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The effect of natural flood management in-stream wood placements on fish movement in Scotland

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Please reference this report as follows: Dodd, J.A., Newton, M & Adams, C.E. (2016) The effect of natural flood management in-stream wood placements on fish movement in Scotland, CD2015_02. Available online crew.ac.uk/publications

Cover photograph courtesy of: The James Hutton Institute

Acknowledgements:

The authors would like to extend their thanks to the members of Steering Group for their input and advice, the attendees and speakers of the workshop at Battleby on the 12th April 2016, and to Dr Colin Bull for his advice during the initial stage of the project. The authors would also like to thank Eleanor Starkey (Newcastle University) and the Haltwhistle Burn Community Project (http://research.ncl.ac.uk/haltwhistleburn/) for providing pictures of the lattice structure.

Executive Summary

RESEARCH QUESTION

- What information is available on the passage of fish at wooden obstacles in small streams?
- Using that information, produce good practice guidelines for the use of wood in small streams, for the purpose of flood management, to minimise the impact on fish movement.

MAIN FINDINGS

- Wood used in rivers for flood management, is considered a positive step towards managing the movement of water in river systems.
- The use of in-stream woody placements has the potential to impact fish movements.
- The physical characteristics of a woody placement that have the potential to affect fish include space underneath the structure, structure height, and sizes of the gaps within the structure.
- All fish species have the potential to be affected by the use of wooden structures, but salmonids, specifically salmon and trout are highlighted as species of most concern.
- There is a lack of field-observed and empirical information on the movements of fish in streams.
- The impact on fish movement will be minimal if the design details within this report are followed.
- Any wooden structure placed in a stream has the potential to move and to change the stream topography. Thus, the structural characteristics of the woody placement that permit fish passage must be monitored and maintained to ensure they do not change significantly, resulting in a structure that presents an impediment to fish passage.
- This report highlights a large gap in knowledge of fine scale temporospatial use of stream habitat by fish. Given the increasing importance of managing this habitat type, there is an urgent requirement to fill this knowledge gap.
- The findings within this report will enable organisations involved with the provision of sustainable flood management options, required under the Flood Risk Management (Scotland) Act 2009, to install in-stream woody placements that should not impede the migration of fish (in compliance with the Water Framework Directive).

BACKGROUND TO RESEARCH

In Scotland, the Flood Risk Management (Scotland) Act 2009 has established a legislative framework through which the management of flood risk will be achieved by the delivery of more sustainable options. The use of wood in rivers to attenuate river flow and alleviate flooding is one such option and is currently being used by various organisations, stakeholders and communities, working together to manage flood risk.

The addition of any structure to a watercourse has the potential to significantly affect the local fauna and flora. At present, the impact on fish populations of the addition of wood to rivers, for the purpose of flood management, is unknown.

RESEARCH UNDERTAKEN

This report provides a review and analysis of information on the passage by fish at wooden obstacles (woody placements), used for flood management, in Scotland. The report covers a series of placement types ranging from those permanently in the wetted stream channel, to those placed on side-bars which are wetted for a low proportion of the year. With an absence of ground tested data, theoretical information from river-barrier assessment tools combined with the output from an expert panel, provide guidelines for good practice for the use of flood management woody placements in small streams, which minimise the impact on fish passage.

This report should be used in conjunction with SEPA's Natural Flood Management Handbook, which details the wider requirements for the correct siting of woody placements.

The following steps summarise the fish specific assessment for woody placements:

» Identify potential site for woody placement following guidelines provided in SEPA's Natural Flood Management Handbook.

» Establish whether the site is utilised by fish. This includes sites that may only be used by fish for short periods of the year. No assumption should be made about impassable waterfalls, as there may be isolated populations of fish (e.g. resident brown trout) upstream. This information should be attained through discussion with local fisheries organisations, or through electrofishing studies if no information is available.

» If fish population present – follow guidelines.

» If fish population not present – woody placement design not restricted to facilitate fish passage.

Wooden placements have been categorised according to fish passage requirements and details about the physical characteristics, which would provide no, or a low, impediment to fish movement have been provided. The general categories for woody placements are:

Category A type placements

Simple timbers (branches removed) spanning the width of the stream. These structures are not hydraulically active under less than bankfull conditions.

Category B type placements

Complex timbers (branches retained) spanning the width of the stream. These structures are hydraulically active under most water flow conditions.

Category C type placements

Structures that do not span the width of the river. These structures may or may not be hydraulically active under less than bankfull conditions.

KEY WORDS
Natural Flood Management, Fish Migration, Woody Placement Design

Glossary of Terms

Bankfull conditions – a non-technical term describing a level of flow within a stream channel where the water is about to overtop the banks

Complex timber – a branch or tree with some or all of the branches retained

Downstream migration - the general (active or passive) movement downstream of fish usually, but not always, associated with specific stages of a species life history (e.g. downstream migration of salmon or trout smolts; downstream movement of silver eels)

Free passage – the unrestricted movement of fish to fulfil all essential elements of their life-cycle, such as growth and reproduction*

High flow – a non-technical term referring to river flows that are elevated from the average conditions, for that time of year

Hydraulic head/height – the difference in water level between either the water flowing over a structure, or the height of a structure (whichever is higher) to the top of the water level immediately below a structure (cf vertical height)

Hydraulics – the movement of water in a confined space

Hydraulically active – when a structure or part of that structure (woody placement or any other structure) engages with the water within a stream and changes local flow dynamics

Hydrology – the movement of water within a landscape in relation to environmental conditions (e.g. rainfall patterns)

Passability – a non-technical term describing the degree to which an in-river structure is passable by a fish species/life-stage

Simple timber – a branch or tree with all the branches removed such that the timber is similar to a post

Smolt – the life history stage of a juvenile salmon or trout when an individual becomes silver in appearance and migrates from freshwaters to the sea for the first time

Woody placement – an arrangement of wooden timbers used within and/or across the stream channel

Upstream migration – the active movement upstream of fish usually, but not always, associated with specific stages of a species life history (e.g. upstream migration of adult salmon or trout to spawning grounds; upstream movement of juvenile eels)

Vertical height – the physical height of a woody structure from its lowermost point to the highest point (cf hydraulic height)

*SEPA guidelines regarding engineering works within river systems "*The authorised activities should not prevent the free passage of migratory fish*" (http://www.sepa.org.uk/help/terms/) and within the NFM handbook, NFM "*structures should [also] be designed to permit fish passage*" (Forbes, et al., 2016). The definition of free passage for fish from the Water Framework Directive is found within the statement regarding the restoration of "high" and "good" ecological status of river continuity. "*The continuity of the river is not disturbed by anthropogenic activities and allows the undisturbed migration of aquatic organisms and sediment transport*" (European Commission, 2000).

Contents

1 Introduction

Emerging evidence from the UK shows an increase in the frequency of short duration heavy rain events. For example, Slingo and colleagues (2014) have shown that events comprising short duration heavy rain, which occurred with a frequency of 1 in 125 days in the 1960's and 1970's have increased to an event now more likely to occur at a frequency of 1 in 85 days. In Scotland, the amount of rain falling over 1-day, 2-day, 5-day and 10-day periods is also increasing (Jones, et al., 2013; Figure 1.1).

Ultimately these changes in rainfall, which are thought to be linked with global climate change patterns (Jones, et al., 2013), coupled with modern land management practices (which increase the conveyance of water over land into waterways) have resulted in rivers reaching flood conditions more frequently than has previously been the case.

Under the banner of Natural Flood Management (NFM), various measures have been introduced to catchments to slow the run-off of water into and within river systems. The creation of wetlands, raised bogs, woodland, online ponds and riverine buffer strips, the reconfiguration/re-meandering of river channels, and the re-introduction of wood into river systems are a few of the many NFM measures currently being used across the UK to alleviate flood waters (Forbes, et al., 2016).

In Scotland, the Flood Risk Management (Scotland) Act 2009 has established a legislative framework to manage flood risk via delivery of sustainable options. The Scottish Environment Protection Agency (SEPA) is required to work in partnership with local authorities and other responsible authorities "to identify the most sustainable actions to reduce flood risk, including natural flood management" (Forbes et al., 2016). One of the key requirements that the responsible authorities must take into consideration when carrying out sustainable flood risk management actions is to "act to secure compliance with the [Water Framework] Directive" (Greig, 2009). Flood risk management plans are being developed to highlight the hazards and risk of flooding from rivers, the sea, surface water, ground waters and reservoirs. The plans set out how organisations, stakeholders and communities will work together to manage flood risk. Within this framework, the woody placements detailed in this report are used in small streams to attenuate river flow and alleviate flooding. Further detail about flood risk management strategies can be found on the SEPA website (http://apps.sepa.org.uk/FRMStrategies/).

The free passage of migratory fish in river systems is a key requirement of the Water Framework Directive (WFD) (2000/60/EC). While this part of the Directive is generally aimed at large, man-made structures, the same moral philosophy should be applied to all structures placed in river systems to ensure ecological connectivity. However, reports on the various NFM projects currently underway across the UK provide little detail about the potential effects (theoretical or actual) NFM measures may have on the fish populations in river systems. In addition, guidance regarding minimising the impact on fish when using NFM measures is scant.

SEPA have developed a series of steps to ensure the correct siting of NFM measures within the landscape (Figure 1.2; Forbes et al., 2016). The steps focus on hydrological, land use and stakeholder engagement considerations. Viewed within this framework, the output from this report should be considered at Step 4 (Figure 1.2). Following from Step 3, the identification of opportunity areas (i.e. where NFM would be effective), Step 4, a Scoping Study should also include an assessment of the ecological criteria that should be considered when siting NFM (Table 1.1). While the focus of this report is on the use of woody placements, we recommend considering the local ecology when siting any form of NFM. One such ecological criteria would be an audit of the local fish species, as this has the potential to affect the choice of- and design of the woody placements used.

The purpose of this study is to investigate the potential effects of the use of woody placements, for NFM (wood used in rivers for other means, e.g. river restoration, is not considered in this report), in small streams on native riverine fish movements. This report does not detail any other advantages and/or disadvantages associated with the placements of wood in rivers in relation to vertebrates and invertebrates. In this review, woody placements refer to any wooden structure placed in-stream or on riverbanks, for the purpose of slowing river flow.

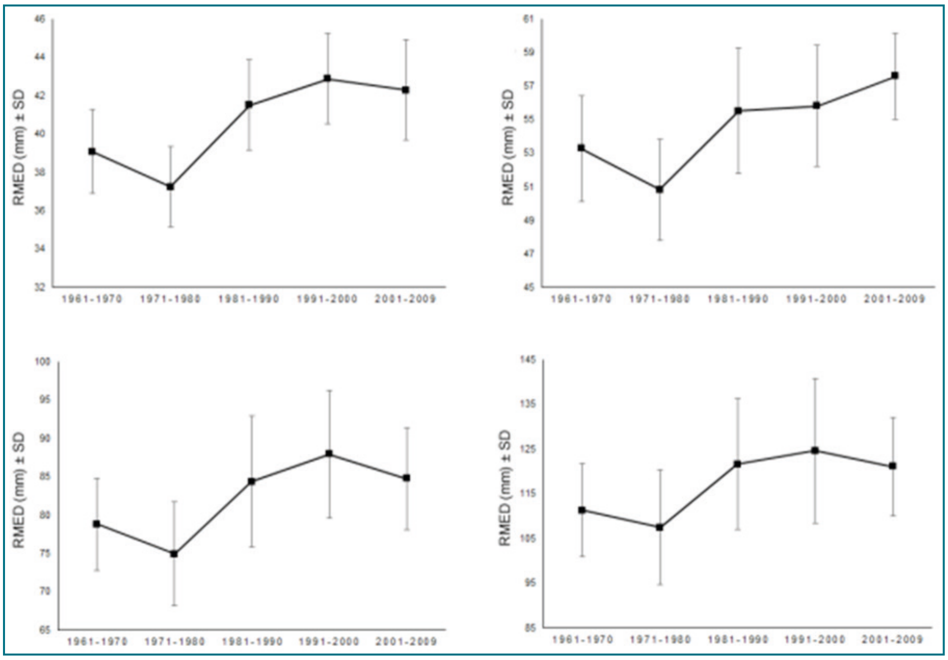


Figure 1.1: Increasing trends in the intensity of rainfall in Scotland (measured as RMED; RMED is defined as the median of annual maximum rainfalls (for a given duration) at a site) for (a) 1 day, (b) 2 day, (c) 5 day and, (d) 10 day durations from 1961 to 2009. Data adapted from Table 2 in Jones et al. (2013).

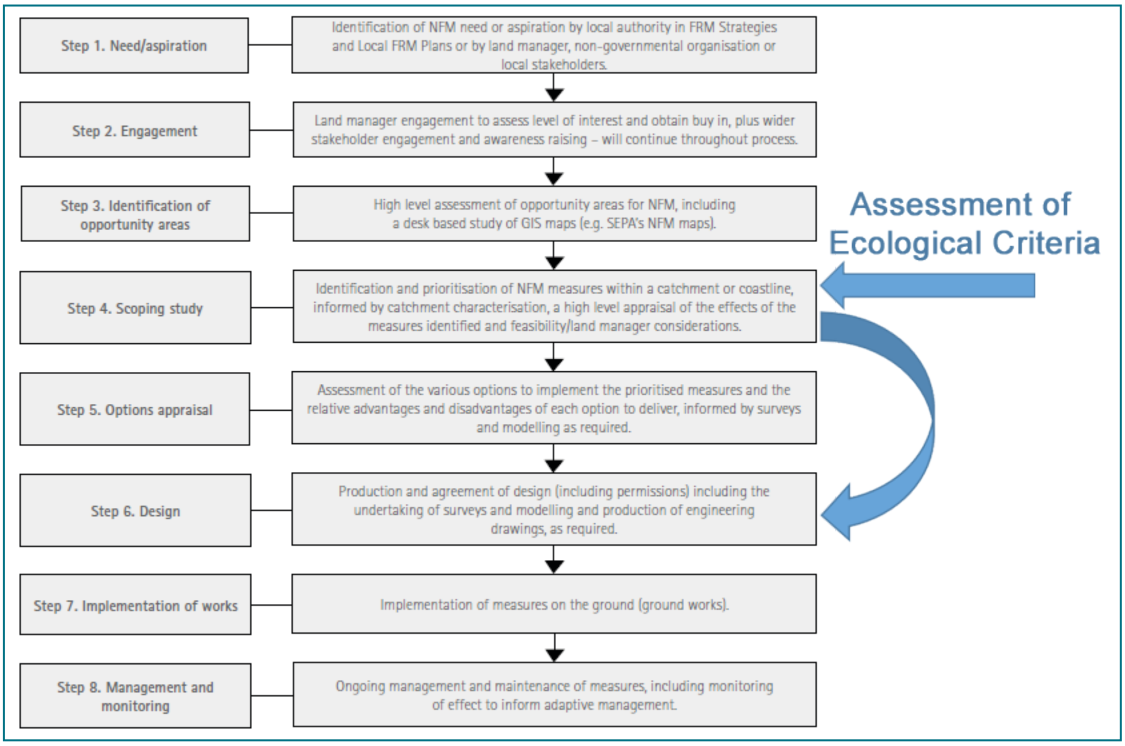


Figure 1.2: The key steps involved in implementing Natural Flood Management as detailed by SEPA (Forbes et al., 2016) and where this report and the report output sits within this framework

This report provides those responsible for the installation of NFM structures with information and guidance to install structures that do not present a significant impediment to the movement of riverine fish species. The report highlights the different designs of wooden structures available (Section 2); the current state of knowledge on the movement of fish in-stream (Section 3, 4 & 5); guidance on what form the physical structure of the woody placements should take (Section 6); and the required research to improve the design of woody placements used for flood management (Section 7).

