Electric-fishing surveys for the River Otter (Devon) Beaver Trial

Authors: Andrew Vowles (asv104@soton.ac.uk) and Paul Kemp (P.Kemp@soton.ac.uk)

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International Centre for Ecohydraulics Research, Faculty of Engineering and the Environment, University Road, University of Southampton, Hampshire, UK, SO17 1BJ.

Executive Summary

Wild-living Eurasian beaver (*Castor fiber*) have been the focus of research and monitoring in the Otter Catchment (Devon, England) since the beginning of the River Otter Beaver Trial in 2015. As part of this monitoring, the International Centre for Ecohydraulics Research (University of Southampton) collected baseline fisheries data on the River Otter near Honiton, at a site that beavers may occupy in the future. More detailed electric-fishing surveys were conducted on the River Tale near Clyst William in 2016 and 2017 in response to the construction of a beaver dam.

In the River Otter, three reaches were surveyed by electric-fishing using a single pass without stop nets. In the River Tale, a control / impact design was employed. Two control reaches were surveyed that were upstream and downstream (and not in close proximity) to the beaver dam. Impacted reaches were sections that were impounded (in 2016 and 2017) and immediately downstream of the beaver dam (2017 only). Reaches were surveyed using a multiple-pass method between stop nets. Physical habitat characteristics (depth, velocity and substrate composition) were also measured.

In the River Otter, eight species and 1067 individual fish were captured in total. The combined sample of fish from the three electric-fishing reaches consisted of 43.4% bullhead (*Cottus gobio*), 37.9% minnow (*Phoxinus phoxinus*), 10.2% stone loach (*Barbatula barbatula*), 3.3% brown trout (*Salmo trutta*), 2.3% three-spined stickleback (*Gasterosteus aculeatus*), 1.9% lamprey (*Lampetra* spp.), 0.9% European eel (*Anguilla anguilla*) and 0.09% Atlantic salmon (*Salmo salar*).

In the River Tale, the beaver dam increased and decreased water depth and velocity and promoted fine sediment deposition. Six fish species were captured in both 2016 and 2017 and in similar numbers (555 in 2016 and 543 in 2017). The general community composition was similar between years, with bullhead, stone loach, brown trout and eel being the first, second, fourth and sixth most abundant species in both 2016 and 2017.

In 2017, fish abundance was approximately four fold lower in the impounded reach compared to the other three reaches sampled. There was a notable reduction in small-bodied species which tend to inhabit swift flow and gravel substrates (e.g. bullhead). Despite a low density of brown trout in the impounded reach, biomass was relatively high, indicating the more lentic habitat created was utilised by larger individuals of this species. European eel were the least common species in the River Tale in both 2016 and 2017. In 2017, most (84%) were found in the control reach upstream of the beaver dam.

The overall fish community of the River Tale changed little between 2016 and 2017. However, localised changes in physical habitat as a result of the beaver dam may have caused certain species and life-stages to redistribute within a small spatial scale. For example, those that tend to utilise shallower, swifter flows and coarser substrates were rare immediately upstream of the beaver. In addition to the continued monitoring of beaver activity (and the dam structure itself), it would be of interest to assess impacts on fish performance. For example, measuring the growth of tagged and recaptured fish within beaver modified and unmodified habitat. The impact of the beaver dam on fish movement was not assessed during these surveys but would also be of interest from an ecological and recreational fisheries perspective.

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Introduction

Following extirpation approximately 400 years ago, there have been numerous drivers behind the reintroduction of the Eurasian beaver (*Castor fiber*) to the UK. Principal among these are the desire to “rewild” the country with native species extirpated by humans and to restore ecological function to freshwater and wetland habitats (Halley & Rosell, 2002; Law *et al*. 2017). These efforts are aided by legislation, such as the EU Habitats Directive 92/43/EEC, which provides a framework for assessing the feasibility and desirability of species reintroduction (Gaywood, 2018).

As ecosystem engineers, beavers are perceived as a particularly suitable species for aiding ecological restoration. The most obvious way they may impact their environment, and thus modulate availability of resources for other organisms, is through dam building. Constructed from felled vegetation, stones and mud, dams create localised lentic habitat in areas that are predominantly lotic. Physically, this creates deeper, slower flowing patches within the river system, increasing habitat heterogeneity which may benefit numerous organisms (Stringer & Gaywood, 2016). Fine sediment and nutrient deposition is also promoted upstream of beaver dams, with cleaner water being discharged below, influencing sediment and nutrient dynamics (Puttock *et al*. 2017). Consequently, beavers exert an influence over biological, physical and chemical characteristics of rivers.

The impact of beavers on fish can be both positive and negative. For example, in the meta-analysis conducted by Kemp *et al*. (2012), 184 benefits compared to 119 costs were identified in the scientific literature. The interactions between impacts can be complex, and are likely to vary spatially, temporally and between species. While water impounded by beaver dams may provide rearing habitat and refuge from adverse flows and predators, they also inundate spawning gravels which are subsequently covered with fine sediment and may impede longitudinal fish movements (for reviews on the impact of beavers on fish, see Collen & Gibson, 2001 and Kemp *et al*. 2012). Consequently, impacts of beaver reintroductions on fish communities should be monitored, particularly in locations where dams are constructed.

In the UK, trial reintroductions of wild-living Eurasian beavers commenced in 2009 in Knapdale (western Scotland; Gaywood, 2018) and more recently in 2015 in Devon (southern England; Elliott et al. 2017). In 2015, approximately nine beavers were living within the Otter Catchment in Devon. By October 2017 this had increased to approximately 27 (M. Elliott pers comm). Devon Wildlife Trust (DWT) on behalf of the River Otter Beaver Trial (ROBT) are tasked with coordinating research and monitoring activities relating to the trial reintroduction. This report details the results of three electric-fishing surveys conducted as part of the ROBT monitoring programme. The first survey was conducted on the River Otter and aimed to provide information on fish species occupying a site currently unmodified by beaver activity. The second and third surveys were conducted on the River Tale, a tributary of the River Otter, in response to beavers constructing a dam. The aim of these surveys was to collect quantitative information on the fish community at a site that beavers occupy.

Methods

Three electric-fishing surveys were conducted at two locations within the $250km^2$ Otter Catchment (Devon, UK). Watercourses within the catchment flow through a predominantly agricultural landscape, which includes arable, sheep and dairy farming, before entering the sea at Budleigh Salterton. The upper catchment in particular is prone to spate flows following prolonged rainfall. The first survey was conducted on the River Otter near Honiton (site owned by the Deer Park Country House Hotel) in September 2015. The second and third surveys were conducted on the River Tale near Clyst William (site owned by Neil Hart) in October 2016 and July 2017.

River Otter

The survey was completed between 2nd and 3rd September 2015 by electric-fishing upstream through 3 approximately 100m long reaches of the River Otter using a single pass (Figure 1a). A pulsed DC current was produced from an Easyfisher control box powered by a 10L Honda generator. Stop nets were not used. One team member operated the anode and moved in an upstream direction, zigzagging across the river. Up to three other team members followed and aimed to catch all fish with hand-nets. Fish were held in aerated river water before being counted, identified to species, measured (to the nearest mm) and weighed (to the nearest 0.1g). Length and weight measurements were taken from only the first 20 individuals of bullhead (*Cottus gobio*), minnow (*Phoxinus phoxinus*) and stone loach (*Barbatula barbatula*) due to the large numbers captured. Measurements were taken for all individuals of all other species. All fish were returned to the electric-fishing reach from which they were captured.

Fish abundance (number captured) in the three reaches were combined and reported per species.

Data on physical habitat were not collected during this survey.

