WILD TROUT TRUST
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Advisory Visit
Lower Rivers Porter & Sheaf

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River	Porter Brook and River Sheaf
Waterbody Name	Porter from source to River Don and Sheaf from Source to River Don
Waterbody ID	**GB104027057760 (Porter)** **GB104027057750 (Sheaf)**
Management Catchment	Don and Rother
River Basin District	Humber
Current Ecological Quality	Moderate
U/S Grid Ref inspected	SK3553586699
D/S Grid Ref inspected	SK3586887740
Length of river inspected	1.3 km

1. Summary

- *Historically-culverted sections of the lower Porter and Sheaf are being assessed for ecological improvement opportunities (including – but not limited to potential daylighting of targeted sections)*
- *Technical consultations on a range of ecological outcomes are being sought – and as part of this, protecting and improving prospects for salmonid fish has important conservation implications*
- *With the existence of "within-niche" habitat conditions for key lifecycle stages of* ***spawning****,* ***juvenile*** *and* ***adult*** *fish for UK BAP species brown trout (Salmo trutta) & bullhead (Cottus perifretum) evident in multiple patches of both the Sheaf and Porter (including underground sections); the critical factor appears to be improved connectivity for up and down-stream migration of individuals throughout their full lifecycle*
- *Such longitudinal connectivity confers much greater protection against local extinction of unique and locally-adapted genetic diversity due to improved prospects for gene-flow between artificially-fragmented populations*
- *The improved potential for emigration and immigration also creates greater capacity to recover from significant habitat disturbance or pollution incidents*

2. Introduction

The Wild Trout Trust were invited by Sheaf and Porter Rivers Trust to give advice on the ecological potential of the lower Porter and Sheaf Rivers – with particular emphasis on extensively-culverted sections in the vicinity of the confluence with the main River Don. Throughout the report, banks are designated as right (RB) and left (LB) while facing downstream.

3. Background

Significant moves are underway to daylight/de-culvert, improve and protect biodiversity alongside creating much greater engagement of the local (and wider) community with the rivers of the lower Porter and Sheaf valleys. There is a complex balance to be struck between different interests and societal values for the amenities supported by the watercourse. The historic site of Sheffield Castle and the population of Daubenton's bats inhabiting the lower sections of culvert are obvious examples of complex considerations.

4. Habitat Assessment

Habitat was assessed, sequentially, in a downstream progression from an upstream limit at the Matilda Street Pocket Park at SK3553586699 (Fig.1). The creation of the pocket park itself was enabled by a previous deculverting project.

Figure 1: Heading downstream from Matilda Street Pocket Park.

Of particular note within the Pocket Park reach is the difficulty in retaining small cobble and gravel-sized substrate within sections of relatively narrow channel. The impressive power of spate flows in the Porter Brook create concentrated areas of bed-scour when confined in narrower sections. While this has the valuable function of maintaining scour-pool habitat, the armoured, artificial bed creates an obvious limit on the depth of scour pool habitat created in this manner.

Areas of wider cross-section – such as some of those that exist in culverted sections downstream of the pocket park, are essential for deposition and retention of gravel deposits.

A short way downstream in the vicinity of the BBC archives, the Porter Brook enters a low brick culvert (Fig. 2) and this gives a good insight into the design and nature of the engineered two-stage channel typical of the historically-modified Porter Brook channel (Fig.3).

Figure 2: Culvert entrance downstream of Matilda Street Pocket Park.

Figure 3: Brick-lined central "low-flow" channel of the Porter Brook where the Leadmill Stream joins along the RB.

Perhaps ironically, the increased depth of water maintained in sections of the artificial low-flow channel are used by adult trout (observed during the visit). Maintenance of some deeper water is one consequence of bed-scour generated in narrowed, reinforced channels (though blockages and infill with rubble/larger substrate also occur, creating a kind of linear pool/riffle sequence). In the event that such channels are modified with the aim to improve ecological endpoints, care must be taken to avoid creating uniformly shallow habitat – while also (crucially) avoiding the creation of depth via impoundment. With that said, more extensive restoration and breaking out of the low-flow channel would increase conveyance and – potentially, provide sufficient cross-sectional width to encourage deposition of substrate to form more varied habitat. In other words, it's important not to gain one type of habitat at the expense of another and half-measures will have negative outcomes.