1.1 Regulatory controls over activities

The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (commonly known as the Controlled Activity Regulations or CAR) applies regulatory controls over activities that may impact on Scotland's water environment. The regulations cover rivers, lochs, transitional waters (estuaries), coastal waters, ground water, and ground water dependant wetlands.

At the time of publication (October 2016) guidelines for the use of woody placements were as follows:

Generally small scale projects which include installation of structures that clearly mimic natural fallen wood should not require SEPA permission. Such projects would be expected to use only a few pieces of fallen natural wood that remain 'leaky' to flows, sediment transport and fish passage and produce only localised changes in flow patterns. Projects of this nature with site specific sensitivities (e.g. conservation status) may require a permission.

Larger projects, such as those intended to build 'formal' structures to impound water, line an entire bank, or deliberately change channel form (e.g. using logs, planks or heavily pinned-and secured elements) might require authorisation depending upon location and impact risk, particularly if they substantially influence river processes. In most cases, a simple licence would be required to authorise such projects (Forbes, H., SEPA, pers comm.)

Practitioners should contact their local SEPA Office for further information.

1.2 Assessment of ecological criteria

Fresh waters are hotspots of biological diversity, and have been highlighted as being under significant threat (more so than marine and terrestrial ecosystems) from increasing human activity (Dudgeon et al., 2006). Globally, fresh water habitats cover only 1% of the Earth's surface, but support up to 10% of global species diversity (Strayer & Dudgeon, 2010). In Scotland, the Scottish Biodiversity List (SBL; available through: http://www.biodiversityscotland.gov.uk/) brings together European, UK and Scottish legislation and conventions to detail "a list of animals, plants and habitats that Scottish Ministers consider to be of principal importance for biodiversity conservation in Scotland". For detail about the process involved in generating the SBL and where it fits within Scottish legislation please refer to Hooker et al. (2015).

The riverine fish species detailed in Table 1.1 are those that are native to our rivers. Information regarding the local distribution of these fish should be sought through direct surveys or local conservation groups (e.g. Fisheries Trusts) as the presence of some species has the potential to limit the type and structural dimensions of the woody placement installed (Section 6). In general, Local Biodiversity Action Plans (LBAPs) underrepresent the presence of fish species (Hooker et al., 2015) and thus should only form part of the process to identify the presence of species.

It should be noted that some fish species may only use streams for a proportion of their life cycle, and thus the results of surveys must take this into account. For example, streams of only a few metres width may support populations of trout alevin and fry (the very early stages of juvenile trout life cycle) in the spring and early summer (Anon, 2012). As these fish grow they move into larger streams, meaning a survey undertaken in autumn may not register the presence of fish. Accessing local knowledge is thus key to revealing a true picture of the local fish community in an area of interest for siting NFM measures.

Table 1.1 Conservation status in a Scottish (SBL) and global (IUCN) context for native riverine fish found in Scotland.

Common Name	Scientific Name	Included in SBL	IUCN status*
River Lamprey	Lampetra fluviatilis	✓	LC
Brook lamprey	Lampetra planeri		LC
Sea lamprey	Petromyzon marinus	✓	LC
European eel	Anguilla anguilla	✓	CE
Common minnow	Phoxinus phoxinus		LC
Stoneloach	Barbatula barbatula		LC
Atlantic salmon	Salmon salar	✓	LR/LC
Brown/sea trout	Salmo trutta	✓	LC
Grayling¥	Thymallus thymallus		LC
Three-spined stickleback	Gasterosteus aculeatus		LC

* IUCN – International Union for Conservation of Nature, designations in increasing order of conservation requirement; LC – Least Concern, LR – Lower Risk, CE – Critically Endangered

¥ Grayling were introduced to Scotland in the 19th Century, but are considered native for the purpose of this report.

The following steps summarise the fish specific assessment of ecological criteria for the siting and design of woody placements:

- Identify potential site for woody placement following guidelines provided in SEPA's Natural Flood Management Handbook.
- Establish whether the site is utilised by fish. This includes sites that may only be used by fish for short periods of the year. No assumption should be made about impassable waterfalls, as there may be isolated populations of fish (e.g. resident brown trout) upstream. This information should be attained through discussion with local fisheries organisations, or through electrofishing studies if no information is available.
- If fish population **present** – follow guidelines.
- If fish population **not present** – woody placement design not restricted to facilitate fish passage.

In addition to fish species, consideration of the aquatic and semi-aquatic invertebrates and vertebrates found in streams should form part of the ecological assessment. This is beyond the scope of this report but details of invertebrates of conservation interest can be found on SBL (see Appendix). Two resources for invertebrate conservation are, in the Scottish context Macadam & Rotheray (2009) and UK context Bug Life (date unknown), and should be consulted.

Other semi-aquatic animals; water vole (Arvicola amphibious), Eurasian otter (Lutra lutra), common toad (Bufo bufo), natterjack toad (Epidalea calamita), great crested newts (Triturus cristatus) and the common kingfisher (Alcedo atthis) are listed in the SBL and their presence should be taken into consideration when siting NFM measures.

2 Woody Placements Used For Flood Management

The presence of wood in rivers has the potential to significantly alter local river morphology and ecology, and influence biota across a wide range of spatial and temporal scales (Harmon, et al., 1986; Gurnell et al., 1995; Gregory, et al., 2003). The addition of wood to rivers has shown positive associations with fish populations through; the creation of spawning and juvenile habitat (DuBois, et al., 2001), an increase in fish cover (Lehane, et al., 2002; Langford, et al., 2012), and enhancement of macroinvertebrate prey abundance (Hilderbrand, et al., 1997). However, the presence of wood in rivers can also have a differential effect (positive and negative) on a range of fish species and on different life stages of the same species. For example, in a study from the New Forest (South England, UK), Langford and colleagues (2012) observed that eels, lamprey and older trout exhibited a positive correlation with the presence of coarse woody material, while 0+ trout (Salmo trutta) and bullhead (Cottus gobio) showed a negative correlation. An increase in the density of older trout was observed in pools with coarse woody material present, compared with pools lacking coarse woody material. Knowledge about the local fish population is essential before any decisions are taken on the addition of any wooden structure to the riverine landscape (Langford et al., 2012).

2.1 Woody placements and fish passage: An organisation of current structural types

The design of woody placements for flood management ranges from an arrangement of logs mimicking natural processes (e.g. man-made log jams; Figure 2.1a), heavily engineered structures (e.g. timber bunds; Figure 2.1b) to hinged trees (Figure 2.1c) and grade control structures (Figure 2.1d). All of these structure types, to greater and lesser degrees, attenuate the discharge of water within the watercourse.

Figure 2.1: Array of structural woody placement types currently in use across the UK; (a) man-made log jam © Quinn et al., 2013; (b) timber bund © Nisbett et al., 2015; (c) hinged trees © WTT, wildtrout.org; (d) grade control placement © C. Adams

To facilitate an assessment of the use of woody placements on the passage of riverine fish, the placement designs are grouped according to the arrangement of timbers within the stream and the implications these designs may have for fish passage. Three general categories, described by Wallerstein & Thorne (1997), encapsulate the implications for fish passage for different woody placement formats: underflow jam, a swim barrier; dam jam, a swim/leap barrier and; deflector jam, a swim around barrier (Figure 2.2).

Applying the three categories described by Wallerstein and Thorne (1997), the different types of woody placements assessed in this review fall into three categories.

- **Category A type** placements span the river with timber that is placed from bank-to-bank. The placement is not in contact with the water for the majority of the time and does not become hydraulically active until river levels reach close to bankfull conditions.

  These placements are only active under very high flow / flood conditions (Figure 2.3). When these placements become hydraulically active, the implications for fish passage are similar to an underflow jam.

- **Category B** type placements span the river with timber that is placed from bank-to-bank. Some elements of the placement are always in contact with the water and are thus permanently hydraulically active. As water levels rise, more of the placement comes in to contact with the water and becomes hydraulically active (Figure 2.4). These placements have implications for fish passage similar to a dam jam.

- **Category C** type placements do not span the river. These placements vary in the degree to which they are in contact with the water ranging from permanently submerged to placements on sidebars of the river channel (Figure 2.5). As these placements do not span the river, the implications for fish passage are similar to a deflector jam.

It must be noted that the behaviour of all woody placements detailed will change under different flow conditions, for example, a simple underflow jam under very high flow conditions will overtop, changing passage implications to include passage possibilities of both swimming under and over the placement as well as leaping. Therefore, these categories are not fixed but do provide a useful starting point to (a) assess the implications for fish passage and (b) provide a framework of guidance for good practice.

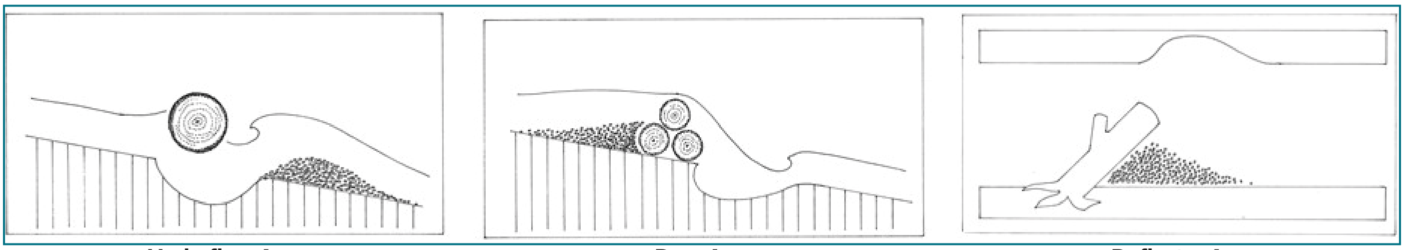


Figure 2.2: Generalised categories of wood in rivers (after Wallerstien & Thorne, 1997)

Figure 2.3: Examples of Category A type placements using simple timber logs (branches removed) arranged (a) with a low vertical height © S. Addy, (b) higher vertical height © Nisbett et al., 2015 and, (c) as a lattice type placement © E. Starkey.

Figure 2.4: Examples of Category B placements arranged (a) complex single timbers © Tweed Forum, (b) man-made log-jams © Quinn et al., 2013, (c) ditch barrier placement © Quinn et al., 2013, (d) grade-control placement © C. Adams and (e) watergate placement © Kravcík, et al., 2012.

Figure 2.5: Examples of Category C placements (a) sidebar woody placements © S. Addy and (b) hinging trees © WTT, wildtrout.org.

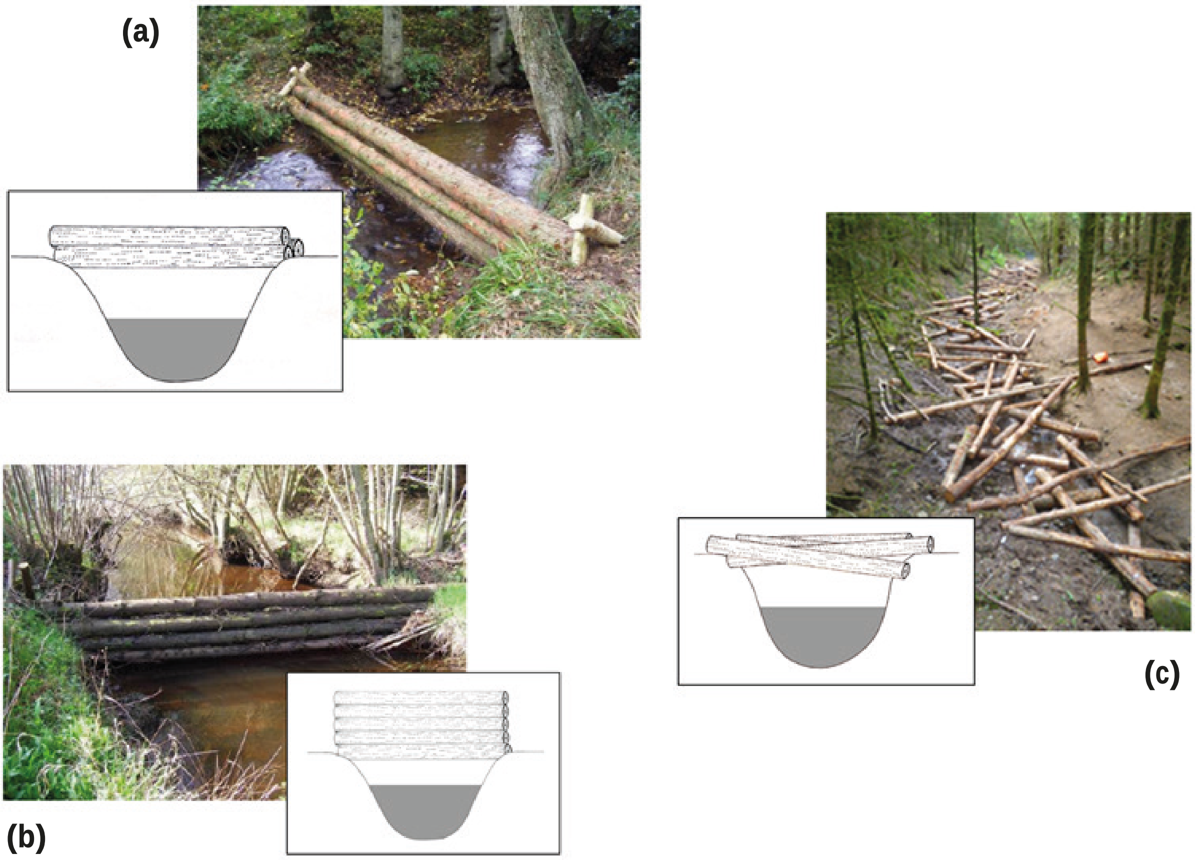


Figure 2.6: Examples of different types of Category A type placements. (a) simple timber with low vertical height © Nisbett et al., 2015 and schematic inset; (b) simple timber with high vertical stack height © Nisbett et al., 2015 and schematic inset; (c) lattice type placement © E. Starkey and schematic inset.

