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Weirs, dams and other river structures: Their effects on wild brown trout – WTT information paper

Introduction– what are the main impacts of weirs?

Man-made structures on rivers which can be a barrier to fish include flumes, sluices, weirs, dams, culverts, barrages and river crossings. The nature of these structures is to alter the flow regime of a river or stream. Impounding a river or stream has possible consequences for: discharge, water velocity, temperature, dissolved oxygen, river bed movement, siltation and suspended solids¹. Some man-made barriers such as low head dams and small weirs may not represent a permanent or insurmountable barrier to fish migration but can still have significant effects on animal movements, flow and temperature regimes, sediment transport, biogeochemistry, and stream habitat². There are also many cases where a structure is completely impassable to fish. For simplicity, all of these man-made structures will be referred to as “impoundments” throughout this document, unless it is appropriate to be more specific. This paper has been produced by the WTT to review the impacts and management of obstructions on wild brown trout (WBT) and their habitat.

Brown trout are flow-loving fish that benefit from the structural variety associated with complex current flow. Adequate spawning, juvenile and adult habitat is important for a healthy WBT population³ and formation of this habitat is favoured under a natural (varied) flow regime. For instance, features such as habitat diversity (e.g. pools, riffles and glides), good water quality (cool, well-oxygenated and low levels of pollutants) and a low amount of sediment are generally regarded as desirable⁴. Indeed, overall species diversity, of both flora & fauna, tends to be associated with diverse physical habitat, favoured by a natural flow regime with its attendant natural processes (erosion & deposition)^{5,6}. Habitat connectivity and diversity are therefore of utmost importance to successful WBT populations. The effects of impoundments on rivers can be divided, broadly, into two main categories:

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| 1. Hampering or preventing migration of aquatic fauna |
| 2. Changes to river habitat |

Whilst the first category of impacts is partially recognised amongst both conservation specialists and the general public, the second category receives far less coverage. This document has been produced by the WTT in order to characterise the impacts of impounding structures and identify potential options for the management of rivers and river habitat for the benefit of WBT and associated river-corridor biodiversity.

1. Impacts on fish passage/access

Although perhaps more widely known, it is still important to recognise the crucial role of free passage for all trout between adult, juvenile and breeding habitat. Brown trout migrations may be

anadromous (migrate to the sea) or potadromous (migrate within a freshwater system –see WBT in Lake Walchensee, Bavaria⁷), but the crucial point is that ALL trout migrate^{8,9,10}. These migrations occur for a number of reasons, for example to exploit richer feeding, to spawn, avoid low flows or the icing up of streams in winter¹⁰ and can be severely affected or curtailed by man-made impoundments^{11–14}.

The ability of fish populations to move freely is therefore crucial; curtailing this movement can adversely affect the populations' abundance and long-term viability. When, for example, upstream migrations and passive downstream drifts (e.g. by fry or smolts) are interrupted by impoundments¹⁵, the net result is a reduced effective breeding population^{11,16,17}. This means, rather than a single, connected population of fish breeding freely in a river system, impoundments fragment populations into small, reproductively isolated units. This in turn fragments the genetic structure of WBT populations^{18,19,20}. Much has been written about the genetic diversity of brown trout and the importance of genetic diversity to the continued survival of the species. While there are situations where fish populations have become genetically impoverished after weir construction²⁰, paradoxically, this fragmentation can cause rapid differentiation between local populations and an initial, rapid increase in genetic diversity¹⁸. But first, it is worth considering genetic drift and natural selection, two driving forces of evolution (Fact box 1).

Fact box 1: Evolution & genetics

Genetic drift: In small populations, genes present are unlikely to reflect the whole range of genetic diversity present in a species. Genetic drift occurs when the population size is limited (for example by impoundments or even natural disasters) and therefore by chance, certain genetic characteristics increase or decrease in frequency. However, unlike natural selection, genetic drift is random and rarely produces adaptations to the environment²¹. It is NOT the same as “inbreeding”, and the two should not be confused.

Natural selection: Under natural selection, some individuals in a population have modifications that allow them to more successfully survive and reproduce and respond to changes in their environment. Their adaptations become more common as a whole due to their increased reproductive success. This leads to “survival of the fittest” (where “fitness” is a measure of survival and reproductive output) and individual beneficial variations are preserved in a population²².

When genetic drift happens in small reproductively isolated populations, genetic variation can be greatly reduced and beneficial adaptations may be permanently eliminated²³. Small ranges put constraints on migration behaviour and spawning site selection. This increases the potential for distinct phenotypic or behavioural subpopulations which are reproductively isolated from other populations²⁴. The ultimate consequence of this is to compromise a population's evolutionary potential¹⁷ (see [Case study box 1](#)).