Connectivity between the reaches shown in Figs. 1 to 3 appears to be good (enabling the various kinds of habitat present to be utilised to a useful proportion of their full potential). For the most part, the habitat is suitable for juvenile and adult trout – but with limited opportunities for spawning. Excellent cover from predation (and roughness to create refugia from spate flows) has persisted and developed well in the modified, deculverted section at Matilda Street Pocket Park. In the future, comparable projects could seek opportunities for widening as well as deculverting sections of channel so as to promote deposition of gravels and some finer sediment during spates, helping to mitigate the artificially confined urban floodplain.

Potentially there is an area where sufficient channel-width and roughness could be created to enable spawning-gravel deposition in the reach running adjacent to the "Q-Park" multi-storey car park at National Grid Reference SK3578586819. This is an above-ground section of the Porter Brook, directly upstream of Sheffield station, that would be a valuable resource to connect to the upstream juvenile and adult habitat noted previously. The downstream limit of the above-ground section (at a monitored flow-gauging location) is visible in the background of Fig. 4.

Figure 4: Culvert entrance at the junction between the reach adjacent to the Q-Park site and Sheffield Station.

Previously, sensitivities have been noted towards any alterations that may impinge on monitoring data. However, it seems really important to understand what those data are for, how to either avoid or mathematically-compensate for any impacts on data-collection, the Environment Agency's responsibility to the environment.

The sloping apron leading down into the culvert – and ultimately the confluence of the Porter Brook and River Sheaf – is a significant obstacle to free passage of fish under most flow conditions (Fig. 5).

Figure 5: Laminar, uniformly-shallow flow down a sloping apron creates a significant obstacle to fish.

It should be possible to design and install relatively low-tech, baffled-flow fish passage easement measures to improve longitudinal connectivity at this location.

For the remainder of the visited reaches, the issue of longitudinal connectivity appears to be the most significant opportunity for ecological improvement for the benefit of a wide range of aquatic species. It is important to note that it is not only the well-known "migratory" species (such as Atlantic salmon and sea trout) that benefit greatly from the ability to access different habitats throughout various stages of their lifecycle.

With that said, it is nonetheless important to note that access to the major tributaries of the River Don would be a significant boon to the ongoing return of salmon and sea trout to Sheffield. At the same time, this should not overtake the importance of longitudinal connectivity to species that remain within freshwater throughout their lifecycle.

The culverted Porter Brook meets the culverted River Sheaf beneath platform 5A of Sheffield station and that confluence is pictured in Fig.6.

Figure 6: Although suffering from poor lighting, it is possible to note another sloping, shallow-water obstacle to fish movement at the confluence of the Sheaf and Porter

Again, the potential benefits of installing fish passage easement structures which create baffled flow could be transformative for the prospects of healthy, self-sustaining fish populations (including species on the UK Biodiversity Action Plan list such as bullhead, eels and brown trout).

Tackling the multiple small “step” barriers (Fig.7) would also be a priority in this respect.

Figure 7: Although seemingly small and insignificant, the shallow water below this step prevents fish from being able to leap this barrier.

Due the overall width of the double-arch culvert, there is far more potential for deposition of riverbed material compared to the highly-constrained above-ground sections of both the Sheaf and Porter. Parallel, “arched-roof” culvert chambers are supported by longitudinal walls or pillars with regular archway gaps which allow flow to pass either side. This can lead to a kind of zig-zagging sequence of pools and low cascades – steered by deposits of bed material (e.g. Figs. 8 & 9).

Figure 8: Archways to the left and right of frame can allow flow to pass down the culvert on either side.

Figure 9: The scouring flow below a cascade can create deep pools (with scoured material deposited at the tail end being dry in low flows and diverting the main flow into the parallel chamber).

