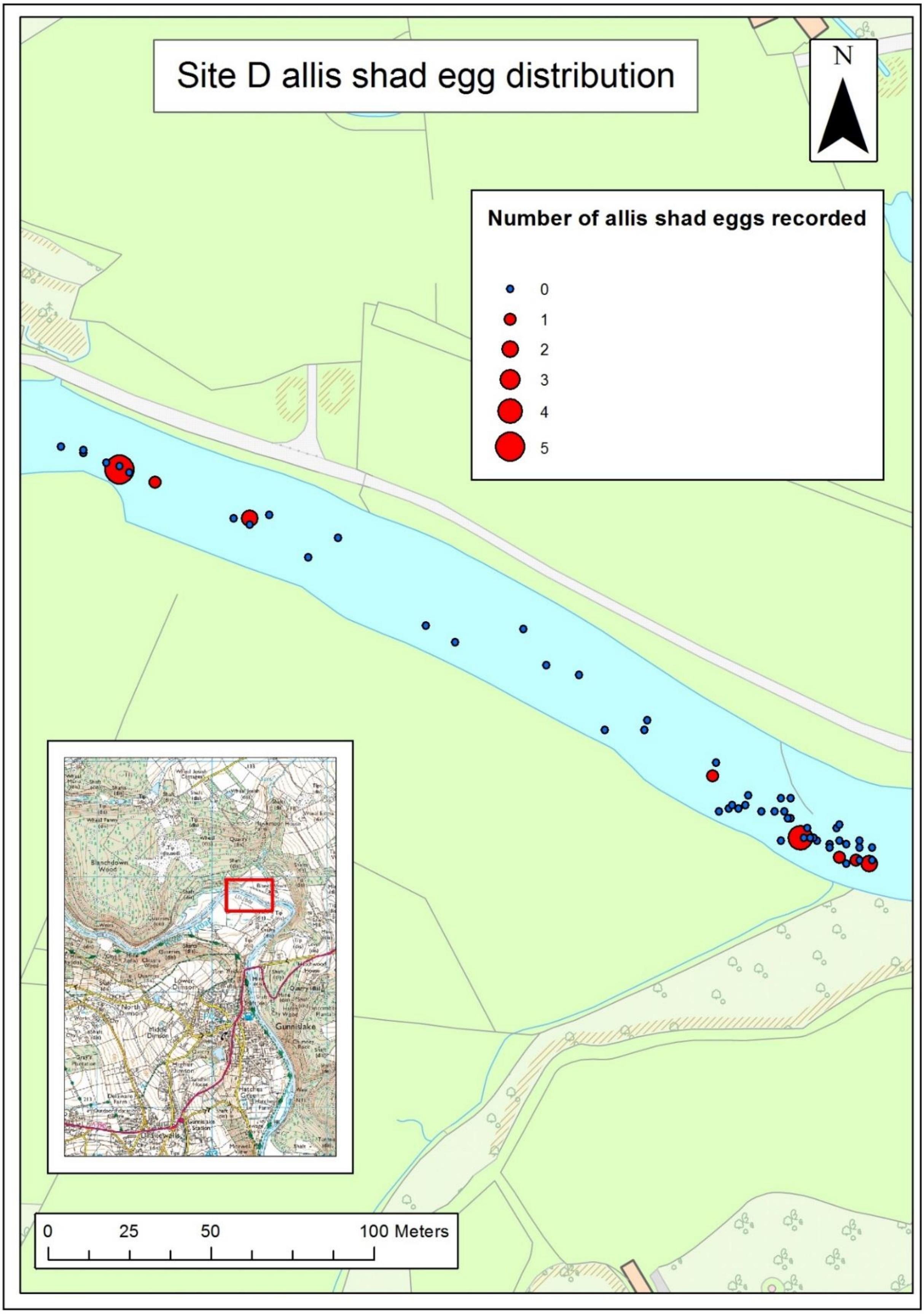

Figure 29. Allis shad egg distribution and relative abundance from all 2019 surveys at Site D (Upstream Blanchdown Pool (D1) and Ochre (D2))

Site E: Downstream Duchess Weir

Downstream Duchess Weir was surveyed on one occasion on 6 June (water temperature 14.2°C); eggs were not present in any of the 10 kick samples undertaken (Figure 30).

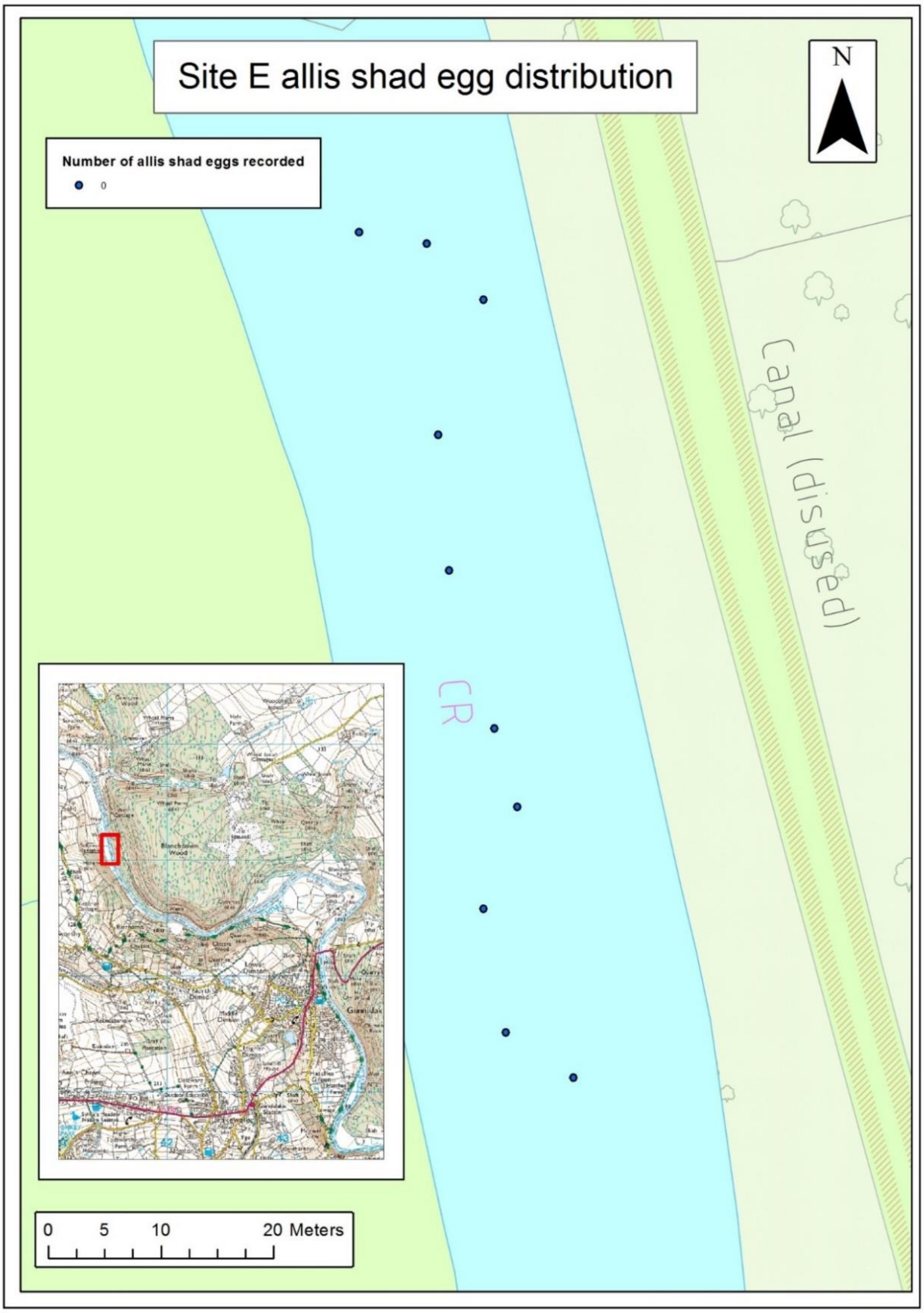

Figure 30. Allis shad egg distribution and relative abundance from all 2019 surveys at Site E (Downstream Duchess Weir)

Summary allis shad egg distribution and relative abundance

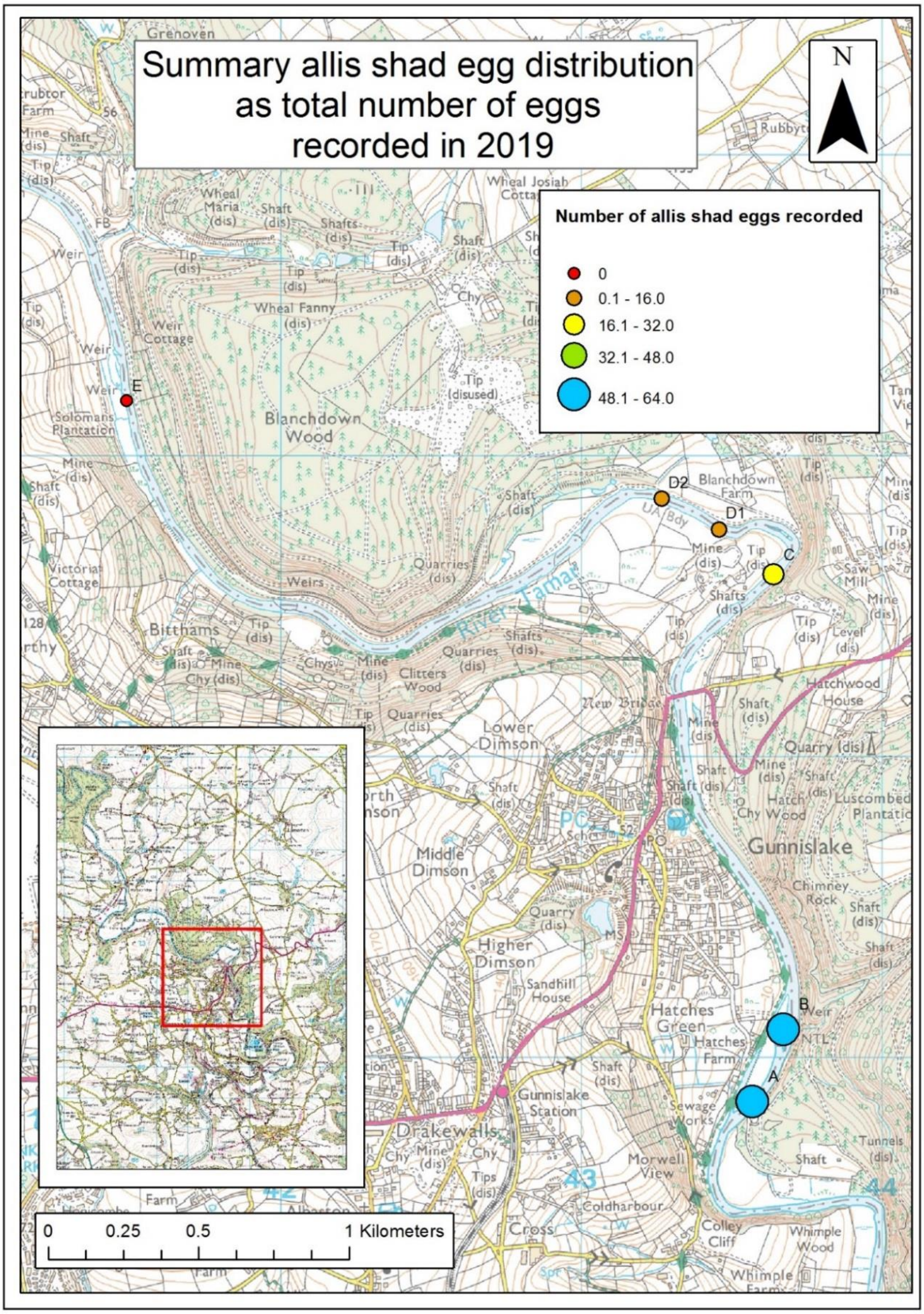

Figure 31. Total number of allis shad eggs recorded in all kick samples at each survey site in 2019 (Site D is split into D1 (Upstream Blanchdown Pool) and D2 (Ochre)). Site survey effort unequal.