River Tale

Surveys were completed between 10th and 11th October 2016 and 3rd and 7th July 2017 by electric-fishing upstream through three (2016) or four (2017) stop netted reaches using a multiple-pass method. In 2016, the reaches were approximately 50m in length and consisted of an upstream and downstream control, and an impounded (impacted) reach (Figure 1b). The control reaches were within the 2km section of river owned by Neil Hart and not in close proximity to the beaver dam. The impounded reach was upstream and as close to the beaver dam as was feasible to sample by wading. In 2017, the reaches were approximately 25m in length and consisted of an upstream and downstream control, impounded (impacted) and a downstream (impacted) reach (Figure 1c). The control reaches were in a similar location to the 2016 survey. The impacted reaches were immediately above and below the beaver dam as it was possible to wade these locations due to lower water levels (aided by a partial breach of the dam in the winter of 2016/17). The same electric-fishing equipment as outlined for the River Otter was used. One team member operated the anode and moved in an upstream direction, zigzagging across the river. Up to two other team members followed and aimed to catch all fish with hand-nets. There was at least 30 minutes between each of the three electric-fishing passes which were completed per reach, allowing time for fine sediment to sufficiently settle and ensure a good level of visibility was maintained. Fish were held in aerated river water before being counted, identified, measured (to the nearest mm) and weighed (to the nearest 0.1g). All fish were returned to the electric-fishing reach from which they were captured. Mortality was low e.g. < 2% during the 2017 survey.

Physical habitat characteristics were quantified for each electric-fishing reach. Key parameters were recorded at five approximately equidistance points along transects which spanned the width of the river at 10m (2016) or 5m (2017) longitudinal intervals. Water depth (cm) and velocity (cm s^{-1}) were measured using a metre rule and electromagnetic flow meter (Valeport Model 801), respectively. In 2016, dominant substrate type was visually assessed at each transect point using a 50cm^2 quadrat according to the Wentworth grain size classification. In 2017, a 100g sample was collected at the first five transects in each electric-fishing reach. Samples for each reach were combined into one 500g sample and taken to the Geotechnical Laboratory at the University of Southampton. Here they were dried in an oven for 48 hours and mechanically sieved. Sieves (> 3.35mm, > 2.00mm, > 1.18mm, > 425μm, > 300μm, > 150μm, > 63μm and < 63μm) were operated for 10 minutes and allowed sediment to be classified into size fractions (expressed as percent of total weight of dried sample). The surface area (m^2) of each reach was calculated using the mean wetted width (which was recorded at each transect) and the distance between the up- and down-stream stop net.

Data Analysis

To estimate the effectiveness of electric-fishing between reaches, capture efficiency (E_c) was calculated for each species for each reach as:

$$E_C = \frac{T}{kN-X} \tag{1}$$

where T is the total number of fish caught in a reach, k is the number of electric-fishing passes per reach, N is the maximum likelihood population estimate and X is an intermediate statistic used in the calculation of N.

X was calculated as:

$$X = \sum_{i=1}^{k}(k-i)C_i \tag{2}$$

where i is the electric-fishing pass number and C_i is the number of fish caught in the i^{th} sample.

N was calculated as:

$$\left[\frac{n+1}{n-T+1}\right]\prod_{i=1}^{k}\left[\frac{kn-X-T+1+(k-i)}{kn-X+2+(k-i)}\right]_i \leq 1.0 \tag{3}$$

where n is the smallest number satisfying equation 3. As estimating N is an iterative process, the initial value of n used was T and was then increased by 1 until equation 3 was satisfied (Lockwood & Schneider, 2000).

An E_c for each reach was calculated as the average E_c values for each species captured within that reach. E_c values for each species can be found in Appendix A and B.

Fish abundance (number captured), mean length, mean weight, density (number per m^2) and biomass (g per m^2) for each species per reach is reported. Initially, density and biomass were standardised by both surface area and river length, but as the nature of differences between reaches were similar independent of method used (Appendix C), only values per m^2 are reported.

If the assumption of normality was violated, as indicated by a Shapiro-Wilk test, non-parametric statistics were performed on data. A Kruskal-Wallis test was used to identify differences in depth, velocity and fish size (for each species) between electric-fishing reaches. Pairwise comparisons used a Bonferroni correction.

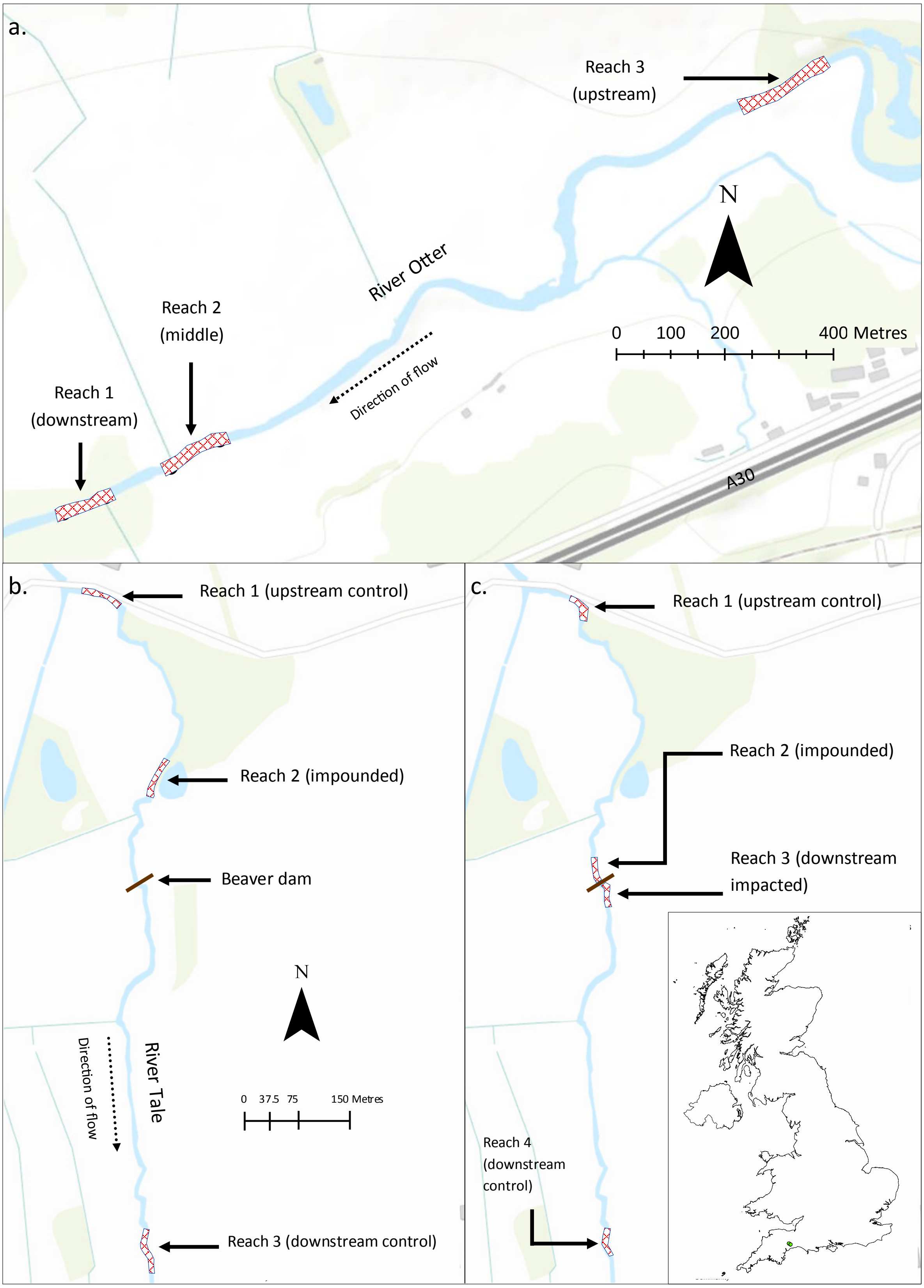

Figure 1. Site on the River Otter (Devon, UK) where single pass electric-fishing was conducted along 3 approximately 100m reaches to collect baseline information on the fish species present (**a**) and a site on the River Tale (Devon, UK) where multiple pass electric-fishing was conducted along 3 approximately 50m reaches (**b**) and 4 approximately 25m reaches (**c**) to determine the impact of a beaver dam on the fish community.

Results

River Otter

The total number of fish captured from the three reaches was 1067. Seven species were found in all three reaches, with an eighth (a single Atlantic salmon, *Salmo salar*) also found in **'Reach 3: upstream'** (Table 1).

Table 1. Number, length and weight statistics for each fish species captured when electric-fishing through three reaches of the River Otter (Devon, England) in September 2015.