2.2 Category A Type Placements Detail

Arrangement of timbers:

- o Simple timber (branches removed) low relative vertical height
- o Simple timber (branches removed) high relative vertical height
- o Lattice type placement

Simple timber (low and high vertical height) and lattice type placements become hydraulically active when river levels reach close to bankfull level. When river levels are less than bankfull, river flow passes within the river channel unhindered (Figure 2.6).

Local flow conditions associated with Type A woody placements (i.e. those that are only hydraulically active when water levels reach close to bankfull conditions) will change as the water level in the stream increases towards flood conditions (Figure 2.7a). As water levels in the stream increase and the placement becomes hydraulically active, fish will experience conditions similar to those common to undershot sluices (Bull & Casas-Mulet, 2011; Figure 2.7b). The velocity of water passing under the placement increases as water levels behind the placement increase.

The vertical height of a structure is linked with the amount of water that can be retained before the structure overtops; a taller structure will retain a larger volume of water before overtopping compared with a structure with a lower vertical height.

As such, the vertical height of the structure has a significant effect on the velocity of the water passing underneath; a taller structure can retain a large volume of water thus the velocity of water passing underneath will be higher when compared with a structure with a lower vertical height.

2.3 Category B Type Placements Detail

Arrangement of timbers:

- o Complex single timbers (branches retained) placed bank-to-bank
- o Man-made log-jams
- o Watergate
- o Grade-control placements
- o Ditch barrier

Local flow conditions associated with Category B type placements (i.e. those that have structural characteristics that are always hydraulically active) are more complex than those associated with Category A type placements, reflecting increased structural complexity. Complex single timbers, man-made log-jams and watergate placements share characteristics that respond in similar ways when hydraulically active. This group of placements will be reviewed together; grade-control placements and ditch barrier placements will be reviewed in separate sections.

Complex single timbers, man-made log-jams and watergate placements

For complex timbers, man-made log-jams and watergate placements under less than bankfull conditions, some disruption in the river flow around the branches/timbers that are hydraulically active will occur (Figure 2.8a). As water levels increase, increasing the hydraulic head, flow will be forced under the placement and between the branches/timbers (Figure 2.8b), increasing water turbulence and creating pockets of relatively lower and higher velocity. The velocity of water passing under the placement increases with the increasing hydraulic head height. Relative to gaps, the vertical height of the placement influences the flow through the placement before the structure overtops (Figure 2.8c).

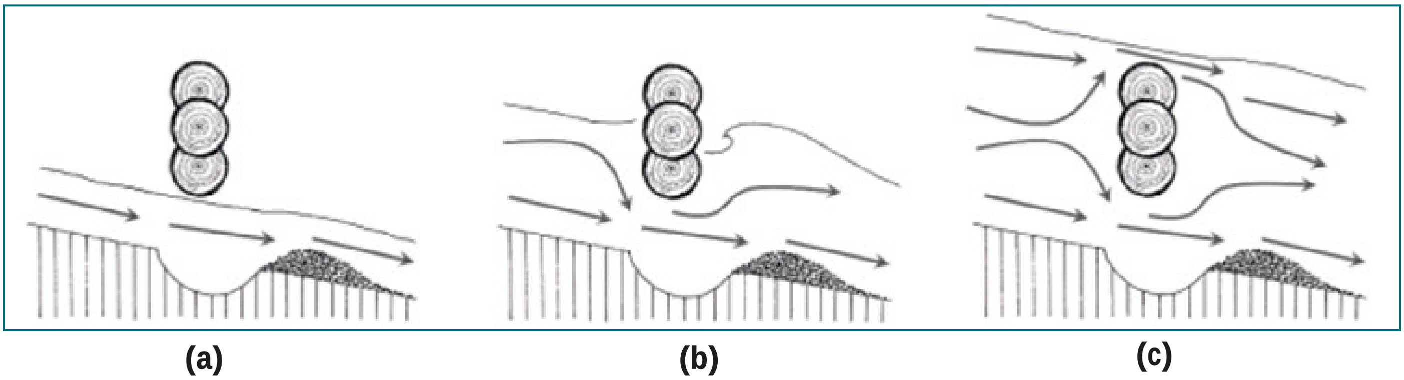


Figure 2.7: Cross-section view of Category A type placements showing the changes in flow conditions under (a) less than bankfull river levels, (b) over bankfull levels and, (c) very high river levels.

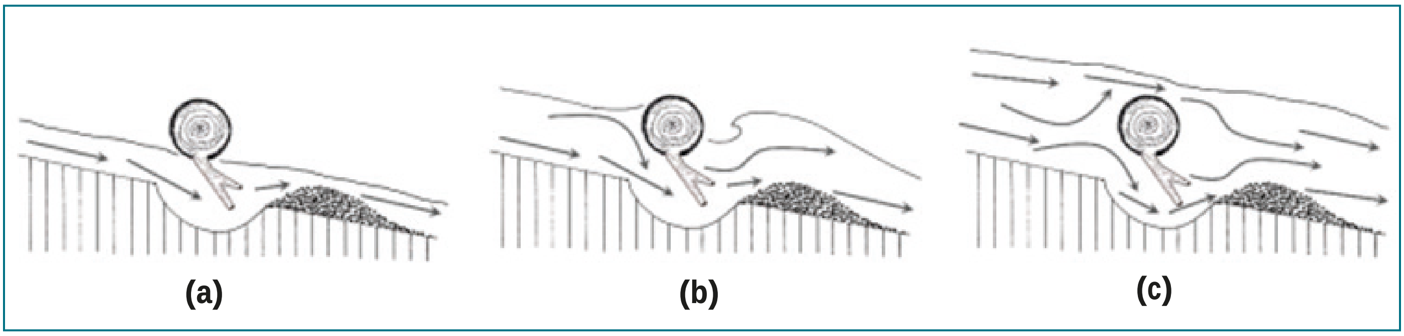
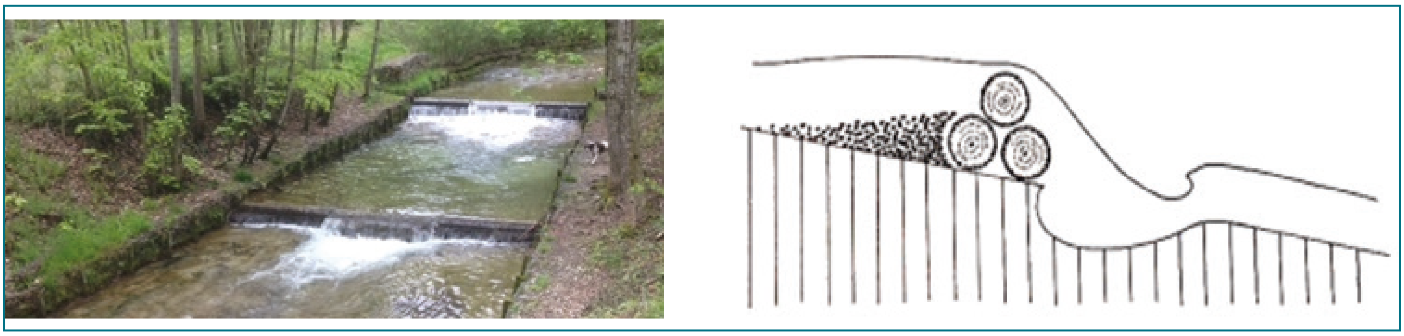


Figure 2.8: Cross-section view of Category B type placements showing the changes in flow conditions under (a) less than bankfull river levels, (b) over bankfull levels and, (c) very high river levels.

Grade-control placements

Grade-control placements (also known as "digger logs") are placed in river systems to help stabilise the riverbed, reduce sediment transport and control flow of water over the riverbed (Figure 2.9).

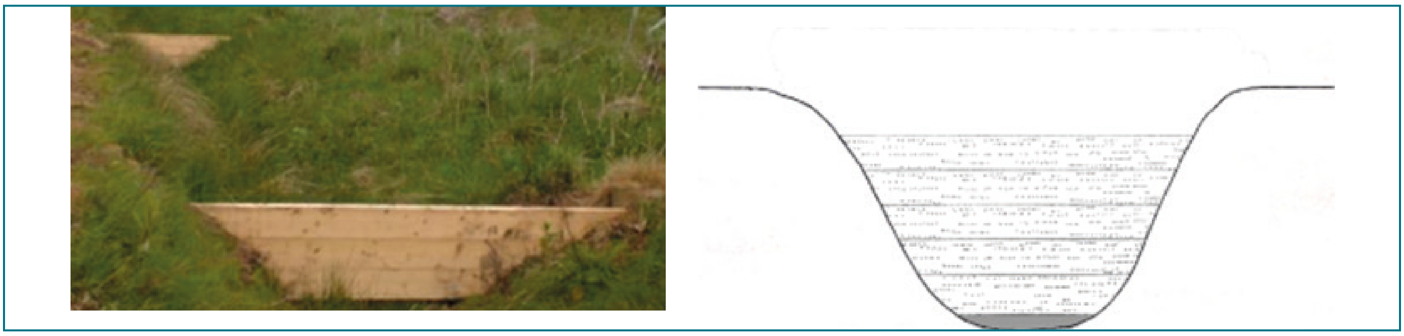


(a) (b)

Figure 2.9: (a) grade control placement © C. Adams (b) cross-sectional view.

Ditch barrier placements

Ditch barrier placements placed in channels virtually block the channel and slow the flow of water (Figure 2.10). These placements often have gaps under the lowermost timber or have notches cut into the lowermost timber to allow some movement of water.



(a) (b)

Figure 2.10: Ditch barrier placements (a) Belford project © Quinn et al., 2009 and (b) cross-section view.

2.4 Category C Type Placements Detail

Arrangement of timbers:

- Hinged trees
- Sidebar woody placements

Wood placed outside or above the wetted proportion of the river channel influences pool formation by directing patterns of scour at bankfull conditions (Dolloff & Warren, 2003). Hinged trees are created by making a cut into the base of a tree close to the riverbank, and hinging it into the channel. The hinged tree can then be trimmed and fixed in position (Figure 2.5b; details accessed from www.wildtrout.org/sites/default/files/library/Managing_Trees_Apr2012_WEB.pdf on 14-02-2016).

Sidebar woody placements involve placing large timbers on river sidebars (Figure 2.5a). Often these timbers are fixed in place to ensure they remain in the desired location after flood waters recede.

2.5 Definition of stream size for the purpose of this study

Stream size can be defined using a variety of measures (e.g. stream order, width, flow, depth) however, width is generally agreed to be the simplest and most easily measured. Six metres and less largely incorporates first and second order streams (Anon, 2012) and will represent an upper threshold for streams considered in this review; hereafter nominally referred to as "small streams".

This study will also include ephemeral streams, farm ditches and those streams that are not wetted for the full year, hereafter nominally referred to as "very small streams" and will cover steams of less than 1.5 metres width.

3 Fish Movements In Small Streams

Fish move continuously in rivers to fulfil essential elements of their life-cycle, such as growth and reproduction. Motivation for movement depends on environmental and physiological cues and movements can range from short distances or small scale daily movements to larger distance movements, occurring over months and years. Within this framework, movements in river systems can arise from basic survival strategies; food acquisition, predator avoidance, avoiding environmental extremes (temperature and flow extremes) and competitive interactions. Movements may be ontogenetic, that is occurring at a particular developmental period in the life of a fish. Thus habitat use within river systems can show temporal trends both seasonally and over longer periods of time.

For most species, the environmental conditions required for successful spawning differ from those required for growth. Distances travelled between habitats used at different life stages show enormous variation between species (compare the spawning migration of 1000s kilometres of the European eel, Anguilla anguilla, with a few metres of the minnow, Phoxinus phoxinus) and between individuals of the same species (Lucas & Bubb, 2005).

From what is known about fish movement and its relationship with river flow conditions, discharge appears to have a significant effect on initiating and sustaining a movement event in fishes. Recent advances in telemetry technology, specifically tag miniaturisation, has meant that tracking the movements of fish in rivers is an active area of study and is providing detailed information about the environmental conditions that correlate with fish movements. At present, information regarding fish movements is heavily weighted to studies on Atlantic salmon (Salmo salar) and brown trout (Salmo trutta).

The native fish fauna in small streams in Scotland comprises; Atlantic salmon, Salmo salar; brown/sea trout, S. trutta; European grayling, Thymallys thymallus; European eel, Anguilla anguilla; sea lamprey, Petromyzon marinus; river lamprey, Lampetra fluviatilis; brook lamprey, L. planeri; minnow, Phoxinus phoxinus; stoneloach, Barbatula barbatula; and three-spined stickleback, Gasterosteus aculeatus (Maitland, 2007). These species will be the focus of this review.

3.1 Salmon and trout

Motivation to move upstream appears to be correlated with a change in river discharge, rather than a specific river discharge, and is generally considered to be the major factor initiating upstream migration of salmonids (Alabaster, 1970; Jonsson, 1991; Thorstad et al., 2008). Evidence suggests that salmonids make upstream spawning migrations under flow conditions that are higher than the average at the time (Alabaster, 1970). However, much of the information detailing salmonid movement relates to movements within large, main stem river systems and, at present, comparatively little is known about the movements of fish in small streams.

Generally, the effects of increasing discharge are enhanced in smaller streams (Jensen et al., 1998) and it has been shown that once the magnitude of suitable flows is exceeded (which may be enhanced in smaller streams, through scaling effects), upstream migration may be retarded, stopped or even reversed, possibly due to increased energetic costs. Rivinoja and colleagues (2001) reported that adult salmon actually turned and migrated downstream when faced with excessive river flows over a riffle section.

As the spawning period approaches, the motivation for salmon to reach the spawning grounds appears to increase the frequency of upstream movements (Thorstad, et al., 1998). Higher discharge in smaller tributaries may assist salmon and sea trout to navigate natural instream obstacles, like waterfalls and shallow riffles (Laughton, 1991; Jensen et al., 1998; Solomon et al., 1999). Ekinaro and colleagues (1999) reported faster rates of passage through shallow riffle areas under elevated discharge.