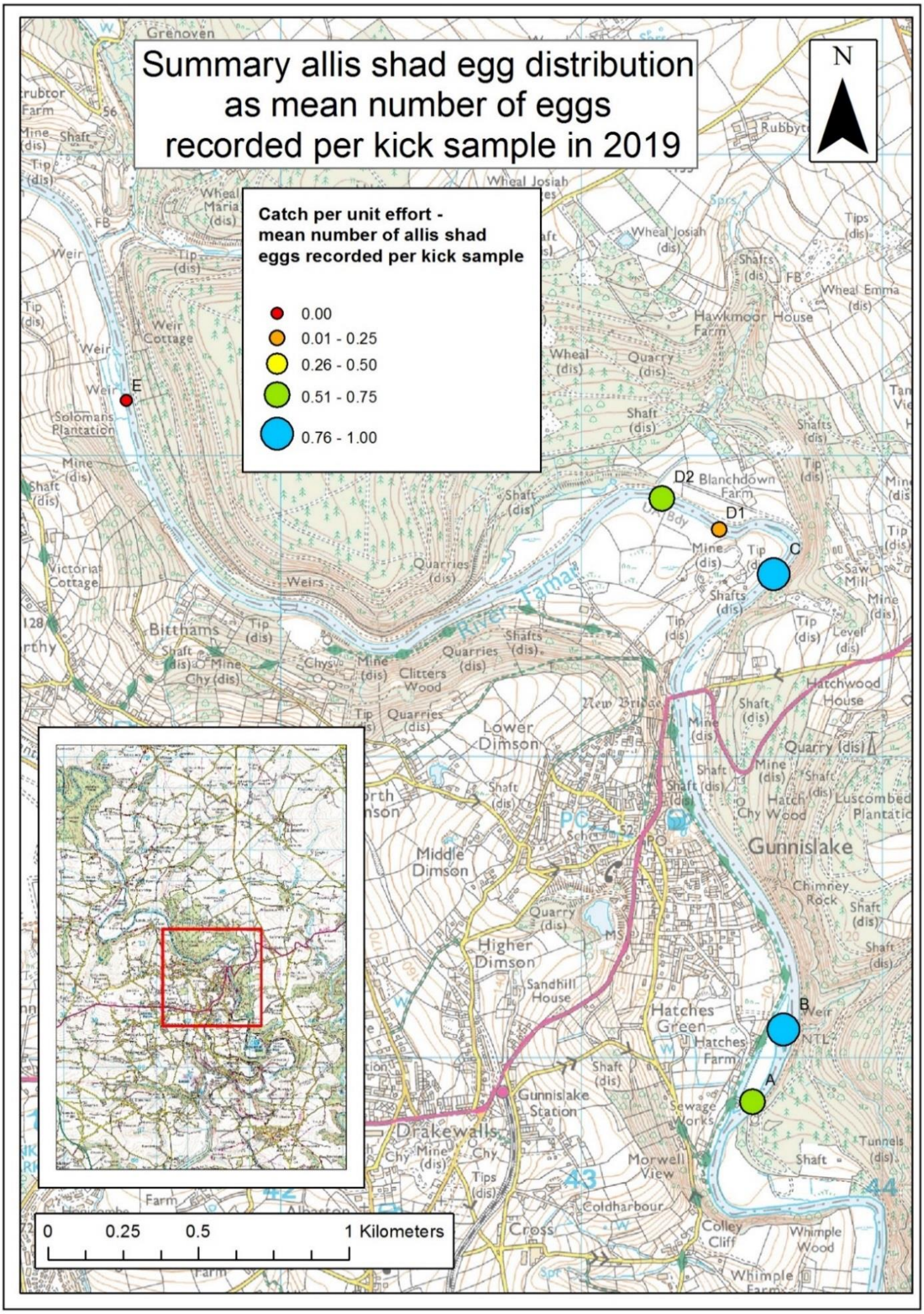

Figure 32. Mean number of allis shad eggs recorded per kick sample at each survey site in 2019. (Site D is split into D1 (Upstream Blanchdown Pool) and D2 (Ochre)).

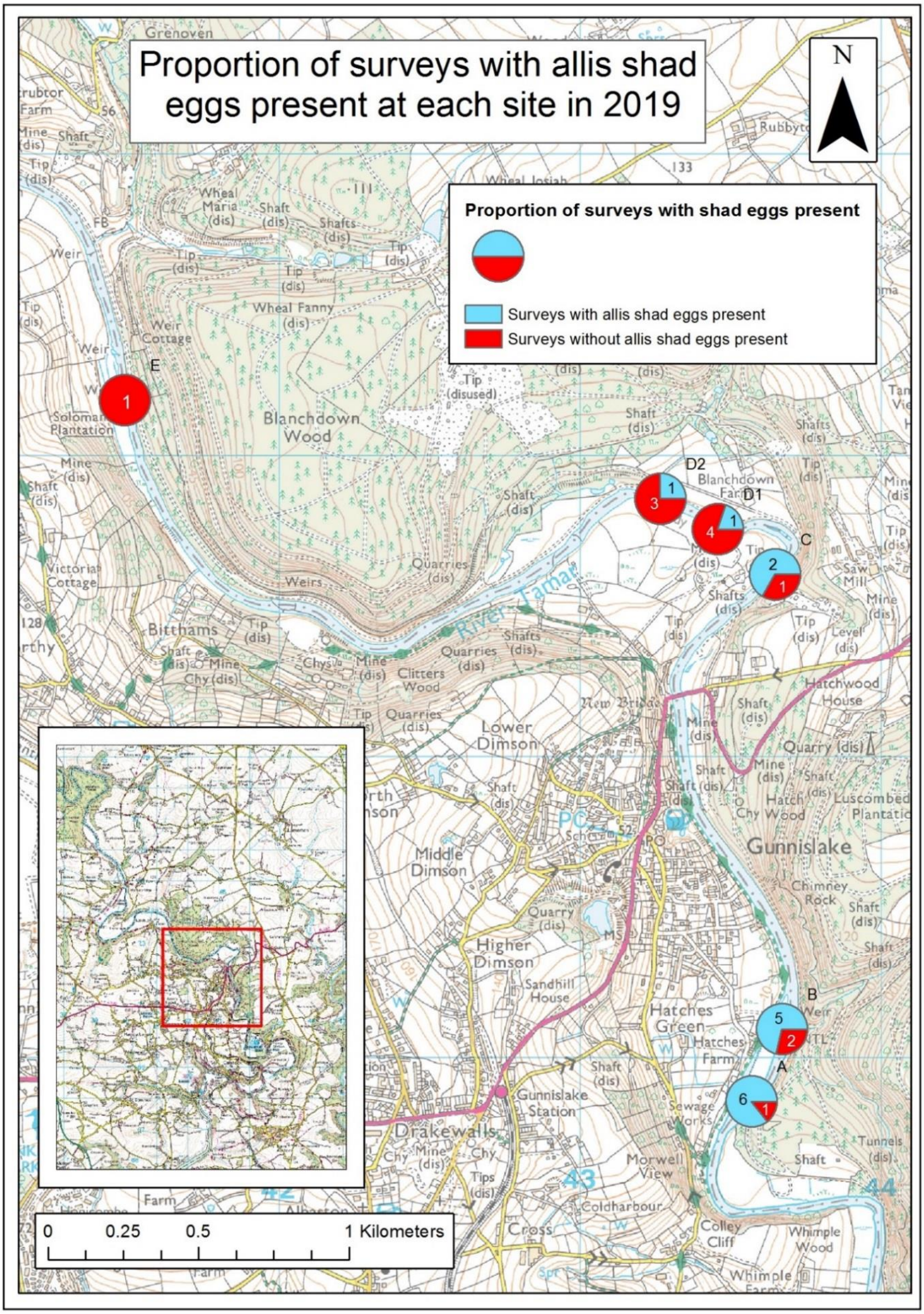

Figure 33. Proportion of surveys undertaken at each survey site in 2019 (17 May to 1 August), with allis shad eggs present. (Site D is split into D1 (Upstream Blanchdown Pool) and D2 (Ochre)).

Features associated with egg presence

Mean flow velocity and type

The mean flow velocity at 39 kick sample locations where shad eggs were present was 42.7cm^{-s} (0.10cm^{-s} to 0.70cm^{-s}), compared to 47.4 cm^{-s} at all 182 sample sites where flow velocity was recorded (Figure 34). Shad eggs were found in unbroken wave (riffle), rippled flow (run) and smooth flow types (glide) at approximately the same proportions as each flow type represented among the sample locations. Rippled flow prevailed at the vast majority of sites where allis shad eggs were found, but run habitat was targeted during most surveys.

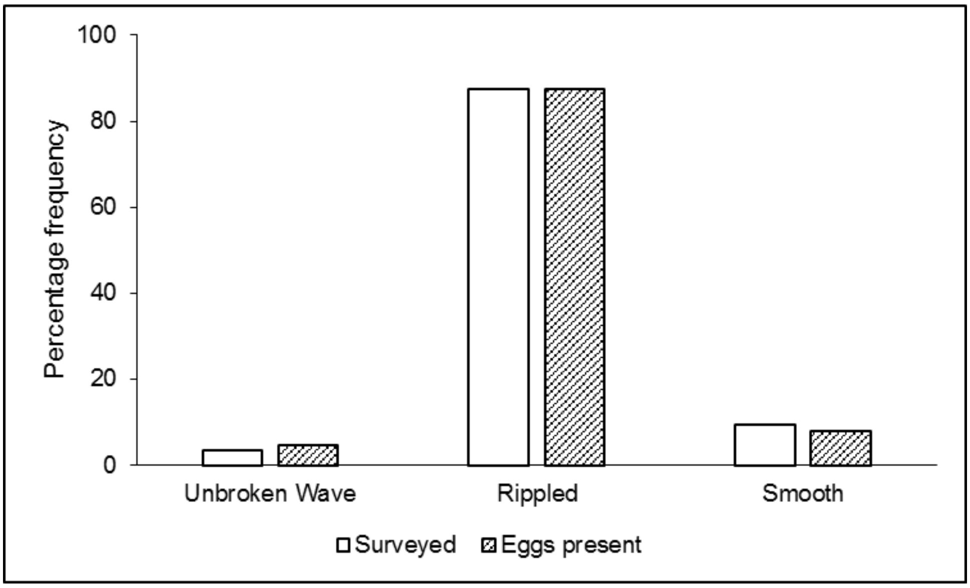

Figure 34. Flow types surveyed at all sample points compared to flow type where allis shad eggs were present

Mean depth

Eggs were found in water depth between 15cm and 96cm (Mean 62cm) at 39 sites, compared to a mean depth of 58cm (7cm to 110cm) at 182 sample sites (Figure 35). Shad eggs were found in a broad range of water depths, broadly reflecting the range of depths sampled. Eggs were found in shallow back-eddies and riffle margins, in runs and glides and in deeper water in Gunnislake Weir Pool. In tidal reaches it is unknown if spawning occurred at high or low tide; the depth presented is the survey depth recorded at low tide.