	Atlantic salmon (*Salmo salar*)			Brown trout (*Salmo trutta*)		
Electric-fishing reach	Number caught	Fork length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Number caught	Fork length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]
1: Downstream	0	N/A	N/A	13	128 ± 46 (84 - 227)	36.5 ± 44.3 (7.0 - 146.5)
2: Middle	0	N/A	N/A	9	166 ± 90 (84 - 312)	106.1 ± 139.8 (7.5 - 376.9)
3: Upstream	1	87	8.8	13	220 ± 84 (84 - 307)	185.4 ± 129.1 (7.6 - 365.5)

	Bullhead (*Cottus gobio*)*			European eel (*Anguilla anguilla*)		
	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]
1: Downstream	60	54 ± 10 (38 - 70)	2.6 ± 1.4 (0.9 - 5.0)	6	248 ± 63 (190 - 352)	34.6 ± 27.6 (12.6 - 84.5)
2: Middle	130	51 ± 13 (34 - 78)	2.1 ± 1.9 (0.1 - 6.6)	3	323 ± 73 (255 - 400)	73.7 ± 47.9 (33.3 - 126.6)
3: Upstream	273	43 ± 8 (32 - 71)	1.2 ± 1.0 (0.5 - 5.1)	1	321	63.3

	Lamprey (*Lampetra* spp.)			Minnow (*Phoxinus phoxinus*)*		
	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Number caught	Fork length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]
1: Downstream	8	132 ± 16 (105 - 162)	6.2 ± 1.8 (3.3 - 8.2)	132	63 ± 14 (27 - 84)	4.0 ± 2.3 (0.9 - 8.3)
2: Middle	10	117 ± 36 (50 - 155)	3.5 ± 2.4 (0.3 - 7.2)	193	54 ± 18 (7 - 73)	2.6 ± 1.6 (0.1 - 5.2)
3: Upstream	2	100 ± 42 (70 - 130)	2.5 ± 2.5 (0.7 - 4.2)	79	68 ± 8 (54 - 83)	4.4 ± 1.7 (1.9 - 8.3)

	Three-spined stickleback (*Gasterosteus aculeatus*)			Stone loach (*Barbatula barbatula*)*		
	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]
1: Downstream	6	Not measured	Not measured	51	82 ± 12 (52 - 103)	5.5 ± 2.1 (0.8 - 10.0)
2: Middle	16	Not measured	Not measured	36	79 ± 12 (49 - 103)	4.3 ± 1.9 (0.8 - 8.5)
3: Upstream	3	Not measured	Not measured	22	85 ± 10 (65 - 103)	5.7 ± 2.2 (2.3 - 10.1)

* Length and weight data based on a random sample of 20 individuals

The fish that were captured were dominated by a few species in terms of abundance (Figure 2). The combined sample from all three reaches consisted of 43.4% bullhead, 37.9% minnow, 10.2% stone loach, 3.3% brown trout (*Salmo trutta*), 2.3% three-spined stickleback (*Gasterosteus aculeatus*), 1.9% lamprey (*Lampetra* spp.), 0.9% European eel (*Anguilla*

anguilla) and 0.09% Atlantic salmon. Similar numbers of brown trout, a species of recreational importance within the catchment, were found in each electric-fishing reach (Table 1). The smallest and largest captured (in terms of fork length) was 84mm and 312mm, respectively, with most being between 75.1 and 100mm (Figure 3).

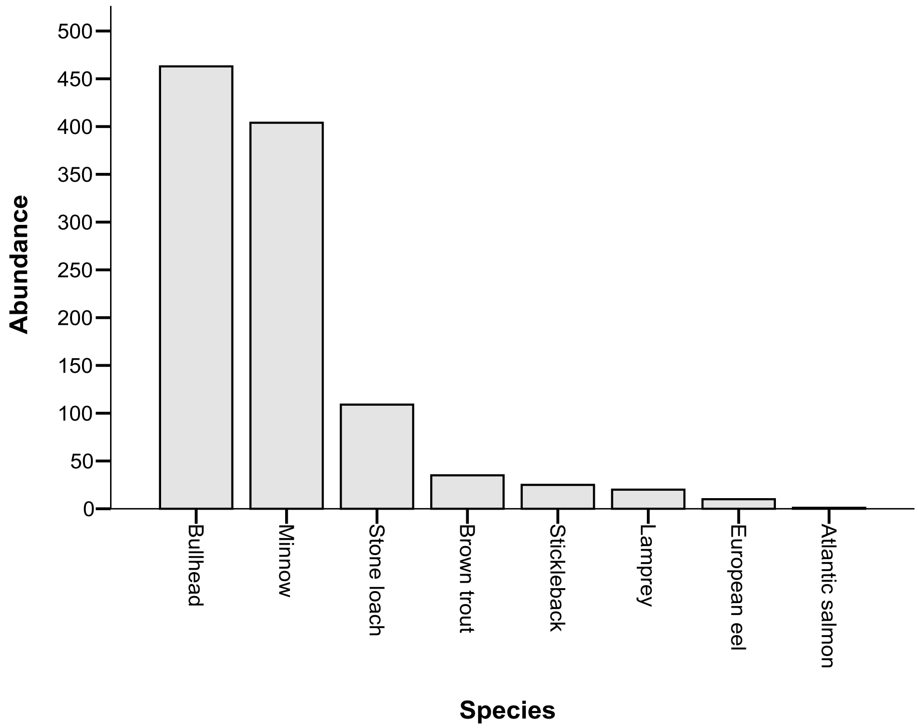

Figure 2. Abundance of each fish species captured in all three electric-fishing reaches of the River Otter in September 2015.

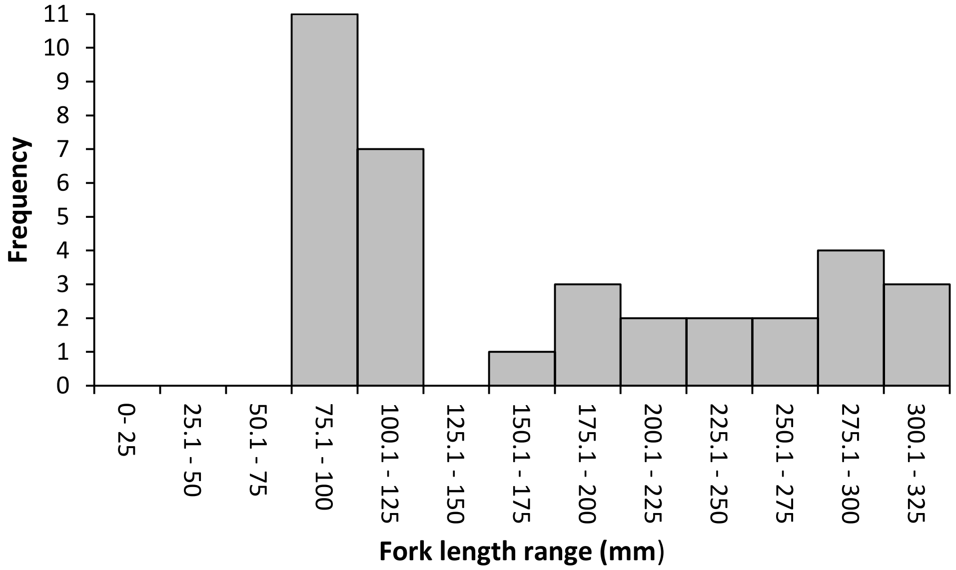

Figure 3. Length frequency distribution for brown trout (*Salmo trutta*) captured from three reaches of the River Otter in September 2015.

River Tale

2016:

Median water depth differed between electric-fishing reaches ($H = 16.5$, d.f. = 2, $p < 0.001$; Figure 4). **'Reach 2: impounded'** was deeper than **'Reach 1: upstream control'** ($p < 0.05$) and **'Reach 3: downstream control'** ($p < 0.001$). Reach 1 and 3 did not differ in depth. Reach 3 had the lowest depth range (25.0cm) while reach 2 had the highest (86cm) and was where the maximum depth (93.0cm) was recorded.

Median water velocity differed between electric-fishing reaches ($H = 11.4$, d.f. = 2, $p < 0.01$; Figure 5), with reach 3 being higher than both 1 ($p < 0.05$) and 2 ($p < 0.01$). Reach 2 had the lowest velocity range (15.9 cm s^{-1}) while reach 1 had the highest (82.2 cm s^{-1}) and was where the maximum velocity (77.8 cm s^{-1}) was recorded (Figure 5).