Case study box 1

Fragmentation & genetics, what are the implications for WBT conservation?

Initial increased genetic diversity

- In the **Mana River**, Norway, research concluded that construction of four hydropower dams from 1906-57 fragmented the wild trout population the overall effect of which was to increase local genetic diversity in the Mana River system.
- The researchers hypothesized that the most likely reason for this rapid differentiation was genetic drift. In small populations, genetic drift is thought to be the main driver of this process. This effect has been observed in other related studies¹⁶, however:

Increasing risk of long term extinction(s)

- As has already been mentioned, genetic drift may not necessarily produce beneficial variation (in this case due to anthropogenic changes) and small, reproductively isolated

populations are however threatened by increased risk of extinction in the longer term^{17,25,26}.

- In a study of white spotted charr in Japan, researchers sampled isolated populations of charr above a reservoir¹⁷. They found that local extinctions were strongly related to isolation period. Impoundments produce long-term evolutionary bottlenecks and serve to reduce the 'evolutionary potential' of a species.
- Meldegaard et al¹⁶ demonstrated rapid genetic differentiation in a weir fragmented population of Danish grayling. This rapid differentiation increases the probability of losing rare alleles, and thereby lowering genetic variability. If grayling, in this case, had to undergo similar rapid differentiation at a future stage, it is crucial that a species has full access to its genetic 'tool-box'.
- It is becoming apparent that many trout populations are structured in ways that we previously did not understand, with different populations of trout and salmon co-existing but separated within the same river system e.g. in the River Tweed²⁷. In the case of Atlantic salmon larger, older multi-seawinter fish tend to enter rivers earlier and spawn higher upstream than younger grilse, which tend to enter later in the season and spawn lower in the system²⁸. Weirs can force both age classes to interbreed and the presumed benefits of assortative mating¹ are lost²⁹ leading to population homogenization. Many WBT populations also display assortative mating characteristics, such as the trout of Lough Melvin, Ireland.
- Further research may be required into whether weirs have this same effect on WBT. The Blackwater, a tributary of the Deveron in Scotland, hosts a run of large trout, once presumed to be sea trout. Preliminary scale readings suggest that these trout are in fact resident brown trout that migrate, either into the main river or the sea³⁰. This is a good example of why connectivity in river systems is so important for the various life histories and strategies of brown trout.

More immediate impacts on fish populations result as impoundments can reduce the carrying capacity of a river system¹¹ (Case Study box 2). For example, impoundments may concentrate juveniles into homogenous habitats where shelter is lacking³¹. When access to spawning²⁴, nursery³² and important foraging habitat³³ is restricted, bottlenecks are created in the different life stages of WBT. Weirs or hydro-schemes can increase the mortality of migrating fish as fish repeatedly attempt to pass impoundments. This depletes energy reserves and results in reduced spawning success and increased spawning mortality^{34,35}. High levels of predation can occur during migrations at impoundments; opportunistic predators (such as the great cormorant *Phalacrocorax carbo*) may use weirs as vantage points³⁶ and impoundments hold up smolting runs, increasing smolt vulnerability to both avian and piscine predators³⁷. The opportunity for smolts to reach the sea is quite narrow and there is recent (as yet unpublished) evidence that even low head impoundments delay smolt migrations to such an extent that up to 80% of a smolt run is lost³⁸.

Case study box 2

Why is connectivity in rivers important for healthy WBT populations?

Access to spawning

- Hydropower developments and weirs are typically built in upper catchments, taking advantage of steeper gradients. This can disproportionately reduce the availability of spawning habitat and force trout to spawn in lower reaches of rivers, where siltation and predation might be a problem¹¹.
- In Northern Spain, 86% of migratory salmonid habitat is inaccessible to spawning fish³⁹ due to

¹Where individuals of different genotypes or phenotype (appearance) within a species mate exclusively. This can lead to increased fitness amongst offspring and in the case of salmon, distinct strains of larger, the multi sea winter spawners so valued by fishing interests.

weir construction. On the **River Badisoa**, with over 140 obstacles, sea trout runs are severely restricted with only 25% of the upstream stem of the River accessible²⁴.

- Moreover, accessibility is also often dependant on flow rate and obstacles often have an associated abstraction use (e.g. irrigation, hydropower). Loss of discharge therefore increases the barrier effect of weirs on tributaries and further isolates upstream sections of tributaries: prime spawning habitat.