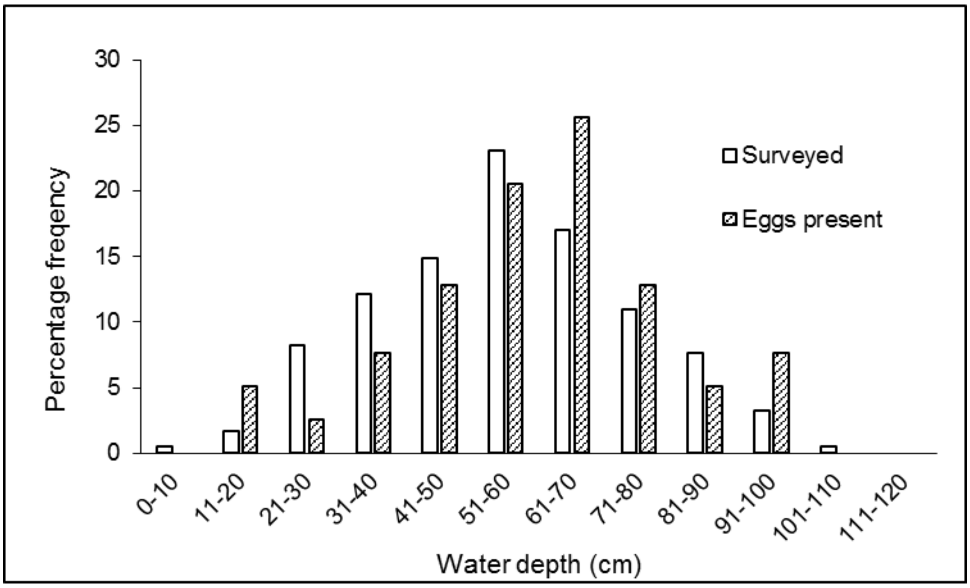

Figure 35. Water depth surveyed at all sample points compared to depth where allis shad eggs were present.

River width

Shad eggs were recorded on the Tamar at sites with a mean channel width of 25m. The narrowest width recorded was 14m, but this was at First Run, between the Cornwall bank and the uppermost part of a mid-channel island. The maximum width was 35m; this was in Gunnislake Weir Pool between the Devon bank and a depositional bar near the Cornwall bank.

Substrate type

Shad eggs were recorded at mean substrate cover values of 10% boulders, 26% cobbles, 31% pebbles, 24% gravel, 8% sand and 1% silt (Figure 36). The dominant substrate where eggs were recorded was most commonly cobbles or pebbles, but occasionally gravel or boulder.

Where eggs were recorded at Cottage Run, the substrate was dominated by pebbles (40%), cobbles (27%) and gravel (21%).

At Gunnislake Weir Pool and First Run the substrate was smaller; gravel (39%) dominated, followed by pebble (33%), sand (12%) and cobbles (11%).

At Downstream Symon's Pool the substrate was relatively coarse; cobbles dominated (36%), followed by boulders (33%), but pebbles, gravel and sand was also present and accounted for 31% of cover.

Cobbles also dominated the substrate where eggs were present at Upstream Blanchdown Pool (41%), with pebbles (23%), gravel (19%) and boulder (13%).

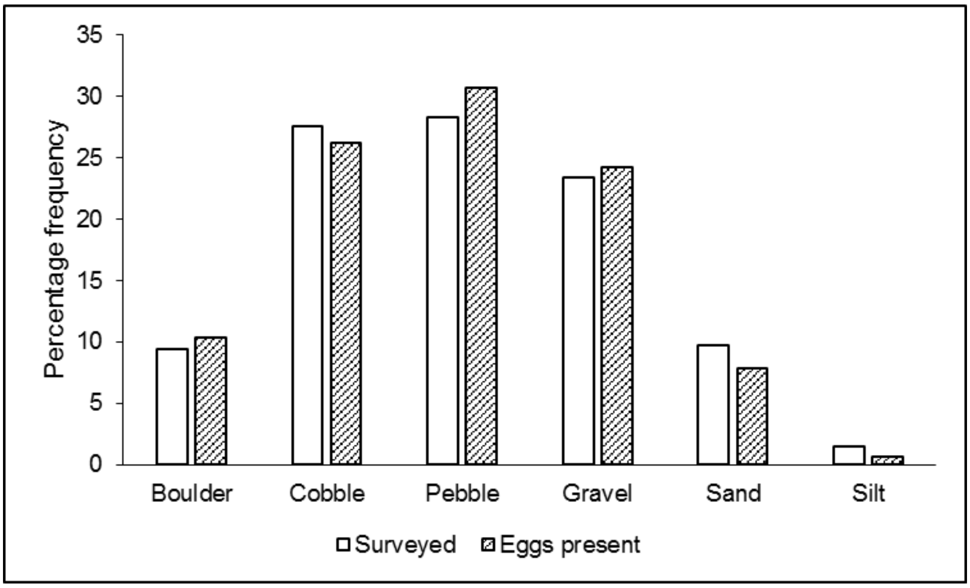

Figure 36. Mean percentage cover of substrate types at sample points surveyed, compared to sites where allis shad eggs were present.

<u>Channel features</u>

Depositional bars

Of the five allis shad spawning sites identified, depositional bars were present at three of them: Cottage Run, Gunnislake Weir Pool/First Run and Ochre. At a fourth site, the presence of a large croy at Upstream Blanchdown Pool probably prevents a depositional bar from forming on the inside of the meander bend.

Marginal deadwater

Marginal deadwater was present at all spawning sites but was extensive three of them. At Cottage Run there is a large area of marginal deadwater on the Cornwall bank downstream of a depositional bar. At Gunnislake Weir Pool/First Run marginal deadwater was recorded towards the Devon-bank of the weir pool, downstream of a depositional bar near the Cornwall bank and along the channel margin, adjacent to a mid-channel island. At Upstream Blanchdown Pool, a fishing croy on the Devon Bank creates a large area of marginal deadwater. At the other two sites, marginal deadwater is limited to areas in the channel margins.

Pools or deep water

Pools or deep water were present at all five spawning sites. At Cottage Run, there is a small weir pool below a tidal weir, with deeper areas of glide habitat upstream of the weir and downstream of Cottage Run. Gunnislake Weir Pool offers a deep, well-oxygenated daytime holding area for allis shad adjacent to the spawning site.

At Downstream Symon's Pool, there is a deep pool immediately upstream of the spawning site and an extensive area of deep, impounded water downstream of the spawning site. Blanchdown Pool offers an excellent daytime holding area for allis shad spawning in the riffle upstream. At Ochre there is a deep pool present.

Discussion

Allis shad spawning distribution

In this survey, five discrete allis shad spawning sites were identified on the River Tamar and tidal reaches, based upon the distribution of eggs; two sites were recorded in the tidal reach (Sites A and B) and three sites in the River Tamar at Blanchdown (Sites C, D1 and D2). One of the freshwater sites at the head of Blanchdown Run, at a fishing beat known as Ochre, was previously unidentified as an allis shad spawning site on the Tamar.

Eggs were found in 2019 at Cottage Run, 300m downstream of the tidal limit- a known allis shad spawning site, where eggs have been recorded annually since 2000. The eggs were found throughout Cottage Run at the edge of the weir pool and in the riffle, but most eggs were found in the run habitat. Allis shad probably spawn at the head of Cottage Run just below Cottage Weir; after spawning the eggs drift in the current before they settle on the river bed downstream where they become embedded in small crevices in the substrate (Bagliniere et al., 2003). Although this reach is tidal, the velocity of upstream tidal currents is very low due to the close proximity to the tidal limit at Gunnislake Weir and therefore it is unlikely that eggs would drift upstream from where they were spawned, if spawning occurred at high tide. The daytime holding area for allis shad spawning at Cottage Run in not known- this could be upstream of Cottage Run Weir, possibly in Gunnislake Weir Pool, or in deeper water below Cottage Run. The weir pool below Cottage Weir is relatively small and shallow and it seems unlikely that allis shad hold up here during the day.

The second 2019 allis shad spawning site in the tidal reach was at Gunnislake Weir Pool and First Run, immediately downstream of the tidal limit. The distribution of eggs at the edge of the weir pool, in a back-eddy below a depositional bar and in the run habitat of First Run indicates that allis shad spawn in the weir pool. The eggs either settle to the riverbed in the weir pool or drift downstream on the current, settling around the depositional bar and in the slower flowing current within First Run. As at Cottage Run, it is very unlikely that eggs would be transported upstream by tidal currents at this site because the upstream tidal current velocity at the tidal limit is negligible. Eggs were present here in 2010, but none were found in 2012 or 2017; however, in 2017 the site had been recently deepened and gravels dredged and there was very limited allis shad spawning habitat in First Run.

In the River Tamar at Downstream Symon's Pool, the egg distribution in 2019 suggests that allis shad spawn just upstream of the riffle. Most eggs were found in the deeper water (70-95cm) of the run below the riffle. Allis shad could either hold up in the pool upstream of this site (Symon's Pool) or in the deep water of the impounded reach downstream of the spawning site.

The distribution of eggs found in 2019 at the lower and upper ends of Blanchdown Run suggest two discrete spawning sites. Eggs were found in the run habitat immediately upstream of Blanchdown Pool; the large, deep pool provides a suitable holding area for allis shad. The egg distribution in the lower part of Blanchdown Run suggests that allis shad spawn within the shallow run habitat. Eggs were also recorded from a second location at the head of Blanchdown Run, in an area known locally as Ochre. Allis shad probably use the deep pool here as a holding area and spawn at the tail of the pool, with eggs drifting into the riffle and run habitat downstream.

More eggs were recorded from sites downstream of Gunnislake Weir compared to sites upstream. However, when adjusted for sampling effort, the mean number of eggs per sample point from all surveys, was similar at the two sites downstream compared to two of the sites upstream. Mean egg numbers were highest at Gunnislake Weir Pool/First Run and at Downstream Symon's Pool.

Perhaps the most important metric is the proportion of sampling occasions when allis shad eggs were present at a site. Eggs were present on most sampling occasions at the two sites in the tidal reach. At Downstream Symon's Pool, eggs were recorded on two of the three sampling occasions. Eggs were recorded just once from five surveys at the Ochre/Upstream Blanchdown Pool site. The site at Downstream Duchess Weir was sampled just once and no eggs were found.

Overall, these results suggest that allis shad tend to spawn at sites in the tidal reach downstream of Gunnislake Weir throughout the spawning season, but less frequently at sites upstream of the weir. This is certainly reflected in previous egg surveys in the River Tamar at Sites C and D, where eggs were present in only two of 12 surveys (17%), compared to every year surveyed at Site A in the tidal reach. However, only three surveys were undertaken at Downstream Symon's Weir in 2019 and eggs were present on two surveys.