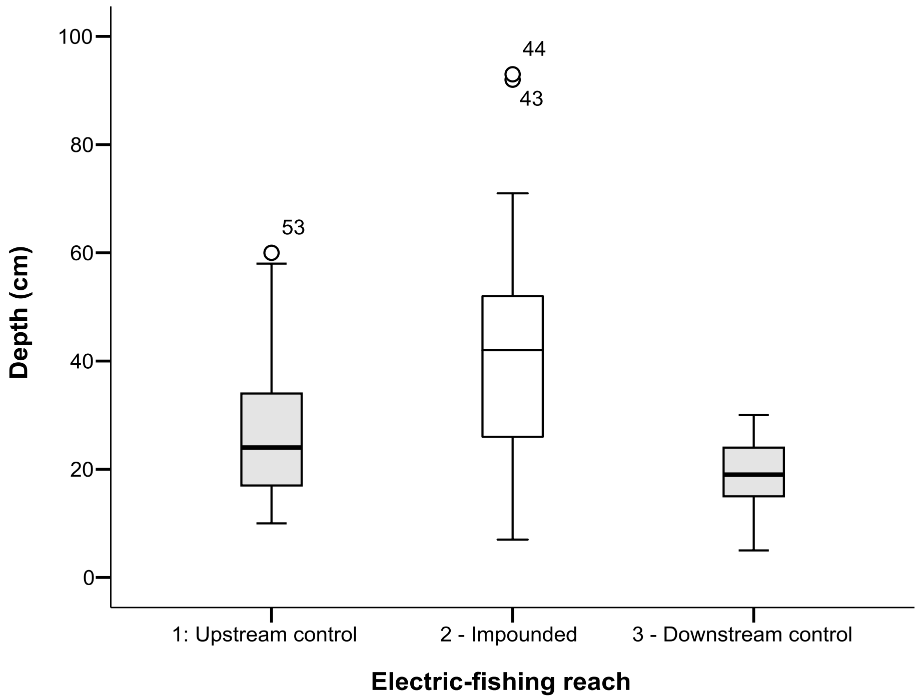

Figure 4. Water depth (cm) in three reaches of the River Tale surveyed by electric-fishing in 2016. The horizontal lines contained within boxes represent median values. Boxes show the 25th and 75th percentile. Vertical whiskers at the top and bottom of the boxes represent maximum and minimum values (excluding outliers), respectively. Outliers (> 1.5 x the interquartile range) are shown as circles.

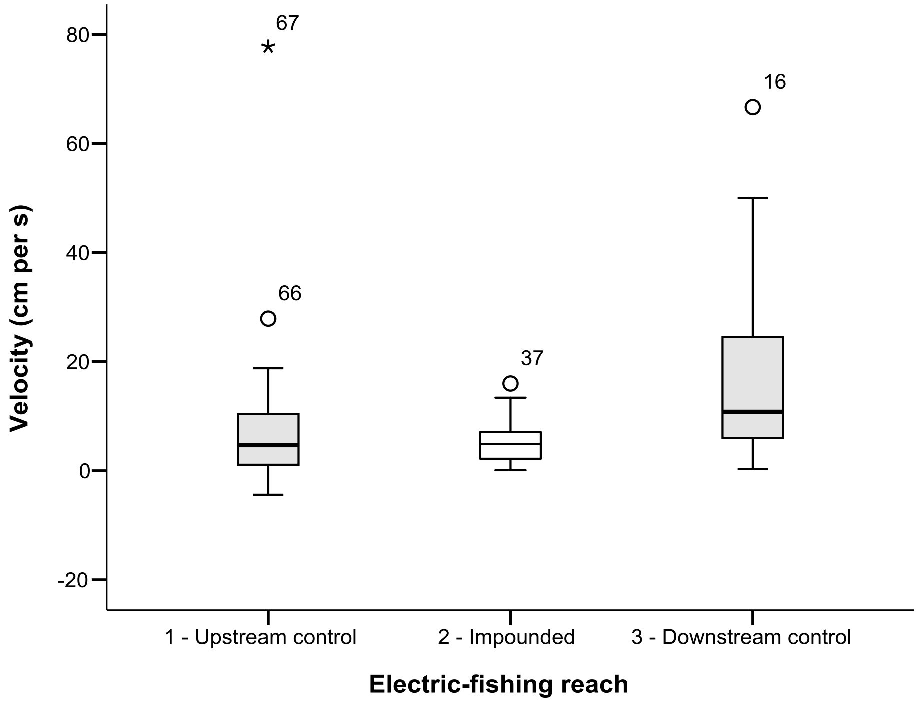

Figure 5. Water velocity (cm^{-1}) in three reaches of the River Tale surveyed by electric-fishing in 2016. The horizontal lines contained within boxes represent median values. Boxes show the 25th and 75th percentile. Vertical whiskers at the top and bottom of the boxes represent maximum and minimum values (excluding outliers), respectively. Outliers are shown as circles (> 1.5 x the interquartile range) and asterisks (> 3.0 x the interquartile range).

The dominant substrate type for reach 1 and 2 was gravel or cobble covered with a fine layer of silt (Table 2). The dominant substrate type at reach 3 was gravel (Table 2).

Table 2. Dominant substrate type, classified according to the Wentworth grainsize scale, within three electric-fishing reaches of the River Tale in October 2016.

	Percent of survey points		
Substrate type	**Reach 1: Upstream control**	**Reach 2: Impounded**	**Reach 3: Downstream control**
Silt (< 0.063mm)	16	16	16
Sand (0.063 - 2mm)	4	0	0
Gravel (2 - 16mm)	24	20	32
Pebble (16 - 64mm)	0	0	0
Cobble (6.4 - 256mm)	8	4	28
Fine layer of silt over larger substrate (gravel or cobble)	48	60	24

The total number of fish collected from three reaches was 555 and consisted of 45.2% bullhead, 16.6% stone loach, 13.9% lamprey, 13.0% brown trout, 6.7% minnow and 4.7% European eel. All six species were found in each of the electric-fishing reaches (Table 3). The average capture efficiency was 0.47, 0.38 and 0.31 for reach 1, 2 and 3, respectively and tended to vary with species (Appendix A).

Table 3. Summary statistics for all six fish species captured when electric-fishing three reaches of the River Tale (Devon, England) in October 2016 at a site where Eurasian beaver (*Castor fiber*) have constructed a dam. Density and biomass values are standardised by surface area (m^{-2}).

	Brown trout (*Salmo trutta*)					Bullhead (*Cottus gobio*)				
Electric-fishing reach	Number caught	Fork length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})
1: Upstream control	33	184 ± 45 (85 - 263)	76.8 ± 46.7 (7.7 - 191.7)	0.19	14.75	112	46 ± 13 (18 - 75)	1.5 ± 1.4 (0.1 - 5.7)	0.65	0.95
2: Impounded	34	167 ± 33 (125 - 255)	56.6 ± 37.7 (21.2 - 186.2)	0.16	8.90	74	48 ± 13 (18 - 71)	1.8 ± 1.5 (0.1 - 7.4)	0.34	0.61
3: Downstream control	5	174 ± 13 (154 - 185)	59.7 ± 11.2 (42.5 - 72.7)	0.03	1.72	65	41 ± 12 (20 - 65)	1.2 ± 1.1 (0.1 - 4.5)	0.37	0.44
	European eel (*Anguilla anguilla*)					Lamprey (*Lampetra* spp.)				
	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})
1: Upstream control	9	313 ± 122 (111 - 470)	146.7 ± 217.0 (2.1 - 620.0)	0.05	7.69	10	133 ± 29 (67 - 164)	4.5 ± 2.6 (0.1 - 8.8)	0.06	0.26
2: Impounded	6	210 ± 78 (133 - 305)	20.6 ± 20.5 (3.1 - 51.4)	0.03	0.57	29	142 ± 18 (80 - 165)	4.8 ± 1.5 (1.3 - 7.9)	0.13	0.65
3: Downstream control	11	253 ± 83 (132 - 348)	33.8 ± 26.7 (3.6 - 71.4)	0.06	2.14	38	122 ± 26 (23 - 154)	3.2 ± 1.4 (0.1 - 6.2)	0.22	0.70
	Minnow (*Phoxinus phoxinus*)					Stone loach (*Barbatula barbatula*)				
	Number caught	Fork length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})
1: Upstream control	5	50 ± 23 (30 - 75)	2.2 ± 2.5 (0.1 - 5.7)	0.03	0.07	27	57 ± 16 (42 - 104)	1.8 ± 2.3 (0.3 - 9.0)	0.16	0.29
2: Impounded	18	58 ± 24 (25 - 87)	3.0 ± 2.5 (0.1 - 6.7)	0.08	0.25	15	66 ± 22 (38 - 110)	3.4 ± 4.2 (0.5 - 13.8)	0.07	0.23
3: Downstream control	14	45 ± 17 (30 - 77)	1.2 ± 1.7 (0.1 - 5.3)	0.08	0.10	50	59 ± 20 (32 - 115)	2.5 ± 2.9 (0.1 - 13.2)	0.29	0.72

Total fish abundance across reaches was similar (Figure 6). While the fish community was dominated by bullhead in all reaches, brown trout were the second most abundant species in reach 1 and 2, in comparison to stone loach in reach 3. The least abundant species in reaches 1, 2 and 3 were minnow, European eel and brown trout, respectively (Figure 6).