Habitat connectivity

- In the **Willamette and Lower Columbia River Basins** of the US Pacific Northwest, historically abundant runs of pacific salmon have crashed. A conservative estimate indicated that 42% of accessible stream habitat was lost to salmonids¹¹.
- Salmon, like trout, require connectivity between the diverse habitats that are suitable for different life history stages. Impoundments clearly reduce stream connectivity and may therefore influence fish population abundance.

Migratory survival rates

- A heavily fragmented river, the **Gudena** in Denmark has seen a crash in sea trout numbers since the early part of the 20th century⁴⁰, partly due to the proliferation of impassable impoundments.
- This cumulative effect of multiple impoundments adversely impacting on salmonid populations across river catchments is well documented in the literature^{41,42}. Recent modelling work⁴³ suggests this negative effect occurs even with the provision of fish passes, and the efficiency of fish passes has a significant effect on the number of fish reaching habitat.
- Time & effort spent by trout waiting downstream of weirs for flow thresholds to be crossed compromises reproductive success & survival⁴⁴. Weirs also hold up returning sea trout kelts; Swedish research found mortality at weirs was far higher than overwintering mortality, 69% mortality in one case⁴⁵.

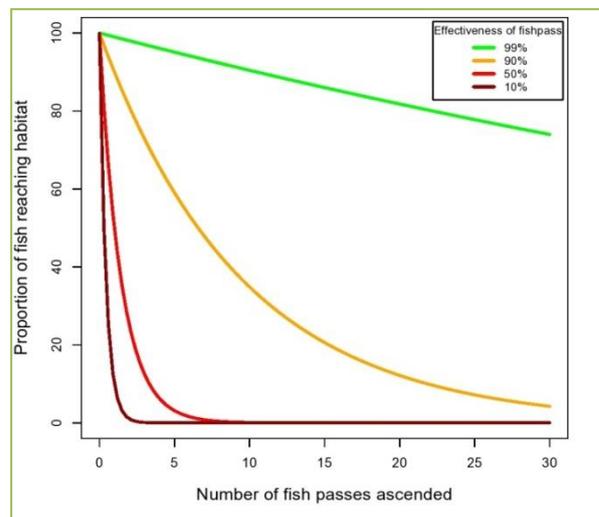


Figure 1; Cumulative impact of multiple fish passes on proportion of migrating fish reaching habitat (Dr E. Shaw, Catchment Science Centre, University of Sheffield, unpublished).

Restricting free passage has a negative effect on the structure and size of WBT populations. Just as serious are the impacts impoundments have on river habitat which in turn has consequences for WBT and fish populations as well as other fauna and river processes.

2. Impacts on habitat

River catchments with a high number of weirs or dams present tend to have both homogenized[†] flows and instream habitat^{5,46}. This is because impoundments replace diverse stream habitats such as riffles, runs and side channels with ponded, deep, slow flowing sections^{47,48}. When this happens, habitat variability is lost⁶ and rivers undergo a change in species composition⁴⁶. Specialist species (e.g. gravel spawners like grayling & WBT) decline⁴⁹ and the ecosystems become dominated by

[†] Similar/generalised

generalist species able to survive in the slow, laminar conditions created by impoundments⁴⁹. This reduction in structural complexity has knock-on impacts for fish productivity³¹. The deep anoxic conditions that exist behind dam walls are ideal conditions for increased methane production⁵⁰, a far more potent greenhouse gas than CO₂.

Disrupting the natural hydrology of rivers can have further consequences for WBT populations. For example, weirs reduce the recruitment of downstream gravels⁵¹ while increasing sediment deposition upstream which can silt up spawning habitat.

In the Great Ouse, a sequence of weirs (Figure 2) has converted the river into a series of relatively deep channels with an absence of salmonid species⁵². Like other heavily modified rivers, habitat homogenization has resulted in an impoverished fish fauna and predominance of generalist fish species. Some people (including anglers) may not recognize a problem with homogenized rivers and their attendant homogenized fish communities. However, in the majority of cases, homogenized environments and ecological communities are less resilient to change than their more diverse counterparts⁵³ (see the **WTT Stocking position statement**, click [here](#) to view, for the analogy with genetically diverse WBT populations versus genetically homogenous stocked fish). For example, flooding impacts are more severe on fish populations in heavily modified stretches than in structurally diverse stretches⁵⁴ and diverse ecosystems and communities are better at withstanding invasive species introductions.⁵⁵

Re-establishing Habitat connectivity – a key step in river restoration

Restoring connectivity in watersheds is often advocated as one of the first steps in restoring catchments to good ecological status and the benefits of barrier removal are inherently obvious (e.g. fish passage) and can be realized relatively quickly when compared with other restoration techniques⁵⁶. When natural flow regimes are re-instated, natural movement of sediment, woody debris and organic materials can occur. Instream habitat enhancements (e.g. large woody debris installation, creating spawning gravels etc.) can often be unsuccessful or temporary in nature because landscape or catchment constraints, such as impoundments, have not been adequately considered⁵⁷. Having said this, while it is important to solve the catchment scale problems that are limiting fish habitat and restricting



Figure 2; Weir on the Great Ouse

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access, this process may take time and instream habitat enhancement is a good way of realizing shorter term gains in biodiversity and fisheries in the meantime. Local stakeholders, such as angling clubs, often cannot afford to wait for the benefits of barrier removal to be realized.