Spawning in the tidal reaches of the Tamar appears to be unique among allis shad populations, compared to some European rivers where the spawning grounds are a considerable distance upstream of the tidal limit (Maitland and Hatton-Ellis, 2003; Acolas et al. 2004). Twaite shad (*Alosa fallax*) have been reported spawning in tidal waters on the Elbe (Hass 1965; Taverny 1991; Thiel et al. 1996).

The kick-sampling method used in this survey of spawning distribution is not without its limitations. The method requires the surveyor to be in wadeable depths, so eggs in areas greater than approximately one metre deep could have been missed. The survey method also requires the sampler to be in the correct area of a given spawning site at a time when eggs are present, so there is a spatial and temporal risk of missing eggs that may been present at a site.

Egg catch per unit effort

The number of eggs found per kick sample was relatively low, with a maximum recorded catch per unit effort of 2.8 eggs per 30-second kick sample at Gunnislake Weir Pool and First Run on 26 June 2019. As an estimate, a 30-second kick sample covers approximately $0.25m^2$ of river bed, and 2.8 eggs per 30-seconds equates to approximately 11.2 eggs m^{-2}. Considering the high fecundity of allis shad this might seem to be on the low side, but the results from this study are comparable to other studies and the following paragraph sets out other considerations for the numbers of eggs recorded.

The weight of 7 female allis shad in spawning condition, examined from the Tamar between 2000 and 2019, ranged from 1.0 to 1.5kg; this equates to a minimum fecundity of 60,000 to 90,000 eggs per female based on fecundity studies of other allis shad populations (Aprahamian et al, 2003). However, there are a number of considerations. Firstly, allis shad eggs are spawned in three to seven batches over a few days (Sabatie, 1993; Cassou-Leins et al., 2000), so not all eggs will be released in one location at the same time. Secondly, kick-sampling is not 100% efficient as some eggs will not be caught in the sampling net. Thirdly, the area of river bed sampled by kick sampling is a tiny proportion of the total area over which eggs were dispersed. Furthermore, the method is limited to areas of wadeable depth. A fourth consideration is that some of the eggs will be consumed by predators, and in the tidal reaches below Gunnislake Weir there are numerous benthivorous fish such as thick lipped grey mullet (*Chelon labrosus*) and common bream (*Abramis brama*) that will consume shad eggs.

At the Agen spawning reserve, River Garonne, prior to the allis shad population decline, the egg density on the riverbed was estimated at 100 per m^2 (Maitland et al., 1995). However, on the River Aulne, a smaller river in Brittany, north-west France, comparable in size and located relatively close to the Tamar, Acolas et al. (2006) reported a much lower number of allis shad migrants compared to the Dordogne and Garonne, so it is reasonable to expect a much lower egg density on the Tamar compared to the Garonne. Compared to other studies, egg sampling on the Tamar produced similar egg numbers per kick sample; for example, Pinder et al. (2016) recorded 108 shad eggs from 116 15-second kick samples on the River Teme; this equates to a mean egg CPUE of 0.9 eggs per 15 second kick (or 1.8 eggs per 30-seconds). By comparison, the mean combined CPUE at Tamar sites A & B in the tidal reaches was 0.8 eggs per 30-seconds, with a maximum of 2.8 eggs per 30-seconds. Garrett et al. (2014) reported kick-sampled mean shad egg CPUE equivalent to 1.3 eggs per 30-seconds in 2013 and 4.2 eggs per 30-seconds in 2014 on the River Tywi, Wales. Garrett et al. reported considerably higher maximum shad egg CPUE (equivalent to 9.1 eggs per 30-seconds in 2013 and 74.0 eggs per 30-seconds in 2014) compared to the Tamar; however, the Tywi is an established and designated shad population and twaite shad (*Alosa fallax*) spawn here in considerable numbers. On the Tamar, the number of returning adult allis shad is unknown but there is no evidence to suggest that the run size is comparable to populations of twaite shad in south Wales or allis shad populations on large European rivers.

Upstream migration of allis shad at Gunnislake Weir

A single allis shad was caught at Gunnislake Fish Trap on 31 May 2019. This individual, like previous allis shad caught in the fish trap, was recovered from the lowest trap compartment, furthest downstream (closest to the weir pool), which becomes submerged at large high tides. By comparison, most salmon and sea trout are recorded from the trap compartment furthest upstream. The presence of allis shad in Gunnislake Fish Trap, especially when recorded in the lowest trap compartment, does not necessarily indicate that allis shad are successfully able to migrate upstream via this route. Allis shad are probably searching for a suitable migration route upstream and occasionally enter the lowest trap compartment.

The fish trap was operated frequently during late-May, June and July 2019, yet we did not record further allis shad in the fish trap. This suggests that either allis shad migrated upstream via the Cornwall trap and fish pass at times when the trap was not operational, or migrated via another route; the Devon fish pass or weir face. Allis shad are observed infrequently on overhead camera footage at the Cornwall Fish Pass suggesting that this is not the route of upstream migration. No allis shad were recorded from camera footage in 2019, although it should be noted that the ability to differentiate shad from salmonids based on overhead camera footage alone is not completely accurate and is predominantly based upon the relatively slim body profile of shad, compared to salmonids. Migration upstream via the weir face on large spring tides is plausible. However, the small boxes that form the Devon Fish Pass contain highly turbulent water with circulating currents which might prove disorientating to allis shad and prevent upstream migration via this route (Larinier et al, 2002); further investigation is needed to identify the migration route is used by allis shad at Gunnislake Weir.

Gunnislake Weir is a partial migratory barrier to allis shad due to their limited swimming capabilities, and their behavioural response to barriers. Migration upstream via the fish trap and fish pass on the Cornwall bank is also likely to be limited due to the following range of issues described by Larinier et al. (2002). Allis shad prefer surface passage during migration which isn't possible in the fish trap; the enclosed, darkened Cornwall fish pass may deter allis shad which are sensitive to changes in light. The narrow channels in the trap do not permit upstream of shoals. The water in the fish trap is highly turbulent, with no clear directional flow, which is likely to disorientate allis shad; indeed, the recirculating currents within the trap are likely to cause fall-back of shoals of migrating allis shad. Allis shad are required to leap into the trap and fish pass, rather than move through preferred laminar flow (this is also true of Devon Fish Pass and Gunnislake Weir High spring tides, where allis shad would need to leap). The turbulent water associated with the plunge from the trap boxes and within the trap itself is likely to deter shad. Allis shad are not good at exploring at the foot of migration structures, so may struggle to locate the entrance to the fish trap and associated pass due to the low attraction flow. Larinier et al (2002) reported that single and paired vertical slot pool passes can be efficient for shad, provided specific design criteria are considered.

Influence of tides on spawning above and below Gunnislake Weir

An interesting observation within the tidal reach is the results on 18 and 19 June at the peak of spring tides. Fresh allis shad eggs were recorded from Cottage Run on 18 June, but there were no eggs recorded at Gunnislake Weir Pool/First Run on 19 June. Low tide on the 18 June was at approximately 02.00, around the peak spawning time for allis shad (Aprahamian et al., 2003). The opposite occurred one week later on 26 and 27 June, during the smallest neap tides of the lunar cycle; fresh eggs were recorded at Gunnislake Weir Pool/First Run on 26 June, but none were present at Cottage Run on 27 June. On 26 June, high water was at approximately 01.30, when allis shad spawning would be expected. One possible interpretation of these observations, is that the spawning site at Cottage run was submerged by the 01.30 high tide on 26 and 27 June, which coincided with the peak time of allis shad spawning activity; this may have deterred allis shad spawning. Another interpretation of these results, is that allis shad struggled to migrate upstream at Cottage Run Weir at low water on the spring tides of 18 and 19 June, rendering sites upstream of Cottage Run Weir (including Gunnislake Weir Pool/First Run) inaccessible for spawning.

Allis shad eggs were recorded at sites upstream of Gunnislake Weir on 3 occasions in 2019; 3 June, 5 June and 21 June. Based upon water temperature and egg development stage we can estimate spawning occurred sometime within two periods; 28 May - 4 June and 15 - 20 June 2019. Peak spring tides occurred on 4 & 5 June and 17 - 19 June, but whether or not allis shad used these larger tides to migrate upstream via the weir face is not known.

Physical parameters at allis shad spawning sites

Most allis shad eggs were recorded from run habitat (rippled flow), but this was the main flow type targeted during surveys so is perhaps to be expected. Allis shad show a preference for spawning in swift currents at the end of pools where gravelly shallows begin (Le Clerc 1941; Hoestland 1958; Boisneau et al. 1990). Caswell and Aprahamian (2001) found that twaite shad eggs were typically found in the River Habitat Survey flow types 'rippled flow' and 'unbroken standing wave'.

The flow velocity where allis shad eggs were recorded on the Tamar ranged from 0.1-0.7m^{-s} (mean 0.43 m^{-s}), but since eggs had typically drifted downstream, the current at the spawning site was certainly greater than this. Maitland and Hatton-Ellis (2003) describe a current of 0.5-1.5 m^{-s} at allis shad spawning grounds on large rivers in mainland Europe, although Acolas et al. (2006) recorded lower current velocities on the River Aulne (a relatively small river similar in size to the Tamar) where the current velocity at the spawning grounds was 0.1-1.3 m^{-s}. Acolas et al. (2006) describe the atypical, ‘forced’ nature of the spawning grounds on the River Aulne being reinforced by the presence of a pool with a relatively slow current (0.2-0.4 m^{-s}), a situation comparable to Gunnislake Weir Pool. The Aulne spawning grounds are also characterised by a narrow jet of water flow created by an island that allowed the current to accelerate; this sounds very similar to the spawning grounds at First Run.

At Cottage Run the mean flow velocity where eggs were present was 0.46 m^{-s}, compared to 0.36 m^{-s} in Gunnislake Weir Pool/First Run, 0.41 m^{-s} at Downstream Symon's Pool and 0.52 m^{-s} at Upstream Blanchdown Pool/Ochre. The exception seems to be Gunnislake Weir Pool, where allis shad eggs were found in deep, slow-flowing water (0.23-0.38 m^{-s}), where they settled on the substrate rather than drifting downstream in the current. The water here is well-oxygenated from the weir turbulence, which presumably makes it suitable for egg development. Eggs were also found in marginal areas of low current velocity (0.10-0.24 m^{-s}) in First Run, including a back-eddy, immediately downstream of a depositional bar near the Cornwall bank.

Allis shad eggs were found at depths of between 15 and 96cm. The sampling method used (kick-sampling) is limited to water approximately 1m deep and as such it was not possible to sample for eggs in water greater than 1m. The presence of eggs in water 91-100cm deep suggests that shad eggs may have also been present in areas too deep to sample by kick-sampling. Aprahamian et al. (2003) describe allis shad spawning at depths of 0.5 - 3.0m in mainland European populations and Maitland et al. (1995) reported that on the River Garonne, France, the river is mostly 1.0 -1.5m deep at allis shad spawning sites. On the Tamar, it is possible that allis shad eggs were present in deeper water than sampled in Gunnislake Weir Pool, the deep run and glide habitat downstream of Site C (Downstream Symon's Pool) and deeper water at the head of Blanchdown Pool (Site D).