Individual body size has also been shown as a factor that influences fish movement. Okland and colleagues (2001) reported that smaller salmon were delayed for less time than larger individuals crossing a riffle. However, the motivation to migrate to spawning habitats is strong, and Webb and Hawkins (1989) describe instances when adult salmon swam whilst turned on their side in order to ascend shallow areas with water depth of less than 0.10 metres.

Downstream migration is frequently reported as passive, however it has also been shown to include active swimming under lower river discharge conditions (Gauld et al., 2013). Reluctance of fish to progress downstream past river barriers has been documented (Haro et al., 1998; Jepsen, et al., 1998). Delays to migration can increase fish mortality; mortality of between 9% and 44% of tagged fish has been observed in downstream migrating sea trout smolts (Gauld et al., 2013). The success of downstream migration can have a correlation with migration speeds, with faster migrating fish generally showing a greater rate of successful migration (Chanseau & Lariner, 1999; Holbrook et al., 2011; Naughton et al., 2005).

In addition to the discharge conditions, habitat availability will likely affect the movements of salmonids in small streams. It has been suggested that Atlantic salmon entering small [spawning] tributaries may delay entry early in the season due to lack of holding areas (pools) (Webb, 1989). Species-specific differences in stream size utilisation occur. Observations from the River Tweed catchment (UK) have recorded Atlantic salmon using streams with a width of 2.5 metres and greater, while trout have been observed in streams of 0.8 metres width (Anon, 2012). Trout fry dominated streams of less than two metres, in the River Tweed (Anon, 2012).

3.2 Grayling

European grayling (Thymallus thymallus) have been observed making within river movements ranging from tens of metres to hundreds of kilometres (Parkinson et al., 1999; Meyer, 2001; Ovidio & Philippart, 2002; Nykänen et al., 2004; Ovidio et al., 2004, Lucas & Bubb, 2005) and individually, display a wide variability in movement distances within populations (Lucas & Bubb, 2005).

Grayling typically move from deep, slower flowing overwintering habitats to shallower, faster flowing spawning and summer habitats (Lucas & Bubb, 2005). Distances moved from overwintering to spawning and summer habitats varies between individuals, with some moving as little as between adjacent river sections (Lucas & Bubb, 2005). Distances moved within habitats exhibit seasonal differences, with significantly shorter daily movements and smaller ranges observed in summer when compared with autumn (Nykänen, et al., 2001). Movement is also correlated with river temperature and discharge conditions in autumn, with increased movement observed at higher temperatures and with lower river discharge (Nykänen, et al., 2001). In contrast, there is no relationship between temperature and discharge in summer months (Nykänen, et al., 2001). Juvenile grayling have been shown (experimentally) to rapidly seek shelter, instead of migrating downstream, to avoid unfavourable flow conditions (Valentin, et al., 1994).

Grayling also exhibit homing. In a tracking study from the River Rye, North Yorkshire, Lucas and Bubb (2005) recorded upstream and downstream movements of translocated grayling over weir systems. Individuals in the study showed some homing response towards the river section from which they were translocated and, homing success was stronger in adults compared with juveniles (although the difference was not significant).

3.3 European eel

European eel (Anguilla anguilla) are capable of exploiting almost all accessible aquatic habitats; combined with the 1000s of kilometres spawning migration from fresh water habitats to the Saragasso Sea. An extensive review of upstream migration and inland movements of anguillid eels has been presented by Feunteun and colleagues (Feunteun et al. 2003) and more recently by Matondo and Ovidio (2016). In general, juvenile eels migrate upstream steadily throughout the summer months. Despite not being able to leap, eels utilise shallow films of water and, when flowing across the correct substrate, enables them to surmount near vertical obstacles. However, their relatively poor swimming ability makes young eels susceptible to river barriers where local water velocities are too high to allow passage by swimming. The growth phase in fresh water can range to over 30 years and, once sufficient lipids (energy reserves) have been accumulated, eels will undergo a gradual morphological and physiological transition into migrant silver eels (Durif et al., 2005). Silvering is a process that all eels go through before beginning their spawning migration, initially downstream in rivers and ultimately across the North Atlantic to spawning grounds in the Sargasso.

The downstream migration for eels is challenging, with survival rates heavily impacted by dams, weirs, hydropower stations and pumping stations. Several studies have revealed the impacts of hydropower impoundment and fisheries on riverine survival of migrating silver eels (Winter et al., 2006; Travade et al., 2010). Downstream migration speeds have been observed as ranging from 0.01 metres per second to 1 metre per second, equating to a distance travelled ranging from two to 88 kilometres per day, in the River Foyle (Ireland/Northern Ireland; Barry, 2015).

3.4 Lamprey species

There are three species of lamprey in Britain; sea lamprey (Petromyzon marinus), river lamprey (Lampetra fluviatilis), and brook lamprey (Lampetra planeri).

Of the three species, the brook lamprey is likely to migrate the least, remaining within fresh water throughout its life cycle. However, some instream movement does occur, with mature lamprey required to move between their juvenile rearing grounds in sandy silt habitats, to the suitable spawning grounds of clean oxygenated gravel (Maitland, 2003). Many brook lamprey populations migrate less than two kilometres and do so in a short three to four week period prior to spawning (Hardisty, 1944; Malmqvist, 1980b). Some populations with movements of up to five kilometres have been observed (Hume, 2011). The spawning migration generally occurs in the spring prior to spawning and begins once water temperature reaches 10 to 11oC (Maitland, 2003).

Sea and river lamprey are both anadromous, growing to maturity in estuaries (river lamprey) and marine environments (sea lamprey). Both species move into fresh water and migrate upstream to spawn. As such, their migrations between rearing and spawning grounds are much greater. In the River Ouse (UK), Gaudron and Lucas (2006) observed movement distances of 40 to 110 kilometres.

Prior to spawning, river lamprey migrate into fresh water between October and December. The spawning migration for sea lamprey generally occurs in April and May with spawning occurring between May and June.

Unlike salmonids, lampreys are not capable of leaping over migration obstacles and have a limited burst swimming ability (Russon & Kemp, 2011). Although some lamprey species, such as the pacific lamprey Entosphenus tridentatus, have the ability to climb steep, smooth surfaces, the majority of lamprey species do not exhibit this behaviour, instead they employ a combination of short bursts of swimming followed by resting behaviour during which they attach to the substrate via their oral disc (Tummers et al 2016, Kemp et al 2011, Russon and Kemp 2011).

Following spawning and a short incubation period for the eggs within the substrate, the juveniles (ammocoetes) are washed downstream by the current to areas of sandy silt in still water where they burrow and feed (Maitland, 2003). Although the newly hatched ammocoetes can swim short distances (Eneqvist, 1938) their migration downstream is generally passive (Maitland, 2003). All adult lampreys die after spawning and thus no adult downstream migration occurs.

3.5 Minnow

The minnow (Phoxinus phoxinus) is found in a range of cold, well-oxygenated habitats including streams and rivers. Minnow overwinter in coarse substrate or within deep pools with little current. In the UK, spawning occurs in late May where adults move onto clean oxygenated shallow gravels (Kottelat & Freyhof, 2007, Froese & Pauly, 2010).

Little information is known about the instream movements of the minnow. Holthe (2005) reported a maximum registered leaping height of 27 centimetres. The same study measured a maximum sustained swimming speed of 10.4 (± 4.0) centimetres per second for fish of 50 to 64 millimetre lengths and 16.0 (± 5.6) centimetres per second for fish of 80 to 105 millimetres in length. Holthe also found fish in the largest class (80 – 105mm) were capable of sustaining a swim speed of 34 centimetres per second for over 25 minutes (Holthe et al, 2009). This indicates the minnow is capable of moving upstream through relatively fast discharge and across relatively high obstacles when motivated to do so. The capacity to move upstream is likely to be dependent on resting locations available to migrants, with the largest individuals having the greatest capacity for longer migrations (Holthe et al, 2009).

3.6 Three-spined stickleback

Three-spine stickleback (Gasterosteus aculeatus) adults may be found in coastal areas, estuaries and freshwater habitats (Froese & Pauly, 2010). Spawning occurs in fresh water with anadromous forms ascending streams to spawn in the spring (Taylor & McPhail, 1986). Observations (Taylor & McPhail, 1986) showed that fish from fresh water populations became fatigued more quickly than individuals from anadromous populations, in prolonged swimming tests. There are little empirical data on maximum burst or sustained swimming abilities. Given the plasticity in both physiology and morphology of the species (Spence et al, 2013), swimming abilities and movement is likely to vary considerably both within and between populations.

3.7 Stoneloach

The migratory needs of the stone loach (Barbatula barbatula) are poorly documented and information on the swimming speeds of stone loach is also lacking. A personal communication from S. Axford cited by Lucas and colleagues (1998) reports stone loach crossing a weir however, the dimensions and water velocities were not reported. Spawning takes place in the spring and, although spawning migrations are not documented, it would not be unreasonable to expect in-stream movement to occur, at least over short distances.

3.8 The attributes of fish that facilitate obstacle passage

The ability of a fish to overcome an obstacle largely depends on the swimming and leaping capabilities of the fish species / life stage, the hydraulic characteristics of the barrier and the local environmental conditions in the river (e.g. temperature, depth, velocity, turbulence). Swimming and leaping capabilities are related to the ecology of a species and its biomechanical morphology.

Fish swimming falls along a continuum from 'sustained' or 'cruising' speeds to 'burst' swimming speeds (Beach, 1984; Peake et al., 1997). Sustained swimming is defined as relatively slow, constant activity that can be maintained, without fatigue, for at least 200 minutes (Beamish, 1978). Burst swimming allows a fish to attain relatively high swimming speed for very short periods of time (seconds) (Beamish, 1978). Prolonged swimming covers swimming speeds between 'sustained' and 'burst', which can be maintained for several minutes but will result in fatigue over time. Different swimming speeds require the use of different muscle groups (Videler, 2003). White muscle, which can function in the absence of oxygen, is employed during periods of 'burst' swimming and dark or red muscle, which functions in the presence of oxygen, is employed for slower 'sustained' swimming (Beach, 1984). Therefore, the composition and arrangement of muscle, which differs between species, has a significant influence on swimming capabilities.

The relationship between a fish's physical attributes (e.g. species, length and condition) and its swimming capabilities has been modelled by several authors (e.g. Wardle, 1975, Beach, 1984, Videler, 2003; Castro-Santos & Haro, 2005) and provides some information about maximum swimming speeds and swimming endurance. Values generated from these models have been used to determine the physical characteristics of in-river barriers that provide passage opportunities for a range of fish species and sizes (e.g. Bull & Casas-Mulet, 2011; Baudoin, et al., 2014).

A few fish species, such as Atlantic salmon, trout and grayling, can take advantage of their leaping ability to clear obstacles. Some species of Cyprinidae are capable of jumping, but this behaviour is highly infrequent (Baudoin, et al., 2015). As with swimming capabilities, the leaping capabilities for some Salmonidae have been modelled (Powers & Osborne, 1985; Videler, 2003) and provide information about the theoretical heights of in-river structures that can be passed by different sizes of some fish species (e.g. Bull & Casas-Mulet, 2011; Baudoin, et al., 2014).

Standing waves have also been shown to affect the success of fish passage. A 'standing wave' or 'free-standing wave' feature is formed by the return of entrained air within water to the surface, having been previously forced downwards by an increased flow or drop in relative height. Such wave features take many different forms and sizes depending on the local hydraulic conditions. All standing waves exhibit a localised increased in water height, some waves exhibiting obvious crests with others less turbulent and smoother. Standing waves may present an obstacle to fish passage through disorientation, excessive turbulence and local velocities, which may exceed swimming ability of the species of concern. However, under specific circumstances, standing waves may also aid fish passage (Stuart, 1963; Hilliard, 1983), though only when very specific, sometimes engineered (e.g. Hilliard, 1983) standing waves appear. Stuart (1962) concludes that the distance to the standing wave from the obstacle influences the success of the leap. Due to the amount of variation within and across waves, each should be assessed individually, to determine its effect on fish passage.

To facilitate barrier passage, a fish must exert effort in the form of swimming and, depending on barrier structure, leaping. It is therefore important that there are areas of slow flow immediately downstream of any obstacle to provide opportunities for resting, "to provide the fish with the means to prepare the effort" (Baudoin, et al., 2014), and to facilitate leaping.

4 Literature Review

A review of the grey and peer-reviewed literature revealed a lack of information (theoretical and actual) regarding the movement of fish in streams relative to the types of woody placements detailed in this review. There is a relatively voluminous literature regarding fish passage and beaver dams (see Kemp et al., 2010 & Beaver Salmonid Working Group (2015) and references therein), where passage success is frequently inferred through the presence of juveniles of migratory species upstream of the structure under review. However, little useable information about the characteristics of the fish and the dam structure that have facilitated successful passage is available.

One useful source of information regarding the characteristics of an in-river structure and the characteristics of the fish that facilitate passage has been from the development of river barrier assessment tools.

4.1 Barrier Assessment Tools

Over the last fifteen years, tools have been developed to assess the degree to which various man-made obstacles present an impediment to fish movements in rivers (e.g. Baudoin et al., 2014; Bull & Casas-Mulet, 2011; James & Joy, 2008; WDFW, 2000). By using known or modelled, swimming and leaping capabilities of fish species in concert with details about the physical characteristics of the obstacle being assessed, a measurement of an obstacle's passability can be made.

Assessments commonly score a suite of obstacle characteristics (e.g. hydraulic head, effective pool depth, gap dimensions, etc.) according to their passability for different life history stages of a series of riverine fish species. The passability of different obstacle characteristics are generally rated from "no/low impediment" to "complete barrier", however slight differences between assessment tools exist. By using information about obstacle characteristics that present no/low impediment to movement, it is possible to characterise the hydraulically active components of in-stream woody placements such that they present little to no impact on fish movements in river systems.

To provide this information for in-stream woody placements used in a Scottish context, the assessment tools were required to provide both information covering obstacle characteristics akin to those found in in-stream woody placements (notably log jams, undershot sluices and underflows) and for an appropriate panel for fish species. Of the various assessment tools available, two met this requirement; the SNIFFER barrier assessment tool from the UK (Bull & Casas-Mulet, 2011; Kemp et al., 2008) and the ONEMA ICE protocol for ecological continuity from France (Baudoin et al., 2014).