Total fish density was similar in all electric-fishing reaches and was 1.14, 0.81 and 1.05 fish m^{-2} in reach 1, 2 and 3, respectively. In contrast total biomass varied between reaches; reach 1 (24.01 g m^{-2}) was about twice that of reach 2 (11.22 g m^{-2}) which was about twice that of reach 3 (5.81 g m^{-2}). Species-specific density and biomass values were variable, with no obvious pattern between reaches (Table 3). For example, no one reach tended to have the highest or lowest density and/or biomass values for most species.

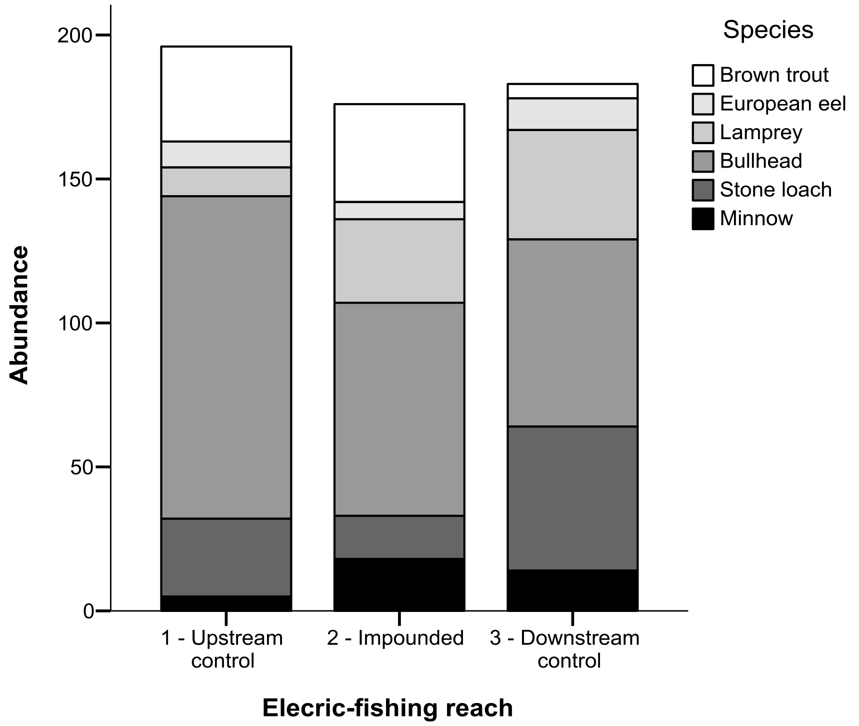

Figure 6. Total abundance of fish within three electric-fishing reaches sampled at a site on the River Tale occupied by Eurasian beaver (*Castor fiber*). Bars are stratified by fish species.

The size (mm) of brown trout (H = 4.7, d.f. = 2, p = 0.094), European eel (H = 3.7, d.f. = 2, p = 0.155), minnow (H = 0.9, d.f. = 2, p = 0.635) and stone loach (H = 2.7, d.f. = 2, p = 0.263) did not differ between electric-fishing reaches (Table 3). Bullhead (H = 11.9, d.f. = 2, p < 0.01) and lamprey (H = 14.9, d.f. = 2, p = 0.001) did differ in size between reaches. For bullhead, those in reach 3 were smaller than in reach 1 (p < 0.05) and 2 (p < 0.01) (Table 3). For lamprey, those in reach 3 were smaller than in reach 2 (p < 0.001) (Table 3).

2017:

Median water depth differed between electric-fishing reach (H = 35.8, d.f. = 3 $p < 0.001$; Figure 7). **'Reach 2: impounded'** was deeper than **'Reach 1: upstream control'** ($p <$ 0.001), **'Reach 3: downstream impacted'** ($p < 0.01$) and **'Reach 4: downstream control'** ($p < 0.001$). Reaches 1, 3 and 4 did not differ in depth. Reach 4 had the lowest depth range (41.0cm) while reach 3 had the highest (69.9cm) and was where the maximum depth (78.1cm) was recorded.

Median water velocity differed between electric-fishing reaches (H = 21.4, d.f. = 3, $p < 0.001$; Figure 8), with reach 2 being lower than reach 1 ($p < 0.01$), 3 ($p < 0.001$) and 4 ($p = 0.001$). Reaches 1, 3 and 4 did not differ in velocity. Reach 2 had the lowest velocity range (10.7 cm s^{-1}) while 3 had the highest (110 cm s^{-1}) and was where the maximum velocity (111.2 cm s^{-1}) was recorded (Figure 8).

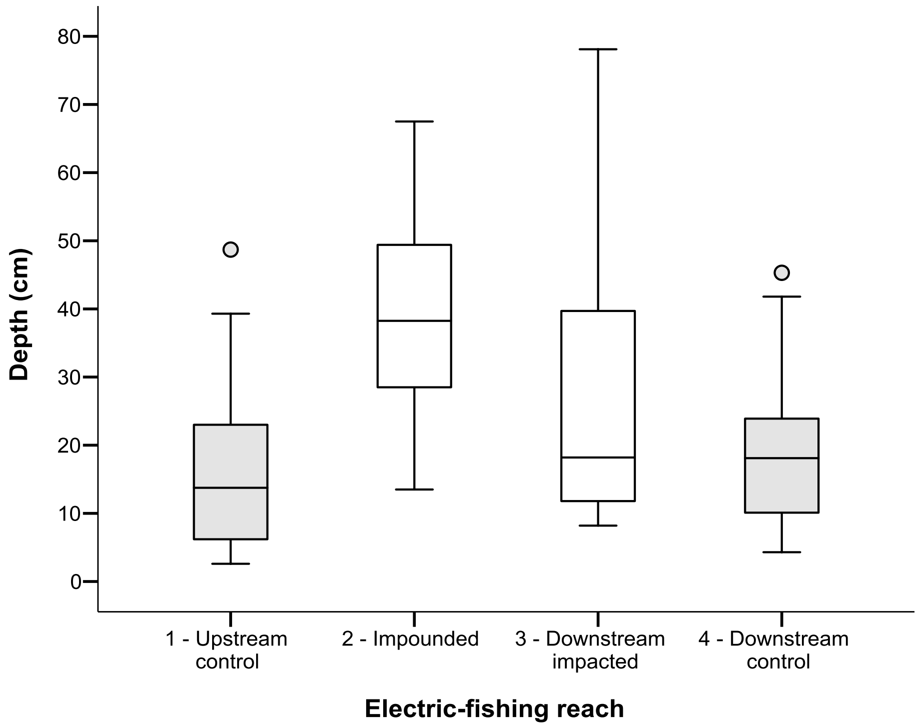

Figure 7. Water depth (cm) in four reaches of the River Tale surveyed by electric-fishing in 2017. The horizontal lines contained within boxes represent median values. Boxes show the 25th and 75th percentile. Vertical whiskers at the top and bottom of the boxes represent maximum and minimum values (excluding outliers), respectively. Outliers (> 1.5 x the interquartile range) are shown as circles.