The 14-35m channel width of the lower River Tamar and upper tidal reaches is at the lower end of descriptions of spawning grounds on rivers in mainland Europe, but within the range used by allis shad. Aprahamian et al. (2003) reported the width of spawning sites ranging from 15m in the River Aulne to 200m in the River Loire. Although a number of migratory barriers impede upstream migratory access on the Tamar, the river width exceeds 15m for many tens of kilometres upstream of the tidal limit and is therefore unlikely to deter allis shad spawning. Maitland and Hatton-Ellis (2003) speculated that preference for wider rivers is probably due to the aversion shown by shad to narrow channels and turbulent flow.

The dominant substrate associated with egg presence on the Tamar was pebbles or cobbles, but sometimes gravel. Cobbles (64-246mm), pebbles (32-64mm) and gravel (2-32mm) accounted for 81% of substrate cover at sites where allis shad eggs were present. This concurs with substrate size at spawning sites on other rivers (Maitland and Hatton-Ellis, 2003; Aprahamian et al., 2003), where the reported range is 30-160mm on the River Garonne (Cassou-Leins & Cassou-Leins (1981) and 20-200mm on the River Dordogne (Fatin & Dartiguelongue, 1995). In contrast, on the River Loire (France), Boisneau et al. (1990) reported that the spawning site consisted mainly of sand followed by gravel (2 to 20 mm).

As reported between other rivers, there were marked differences in substrate type between the spawning sites on the Tamar. At sites in the tidal reaches, the dominant substrate was gravel and pebble, whereas at sites in the River Tamar at Blanchdown the substrate was coarser and dominated by cobbles, with more boulders present. However, gravel and pebble were also important at these sites.

Caswell & Aprahamian (2001) found that marginal deadwater and channel bars (side-, point- or mid-channel bars) were likely to be present at twaite shad spawning sites on UK rivers. The authors associated the presence of bars with an active river system and regular turnover of substrate, ensuring the removal of accumulated fines and therefore probably contributing to the survival of eggs. Depositional bars were present at three of the five Tamar spawning sites, suggesting that they are also associated with allis shad spawning habitat. Both of the tidal freshwater Tamar spawning sites featured a depositional side bar and an extensive side bar was also present at the Ochre spawning site in the River Tamar. A large croy upstream of Blanchdown Pool, adjacent to a spawning site, probably prevents substrate deposition on the inside of the meander bend here.

Timing of allis shad spawning

Based upon the development stage of allis shad eggs and the prevailing water temperature, it is possible to estimate spawning dates. In the tidal reach allis shad spawned on the estimated dates as follows; 16 May, 24-29 May, 17 June, 25 June to 2 July, 5-8 July, 18 July, 25-28 July 2019. This suggests a minimum of seven periods of spawning activity during May, June and July 2019 in the tidal reaches, with multiple spawning dates likely within each period. The timing of the allis shad spawning period concurs with other studies (Maitland and Hatton-Ellis, 2003; Acolas et al., 2006).

Based upon sampling results between 28 May and 3 July, spawning took place in the River Tamar within a minimum of two estimated periods; 28 May to 4 June and 15-20 June 2019. An allis shad was caught in Gunnislake Fish Trap on 31 May, which corroborates the timing of these estimated spawning migrations into freshwater.

A period of elevated turbidity, increased river flow and low water temperatures between 8 and 16 June 2019 probably deterred allis shad spawning at this time. Boisneau et al. (1990) found that spawning activity was inversely related to flow and Maitland and Hatton-Ellis (2003) concluded that high flows are detrimental to allis shad, by hindering access to spawning grounds but also by lowering recruitment after spawning, probably due to eggs and fry being swept downstream into the sea. Furthermore, the turbid nature of the River Tamar after rainfall is likely to deter shad spawning due to the reduced recruitment success from the smothering effects of suspended sediment on eggs.

Allis shad eggs are sensitive to water temperatures below 16-18°C (Hoestlandt 1958; Cassou-Leins & Cassou-Leins 1981), so temperatures above 18°C in June and July should be most favourable for incubation (Maitland and Hatton-Ellis, 2003). In 2019, the water temperature did not exceed 16°C during May. In June the water temperature only exceeded 16°C for a three-day period between 1 and 3 June, until temperatures climbed steeply from 25 June onwards. Between 27 June and 9 August 2019, water temperature regularly exceeded 18°C, suggesting that this was the optimum period for allis shad egg development. Acolas et al. (2006) found that reproduction on the River Aulne was inhibited at temperatures below 13.9°C but no maximum temperature was recorded, despite temperatures observed during spawning of up to 23°C. This certainly suggests that allis shad require warm water temperatures for spawning, which on the Tamar tend to prevail in late June and July.

In hindsight, greater sampling effort should have been afforded at sites upstream of Gunnislake Weir during July, which appears to be a more important month for allis shad spawning on the Tamar than considered previously, due to the prevailing water temperature.

Conclusion

In 2019, allis shad spawned at five discrete sites; two in the tidal reaches and three within close proximity in the lower River Tamar. At sites in the tidal reaches, eggs were found on most surveys over a wide period from May to July inclusive, whereas in the river, eggs were found on only a third of surveys and spawning appeared to be limited to two periods in June. However, the riverine sites were not sampled after the beginning of July and late spawning could have been missed. A minimum of at least seven spawning periods are estimated in the tidal reaches compared to two in the River Tamar. This suggests that allis shad were not always able to access riverine spawning areas throughout the spawning season.

The timing of the two spawning periods identified at river sites coincided loosely with spring tides, which tends to suggest allis shad utilise spring tides to migrate upstream at

Gunnislake Weir. The absence of all but one individual allis shad from the Cornwall fish trap monitoring in 2019 further suggests that the upstream migration route successfully used by allis shad was not the Cornwall fish pass and trap, and that shad migrate upstream via either the weir face or Devon fish pass on larger tides at high water. In summary, the timing and spawning distribution of allis shad on the Tamar appears to be limited by the migratory barrier at Gunnislake Weir.

The physical parameters recorded at allis shad spawning sites were comparable to those described in the literature, but the Tamar situation of spawning in the tidal reaches appears to be unique among allis shad populations.

Water temperature during May and much of June 2019 was probably too low for successful incubation. Favourable temperatures for egg incubation did not prevail until late June and July 2019, suggesting that the most important spawning and incubation period on the Tamar is later than previously considered.

Recommendations

1. If kick-sampling surveys were repeated in future, a simplified method (removing the measurement of some parameters such as flow velocity), would enable greater spatial and temporal survey coverage at the sacrifice of collection fewer parameters.
2. When collecting GPS data in future, consideration should be given to a system capable of data collection in areas of poor satellite reception.
3. This study was limited to the sites most likely to be used by allis shad for spawning, located downstream of a significant migratory barrier at Duchess Weir. Future studies should include sites further upstream and repeat the survey immediately downstream of Duchess Weir.
4. When surveying allis shad spawning in future, greater sampling effort should be afforded in July, when water temperature is often favourable for successful egg incubation.
5. Kick-sampling is limited to water depths of approximately one metre. Future sampling should consider other methods capable of sampling in deeper water.
6. Monitoring using acoustic listening stations would confirm spawning activity at key locations and also provide information on the timing and relative intensity of spawning activity on a site-by-site basis.

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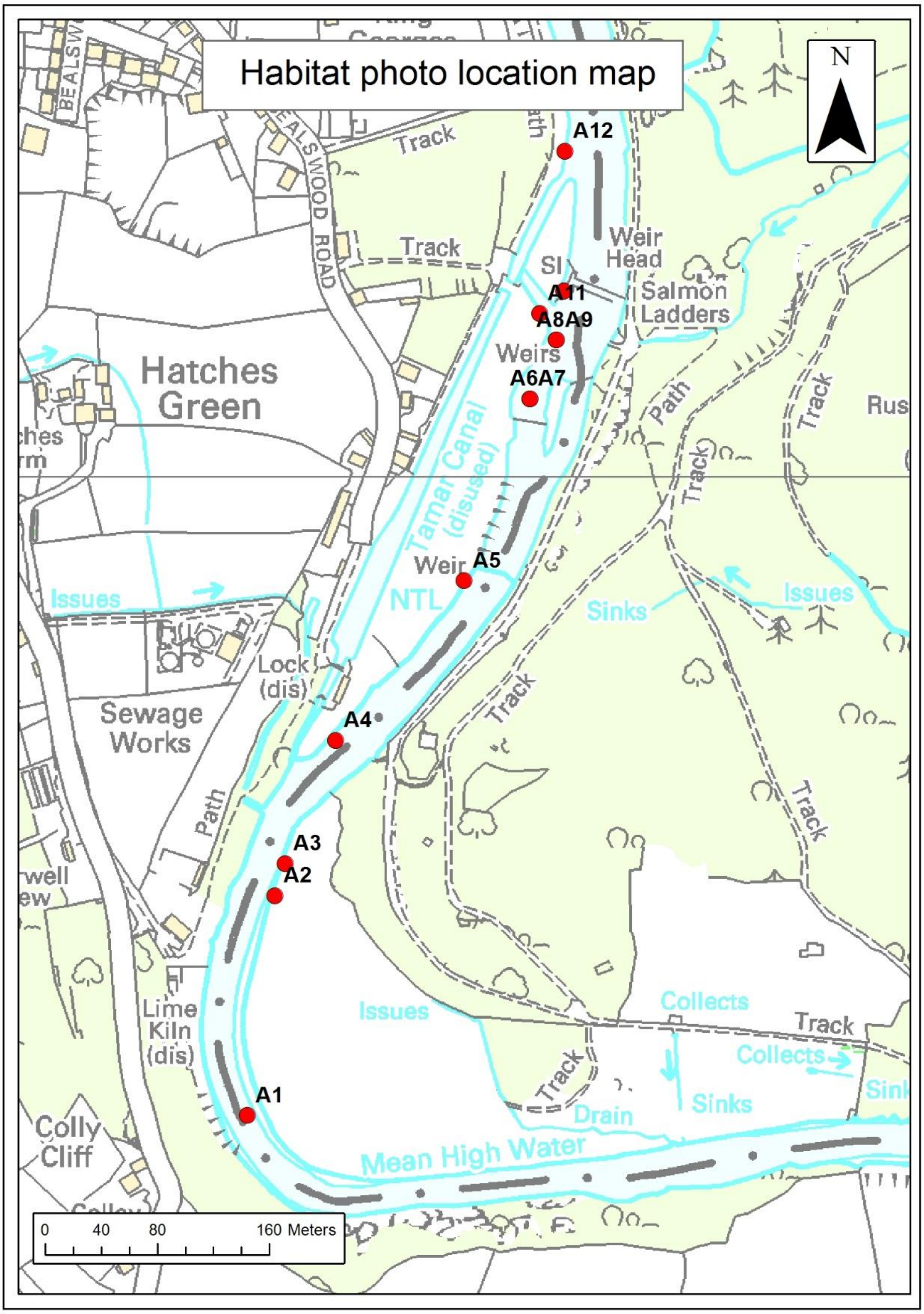
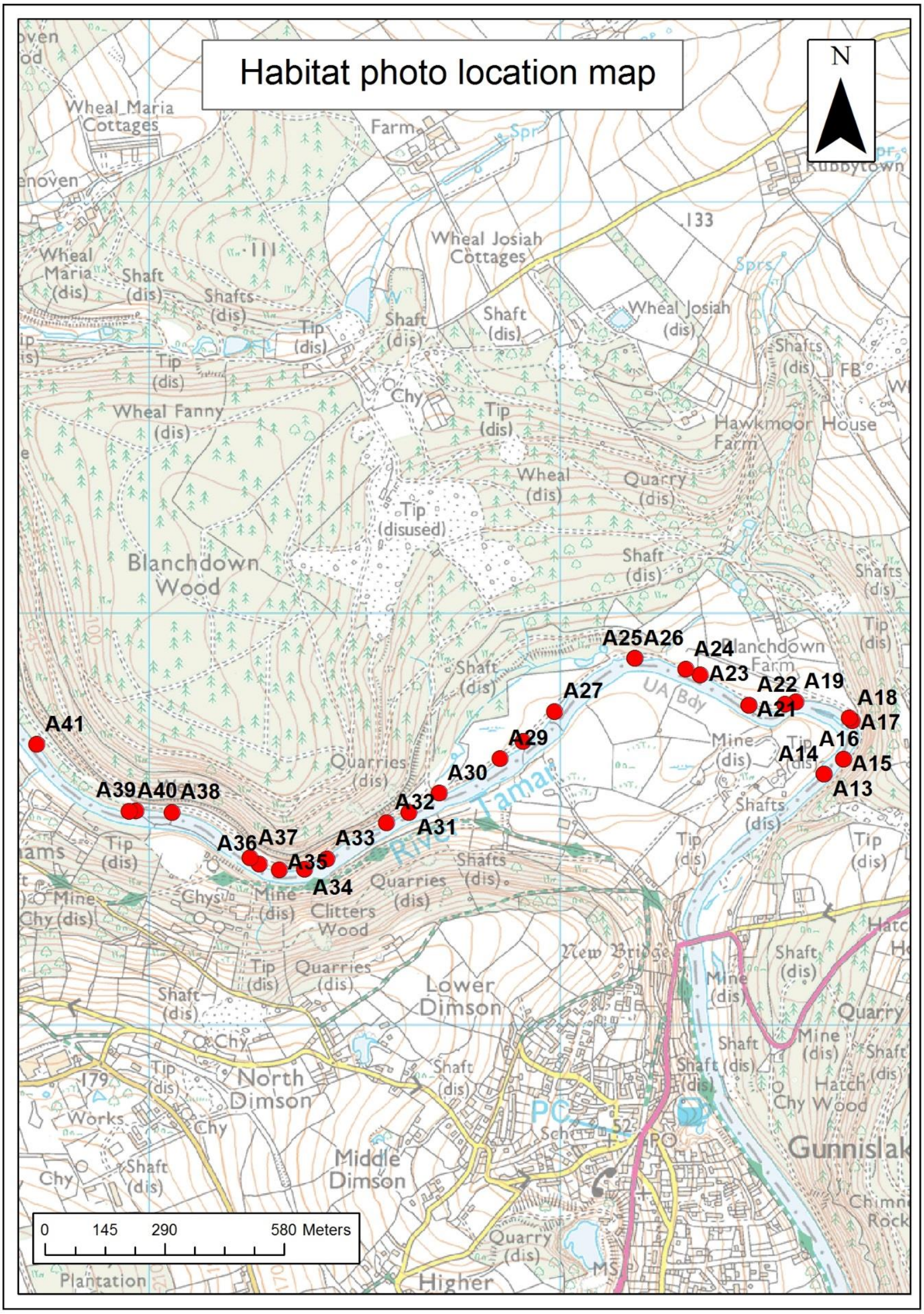
Habitat mapping photo appendix