From these two assessment tools, no/low impact was defined as:

"The obstacle does not represent a significant impediment to the target species/life-stage, or species guild, and the majority of the population will pass during the majority of the period of migration (movement). This does not mean that the obstacle poses no costs in terms of delay, e.g. increased energetics, or that all fish will be able to pass" in the SNIFFER Barrier Assessment Tool (Bull & Casas-Mulet, 2011)

and as:

"The barrier is not a significant obstacle to the migration of the species/stages of the given species group. Most of the population can overcome the obstacle within a short time span and without injury. However, that does not mean that the obstacle does not cause delays in migration or that all fish in the given group can overcome it without injury" in the ONEMA ICE protocol (Baudoin et al., 2014).

Information about the physical dimensions of hydraulically active components (e.g. structure height, gap size), which represent "no/low impediment" have been applied to the analogous characteristics in woody placements. Applying the precautionary principle, the most conservative physical dimension for each appropriate component from the two assessment tools is used as an absolute minimum size benchmark.

4.2 Caveats and limitations

The information regarding the physical dimensions (e.g. heights, depths, gap sizes, etc.) detailed in Barrier Assessment Tools, which permit the free passage of fish, represents the best available information at the time of writing. The information in these reports is based on modelled information, published literature and expert opinion. To date, no adequate empirical testing of the information with well-designed field or mesocosm experiments has been undertaken. For example, a gap size of 50cm diameter to permit the passage of an adult salmon may seem excessively large, but this must be considered in relation to the possible water velocities that may be experienced through this gap by any upstream migrating individual, which, under high flow conditions, could be considerable. The purpose of these, what can appear conservative, sizes is to ensure that fish passage is unimpeded in line with the requirements of the Water Framework Directive. For example, even though some fish may be able to fit through smaller gaps (e.g. Guiny et al., 2003), this does not equate to 'free' movement as required by legislation.

5 Expert Panel Workshop

Given the lack of appropriate information about the movements of fish available in the literature and to extend the information gleaned from the barrier assessment tools, the Delphi technique was applied to access the knowledge base available from the Scottish Fishery Trusts, Scottish District Salmon Fishery Boards, and academic and industry personnel.

The Delphi technique, largely developed in the 1960s by Dalkey and Helmer (1963), is designed as a group communication process, taking advantage of real-world knowledge solicited from experts within a specific area. This process is particularly suitable for addressing multifaceted issues, especially when information is limited (Mukherjee et al., 2015). The Delphi technique is an established method in a range of disciplines such as medicine (Sinha et al., 2011), nursing (Hasson et al., 2000), social policy (Adler & Ziglio, 1996), tourism (Donohoe & Needham, 2009) and sustainability science (Hugé et al., 2010).

In ecology, this technique has been applied to a range of issues, including horizon scanning for invasive species, prioritising restoration efforts, and predicting ecological impacts of climate change (Mukherjee, et al., 2015).

The Delphi technique was applied in the form of a workshop held on 12th April 2016. The workshop split into two sessions, the first involved a series of talks to "set the scene" on the use of the wood in rivers for flood management as well as detailing the state of current knowledge on fish movements in small rivers (see Appendix for details of the talks presented). The second session was a practical exercise where meeting attendees were invited to discuss fish passage for a series of placement types in a structured and replicated assessment session.

5.1 Attendees

Twenty-two people covering a wide range of organisations with freshwater science and fisheries ecology expertise attended the workshop (see Appendix for details). While the range of fish ecology/management experience was weighted to the salmonids, expert knowledge of all fish species was covered within the panel and groups were organised such that each group had knowledge of all species under review. Of the attendees, 32% had experience of the use of wood in rivers, mostly in relation to increasing ecological diversity.

5.2 Practical exercise

In three teams, meeting attendees were presented with pictures and a set of schematics for a series of woody placement types (Table 4.1). Attendees were asked to discuss the implications placements may have for up- and downstream migration and within river movements for a suite of fish species and life-history stages (Table 4.1) in "small streams" and "very small streams". The pictures and schematics provided an indication of how each placement type would function under three stream conditions; less than bankfull, bankfull and over bankfull (see Appendix). Each placement type was examined separately and team members were encouraged to discuss both fish passage and, monitoring and management of the placement. The assumptions of the discussions were that (a) fish passage assessment was based on the placement in perfect working condition, (b) fish can arrive at the placement, and (c) structural engineering is appropriate, i.e. the placement is "made well". Team leaders recorded the details of the discussions.

On conclusion of the workshop, details from the discussions were interrogated for information and suggestions. These covered: a) the impact each placement type may have on the movement of the series of species and life-history stages; b) how to improve structural design for fish movements, c) management and monitoring of placements and general comments/concerns about the use of each placement type.

Placement types assessed	**Category A type placements** 1. simple (branches removed) timber with low relative vertical height 2. simple timbers with high relative vertical height 3. lattice placement **Category B type placements** 4. complex (branches retained) single timber 5. man-made log-jam 6. watergate placement 7. ditch barrier 8. grade-control placement **Category C type placements** 9. sidebar large woody placements 10. hinging trees
Life-history stage and fish species assessed	**Upstream migration/movement** • adult salmon • adult sea trout • adult brown trout • adult grayling • adult eel • elver • adult lamprey **Downstream migration/movement** • adult salmon • adult sea trout • adult brown trout • adult grayling • salmon and sea trout smolts • adult eel • adult lamprey **General within stream movements** • all of the above • minnow • stoneloach • stickleback

6 Recommendations For Woody Placement Design

Information from the barrier assessment tools regarding the physical characteristics of woody placement design that should not impede fish passage are combined with recommendations/suggestions from the expert panel workshop to provide good practice recommendations for the use of woody placements.

In the following section, monitoring and management specifically refers to the monitoring of the physical structure of the woody placement and the stream channel into which it has been placed. Management of the woody placement will involve correcting any structural change and removing debris build-up that would decrease fish passability.

6.1 General comments from the expert panel

There were four consistent conclusions drawn from the expert panel

- o Monitoring must be adapted for each placement type and reflect local hydrological and environmental conditions at each site
  - At a minimum, monitoring and management of a placement must be made after every flood event and before migration periods of species of concern
- o Management of woody placements were a key concern
- o Salmon and trout are most likely to be affected by the use of woody placements
- o European eel and lamprey species are likely to be affected by certain types of woody placements

Opinion regarding the use of wood placements in small streams was generally, very positive. The overarching general concern, consistently and vigorously expressed by the expert panel, was the requirement for robust and effective monitoring and management of the physical integrity of the structure for all types of woody placements, to ensure fish passage is unaffected. The expert panel highlighted problems with placing fixed structures into dynamic systems; all placements would eventually degrade, with rates of degradation being site specific. Monitoring and management of woody placements would thus need to be variable and adaptive.

As each placement responds differently to local environmental conditions, no definitive, general rules for monitoring and management can be defined. As such, the recommendations and considerations provided for each placement type must be considered against the background of local hydrological conditions to be taken into account when setting up a monitoring and management programme.

With increasing structural complexity (e.g. simple timber cf man-made log-jam), the investment in monitoring and management will likely increase, due to the increasing likelihood of debris entrainment and local scouring and deposition. In addition, fixing a structure in a dynamic system will result in changes to local hydromorphology through scouring of the river banks and river channel, and changes in the deposition of sediment and debris. The amount of sediment and debris retained by a structure is also correlated with upstream land characteristics, river bed mobility and the age of a structure (Beckman & Wohl, 2014).

Of all species considered during the discussions, up- and downstream migrating salmon and sea trout were highlighted as the species' most likely to be adversely affected by woody placements. Lamprey species will also be adversely affected by increasing water velocities found at some placement types under high/flood flow conditions.

There was consensus that there was little difference between small (1.5m to 6m width) and very small (less than 1.5m width) streams, but that there is a remarkable lack of knowledge about the use of very small streams by fish, thus more information is required. Information about the passage of structures by lamprey species and European eel was also highlighted as knowledge deficient.

6.2 Types of wood used for placements

Local environmental conditions (e.g. air and water temperature, exposure to sunlight, humidity and the frequency of wetting) will vary from site to site and all have the potential to affect the longevity of a structure. The type of wood used for the structure will also significantly affect its longevity (Dolloff & Warren, 2003). Softwoods generally decay faster than hard woods, but hemlock, Tusga spp., for example has high levels of tannins that increase resistant to decay (Dolloff & Warren, 2003). Wood that is permanently wetted will not decay as quickly as wood that alternates between being wet and dry (Dolloff & Warren, 2003).

The expert panel identified the branching structure of the tree species as an important consideration. For example, for complex single timber woody placements (where branches are hydraulically active; Category B type) the branching pattern of the tree species has the potential to affect fish passage. Spruce type species (Picea spp.) have highly dense branching patterns compared to broadleaf species (e.g. oak (Quercus spp.)). This should be considered against the background of locally available timber, as branches can be trimmed to meet specifications on site.

Wood treated with chemical preservative should not be used for the construction of woody placements that are or will be hydraulically active due to the leaching of chemicals into the watercourse.

6.3 Category A type woody placements

Information from the barrier assessment tools identified two physical characteristics of the Category A type woody placements that must be considered in relation to the fish fauna present:

1. The distance between the riverbed and the lowest point of the placement and,
2. The vertical height of the placement (Figure 6.1; Table 6.1).

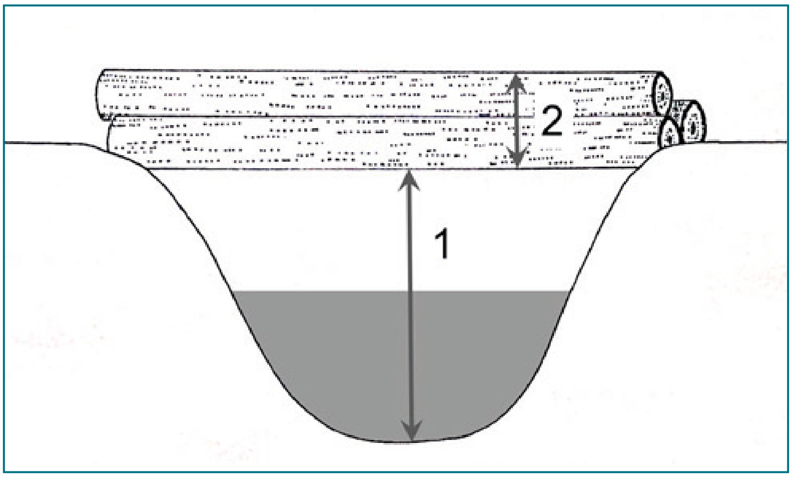


Figure 6.1: In-river view schematic of Category A type placements detailing the two physical attributes to be considered with respect to the fish fauna present at a site (1) the minimum distance between the bed of the river and the bottom of the woody placement and, (2) the vertical height of the placement

Table 6.1: Details of the distances for characteristic 1 (between riverbed and base of placement), characteristic 2 (vertical height of placement) and characteristics 3 (gap size). See Figure 6.1 & 6.4 for detail. Characteristics given in metres. Characteristic 1 & 3 derived from Bull & Casas-Mulet (2011) and Characteristic 2 derived from Baudoin et al. (2014).

Species	Characteristic 1 Minimum distance between lowermost timber and stream bed (m)	Characteristic 2 Maximum vertical height of the placement (m)	Characteristic 3 Minimum diameter of gap size within placement (m)
Adult salmon	0.60	1.00	0.50
Adult sea trout	0.60	1.00	0.50
Adult trout	0.60	1.00	0.30
Sea lamprey	0.60	0.60	0.15
Adult grayling	0.60	0.45	0.30
River/Brook lamprey [1]	0.50	0.10	0.15
Stoneloach	0.50	0.10	0.20
Eel [2]	0.50	0.10	0.20
Three spined stickleback	0.50	0.05	0.20
Minnow	0.50	0.05	0.20

[1] Due to difficulties surrounding identification of brook and river lamprey the values for these species have been combined

[2] The values indicated for eels correspond to passability accounting for only swimming ability and does not account for crawling

The expert panel highlighted the use of simple timber placements (low or high vertical height) in series has the potential to have an increased negative effect on fish passage and that the serial negative effect would likely become more severe as the height of the placements increased. Theoretical modelling of the effects of small (~0.50m hydraulic head) bridge footings in series, have been shown to delay the arrival time of adult salmon to spawning grounds by several months (Bryce, 2012). Information about effects of woody placements in series on fish passage was highlighted as knowledge deficient.

6.3.1 Management considerations for Category A woody placements

The build-up of debris behind Category A type placements has the potential to change its functioning. For example, the build-up of debris behind a simple timber with a low stack height has the potential to change it to something more akin to a grade-control placement (Figure 6.2), with the potential to be a barrier to fish through the lack of a pool immediately below the placement to facilitate leaping.

(a) **(b)**

Figure 6.2: (a) Simple timber with low vertical height © S. Addy and (b) build up of sediment behind timbers creating a 'stepped' stream profile, similar to the effect created by grade-control placements © S. Addy.

Figure 6.3 Detail of sediment build-up in lattice type woody placement © E. Starkey

Given the structural complexity, the management of sediment and debris build-up for lattice type placements requires significantly more effort than any of the other Category A type placements (Figure 6.3).

The expert panel highlighted the longitudinal length of the lattice placement as having a possible influence on fish passage.

The expert panel highlighted scouring around Category A placements (both under the placement affecting the riverbed and around the anchor points in the river bank) would be a key consideration for monitoring and management. The vertical height of the placement influences the volume of water retained and thus scouring of the river bed will likely become more severe with increasing vertical height.

The effects of scouring should be monitored to ensure that structural integrity is maintained. Structural checks will ensure that physical dimensions of characteristics are maintained in line with those detailed in Table 6.1, to ensure the placement remains passable by local fish fauna.

The expert panel raised concerns regarding the passage of downstream migrating salmon and sea trout smolts. The guidance from the barrier assessment tools for similar barrier types states that; "For downstream passage (assuming predominantly passive migration) the structure should have unimpeded flow under or over the entire structure, with low acceleration of water velocity under/over the structure and minimal turbulence" (Bull & Casas-Mulet, 2011).