A more detailed study to confirm the ability of fish to pass freely through those zig-zagging sections is required since free passage is likely to be complicated by the existence of staggered, small step weirs in the parallel chambers. In all cases, notching of the small step-weirs (such as those pictured in Figs. 7 and 8 – and the one upon which the camera was positioned in Fig.9) should be undertaken to improve passage. Due to the huge increases in flow velocity during spate conditions – areas which lack deposited bed material are unlikely to be passable under high flows. Consequently, if the channels are not passable under low flow conditions, the only opportunity for movement may be under a very finely-balanced mid-level of flow; though that optimum flow will vary for different species and is far from a guarantee of free movement.

The deceptively innocuous low steps and small impoundment problems are not limited to the below-ground sections of river. The Sheaf at Ponds Forge sports a perched culvert step at its upstream end (Fig. 10) and a sheet-piling impoundment just upstream of its entrance into the subsequent culvert downstream (Fig. 11).

Figure 10: Double-arched ceiling, perched parallel culverts discharging into the short open-air section of the Sheaf at Ponds Forge. At low discharges, the only appreciable flow comes down the chamber on the right of this picture. However, the steep entrance and very shallow, laminar flow is in itself extremely difficult for fish to pass.

The power of the water discharging over this step (particularly to the right of the frame in Fig.10) has scoured out a substantial pool – holding large adult trout. The displaced bed material forms a mid-channel island within the open-air reach and may, possibly, provide marginal spawning opportunities. However, the fish in this section are essentially penned in and gene-flow will be extremely restricted on a River Sheaf meta-population scale. These issues are expanded upon in the contents and associated URL links within Appendix 1 to this report.

Figure 11: Sheet piling impounding structure and barrier to free fish passage.

Notching the sheet piling down to bed level would substantially improve fish passage and sediment transport prospects at this location. The perched culvert would require an easement designed specifically for that location (which could still be achieved in a relatively low-tech and cost-effective manner).

In the below-ground section (inside the culvert below the weir shown in Fig. 11) a small bullhead was observed via headtorch (Fig.12).

Figure 12: Bullhead (another UK BAP species) inhabiting a below-ground section of the River Sheaf.

A recently-completed study (due for formal publication in January 2022) highlights the importance of restoring connectivity in previouslyfragmented, post-industrial stream sub-catchments just like the Sheaf and Porter. The huge increase in bullhead numbers is particularly noteworthy. This small, UK BAP species is typically (though incorrectly) assumed to be more independent of habitat connectivity due to its small home-range. The study is available as an open-access document on the following link:

https://www.sciencedirect.com/science/article/pii/S0048969721047951

Finally, one of the biggest challenges (and simultaneously biggest opportunities) will be the reconnection of the confluence of the Sheaf and main river Don. Currently, after flowing beneath the brick arch sometimes referred to as the Megatron (Fig. 13; although that name is also used for the entire lower Porter/lower Sheaf culvert system), the Sheaf discharges into the Don from a perched outfall at Blonk Street.

Figure 13: Brick arch originally constructed as part of Sheffield's tram station infrastructure and known by urban explorers as the defining feature of the Megatron culvert network. The sunlight in the background is coming from the outfall of the Sheaf into the River Don.

Overcoming the "step" between the base of that outfall and the surface of the River Don (while accommodating the upstream water level on the Sheaf) will require an engineering intervention such as a long, low-gradient rock-ramp. However, the engineering aspect is not the only challenge at this location – owing to the installation (and subsequent colonisation) of bat-boxes in this section of the culvert. The man-made "cave" habitat with moderated climate and protection from predation enables near constant day and night-time feeding for the Daubenton's bats occupying this section. To help inform complex decisions around overall ecological restoration/renaturalisation goals for various components of the river corridor foodweb, pooling of existing knowledge will be essential.

For instance, one of the notable observations that was, unfortunately, not possible to photograph during the visit was the copious numbers of adult caddis flies which had hatched from the rivers below ground. These are one of the main prey species of Daubenton's bats – along with chironomid midges. While high densities of midge larvae tend to require deposition of fine sediment (associated with impounded flows or stillwaters), caddis often favour faster-flowing, rockier environments. Consequently, the steeper, rockier conditions implied by a rock-ramp to connect the Sheaf to the Don need not be an impediment to a continuation of 24/7 bat foraging. Similarly, the multitude of species making up the Chironomid family includes many representatives that occupy faster flowing habitat.