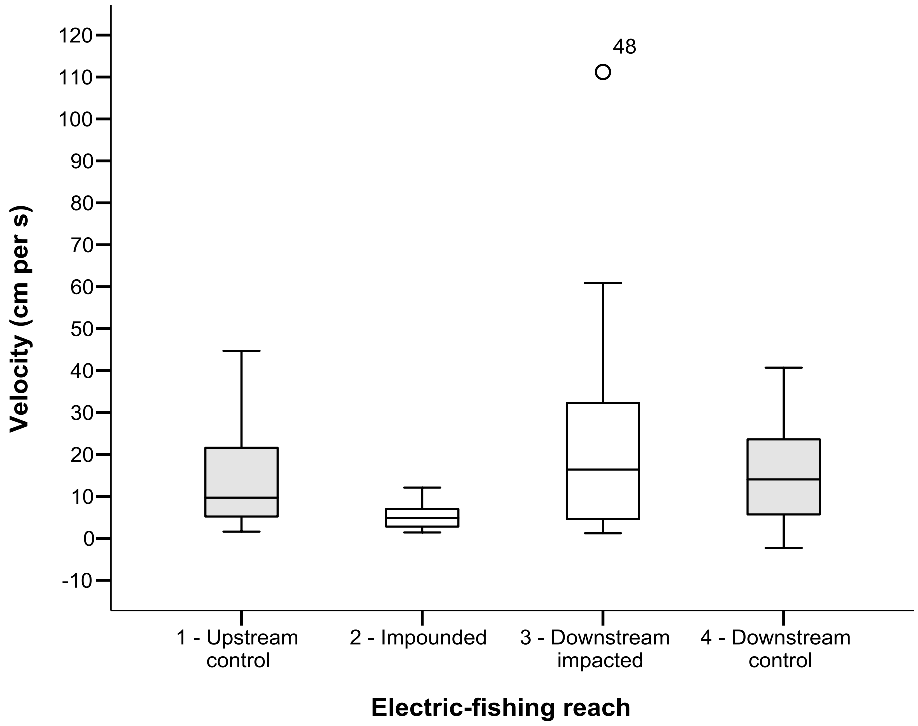

Figure 8. Water velocity (cm^{-1}) in four reaches of the River Tale surveyed by electric-fishing in 2017. The horizontal lines contained within boxes represent median values. Boxes show the 25th and 75th percentile. Vertical whiskers at the top and bottom of the boxes represent maximum and minimum values (excluding outliers), respectively. Outliers (> 1.5 x the interquartile range) are shown as circles.

Substrate for all four reaches was composed of predominantly (> 50%) fine gravel or larger material (Figure 9). A greater percentage of the sediment sample was composed of this largest size fraction at the control reaches (reach 1 and 4) in comparison to the impacted reaches (reaches 2 and 3) (Figure 9). The impacted reaches contained a higher percentage of all other size fractions (very fine gravel or finer) in comparison to the control reaches (Figure 9).

The total number of fish collected from the four reaches was 543 and consisted of 36.3% bullhead, 20.3% stone loach, 16.2% minnow, 15.3% brown trout, 8.5% lamprey and 3.5% European eel. All six species were found in all but one reach; no European eel were captured in reach 3, immediately downstream of the beaver dam (Table 4). The average capture efficiency was similar between electric-fishing reaches and was 0.40, 0.47, 0.44 and 0.41 for reach 1, 2, 3 and 4, respectively, and tended to vary with species (Appendix B).

Total fish abundance in reach 2 was approximately four fold lower than the other reaches, where total abundance was similar (Figure 10). Bullhead were the most abundant species in reaches 1 and 3 in comparison to brown trout and stone loach in reaches 2 and 4, respectively (Figure 10). Eel were rare in most reaches, with 84.2% being caught in reach 1.

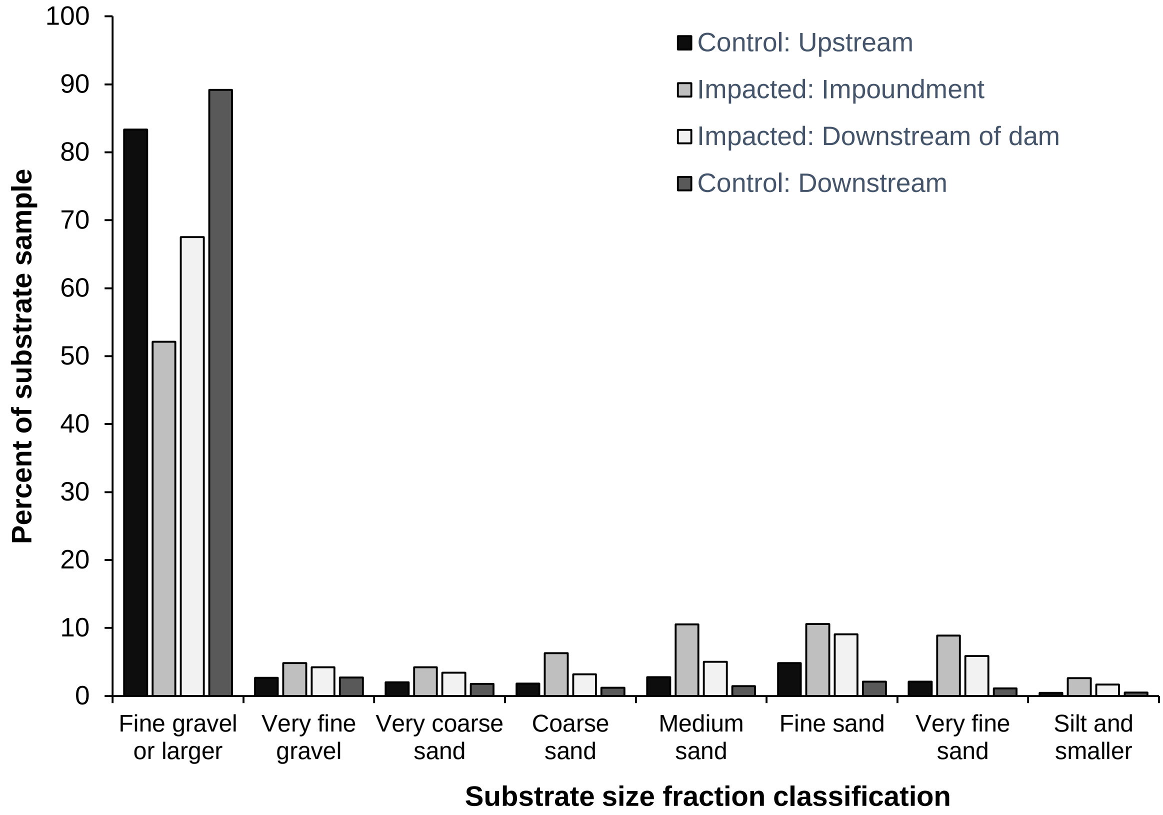

Figure 9. Size fractions of 500g sediment samples collected from four reaches of the River Tale that were electric-fished in 2017.

Total fish density was similar in reach 1 (1.75 fish m^{-2}), 3 (2.00 fish m^{-2}) and 4 (1.80 fish m^{-2}), but lower in reach 2 (0.33 fish m^{-2}). The highest biomass was in reach 1 (26.00 g m^{-2}) followed by reach 3 (11.18 g m^{-2}), reach 2 (7.77 g m^{-2}) and reach 4 (7.13 g m^{-2}). While species-specific density and biomass values varied between reaches, there were a few patterns. Reach 4 contained the highest density of most species (four) (Table 4). Conversely, reach 2 contained the lowest density of most species (four) (Table 4). There was no one reach which contained the highest biomass for the majority of species. Reach 2 was the only site with the lowest biomass values for multiple (three) species (Table 4).

The size (mm) of minnow (H = 1.6, d.f. = 3, p = 0.659) and stone loach (H = 5.6, d.f. = 3, p = 0.132) did not differ between electric-fishing reaches (Table 4). Brown trout (H = 14.3, d.f. = 3, p < 0.01), bullhead (H = 10.9, d.f. = 3, p < 0.05) and lamprey (H = 15.2, d.f. = 3, p < 0.01) did differ in size between reaches. Brown trout were smaller in reach 4 compared to reach 1 (p < 0.05) and reach 2 (p < 0.01). Bullhead were smaller in reach 4 compared to 1 (p < 0.05). Lamprey were smaller in reach 4 compared to reach 2 (p = 0.01) and reach 3 (p < 0.01). No statistical tests were performed for European eel due to the low numbers caught.