6.3.2 Summary recommendations for Category A type woody placements

- Simple timber (branches removed) low relative vertical height
- Simple timber (branches removed) high relative vertical height
- Lattice type placement

Recommendations for Category A Woody Placement
Type: Simple timber (branches removed) low vertical height
(Figures 2.3a & 2.6a)

Structural requirements

- Must meet the minimum requirements detailed in Table 6.1
- Distance between the riverbed and the lowest point of the placement
- Vertical height of the placement

Expert panel highlighted species of most concern

- Salmon- spawning migration
- Trout (resident & migratory forms) – spawning migration
- Salmon & sea trout smolts

Overall conclusions from the expert panel

- Majority of the time no fish passage issues will result
- Placement will be hydraulically active during the upstream spawning migration of salmon and trout
- Sediment retention behind placement will change placement dynamics and has the potential to significantly alter the placement and thus has implications for fish passage (Figure 6.3).
- Monitoring and management of woody placement should be made after a flow event when the placement has been hydraulically active
- Monitoring and management of woody placement should be made before the migration period of species of most concern

Recommendations for Category A Woody Placement
Type: Simple timber (branches removed) high vertical height
(Figures 2.3b & 2.6b)

Structural requirements

- Must meet the minimum requirements detailed in Table 6.1
- Distance between the riverbed and the lowest point of the placement
- Vertical height of the placement

Expert panel highlighted species of most concern

- Salmon- spawning migration
- Trout (resident & migratory forms) – spawning migration
- Salmon & sea trout smolts
- European eel & lamprey species

Overall conclusions from the expert panel

- Majority of time will result in no fish passage issues
- Placement will likely be hydraulically active during the upstream spawning migration of salmon and trout
- With increasing height of the placement, under flood flows the water velocity will negatively affect passage for Europe an eel and lamprey species
- Placements with a high vertical height have the potential to cause additional negative effects on fish passage if more than one is used over a river section (i.e. placements with a high vertical height should not be used in series)
- Scouring under and around placement must be monitored
- Monitoring and management of woody placement should be made after a flow event when the placement has been hydraulically active
- Monitoring and management of woody placement should be made before the migration period of species of most concern

Recommendations for Category A Woody Placement
Type: Lattice type
(Figures 2.3c & 2.6d)

Structural requirements

- Must meet the minimum requirements detailed in Table 6.1
- Distance between the riverbed and the lowest point of the placement
- Vertical height of the placement

Expert panel highlighted species of most concern

- Salmon- spawning migration
- Trout (resident & migratory forms) – spawning migration
- Salmon & sea trout smolts

Overall conclusions from the expert panel

- Majority of time will result in no fish passage issues
- Placement will be hydraulically active during the upstream spawning migration of salmon and trout
- Placement will increase local flow heterogeneity and provide pockets of low water velocity for resting
- The management of sediment and debris-build up is a significant consideration (Figure 6.3).
- Monitoring and management of woody placement should be made after a flow event when the placement has been hydraulically active
- Monitoring and management of woody placement should be made before the migration period of species of most concern

6.4 Category B type woody placements

- o Complex single timbers (branches retained) placed bank-to-bank
- o Man-made log-jams
- o Watergate
- o Grade-control placements
- o Ditch barrier

For the complex single timber, man-made log jam and watergate type of Category B placements, three measurable characteristics of the physical design must be considered in relation to the fish fauna present.

1. The distance between the riverbed and the lowest point of the placement
2. The vertical height of the placement
3. The size of the gaps between branches/timbers (Figure 6.4; Table 6.1).

6.4.1 Complex single timber, man-made log jam & water gate types: Upstream passage

According to the barrier assessment tools, for upstream passage of fish past Category B type (complex timber, man-made log-jam and watergate) placements, characteristics 1 and 2 are identical to those for Category A type placements (Table 6.1). Gap sizes between branches/timbers (characteristics 3), must be greater than 0.50m for adult salmon and sea trout and greater than 0.30m for adult resident trout and adult grayling, 0.20m for European eel and cyprinids and 0.15 from lamprey species (Table 6.1; Bull & Casas-Mulet, 2011). If gap sizes are less than those detailed, the placement will only be passable by leaping species or by elvers and lamprey where suitable climbing material is available.

For complex timber placements, manamde log-jams and watergate placements which have within placement gap sizes smaller than those required to allow upstream passage, information regarding no/low impact passage criteria for overtopped sluices may be applied to ensure woody placements do not present a fish passage impediment. Placements with a hydraulic height of greater than 0.10m are not passable by juvenile salmonids or cyprinids and those with a height greater than 0.15m are impassable by adult lamprey (Table 6.2). For leaping species, adult salmon, adult trout and adult grayling, upstream passage is only achieved when the hydraulic head height is less than 0.60m, 0.40m and 0.20m respectively (Table 6.2). In addition to hydraulic head height, the presence of a pool immediately downstream of the placement must be present to facilitate leaping. The depth of the pool must be at least as deep as the hydraulic head (Table 6.2).

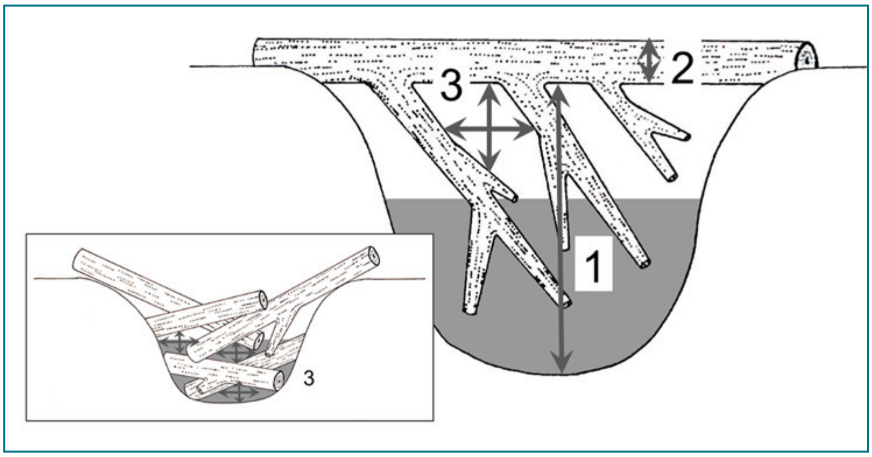


Figure 6.4: In-river view schematic of Category B type placements (complex timber, manmade log-jams and watergate types) detailing the three physical attributes to be considered with respect to the fish fauna present at a site. These include; (1) the minimum distance between the bed of the river and the bottom of the woody placement, (2) the vertical height of the placement and, (3) the size of the gap between branches/timbers in the placement. Inset image detailing characteristic 3 for man-made log-jams.

Criteria	AS	AT	AG	CP	JS	AL
Hydraulic head	≤ 0.60m	≤ 0.40m	≤ 0.20m	≤ 0.10m	≤ 0.10m	≤ 0.15m
Effective pool depth	pool depth ≥ hydraulic head			-	-	-
Effective resting locations for fish downstream	Present					
Lip and/or standing wave present	May be present but does not restrict fish passage					
Water turbulence associated with placement	Low					
Debris/sediment blockage	If present should not restrict fish passage					

Table 6.2: Upstream movement requirements for different species/guilds for log dams with within placement gap sizes less than those detailed as character 3 in table 6.2 (adapted from Bull & Casas-Mulet, 2011); AS=adult salmon; AT=adult trout; AG=adult grayling; CP=cyprinids; JS=juvenile salmonids; AL=adult lamprey.

6.4.2 Complex single timber, man-made log jam & water gate types: Downstream passage

According to the barrier assessment tools, the downstream injury rate should be at most "slight damage to salmonids migrating downstream". To achieve this, the physical characteristics of the woody placement should have a drop difference of the barrier less than 10 metres AND sufficient water depth in tailwater (at least 25% of the drop difference).

There should be no obstacles or other structures present that could damage fish (Kemp, et al., 2008), and the depth of the water flowing over the placement (depth at crest) should be greater than: 0.15m for adult salmon; 0.1m for adult trout, grayling and cyprinid species (Table 6.3); and 0.08m for juvenile salmonids (Table 6.3).

6.4.3 Grade-control placements

For grade control placements, it is the vertical height of the placement as a physical characteristic, which influences fish passage (Figure 6.5).
According to the barrier assessment tools, specifically from Baudoin et al. (2014), the maximum height of a step structure passable by adult salmon is 0.35m, for sea trout 0.20m, and for resident trout 0.10m. The maximum height for grade control placements for all species is detailed in Table 6.4.

6.4.4 Ditch barrier placements

The expert panel advised that these present a complete barrier to fish species and should only be used where there is evidence that the site does not support, at any time, freshwater fish species.

Criteria	AS	AT	AG	CP	JS	JL	AE
Maximum depth at crest	>0.15m	>0.10m	>0.10m	≤ 0.10m	>0.08m	>0.02m	>0.08m
Minimum gap dimensions	>0.5m	>0.3m	>0.3m	>0.3m	>0.15m	>0.05m	>0.15m
Damaging structures	No structures present that could damage fish moving downstream over obstacle						
Debris blockage	If present should not restrict fish passage						

Table 6.3: Downstream movement requirements for different species/guilds for log dams with gap sizes less than those detailed in table 6.2 (adapted from Bull & Casas-Mulet, 2011); AS=adult salmon; AT=adult trout; AG=adult grayling; CP=cyprinids; JS=juvenile salmonids; JL=juvenile lamprey; AE=Adult eel.

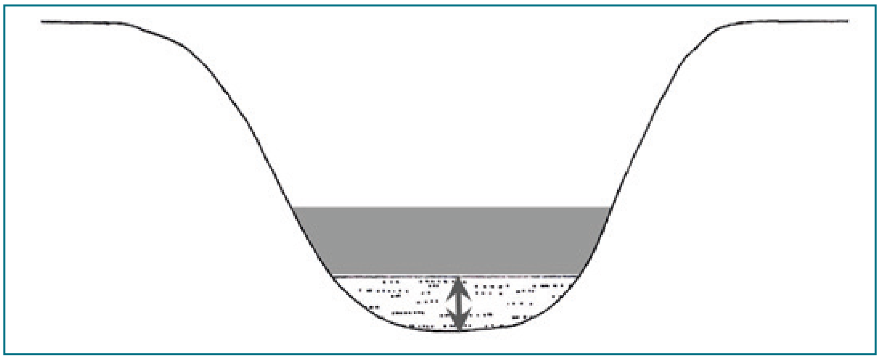


Figure 6.5 The height of the timber, measured from the river bed to the top of the timber is the key physical characteristics of this woody placement type

Species	AS	ST	AT	AG	CP	AL
Maximum height	0.35m	0.20m	0.10m	0.15m	0.05m	0.05m

Table 6.4: Maximum height (see Figure 6.3) of grade control placements that permit fish passage Baudoin et al. (2014); AS=adult salmon; ST=sea trout; AT=adult trout; AG=adult grayling; CP=cyprinids; AL=adult lamprey

6.4.5 Modifications to Category B type woody placements improve fish passage opportunities

Similar to Category A type woody placements, and particularly for grade control placements, notching of the uppermost surface of the placement would disrupt laminar flows and provide better passage opportunities for fish species.

The expert panel suggested a hybrid design for single timber bank-to-bank type woody placements. This design involves the lowermost edge of the timber being clear of branches and the uppermost edge with branches retained (Figure 6.6). This design would allow unimpeded river flow under less than bankfull conditions (cf. Category A type).

With flow levels over bankfull, the upward pointing branches would slow river flow. The design requires less intensive monitoring and management but would likely provide better flow reduction capacity at high flows, compared with category A simple timber types.

6.4.6 Management considerations for Category B woody placements

Due to the increased structural complexity of the hydraulically active components of complex single timbers, man-made log jams, and watergate placement types, the likelihood of debris blockage is high. The expert panel highlighted the management and monitoring requirements of these placement types will be very intensive. For example, something as small as a plastic bag floating in the stream and becoming entrained in these placement types has the potential to block gaps, changing gap sizes and thus reducing passage opportunities for fish. Monitoring changes in the height of hydraulic head is recommended to provide an indication of the degree of blockage of these placement types.

Erosion and scouring were highlighted as the main sources of degradation of grade control placements. Bank erosion and under scouring have the potential to significantly change placement integrity and thus change the opportunities for fish passage. For example, under-scouring of grade control placements can change the physical attributes to something more akin to Category A, simple timbers with a low vertical height (Figure 6.7). The small distance between the stream bed and the underside of a scoured timber would render it impassable to most fish species (e.g. details in Table 6.1).

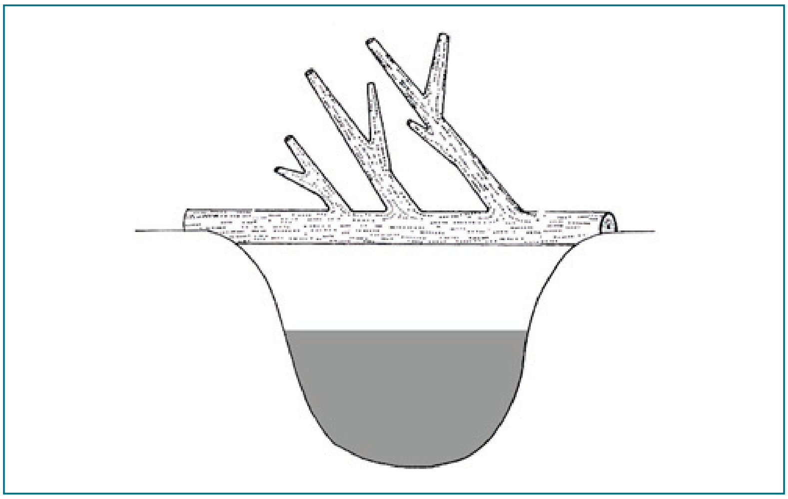


Figure 6.6: Schematic representation of modification to woody placement suggested by expert panel

Figure 6.7: Under-scouring of grade-control placement (white arrows) © S. Addy.

6.4.7 Summary recommendations for Category B type woody placements

- Complex single timbers (branches retained) placed bank-to-bank
- Man-made log-jams
- Watergate
- Grade-control placements
- Ditch barrier

Recommendations for Category B Woody Placement
Type: Complex single timbers placed bank-to-bank
(Figure 2.4a)

Structural requirements

- Must meet the minimum requirements detailed in Table 6.1
- Distance between the riverbed and the lowest point of the placement
- Vertical height of the placement
- Gap dimensions between branches within placement

Expert panel highlighted species of most concern

- Salmon- spawning migration
- Trout (resident & migratory forms) – spawning migration
- Salmon & sea trout smolts

Overall conclusions from the expert panel

- If well maintained, low impact on fish passage
- Downward pointing branches will act like litter screens and will require monitoring for debris build-up
- Choice of tree species will (to some extent) dictate the density of branches and thus the gap sizes of the placement
- Management and monitoring will have to be adaptable
- Monitoring and management of woody placement should be made after a flow event when the placement has acted as a flood prevention measure
- Monitoring and management of woody placement should be made before the migration period of species of most concern

Recommendations for Category B Woody Placement
Type: Man-made log jams
(Figure 2.4b)

Structural requirements

- Must meet the minimum requirements detailed in Table 6.1
- Distance between the riverbed and the lowest point of the placement
- Vertical height of the placement
- Gap dimensions between branches within placement

If the structural requirements do not meet those detailed in Table 6.1, the placement is only passable by leaping species and the physical characteristics of the placement must meet those detailed in Table 6.2. Minimum gap sizes to facilitate unimpeded down-stream passage must meet the criteria detailed in Table 6.3.