And while a holistic, catchment-based approach is required to reach the ultimate goal of habitat connectivity, local actions and improvements at key obstacles can have a catchment wide effect. For example, walkover surveys of the River Tweed illustrated the presence of 861 natural & man-made obstacles; in the short term it is not feasible to tackle all of these barriers but a catchment perspective can identify barriers that are having a disproportionate impact on river habitat. Some notable and current examples include:

- **Cromwell weir** in the tidal reaches of the River Trent which currently hinders lamprey and eel migration to the rest of the catchment^{58,59}.
- **Norbury weir** on the Dove which is effectively impassable to Atlantic salmon in all but the highest flows and the upstream limit to their distribution on the River Dove.

Are all barriers impassable?

The effect of an impoundment on fish passage can depend on impoundment type, flow conditions and fish species⁶⁰ so it is important that impoundments are consistently assessed when prioritizing removal/modification options. A wide range of techniques for assessing the impact of impoundments on fish passage exist⁶¹, all with inherent biases and constraints. A recent method has been developed for UK agencies to provide a means to consistently assess fish passage across the full range of obstacles found on British rivers. The appropriate regulatory agency should therefore be consulted whenever weir removal is considered. The Water Framework Directive emphasizes the need for connectivity in river systems and anglers can play a key role in identifying and cataloguing impoundments along watercourses. A simple, non-technical recording form can be used to report potential problems (click [here](#) for the WTT online Upland River Manual with an example).

Once an initial survey of obstructions has been undertaken, problems can be prioritized. Modifying larger weirs, dams or road culverts can take considerable time to go through planning and various impact assessments.

Fact box 2: Examples of fish passage easements^{71,72}

Pre barrage boulders: are used to improve passage mainly at low obstacles and on small watercourses.

Bypass channels: a shallow channel mimicking a natural watercourse and linking the sections below and above the obstruction. Water velocity in the channel is reduced and a rough bottom dissipates energy in the channel, this is combined with a series of constrictions and expansions of the flow created by blocks, groynes and weirs. Well-designed channels have proven to be a highly successful restoration technique⁶⁵ and are even used as habitat by brown trout⁷³.

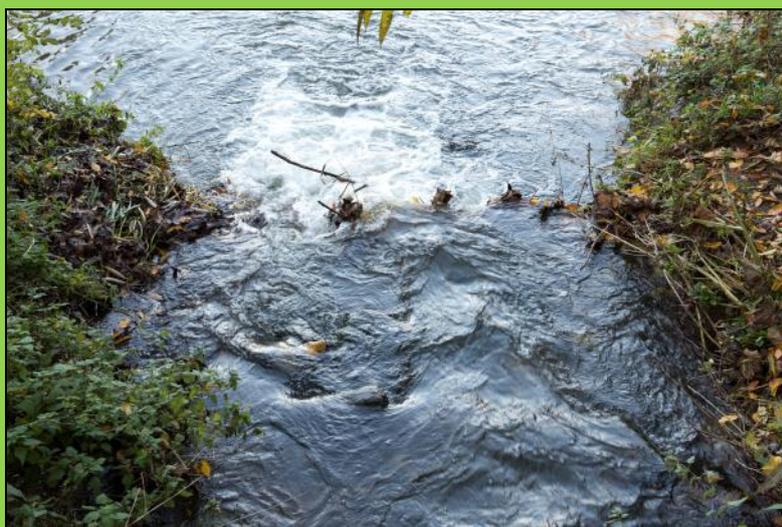


Figure 1; Bypass channel on the River Cam, Cambridge, showing outlet structure and rock baffles ©Thomas Smith

Low flow notches: a low flow notch serves to concentrate flows, usually at the centre of a weir and at low flows. This type of easement produces a concentrated plume (with as little turbulence as possible) of water and is particularly suitable for salmonids.