A key consideration, therefore, will be the incorporation of a broad range of flow depths and velocities (and associated deposition/erosion properties) within any constructed riverbed. In this way, provision is made for benthic invertebrate diversity and abundance – which in turn enables top predators in both aquatic and terrestrial components of the river corridor to be supported.

As well as the habitat and associated species at that specific location, the value of a viable migration corridor for metapopulation dynamics of aquatic species at the catchment scale and beyond needs to be given appropriate weight in any ecological restoration project. It is especially important to note that high-quality habitat which is not utilised because of a lack of connectivity effectively represents degradation of that habitat. That guiding principle is key to discussions around the culverted and de-culverted sections of the lower Porter and Sheaf valleys. In the majority of the below-ground artificial channel reaches, the localised habitat value and diversity will be significantly constrained. However, the ability for that habitat to form a viable migration corridor has huge ecological value. What's more, habitat does (and will) exist below ground which is suitable to sustain aquatic lifecycles – either in part or in whole – depending on the species.

5. Recommendations

In the event that any habitat intervention work is undertaken, ALL appropriate legal permissions must be sought before commencing work on site. These are not limited to landowner permissions but will also involve regulatory authorities such as the Environment Agency and multiple additional stakeholders.

Assuming that all legal requirements have been met for relevant activities, a summary of the recommended actions are:

- Undertake a more detailed assessment and feasibility study to re-establish longitudinal connectivity of the lower River Sheaf and Porter Brook to the River Don.
    - It is advisable to treat every obstacle as a unique case (and avoid a cookie-cutter approach) in order to arrive at the best design for each structure.
    - Where notching of any impounding structures (i.e. those holding water back on their upstream side) is possible, notches should be made down to the bed-level (or below) on the downstream side of the structure to ensure river-bed continuity.
    - Low tech easements may be appropriate to some of the barriers noted in this report (and have been observed to provide highly significant benefits – for example the re-establishment of sea trout spawning activity upstream of culverts on the Cong Burn following low-tech baffle installation in culverted sections: https://www.gov.uk/government/news/trout-make-spawning-return-to-north-east-river
- Formal assessment of the potential for rock-ramp construction at the confluence of the Sheaf and Don is recommended – and a key part of any subsequent design brief needs to be the avoidance of "steps" either at the downstream (River Don) or upstream (River Sheaf) extremities of any planned structure.
- Kick-sampling of below-ground sections is recommended to establish a baseline of benthic invertebrate diversity and abundance (with a view to gauging implications for dependent aquatic and terrestrial predators).
- Maintain awareness of the potential to create areas of wider channel within above-ground reaches in a bid to encourage localised gravel and cobble deposition.

6. Further information

The WTT may be able to offer further assistance such as:

- WTT presentation/Q&A session
    - Where recipients are unsure about the issues raised in the AV report, it is possible that your local conservation officer may be able to attend a meeting to explain the concepts in more detail.

In these examples, the recipient would be asked to contribute to the reasonable travel and subsistence costs of the WTT Officer.

The WTT website library has a wide range of free materials in video and PDF format on habitat management and improvement:

www.wildtrout.org/content/wtt-publications

We have also produced a 70-minute DVD called 'Rivers: Working for Wild Trout' which graphically illustrates the challenges of managing river habitat for wild trout, with examples of good and poor habitat and practical demonstrations of habitat improvement. Additional sections of film cover key topics in greater depth, such as woody material, enhancing fish populations and managing invasive species.

The DVD is available to buy for £10.00 from our website shop www.wildtrout.org/shop/products/rivers-working-for-wild-trout-dvd or by calling the WTT office on 02392 570985.

7. Acknowledgements

The Wild Trout Trust would like to thank the Environment Agency for their continued support of the advisory visit service, in part funded through monies from rod licence sales. The advice and recommendations in this report are based solely on the expert and impartial view of WTT's conservation team.

8. Disclaimer

This report is produced for guidance; no liability or responsibility for any loss or damage can be accepted by the Wild Trout Trust as a result of any other person, company or organisation acting, or refraining from acting upon guidance made in this report.

N.B. See Appendix 1, over.