Expert panel highlighted species of most concern

- Salmon- spawning migration
- Trout (resident & migratory forms) – spawning migration
- Salmon & sea trout smolts
- Lamprey species, stickleback, stone loach and minnow

Overall conclusions from the expert panel

- Under periods of high flow or flood conditions this placement has the potential to cause localised areas of very high water velocity as water is forced through gaps. This has implications for the passage of non-leaping species, specifically lamprey
- Placement monitoring will have to be frequent to ensure gap sizes are maintained throughout the year
    - Monitoring the height of the hydraulic head is suggested as an easy way to monitor if the placement is becoming blocked; the hydraulic head would increase as the placement becomes blocked
- Maintenance will be high due to structural complexity
- Monitoring and management of woody placement should be made after a flow event when the placement has acted as a flood prevention measure
- Monitoring and management of woody placement should be made before the migration period of species of most concern

Recommendations for Category B Woody Placement
Type: Watergate
(Figure 2.4c)

Structural requirements

- o Must meet the minimum requirements detailed in Table 6.1
- o Distance between the riverbed and the supporting wooden beam
- o Vertical height of the supporting wooden beam
- o Gap dimensions between wooden uprights

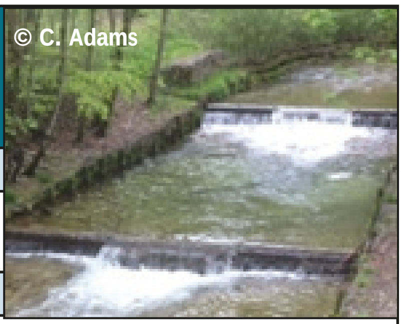
Expert panel highlighted species of most concern

- o Salmon- spawning migration
- o Trout (resident & migratory forms) – spawning migration
- o Salmon & sea trout smolts
- o Lamprey species, stickleback, stone loach and minnow

Overall conclusions from the expert panel

- o Placing this placement at an angle across the river bed (opposed to running at right angles to the river bank) may improve the opportunities for fish passage through the creation of heterogeneity in water velocities
- o Under periods of high flow or flood conditions this placement can cause localised areas of very high water velocity as water is forced between the uprights, with implications for the passage of non-leaping species, specifically lamprey
- o Frequent monitoring will be required to ensure gap sizes within the placement are maintained throughout the year
- o Maintenance will be high due to structural complexity
- o Monitoring and management of woody placement should be made after a flow event when the placement has acted as a flood prevention measure
- o Monitoring and management of woody placement should be made before the migration period of species of most concern

Recommendations for Category B Woody Placement
Type: Grade control placements
(Figure 2.4d)



Structural requirements

- o Must meet the minimum requirements detailed in Table 6.1
- o Height between the river bed and the top of the timber beam

Expert panel highlighted species of most concern

- o Salmon and sea trout smolts
- o Lamprey species, stickleback, stone loach and minnow

Overall conclusions from the expert panel

- o Placements have some ecological values through the creation of pool-riffle sequences
- o These placements have a very high potential of being barriers to fish passage at low flows
- o Notching of the uppermost surface of the timber will disrupt laminar flow and present more opportunities for fish passage
- o Erosion around the banks and scouring under the placement has the potential to significantly change the function and fish passability
- o The inclusion of a plunge pool immediately downstream of these placements would significantly increase passage opportunities through leaping
- o Monitoring and management must be focussed on the effects of erosion and scouring
- o Monitoring and management of woody placement should be made after a flow event when the placement has acted as a flood prevention measure
- o Monitoring and management of woody placement should be made before the migration period of species of most concern

Recommendations for Category B Woody Placement **Type: Ditch barrier** **(Figure 2.4e)**
Structural requirements
o This placement is a complete barrier to fish in any form
Expert panel highlighted species of most concern
o All freshwater species
Overall conclusions from the expert panel
o This placement type is considered a complete barrier to all fish species and all life stages o This placement type should only be used in the absence of any evidence that the sites is inhabited (at any time) by any obligate freshwater species

6.5Category C type woody placements

- o Sidebar woody placements
- o Hinged trees

As these woody placement types do not span the river channel they are not considered a barrier under the guidance of the barrier assessment tools, and this was reflected in comments from the expert panel. However, even wood outside or above the wetted proportion of the river channel influences pool formation by directing patterns of scour at bank full conditions (Dolloff & Warren, 2003) and the panel highlighted the potential these placement types have in changing local river hydromorphology.

No passage concerns for any fish species were highlighted for Category C placement types.

6.5.1 Sidebar woody placements

The expert panel highlighted the size of these woody placements, relative to channel width, would need to be considered. Relatively large sidebar woody placements would have a relatively large effect on local stream hydromorphology. In addition to their size, adequate fixing of the placement on the sidebar would ensure it does not move during periods of high flow or during flood conditions. Monitoring and management of sidebar woody placements should be conducted following any period of flow when the placement becomes hydraulically active. Specific attention should be made to ensure that structural fixings are still "good".

6.5.2 Hinged trees

Hinged trees were highlighted as providing high ecological value to the local area through the provision of habitat for fish. The stream direction at the hinged tree placement is a key consideration for placement success. Trees pointing downstream (i.e. pointing with the stream flow) were thought to have a higher success rate compared with those pointing upstream, against the stream flow.

As these placements are permanently hydraulically active, the expert panel highlighted monitoring of local hydromorphology should be undertaken periodically in line with the activity of the stream channel to ensure no significant changes in stream morphology may be negatively affecting riverbank stability. This should be considered against the backdrop of local land use, for example near public infrastructure or agricultural land where changes in stream bank morphology may have a negative impact.

Recommendations for Category C Woody Placement **Type: Sidebar woody placements** **(Figure 2.5a)**
Structural requirements
o This placement is not recognised as a barrier to fish
Expert panel highlighted species of most concern
o No species
Overall conclusions from the expert panel
o This size of the placement should be considered relative to the stream channel o Fixing the placement to ensure no movement under periods of high water level must be considered to ensure the placement does not move downstream o Monitoring and management of placement type should be after any stream flow event when the placement becomes hydraulically active

Recommendations for Category C Woody Placement
Type: Hinged trees
(Figure 2.5a)

Structural requirements

- o This placement is a complete barrier to fish in any form

Expert panel highlighted species of most concern

- o No species

Overall conclusions from the expert panel

- o Highlighted as high ecological value
- o Within stream direction (upstream or downstream) pointing will have significant influence of the success of this placement type
- o Periodic monitoring and management to ensure changes to local stream morphology are not negatively influencing local current land use

7 General Conclusions

The use of woody placements in-stream for slowing the flow of water to attenuate flood discharge, at present, does not include any formal consideration of the ecological component of the stream ecosystem. While the ethos of NFM is to mimic natural processes, the degree to which this is achieved is un-tested from the perspective of the biotic community. Structures placed in rivers should comply with the requirements of the WFD, such that they do not impede the free movement of fish within river systems.

This work sits within the wider framework of identifying NFM opportunities detailed by SEPA and feeds into the scoping and design phases of a NFM project. An audit of the ecology of the area in which the NFM measures are to be deployed should form part of the scoping process. Once a fish species list has been compiled, the specifics of the woody placement design can be defined in line with the recommendations in this report.

In the absence of experimentally tested information, we have used information from UK and EU Barrier Assessment Tools to provide guidance on the structural dimensions of woody placements that should have only a low (or no) impact on fish movement. There is anecdotal (e.g. Newton, M. & Brackley, R. pers comm) and some published (Guiny, et al., 2003) information that fish will pass through gap sizes much smaller than those detailed in this report.

While some fish may be able to navigate barriers with smaller gap sizes, this does not represent ‘free’ movement as required by the WFD. There is a lack of empirical data across fish species however, with details of individual characteristics (e.g. body size, sex, maturation) associated with successful passage or information about the paths through an obstacle under different flow conditions. These data are urgently needed.

8 Recommendations For Further Research

8.1 Fish movements in small streams

The inadequacy of information available regarding the movements and spatial use of small streams by fish has been highlighted previously (Beaver Salmonid Working Group, 2015; Anon, 2013). The lack of fine scale information (peer-reviewed or grey) regarding the movements of fish in small streams has resulted in what may, or may not, be conservative physical dimensions for woody placement structures. There is a pressing need for research investigating the spatial and temporal use of small streams by native fish species, but this must be undertaken at a scale fine enough to enable us to find the correct balance between management of the physical environment and maintenance of connectivity. Recent advances in telemetry (spatial and temporal animal tracking) systems and reductions in production costs have meant that it is a possible to track fish in rivers at a scale suitable to provide useable information.

8.2 Empirical testing of Barrier Assessment Tools

The Barrier Assessment Tools detailed in this report represent the best knowledge available at the time of writing, however these tools have not been empirically tested to any great extent. Empirical testing of Barrier Assessment Tools is required both to validate their use for the assessment of man-made barriers, but also for their use within the context of building in-stream structures that do not, (or minimally) impact the movement of aquatic fauna.

8.3 Hydrological modelling

Information is required to investigate the differences between the various woody placement structure types highlighted in this report. Currently very little information is available about the physical movement of water through and around woody placement structure types. Modelled information would provide some indication about the range of local water velocities experienced by fish when approaching a woody placement. While modelling will provide information on the movements of water around a structure, this information must be supported by direct observations of the animal’s response in the field.

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10 APPENDIX

Freshwater invertebrate species listed in the Scottish Biodiversity List which Scottish Ministers consider to be of principal importance for biodiversity conservation in Scotland.

Scientific Name	Common name
Hirudo medicinalis	medicinal leech
Austropotamobius pallipes	freshwater white-clawed crayfish
Triops cancriformis	tadpole Shrimp
Agabus (Agabus) uliginosus	a water beetle
Augyles maritimus	a water beetle
Bagous (Abagous) lutulentus	a water beetle
Bagous (Bagous) collignensis	a water beetle
Berosus (Berosus) luridus	a water beetle
Bidessus minutissimus	minutest diving beetle
Cercyon (Cercyon) alpinus	a water beetle
Cercyon (Cercyon) convexiusculus	a water beetle
Cercyon (Cercyon) depressus	a water beetle
Cercyon (Cercyon) melanocephalus	a water beetle
Cercyon (Cercyon) nigriceps	a water beetle
Cercyon (Cercyon) quisquilius	a water beetle
Cercyon (Cercyon) terminatus	a water beetle
Cryptopleurum minutum	a water beetle
Cyphon kongsbergensis	a water beetle
Cyphon ochraceus	a water beetle
Cyphon pubescens	a water beetle
Cyphon punctipennis	a water beetle
Donacia aquatica	zircon reed beetle
Donacia cinerea	a reed beetle
Donacia crassipes	water-lily reed beetle
Donacia impressa	a reed beetle
Donacia marginata	a reed beetle
Donacia obscura	a reed beetle
Donacia sparganii	a reed beetle

Scientific Name	Common name
Donacia thalassina	a reed beetle
Donacia vulgaris	a reed beetle
Dryops (Dryops) similaris	a water beetle
Dryops (Yrdops) nitidulus	a water beetle
Elodes minuta	a water beetle
Elodes pseudominuta	a water beetle
Enochrus quadripunctatus	a water beetle
Enochrus testaceus	a water beetle
Gyrinus distinctus	a water beetle
Gyrinus paykulli	a water beetle
Gyrinus suffriani	a water beetle
Haliplus (Haliplinus) apicalis	a water beetle
Helochares punctatus	a water beetle
Helophorus (Cyphelophorus) tuberculatus	a water beetle
Helophorus (Empleurus) porculus	a water beetle
Helophorus (Helophorus) griseus	a water beetle
Helophorus (Trichohelophorus) alternans	a water beetle
Heterocerus flexuosus	a water beetle
Heterocerus fossor	a water beetle
Hydraena pulchella	a water beetle
Hydraena pygmaea	a water beetle
Hydrochus angustatus	a water beetle
Hydrochus brevis	a water beetle
Hydrochus elongatus	a water beetle
Hydroporus elongatulus	a water beetle
Hydroporus glabriusculus	a water beetle
Hydroporus longulus	a water beetle
Hydroporus rufifrons	oxbow diving beetle
Hygrotus (Hygrotus) versicolor	a water beetle
Ilybius wasastjernae	a water beetle
Laccobius atratus	a water beetle

Scientific Name	Common name
Liopterus haemorrhoidalis	a water beetle
Megasternum concinnum	a water beetle
Ochthebius (Asiobates) auriculatus	a water beetle
Ochthebius (Hymenodes) punctatus	a water beetle
Ochthebius (Ochthebius) lenensis	a water beetle
Ochthebius (Ochthebius) viridis	a water beetle
Oreodytes alpinus	a water beetle
Pelenomus canaliculatus	a water beetle
Plateumaris rustica	a water beetle
Poophagus sisymbrii	a water beetle
Prionocyphon serricornis	a water beetle
Rhantus (Rhantus) frontalis	a water beetle
Rhantus (Rhantus) suturalis	a water beetle
Scirtes hemisphaericus	a water beetle
Sphaeridium bipustulatum	a water beetle
Sphaeridium lunatum	a water beetle
Thryogenes nereis	a water beetle
Coenagrion hastulatum	Northern damselfly
Nigrobaetis niger	iron blue mayfly
Anodonta (Anodonta) cygnea	swan mussel
Margaritifera (Margaritifera) margaritifera	freshwater pearl mussel
Pisidium henslowanum	Henslow's pea mussel
Theodoxus (Theodoxus) fluviatilis	river nerite