Improving connectivity in your river

Because of the importance of fish access and habitat, the WTT often identifies obstacles as major factors limiting fish production on its Advisory Visit programme. Small streams are often undervalued as an angling resource (they do not hold as many adult fish and access is difficult) but they are vitally important spawning and nursery habitat^{1,62}.

Small-scale easement and fish passage, on small obstacles, can be achieved by simple engineering solutions such as bypass channels, low flow notches & pre barrage boulders. Road culverts are commonly encountered barriers to fish passage, particularly on small streams. Inadequate water depth, perch height, excessive water velocity or a combination of all three may restrict fish passage⁶³. Culverts can be modified or removed to assist with fish passage⁶⁴ and a number of studies have demonstrated the effectiveness of replacing stream culverts to restore fish access^{65,66&67}.

Case Study Box 3

Improving WBT habitat through weir removal

- **Cong Burn, River Wear, County Durham⁶⁸:** The Wear drains a post-industrial landscape and consequently, this legacy has left the Wear with heavily modified and with numerous weirs which once drove local industry. On the main river, many of the weirs have been dealt by the EA or have scheduled works to improve fish passage. On smaller burns however, numerous barriers to migration exist which the authorities understandably lack the capacity to deal with. It is in situations like this that angling clubs, rivers trusts and the WTT can fill the void and make a real difference.
- **Approach:** Working in partnership with the Chester le Street and District Angling Club (CDAC), project to improve fish passage on the Cong Burn, a major spawning tributary of the Wear system. The project involved the removal of a redundant weir and installation of baffles in road culverts and the WTT was able to support CDAC in sourcing over £20,000 to complete the work. Within hours, sea trout of up to 5lbs were observed above previously impassable obstacles (Figure 5).



Figure 2: Male sea trout with dorsal & tail out the water, after barrier easement

The role of angling clubs in restoring catchment wide connectivity

- **River Stepenitz, Germany:** In the Stepenitz catchment, a tributary of the Elbe in Germany, Atlantic salmon and sea trout had become extinct by the 19th century, due to widespread modifications of the river. In 1997, the Brandenburg Angler Association partnered with fisheries researchers to re-establish migratory fish into what was then a heavily modified and fragmented river. A stock restoration programme was combined with an ambitious programme of easements & removals leading to 50% of impoundments being removed by 2008⁶⁹. The project was successful because anglers, working in partnership with professional fisheries biologists and water management professionals were able to build up momentum and attract funding. 64% of potential spawning habitats are now open and since 2002 returning adult salmon have been routinely observed.

Summary

When assessing options for barrier removal/easement, fisheries managers should bear in mind that the presence of impoundments does not just affect WBT passage, but also habitat. Restoring fish passage and improving habitat for fish and biodiversity should be the primary management goals; fish passes need continual maintenance and may not be effective in all flows⁷⁰. However, removal of weirs is not always feasible or desirable and in cases like this, easements or provision of passage may be the only options. Charismatic species like brown trout and Atlantic salmon can be used to effect the catchment wide environmental enhancements that will come about with improved passage and habitat connectivity.

Simple dos and don'ts:

- **DON'T** assume that weirs are providing good holding habitat for fish. A properly functioning river system with sufficient flows will produce a much greater diversity & density of deeper pool areas without the negatives associated with weirs.
- **DO** maintain access for trout, even in **small un-fished streams**; these are often breeding and nursery areas and can produce the majority of juvenile trout in many river systems.
- **DO** continue to improve **instream habitat** on your river, in spite of the presence of weirs and their overarching impact on habitat connectivity & quality in a river. It is still important that reach scale problems are addressed whilst long term objectives (free fish passage) are addressed. In this way, when they are resolved, the benefits associated with habitat improvements will be maximized.
- **DO** liaise with the relevant regulatory agency personnel who will establish (and potentially influence) the sequence of fish passage solutions. There are many different designs of fish passes suitable for different locations and species and will require specialist input to ensure their effectiveness. In these cases, angling clubs are usually the catalyst & driver for getting the process underway.
- **DO** involve landowners from the outset and educate them on what you are trying to achieve.
- **DO** 'encourage' gradual weir removal. On high energy, spate rivers, weirs can erode away over time. Removing a few choice pieces of the upper structure provides the spate flows something to work with to 'naturally' remove the weir.
- **DO** encourage the controlled removal of weirs or create notches in weirs which will allow the upstream river bed to re-align itself gradually.
- **DO** prioritize removal over fish pass provision where possible. Fish passes should be as a last resort as they do not adequately address the problems of habitat connectivity and degradation.



Figure 3; Section of Sussex Ouse showing ponded, homogenous habitat before (a) and after (b) weir removal and riffle installation ©Andy Thomas

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