Appendix 1: Weirs: Impacts & Issues Summary

The most apparent issues with weirs impeding upstream migration are important but not always the most significant when compared to less obvious effects. Of course, with reports of salmon trying to return to many post-industrial rivers, the issue of upstream migration is crucial. Similarly, the **less-frequently considered downstream migration of juvenile fish** is every bit as important for the completion of anadromous (marine-migratory) fish lifecycles as well as "freshwater-resident" species.

In sections where water is held back behind an obstruction (or "impounded"), that downstream migration is significantly hampered. Firstly, the simple and slow-flowing habitat greatly increases the efficiency of mobile predators (such as fish-eating birds). Secondly, because juvenile salmonid fish largely navigate downstream "tail-first" – they rely on the guidance of natural current-flows. Impounded sections of river cause a stalling of that downstream migration – *potentially creating delays that are long enough for the physiological window for "smolts" (juvenile salmonid fish capable of transferring into salt-water environments) to expire*.

Huge losses of smolt outputs from rivers systems have been recorded (including over 80% of total smolt output lost from a major tributary of the Tweed system) and assigned to impacts of low-head weir-impoundment (Gauld et. al 2013, Science of The Total Environment Volumes 458–460, Pages 435-443;

https://www.sciencedirect.com/science/article/abs/pii/S004896971300497X).

The variable performance of fish passage easements and technical fish passes, whose efficacy differs between fish species and also flow conditions, is essential to highlight. No fish pass is ever 100% efficient even for a single, target, species of fish. In fact, the efficiency (i.e. number of fish successfully ascending as a proportion of total attempting to ascend) varies widely for different species which have different preferences and swimming abilities. The above measure of efficiency also fails to account for the delays and exhaustion effects of multiple attempts made by fish which ultimately manage to ascend. These too can greatly reduce fertility and ultimate spawning success.

To that point, it is also important to take into account the cumulative effect of multiple barriers. Here's a simple illustration (based on the work of Dr. Ed Shaw during his PhD) showing the rate of attrition for 100 hypothetical salmon attempting to pass a series of barriers (Fig.A1). For the sake of illustration, passage efficiencies of 99%, 75%, 50% and 20% are shown as if they were consistent for each barrier in the series.

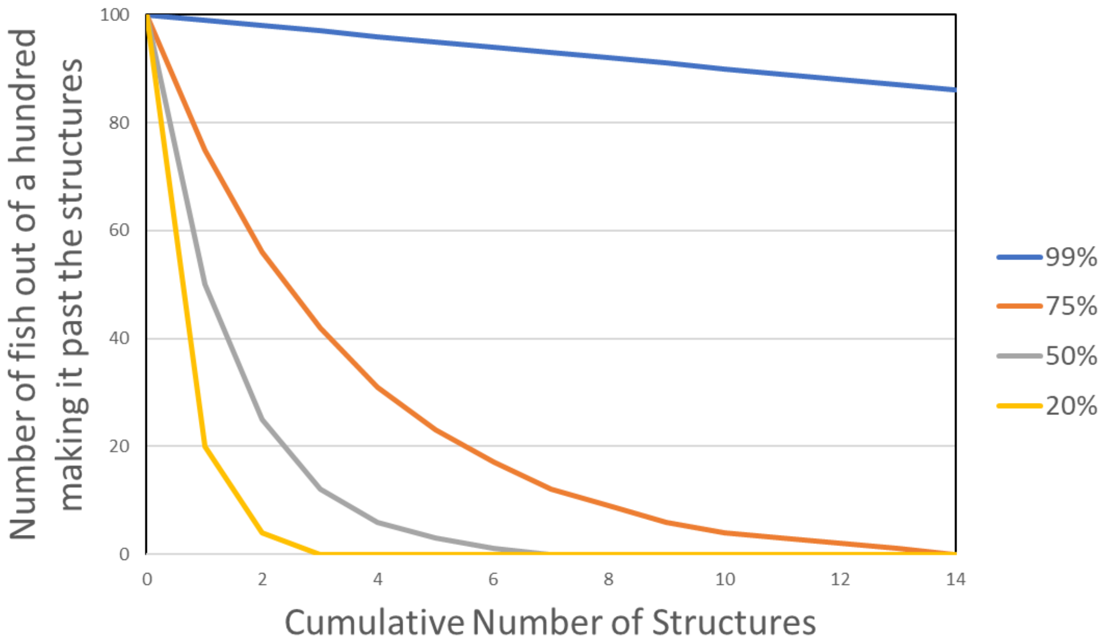

Figure A1: Cumulative impact of a series of barriers on the proportion of fish ascending to reach spawning grounds plotted at different passage efficiencies for that series - after Shaw, "*Weir Management: Challenges, analysis and decision support*"; PhD Thesis, University of Sheffield (2013)