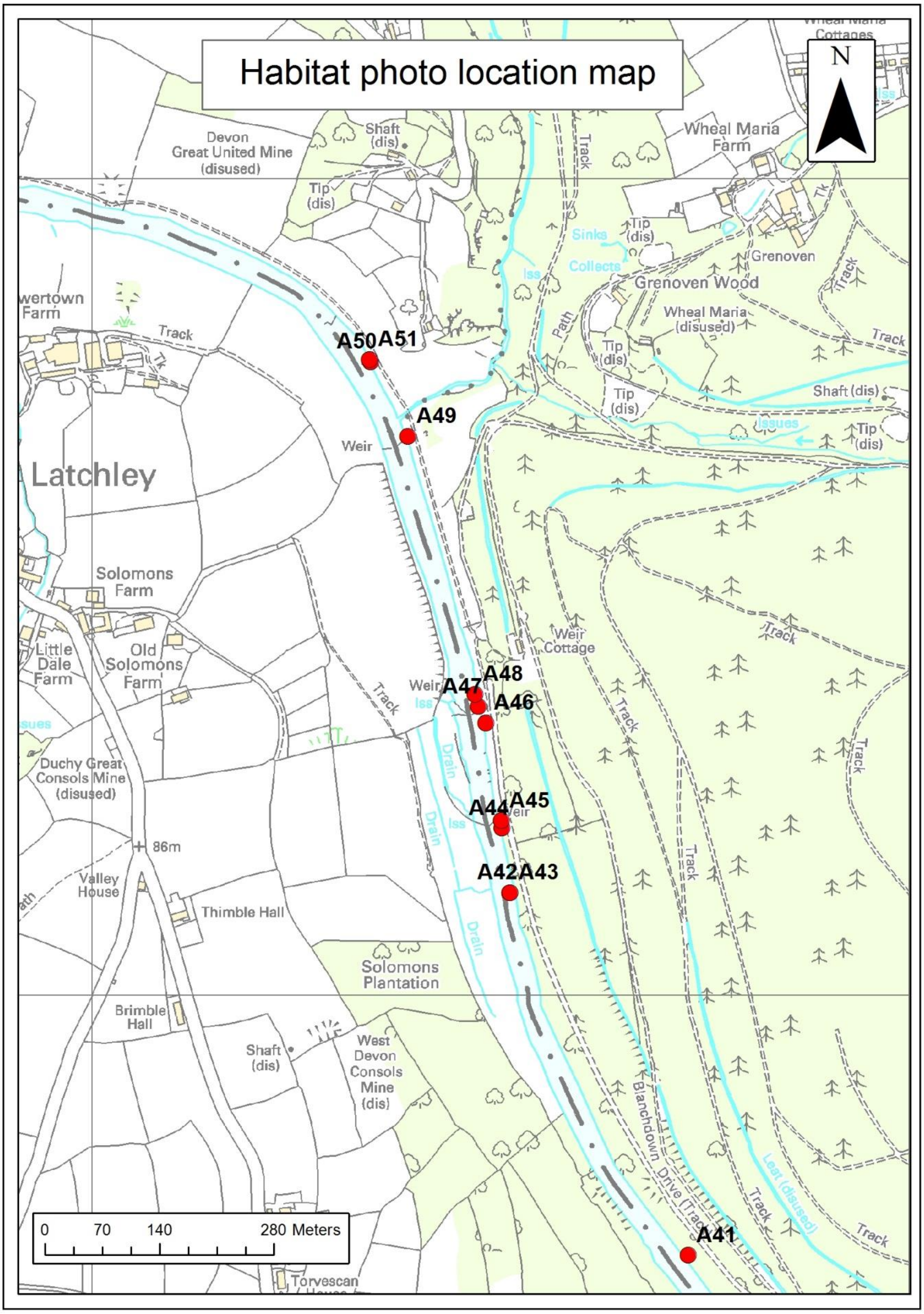
All photographs were taken in May 2019 unless otherwise stated.



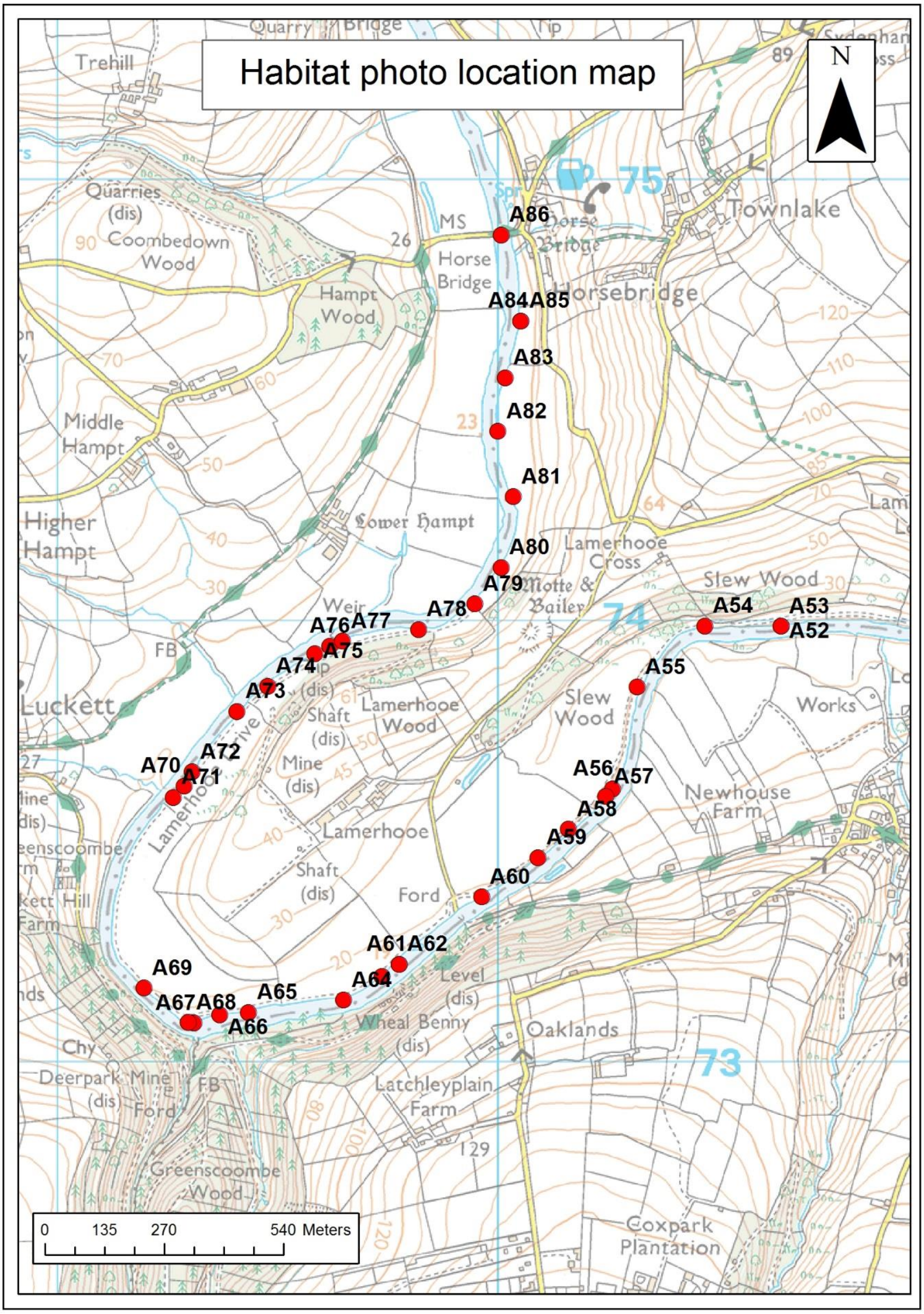
Appendix Map 1. Habitat photo locations A1 to A12.



Appendix Map 2. Habitat photo locations A13 to A41.