Table 4. Summary statistics for six fish species captured when electric-fishing four reaches of the River Tale (Devon, England) in July 2017 at a site where Eurasian beaver (*Castor fiber*) have constructed a dam. Density and biomass values are standardised by surface area (m^{-2}).

	Brown trout (*Salmo trutta*)					Bullhead (*Cottus gobio*)				
Electric-fishing reach	Number caught	Fork length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})
1: Upstream control	25	132 ± 78 (55 - 263)	61.7 ± 75.7 (2.5 - 223.4)	0.27	16.65	68	49 ± 13 (21 - 81)	2.3 ± 1.6 (0.1 - 7.5)	0.73	1.66
2: Impounded	12	161 ± 65 (51 - 248)	69.1 ± 53.1 (1.8 - 168.0)	0.09	6.55	4	53 ± 7 (47 - 62)	2.6 ± 1.5 (1.6 - 4.7)	0.03	0.08
3: Downstream impacted	19	107 ± 56 (56 - 200)	30.7 ± 36.8 (2.6 - 97.5)	0.22	6.84	88	44 ± 14 (20 - 73)	1.7 ± 1.5 (0.1 - 7.5)	1.03	1.75
4: Downstream control	27	70 ± 22 (52 - 172)	6.5 ± 11.9 (2.3 - 65.3)	0.29	1.87	37	42 ± 15 (19 - 84)	1.6 ± 1.8 (0.1 - 9.3)	0.40	0.64

	European eel (*Anguilla anguilla*)					Lamprey (*Lampetra* spp.)				
	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})
1: Upstream control	16	247 ± 80 (106 - 368)	146.7 ± 217.0 (2.1 - 620.0)	0.05	7.69	4	127 ± 31 (83 - 151)	4.3 ± 2.4 (0.9 - 6.2)	0.04	0.19
2: Impounded	1	281	39.7	0.01	0.31	9	151 ± 12 (134 - 175)	6.5 ± 1.8 (4.7 – 10.2)	0.07	0.46
3: Downstream impacted	0	N/A	N/A	N/A	N/A	13	147 ± 31 (61 - 179)	6.2 ± 2.9 (1.0 – 10.6)	0.15	0.94
4: Downstream control	2	253 ± 199 (112 - 282)	59.7 ± 81.5 (2.1 – 117.3)	0.02	1.28	20	102 ± 40 (49 - 167)	2.7 ± 2.2 (0.3 – 7.3)	0.21	0.59

	Minnow (*Phoxinus phoxinus*)					Stone loach (*Barbatula barbatula*)				
	Number caught	Fork length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})	Number caught	Total length [mean ± SD (range), mm]	Weight [mean ± SD (range), g]	Density (fish m^{-2})	Biomass (g m^{-2})
1: Upstream control	24	57 ± 14 (43 - 87)	2.8 ± 2.2 (0.8 – 8.4)	0.26	0.73	25	67 ± 16 (27 - 86)	3.1 ± 1.4 (0.1 – 6.3)	0.27	0.85
2: Impounded	9	49 ± 5 (40 - 57)	1.7 ± 0.6 (0.7 – 2.7)	0.07	0.12	7	77 ± 14 (65 - 105)	4.4 ± 2.7 (2.1 – 9.9)	0.06	0.25
3: Downstream control	22	54 ± 10 (44 - 76)	2.4 ± 1.5 (1.2 – 6.2)	0.26	0.61	29	69 ± 8 (55 - 85)	3.1 ± 1.0 (1.6 – 5.0)	0.34	1.05
4: Downstream control	33	52 ± 9 (37 - 75)	2.2 ± 1.4 (0.8 – 6.7)	0.35	0.77	49	72 ± 15 (24 - 98)	3.8 ± 1.7 (0.1 – 8.1)	0.52	1.98

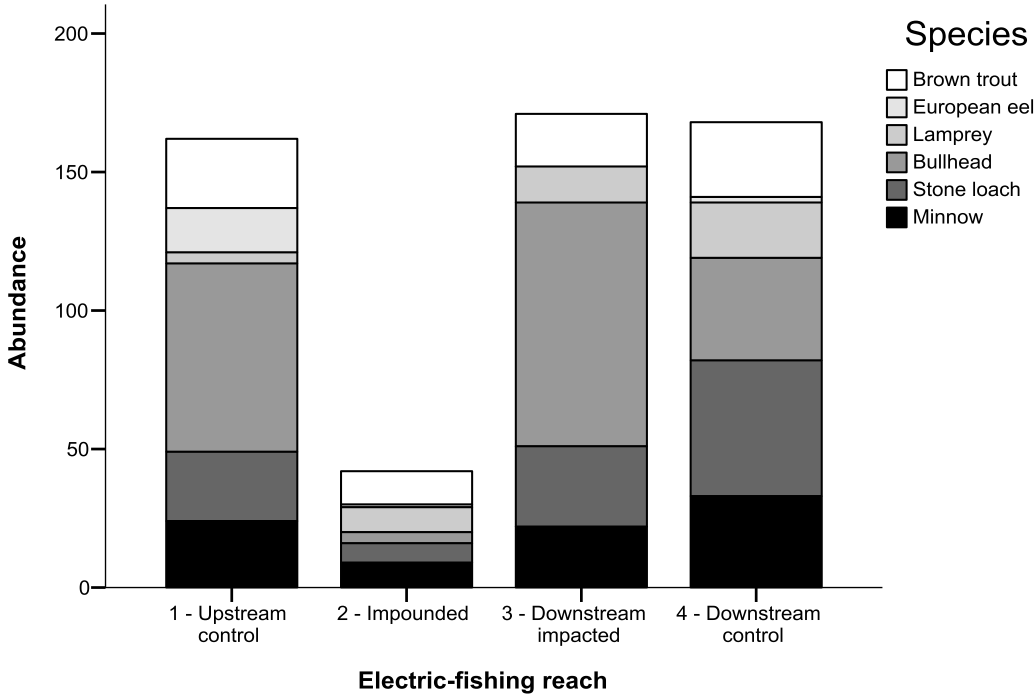

Figure 10. Total abundance of fish within four electric-fishing reaches sampled at a site on the River Tale occupied by Eurasian beaver (*Castor fiber*). Bars are stratified by fish species.

Discussion

The fish species captured in the River Otter were typical of those that occupy swift flows and gravel substrates e.g. bullhead and stone loach (Maitland, 2004). Species that require high water quality (such as brown trout) were also present in each of the three reaches electric-fished. Diadromous species (European eel and Atlantic salmon) were the least commonly observed during this survey. However, their presence demonstrates that passage at anthropogenic structures (e.g. tidal sluices and weirs) lower in the catchment is possible for at least some individuals.

The beaver dam constructed on the River Tale affected the physical characteristics of the river. In 2016, the impounded reach was deeper than the two control reaches. While the velocity range was the lowest, suggesting relatively uniform hydraulic conditions at this location, it did not differ to that recorded for the upstream control reach. In 2017, the effect of the beaver dam on depth and velocity was more pronounced. The impounded reach was deeper and slower than the two controls and impacted reach immediately downstream of the beaver dam. In 2017, the impounded reach was immediately upstream of the beaver dam, whereas in 2016 it was approximately 140m upstream. The more pronounced difference between the impounded reach and to the other sites surveyed in 2017 compared to in 2016 may indicate that the influence of the beaver dam is small in terms of spatial scale. However, the extent of impact is likely to vary temporally, e.g. in relation to dam integrity and discharge.

The qualitative assessment of dominant substrate type suggested some fine sediment deposition in the upstream control and impounded reach in 2016. The quantitative assessment in 2017 illustrated greater deposition around the beaver dam (both up- and down-stream) in comparison to the control reaches. In the impounded reach, this was likely mediated by the deeper, slower flow. Immediately downstream, there was a fairly deep pool where fine sediment accumulated in slow/slack water areas. Indeed, this was the location where the maximum depth was recorded during the 2017 survey. Increased siltation upstream of beaver dams may compromise quality of spawning habitat for some species (e.g. salmonids) but benefit others (e.g. lamprey). Impacts at the population level are unknown, but if beaver dams are sparse, then their impact on the total amount of spawning habitat may be small. Furthermore, the improved water quality further downstream of beaver dams (see Puttock *et al*. 2017) may improve spawning habitat in areas prone to siltation.