It is surprising (and sobering) to see how few structures it takes before the proportion of migrating fish tends to zero (especially in the context that 75% passage efficiency is hard to achieve in practice).

That being said, fish passage easements (and formal fish pass structures) could be an essential "least worst" option in cases where weir removal is prohibitively challenging. Creating and maintaining access to high quality habitat is an important consideration. Designs of easements should incorporate the aim of avoiding a need for additional debris-clearance over and above the existing conditions within the lower-gradient sections of the culvert.

However, as mentioned previously, the less-commonly considered impacts of weirs on the quality of habitat within rivers is just as important as their effects on migration. In particular, the creation of simplified, slow-flowing habitat and the interception of riverbed material that would otherwise be transported downstream are two key effects.

In terms of maximising biodiversity and the resilience of aquatic communities, habitat needs to have structural variety – and that physical diversity needs to adapt over time. On the one hand, massive structural upheavals that are too frequent will constrain biodiversity to "live fast/die young" only species. On the other, habitat that is locked in place will tend to become dominated by a smaller number of highly-specialised "climax community" species. Biodiversity is maximised somewhere in the middle of those extremes.

One of the key drivers that maintains structural variation over time is the transport of riverbed material from the upper to lower catchment. A very obvious example is the supply and turnover of spawning gravels.

Weirs interrupt the “conveyor belt” process of transporting broken-up/weathered rocks from the headwaters downstream. This hinders the creation and maintenance of spatially and temporally-variable habitat; a good example of “locking habitat in place” (Fig.A2).