Appendix Map 3. Habitat photo locations A41 to A51.



Appendix Map 4. Habitat photo locations A52 to A86.

Tidal Tamar downstream of Gunnislake Weir

Figure A1. SX4345170543. Tidal Tamar at Impham Meadow, showing clean gravel/pebble/cobble substrate. Viewed from channel looking upstream. Photo taken in February 2018.

Figure A2. SX4347170700. Tidal Tamar at Lower Cottage Run, showing clean gravel/pebble/cobble substrate (near bank). Viewed from Devon bank looking downstream. Photo taken in February 2018.

Figure A3. SX4347870723. Tidal Tamar at Lower Cottage Run, showing clean gravel/pebble/cobble substrate (near bank). Viewed from Devon bank. Photo taken in February 2018.

Figure A4. SX4351470811. Cottage Run viewed from channel looking upstream to Cottage Run Weir (background).

Figure A5. SX4360670925. Cottage Run Weir viewed from Cornwall bank side bar looking upstream. Photo taken in February 2018.

Figure A6. SX4365371055. View downstream from channel at the tail end of First Run through fishing croys.

Figure A7. SX4365371055. Run habitat in First Run; potential spawning habitat. Viewed from Cornwall side-channel at Gunnislake Island, looking upstream.

Figure A8. SX4367271097. Gravel/pebble substrate and riffle/run potential spawning habitat in First Run, adjacent to depositional side bar (right foreground). Stone promontory from Gunnislake Island and croy (background left) and Cornwall side-channel at Gunnislake Island (right) with fishing croys (background right). Viewed from side bar on Cornwall bank looking downstream.

Figure A9. SX4367271097. Gravel/pebble substrate at tail and margins of Gunnislake Weir Pool and head of riffle habitat in First Run, adjacent to depositional side bar; potential spawning habitat. Viewed from side bar on Cornwall bank looking upstream to Gunnislake Weir.

Figure A10. SX4367771132. Gunnislake Weir Pool (left foreground) offers holding habitat with spawning habitat in the faster flow downstream. View from Cornwall bank looking downstream, at depositional side bar and Cornwall side channel at Gunnislake Island (known as First Run).

Figure A11. SX4366071116. Gunnislake Weir (tidal limit) with weir pool and depositional side bar. Holding habitat in weir pool. Viewed from Cornwall bank

Gunnislake Weir to Duchess Weir

Figure A12. SX4367871232. River impounded by Gunnislake Weir. Viewed from Cornwall bank.

Figure A13. SX4364472608. Spawning habitat; riffle, run and glide sequence. Viewed from channel looking downstream.

Figure A14. SX4364472608. Spawning habitat (foreground) and holding habitat (background). Viewed from channel looking upstream.

Figure A15. SX4369172644. Upstream Symon's Pool riffle, looking downstream from Devon bank. Spawning habitat.

Figure A16. SX4369172644. Downstream Symon's Pool, looking upstream from Devon bank. Holding area in deep glide and pool.

Figure A17. SX4371172737. Symon's Pool looking downstream on the Devon bank side channel at Blanchdown Island. A deep glide provides a potential holding area downstream.

Figure A18. SX4370472744. View upstream from Devon bank side channel at Blanchdown Island, adjacent to side bar. Possible spawning habitat.

Figure A19. SX4357572784. View downstream of Cornwall bank side channel at Blanchdown Island. Stone croy in foreground with possible spawning habitat downstream.

Figure A20. SX4354872778. Blanchdown Pool looking upstream from Devon bank. Extensive holding area.

Figure A21. SX4346172776. Fishing Croy and platforms in channel at Upstream Blanchdown Pool looking downstream from Devon bank. Spawning habitat.

Figure A22. SX4346172776. Fishing Croy in channel at Upstream Blanchdown Pool looking downstream from Devon bank. Cobble/pebble substrate. Spawning habitat.

Figure A23. SX4334372849. Blanchdown run habitat with exposed boulders, viewed from Devon bank looking upstream. Spawning habitat.

Figure A24. SX4330772863. Run habitat downstream of Ochre Pool. Viewed from Devon bank looking upstream. Spawning habitat.

Figure A25. SX4318472889. View of Ochre Pool and riffle/run habitat downstream, looking downstream from Devon bank. Point bar on Cornwall bank. Spawning habitat.

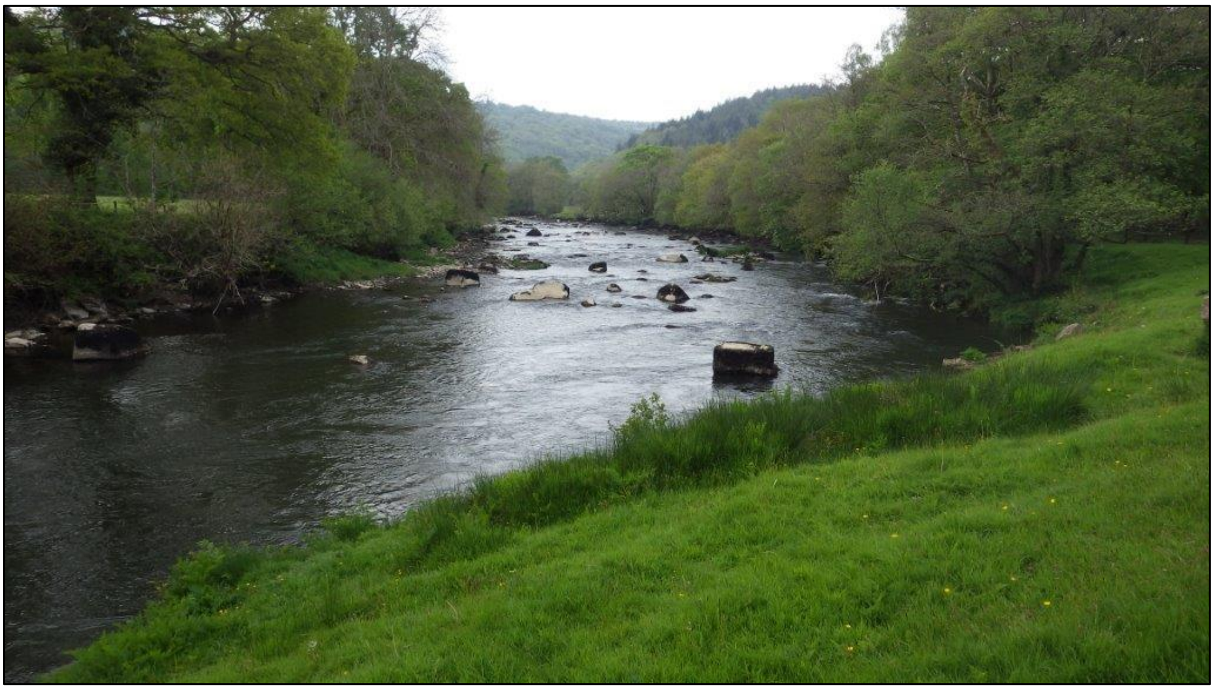


Figure A26. SX4318472889. Channel with large exposed boulders and rapids in the reach upstream of Blanchdown; viewed from Devon bank looking upstream.

Figure A27. SX4298972760. Fishing croys viewed from Devon bank, looking upstream. Exposed large boulders and rapids. Marginal deadwater below croys.

Figure A28. SX4291272688. Fishing croys viewed from Devon bank, looking upstream. Exposed large boulders and rapids upstream. Marginal deadwater below croys.

Figure A29. SX4285672646. Rapids and exposed boulders viewed from Devon bank.

Figure A30. SX4270872562. Foreground: Fishing croy on Devon Bank. Background: low head weir across entire channel width.

Figure A31. SX4263472515. Impounded water at Blanchdown EA Gauging Station. Viewed from channel looking upstream.

Figure A32. SX4258072490. Rapids and exposed boulders. Viewed from Devon Bank looking upstream.

Figure A33. SX4243572402. Sequence of rapids and run habitat. Viewed from Devon bank looking downstream.

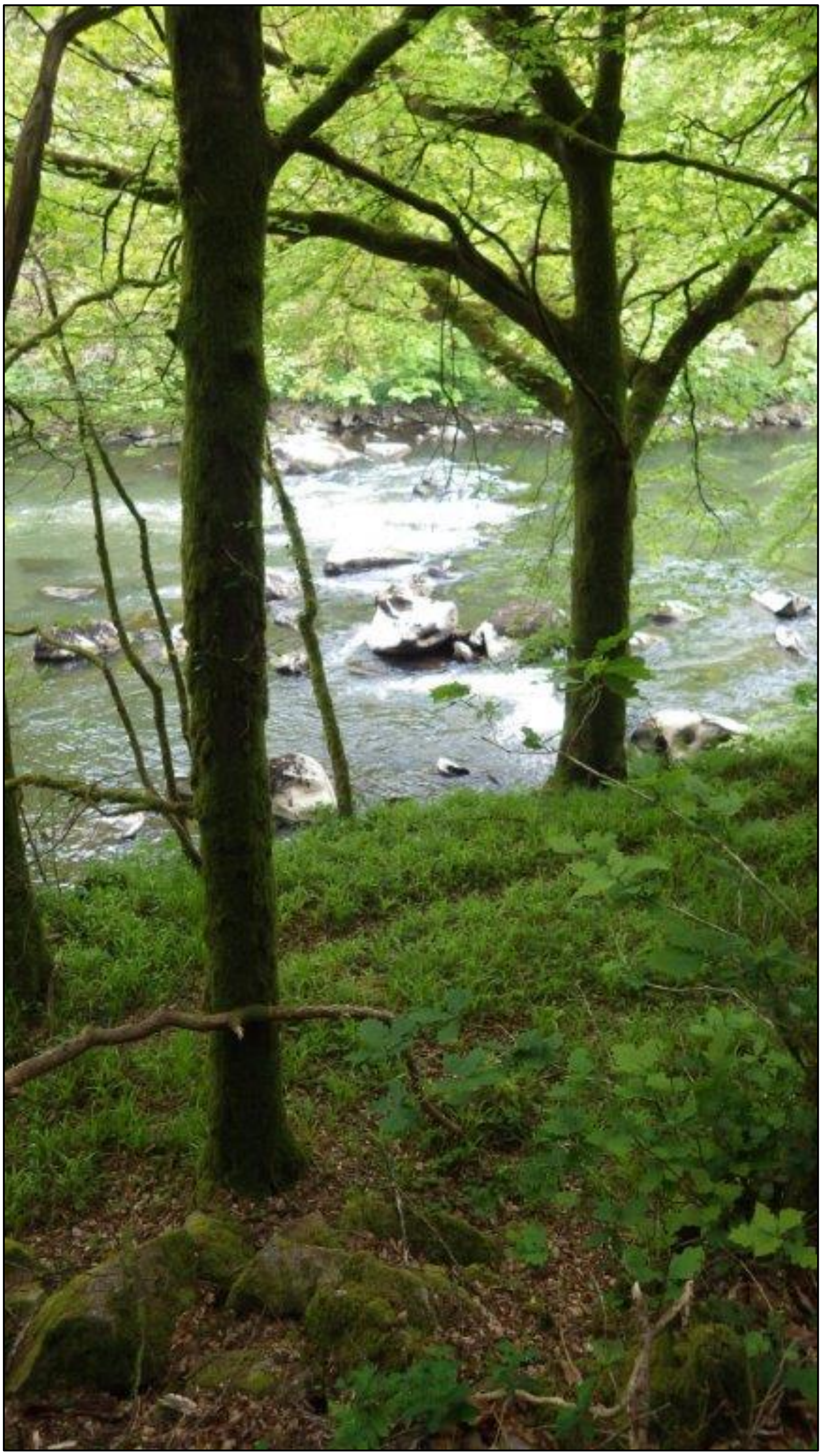


Figure A34. SX4238172377. Large boulders across channel. Viewed from Devon bank.