Although a different number of reaches were surveyed and in slightly different locations in 2016 compared to 2017, the total river length fished was similar (155m in 2016 compared 112m in 2017) as was the total number of fish captured (555 compared to 543). Furthermore, the order of species in terms of abundance was the same for four of the six species; bullhead, stone loach, brown trout and eel were the first, second, fourth and sixth most abundant species in 2016 and 2017. While lamprey and minnow were proportionally rare and common, respectively in 2017 compared to 2016, this overall pattern in species abundance suggests the composition of the fish community has changed little between the two electric-fishing surveys.

Total fish abundance was similar in all reaches in 2016. In 2017 the total abundance in the impounded reach was around four fold lower than immediately downstream of the beaver dam and the control reaches. There was a notable reduction in the number of bullhead, stone loach and minnow, resulting in the lowest density and biomass values for these species recorded in this reach. Bullhead and stone loach tend to occupy areas with moderate velocity and coarse substrate where they can seek shelter, feed on invertebrates and spawn (Freyhof, 2011; Tomlinson & Perrow, 2003). The localised physical characteristics (deep, slow flow with a greater proportion of fine substratum) in the impounded reach are therefore a likely explanation for their reduced numbers. For minnow, the increased risk of predation from brown trout, the most common species occupying this location, may have resulted in them seeking refuge in other areas within the river. Indeed, as this was a relatively recently inundated reach, there appeared to be little submerged woody material away from the beaver dam for smaller fish to shelter within (although this was not quantified during the survey).

While total fish density was low in the impounded compared to other reaches in 2017, biomass was not. Indeed it was greater than that in the downstream control. Biomass of brown trout was particularly high considering their densities in this reach. For example, biomass was similar immediately downstream and upstream of the beaver dam, despite density being more than two fold greater in the downstream location. This indicates that trout occupying the location immediately upstream of the dam tended to be larger, supporting the common suggestion that beaver ponds provide suitable rearing and/or refuge habitat for salmonids (Collen & Gibson, 2001; Kemp *et al*. 2012).

Conclusions

The beaver dam on the River Tale increased water depth, decreased velocity and promoted fine sediment deposition immediately upstream. There was no obvious influence on the fish community approximately 140m upstream of the beaver dam (see results from 2016). However, there was a reduction in the number of fish from small-bodied species immediately upstream of the beaver dam (see results from 2017). These species tend to occupy shallower, swifter flows and gravel substrates. The localised changes in physical habitat because of the beaver dam may have caused these species to redistribute within a small spatial scale. The high biomass relative to density of brown trout immediately upstream of the beaver dam suggests this to be a suitable habitat for larger individuals of this species.

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Appendix A. Number of fish captured in the River Tale in 2016 with an estimate of population and electric-fishing capture efficiency.

	Brown trout (*Salmo trutta*)		
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream control
Total catch	33	34	5
Population estimate	35	38	5
Capture efficiency	0.57	0.50	0.71

	Bullhead (*Cottus gobio)*		
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream control
Total catch	112	74	65
Population estimate	145	174	79
Capture efficiency	0.38	0.17	0.43

	European eel (*Anguilla anguilla*)		
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream control
Total catch	9	6	11
Population estimate	9	6	18
Capture efficiency	0.53	0.60	0.24

	Lamprey (*Lampetra* spp.)		
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream control
Total catch	10	29	38
Population estimate	14	157	221
Capture efficiency	0.30	0.06	0.06

	Minnow (*Phoxinus phoxinus*)		
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream control
Total catch	5	18	14
Population estimate	5	20	27
Capture efficiency	0.45	0.49	0.20

	Stone loach (*Barbatula barbatula*)		
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream control
Total catch	27	15	50
Population estimate	28	17	92
Capture efficiency	0.59	0.45	0.23

Appendix B. Number of fish captured in the River Tale in 2017 with an estimate of population and electric-fishing capture efficiency.

	Brown trout (*Salmo trutta*)			
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream impacted	Reach 4: Downstream control
Total catch	25	12	19	27
Population estimate	25	13	19	70
Capture efficiency	0.68	0.48	0.66	0.14

	Bullhead (*Cottus gobio)*			
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream impacted	Reach 4: Downstream control
Total catch	68	4	88	37
Population estimate	172	4	149	40
Capture efficiency	0.15	0.40	0.25	0.54

	European eel (*Anguilla anguilla*)			
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream impacted	Reach 4: Downstream control
Total catch	16	Insufficient data		
Population estimate	19			
Capture efficiency	0.42			

	Lamprey (*Lampetra* spp.)			
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream impacted	Reach 4: Downstream control
Total catch	4	9	13	20
Population estimate	4	9	28	24
Capture efficiency	0.44	0.56	0.17	0.42

	Minnow (*Phoxinus phoxinus*)			
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream impacted	Reach 4: Downstream control
Total catch	24	9	22	33
Population estimate	50	13	22	37
Capture efficiency	0.19	0.28	0.67	0.49

	Stone loach (*Barbatula barbatula*)			
	Reach 1: Upstream control	Reach 2: Impounded	Reach 3: Downstream impacted	Reach 4: Downstream control
Total catch	25	7	29	49
Population estimate	27	7	34	58
Capture efficiency	0.53	0.64	0.45	0.45

Appendix C. Comparison between density and biomass values for fish captured during electric-fishing surveys on the River Tale in 2016 and 2017 standardised by surface area and river length.

2016

Species	Reach	Density (fish m^{-2})	Density (fish m^{-1})	Biomass (g m^{-2})	Biomass (g m^{-1})
Trout	Upstream control	0.19	0.73	14.75	56.4
	Impounded	0.16	0.71	8.90	40.1
	Downstream control	0.03	0.09	1.72	5.5
Bullhead	Upstream control	0.65	2.49	0.95	3.6
	Impounded	0.34	1.54	0.61	2.8
	Downstream control	0.37	1.20	0.44	1.4
Eel	Upstream control	0.05	0.20	7.69	29.4
	Impounded	0.03	0.12	0.57	2.6
	Downstream control	0.06	0.20	2.14	6.9
Lamprey	Upstream control	0.06	0.22	0.26	1.0
	Impounded	0.13	0.60	0.65	2.9
	Downstream control	0.22	0.70	0.70	2.3
Minnow	Upstream control	0.03	0.11	0.07	0.2
	Impounded	0.08	0.37	0.25	1.1
	Downstream control	0.08	0.26	0.10	0.3
Stone loach	Upstream control	0.16	0.60	0.29	1.1
	Impounded	0.07	0.31	0.23	1.1
	Downstream control	0.29	0.93	0.72	2.3

2017

Species	Reach	Density (fish m^{-2})	Density (fish m^{-1})	Biomass (g m^{-2})	Biomass (g m^{-1})
Trout	Upstream control	0.27	0.84	16.65	51.61
	Impounded	0.09	0.44	6.55	30.33
	Downstream impacted	0.22	0.69	6.84	21.26
	Downstream control	0.29	0.96	1.87	6.24
Bullhead	Upstream control	0.73	2.28	1.66	5.16
	Impounded	0.03	0.15	0.08	0.38
	Downstream impacted	1.03	3.21	1.75	5.45
	Downstream control	0.4	1.32	0.64	2.14
Eel	Upstream control	0.05	0.54	7.69	18.38
	Impounded	0.01	0.04	0.31	1.45
	Downstream impacted	n/a	n/a	n/a	N/A
	Downstream control	0.02	0.07	1.28	4.25
Lamprey	Upstream control	0.04	0.13	0.19	0.58
	Impounded	0.07	0.33	0.46	2.15
	Downstream impacted	0.15	0.47	0.94	2.92

	Downstream control	0.21	0.71	0.59	1.95
Minnow	Upstream control	0.26	0.80	0.73	2.26
	Impounded	0.07	0.33	0.12	0.55
	Downstream impacted	0.26	0.80	0.61	1.88
	Downstream control	0.35	1.18	0.77	2.55
Stone loach	Upstream control	0.27	0.84	0.85	2.62
	Impounded	0.06	0.26	0.25	1.14
	Downstream impacted	0.34	1.06	1.05	3.26
	Downstream control	0.52	1.75	1.98	6.61