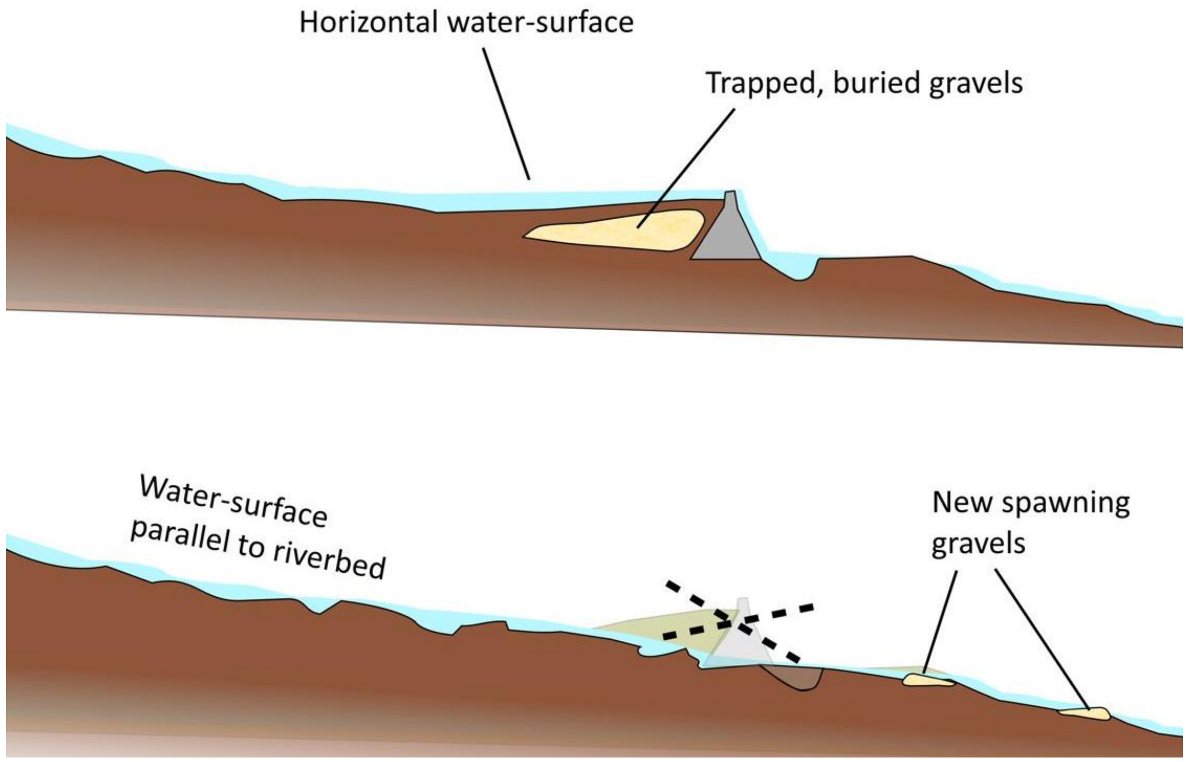

Figure A2: The stepped profile of a river created by impounding structures locks habitat in place by interrupting the natural transport of bed-materials (including gravel)

One consequence is a reduced ability to provide each of the three key habitat types needed for complete wild trout lifecycles (spawning, juvenile and adult habitats).

Another is impact on predator/prey interactions – with the efficiency of avian predators greatly increased in simplified, impounded river sections (Fig. A3). The risk of local extinctions of certain fish populations is greatly increased when mobile predation efficiency is substantially-elevated by such habitat simplification.

In contrast, where there is greater variety in both riverbed structure and the pace/depth of current flows within that channel, predation efficiency is reduced. An obvious example of this contrasting condition is found in un-impounded sections below weirs. This varied, complex habitat improves the chances that prey capture efficiency reduces to an unprofitable level for the predators *before* all prey is eradicated (Fig. A4).