Figure A35. SX4232072375. Fishing croy. Viewed from Devon bank looking upstream.

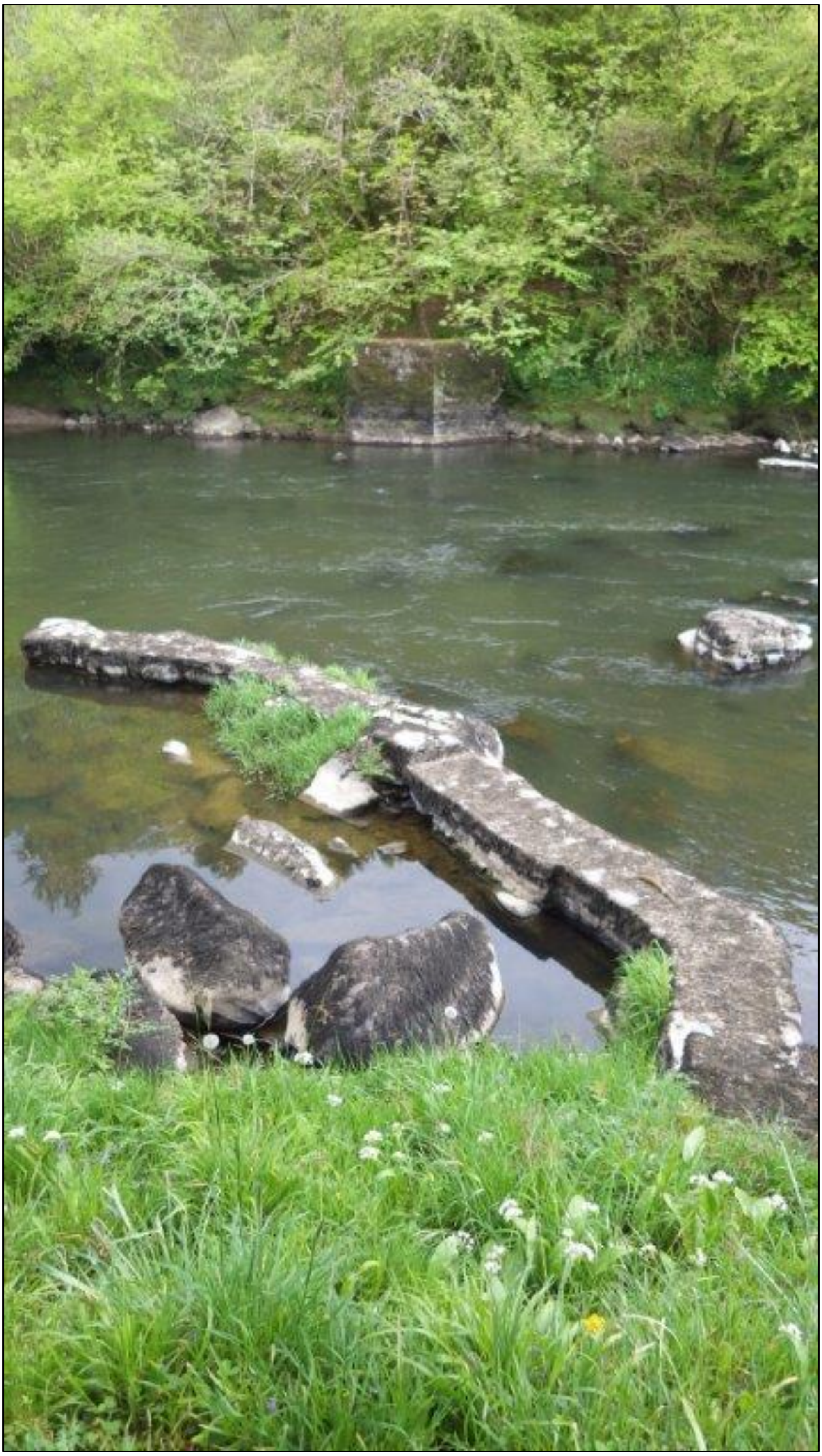


Figure A36. SX4227172390. Large fishing croy. Viewed from Devon bank.

Figure A37. SX4224872404. Large fishing croy. Viewed from Devon bank looking upstream.

Figure A38. SX4205972515. Foreground: Double fishing croys. Background: boulder weir across entire channel width. Viewed from Devon bank looking upstream.

Figure A39. SX4197172519. Boulder weir across channel. Viewed from Devon bank, looking downstream.

Figure A40. SX4195472518. Impounded, slow flowing river. Viewed from Devon bank, looking upstream.

Figure A41. SX4173072680. Impounded, slow flowing river. Viewed from Devon bank, looking downstream.

Figure A42. SX4151273124. Clean gravel/pebble substrate and run habitat downstream of Duchess Weir. Viewed from channel, looking upstream to Duchess Weir. Spawning habitat.

Figure A43. SX4151273124. Clean gravel/pebble substrate downstream of Duchess Weir. Spawning habitat.

Figure A44. SX4150273203. Duchess Weir. Significant migratory barrier to shad. Viewed from Devon bank.

Duchess Weir to Lamerhooe Weir

Figure A45. SX4150173212. View upstream from Duchess Weir. Fishing croys along Devon bank and another weir in the background.

Figure A46. SX4148273332. First weir immediately upstream of Duchess Weir, adjacent to Weir Cottage. Barrier probably passable to shad due to laminar flow over shallow weir face. Viewed from Devon bank looking upstream.

Figure A47. SX4147373352. First weir immediately upstream of Duchess Weir, adjacent to Weir Cottage. View from Devon bank looking downstream.

Figure A48. SX4146973367. Small weir across channel adjacent to Weir Cottage. Viewed from Devon bank looking upstream.

Figure A49. SX4138773683. Double fishing croys. Potential barrier to shad. Viewed from Devon bank looking downstream.

Figure A50. SX4134173774. Fishing croy on Devon bank, river impounded by croys downstream. Viewed from Devon bank, looking downstream.

Figure A51. SX4134073777. Single arm, large fishing croys in the channel, background and foreground. Viewed from Devon bank looking upstream.

Figure A52. SX4064273985. Numerous fishing croy standings in channel along the Devon bank. Viewed from channel looking downstream.

Figure A53. SX4064273985. Potential spawning habitat (coarse substrate) with exposed bedrock and boulders near Devon bank. Viewed from channel looking upstream.

Figure A54. SX4047073986. Deep glide with exposed bedrock in channel, with potential spawning habitat in background. Viewed from Devon bank looking downstream.

Figure A55. SX4031673847. Deep glide with underwater bedrock sill on either side of channel, with fishing croy on Devon bank in background. Viewed from Devon bank looking upstream.

Figure A56. SX4026073617. Potential spawning habitat (coarse substrate) mid-channel with bedrock on both banks and extending into the channel. Viewed from Devon bank looking upstream.

Figure A57. SX4024573599. Potential spawning habitat (coarse substrate) mid-channel with bedrock on both banks and extending into the channel. Viewed from Devon bank looking downstream.

Figure A58. SX4016173525. Potential spawning habitat (coarse substrate) with bedrock on Cornwall bank. Viewed from Devon bank looking upstream.

Figure A59. SX4009273461. Potential spawning habitat (coarse substrate) with cobble/boulder side bar on Devon bank. Viewed from Devon bank.

Figure A60. SX3996473372. Potential spawning habitat (coarse substrate) and holding habitat at ‘New Pool’. Viewed from Devon bank looking downstream.

Figure A61. SX3977773219. Potential spawning habitat with clean but coarse substrate, with cobble/boulder side bar on Devon bank. Viewed from Devon bank looking downstream.

Figure A62. SX3977773219. Potential spawning habitat with clean but coarse substrate. Viewed from Devon bank looking downstream.

Figure A63. SX3973873191. Glide habitat with fishing croy on Devon bank with cobble bar on upstream side. Viewed from Devon bank.

Figure A64. SX3965173138. Potential spawning habitat with coarse substrate. Bedrock sill extending from toe of Devon bank into channel. Viewed from Devon bank looking upstream.

Figure A65. SX3943673110. Potential spawning habitat with coarse substrate with mid-channel bar near Cornwall bank. Viewed from Devon bank looking downstream.

Figure A66. SX3937073104. Potential spawning habitat with coarse substrate of large cobbles. Side bars on Cornwall bank downstream of riffle. Viewed from Devon bank.

Figure A67. SX3931273086. Potential spawning habitat with coarse substrate of large cobbles and boulders. Viewed from Devon bank.

Figure A68. SX3929973087. Potential spawning habitat (coarse substrate) with potential holding habitat upstream. Viewed from Devon bank looking downstream.

Figure A69. SX3919973165. Deep glide and potential holding habitat.

Figure A70. SX3929073623. Run habitat in foreground, glide in background at confluence with Luckett Stream on Cornwall bank (side bar present). Viewed from Devon bank looking downstream.

Figure A71. SX3926573597. Potential spawning habitat at riffle. Viewed from Devon bank looking upstream.

Figure A72. SX3930873655. Potential spawning habitat at riffle. Viewed from Devon bank.

Figure A73. SX3941073792. Potential spawning habitat in background. Viewed from Devon bank looking upstream.

Figure A74. SX3947973849. Potential spawning habitat (coarse substrate). Viewed from Devon bank.

Figure A75. SX3958673923. Fishing croy on Cornwall bank downstream of Lamerhooe Weir.

Figure A76. SX3962073940. Lamerhooe Weir and bedrock on Devon bank. Significant barrier to shad. Viewed from Devon bank.

Figure A77. SX3964973951. Lamerhooe Weir and bedrock on Devon bank downstream. Significant barrier to shad. Viewed from Devon bank looking downstream.

Figure A78. SX3982173978. Fishing croy and bedrock on Devon bank, platforms in channel. Viewed from Devon bank looking downstream.

Figure A79. SX3994874036. Fishing croy and platforms on Devon bank. Viewed from Devon bank looking downstream.

Figure A80. SX4000874118. Fishing croy and bedrock on Devon bank and platforms in channel. Viewed from Devon bank looking downstream.

Figure A81. SX4003674279. Glide habitat. Viewed from Devon bank looking upstream.

Figure A82. SX4000174427. Gravel spit on Devon bank. View from Devon bank looking downstream.

Figure A83. SX4001774548. Run habitat over bedrock and coarse substrate. Viewed from Devon bank looking upstream.

Figure A84. SX4005374677. Potential spawning habitat (coarse substrate) downstream of Horsebridge. Side bars on Cornwall bank, bedrock on Devon bank. Viewed from Devon Bank looking downstream.

Figure A85. SX4005374677. Potential spawning habitat (coarse substrate) downstream of Horsebridge. Side bar on Cornwall bank. Viewed from Devon Bank looking upstream.

Figure A86. SX4000874872. View downstream from Horsebridge road bridge.