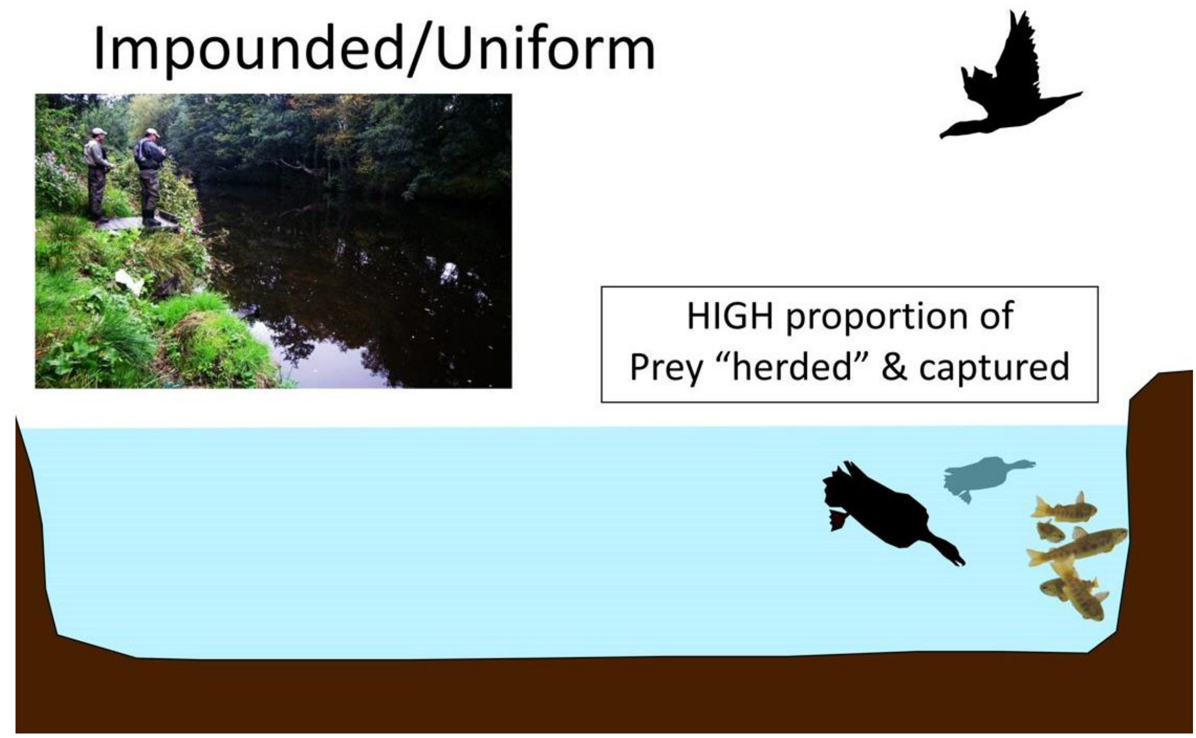

Figure A3: Simple, slow-flowing habitat increases prey-capture efficiency

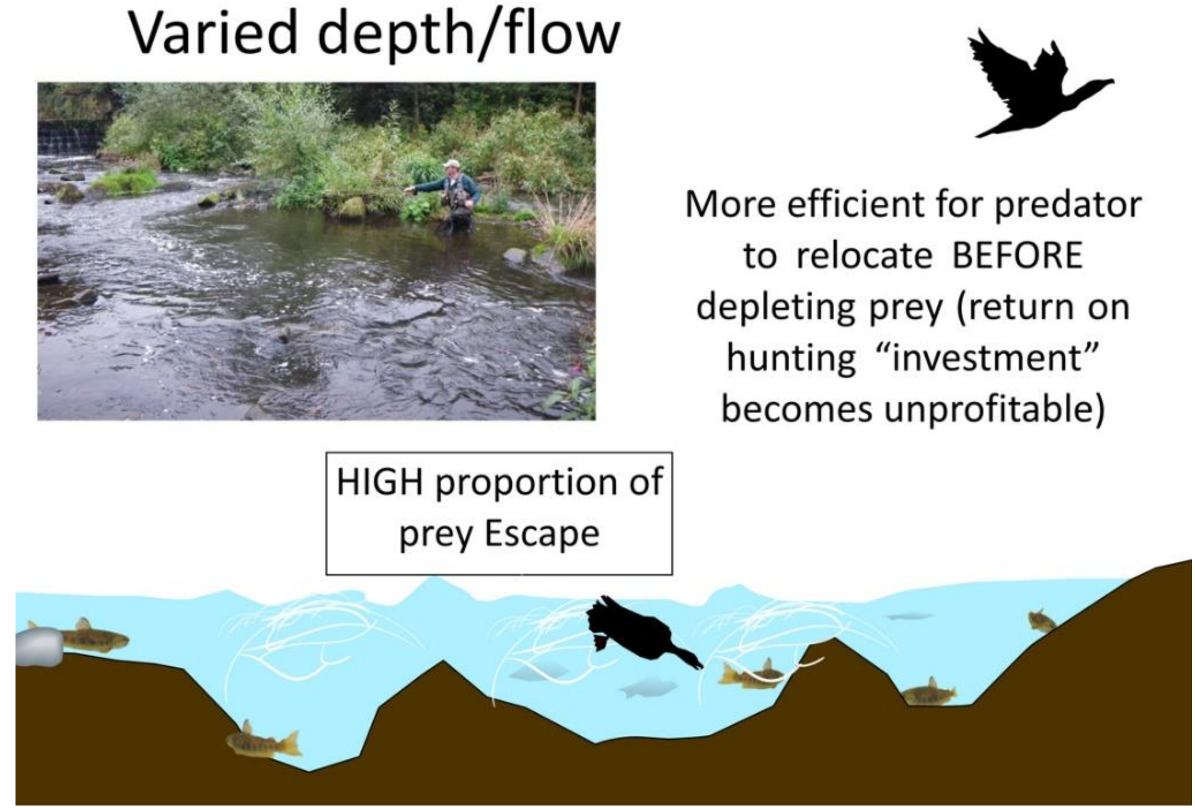

Figure A4: Complex habitat and currents rebalances predator/prey interactions in favour of more stable and persistent populations

A more detailed consideration of the issues pertaining to weirs is given in the article on the Wild Trout Trust website here: https://www.wildtrout.org/wttblog/why-presume-remove-weirs-river-dove-case-study