Details of the Expert Panel Workshop held at Battleby on 12th April 2016

Attendees

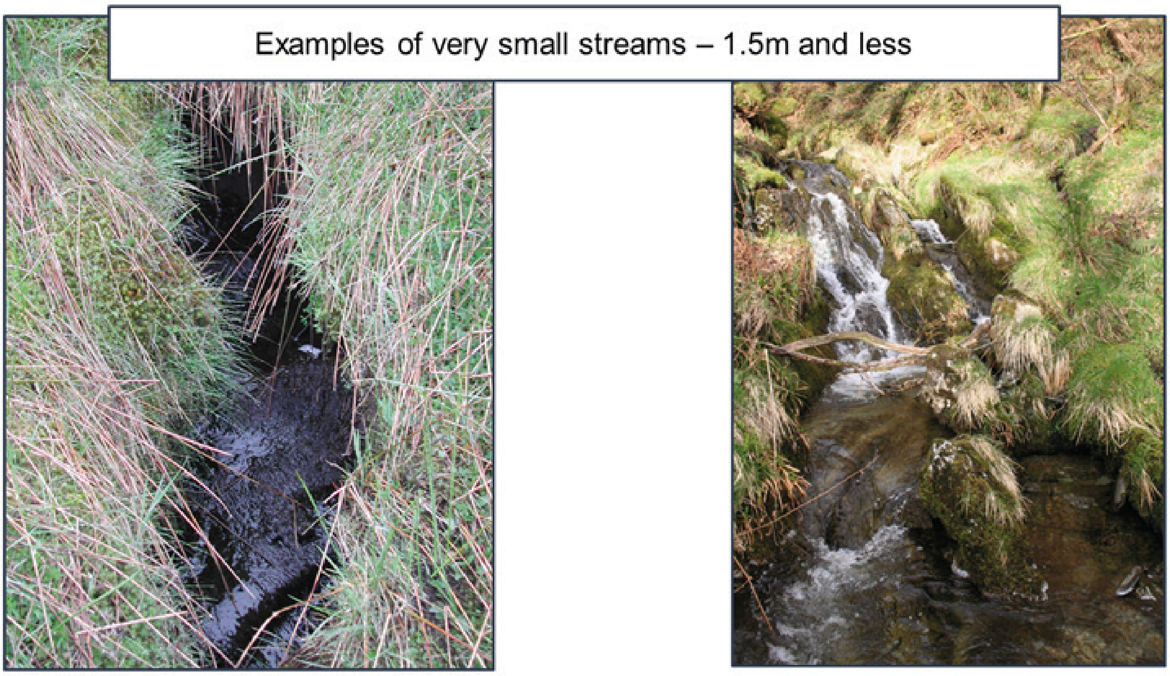
Attendee	Organisation	Field of Expertise
C. Adams	University of Glasgow	Fisheries Scientist
S. Addy	James Hutton Institute	Hydromorphologist
C. Bean	Scottish Natural Heritage	Fisheries Scientist
L. Belleni	River Forth Fishery Trust	Catchment Management
L. Bond	Scottish Environment Protection Agency	Ecologist
C. Bull	University of Stirling	Fisheries Scientist
R. Campbell	The Tweed Foundation	Fisheries Manager
C. Chalmers	Angus Council	Civil Engineer
H. Chalmers	Tweed Forum	Fisheries Scientist
J. Dodd	University of Glasgow	Freshwater Ecologist
N. Dodd	Centre of Expertise for Waters	Project Manager
A. Duguid	Scottish Environment Protection Agency	Fisheries Scientist
D. Ferguson	Spey District Salmon Fishery Board	Fisheries Manager
K. Galt	The Tweed Foundation	Fisheries Manager
A. Kettle-White	Argyll Fisheries Trust / Wild Trout Trust	Fisheries Manager
A. Law	University of Stirling	Freshwater Ecologist
T. McDermott	River Forth Fishery Trust	Fisheries Scientist
M. Newton	University of Glasgow	Fisheries Scientist
T. Nisbet	Forest Research	Forest Hydrologist
D. Summers	Tay District Salmon Fishery Board	Fisheries Manager
E. Third	Dee / Don Salmon Fishery Board	Fisheries Manager
C. Thomas	East Lothian Angling Association	Geomorphologist

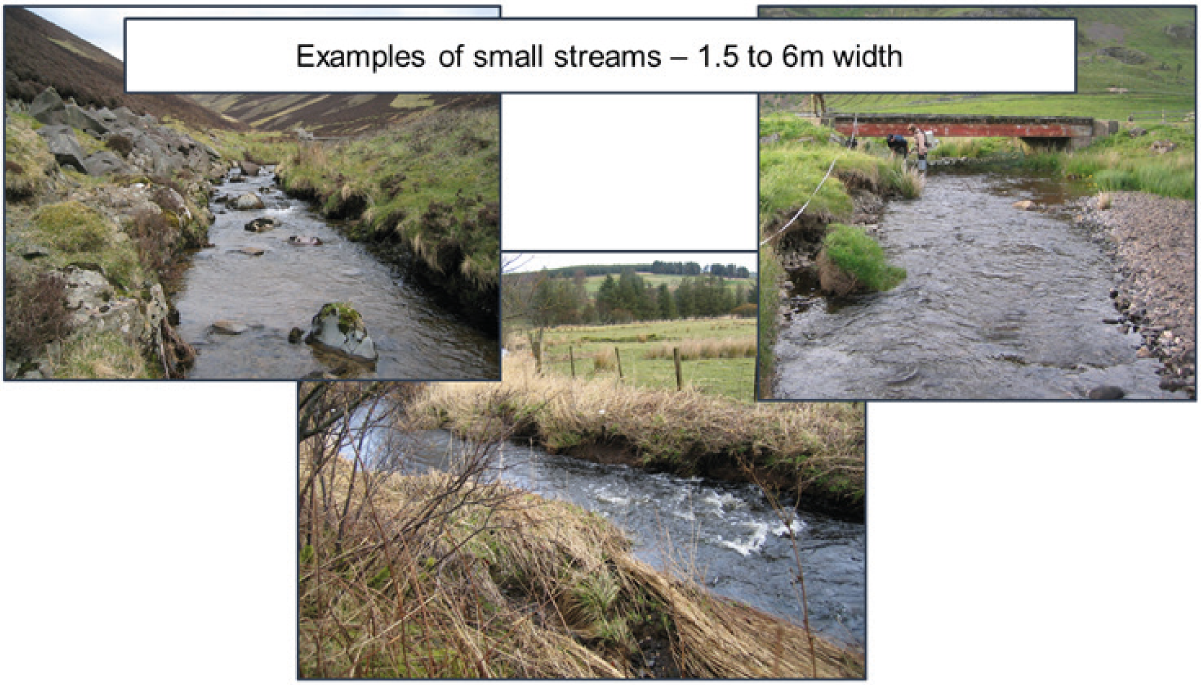
Workshop Timetable

10:00 – 10:15	Introduction to the project	Colin Adams
10:15 – 10:45	The Pickering Project	Tom Nisbett
10:45 – 11:05	Stream characteristics & fish passage	Colin Bull
11:05 – 11:20	Beaver dams & fish passage	Alan Law
11:20 – 11:50	Short Talks	Stakeholders
11:50 – 12:00	Introduction to the Practical Exercise	Jennifer Dodd
12:00 – 12:45	Lunch	
12:45 – 15:00	Practical Exercise	
15:00 – 15:30	Tea & Coffee	
15:30 – 16:30	Closing Discussion	

Practical Exercise

Example of very small and small stream photographs – these pictures were provided to help participants assess placements based on a similar understanding of stream size.





Each placement was assessed based on the following assumptions:

Assumptions for the exercise

Fish passage assessment is based on:

These structures will have the potential to change, assessment is based on **perfect working condition**

Fish can arrive at the structure

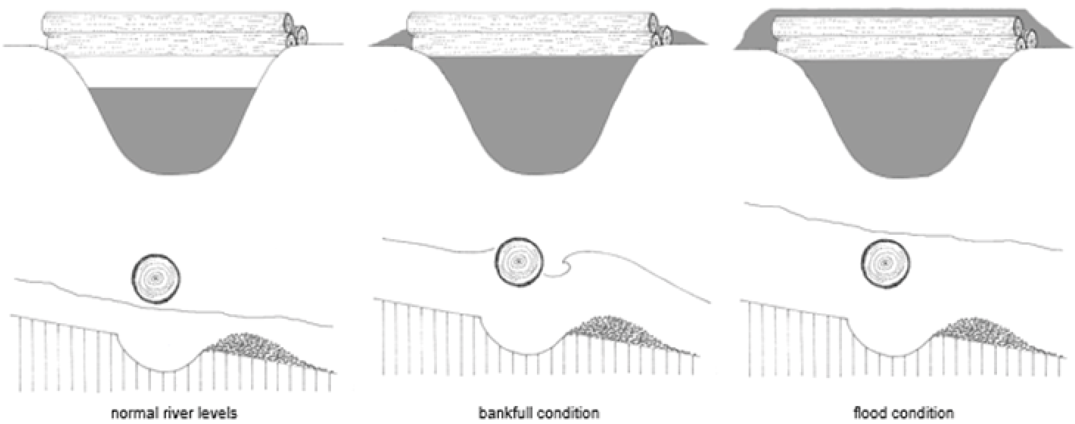
Structural engineering is appropriate – i.e. structure is "made well"

Photographs and schematics were provided for all placements being assessed. Photographs detailing a wide variety of flow conditions for each of the placement were not available. The schematics thus provided the best substitute to allow participants to visualise the different placements under ecologically relevant flow conditions.

Category A type placement: simple timber (branches removed) low vertical height.

Photographs

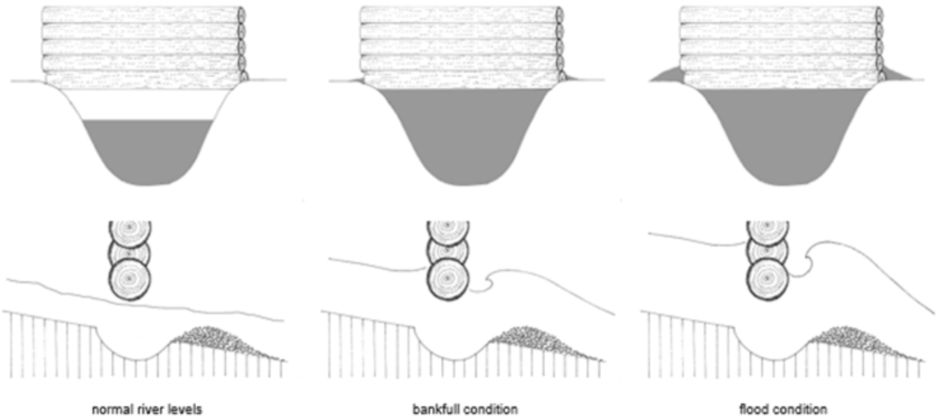
Schematics



Category A type placement: simple timber (branches removed) low vertical height.

Photographs

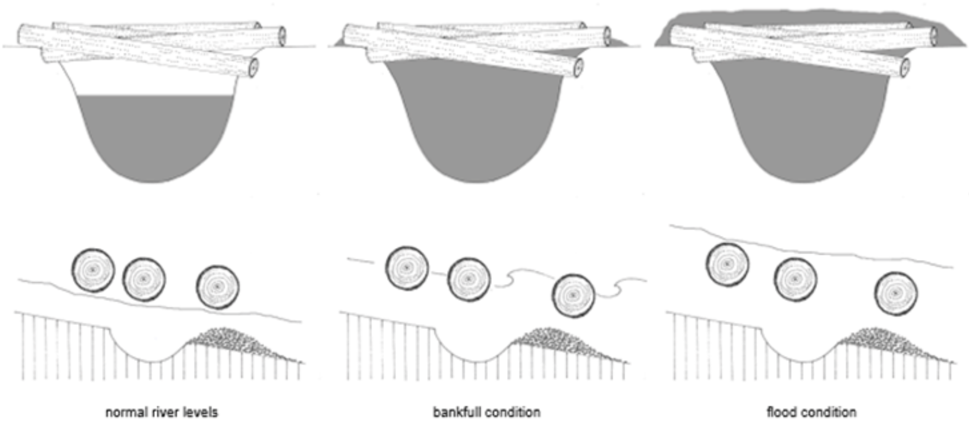
Schematics



Category A type placement: lattice placement

Photographs

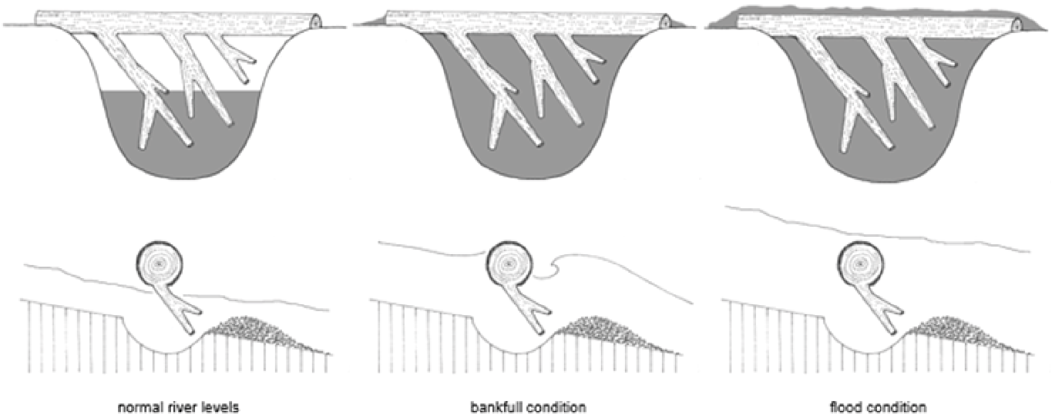
Schematics



Category B type placement: complex single timber (branches retained) placed bank-to-bank

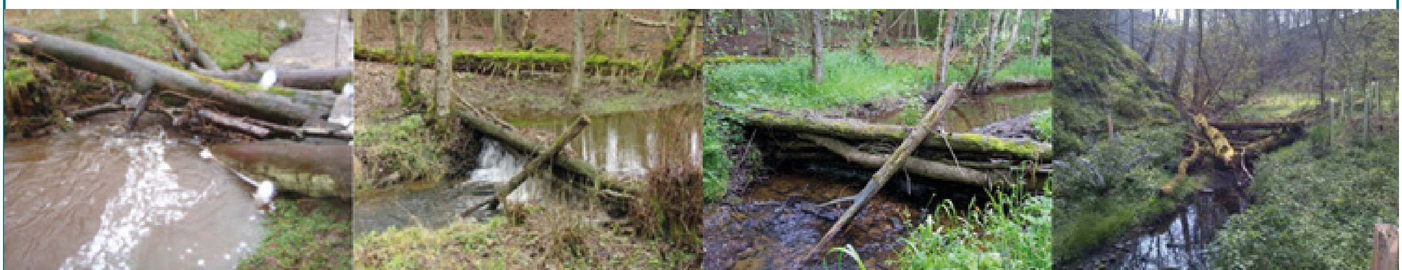
Photographs

Schematics

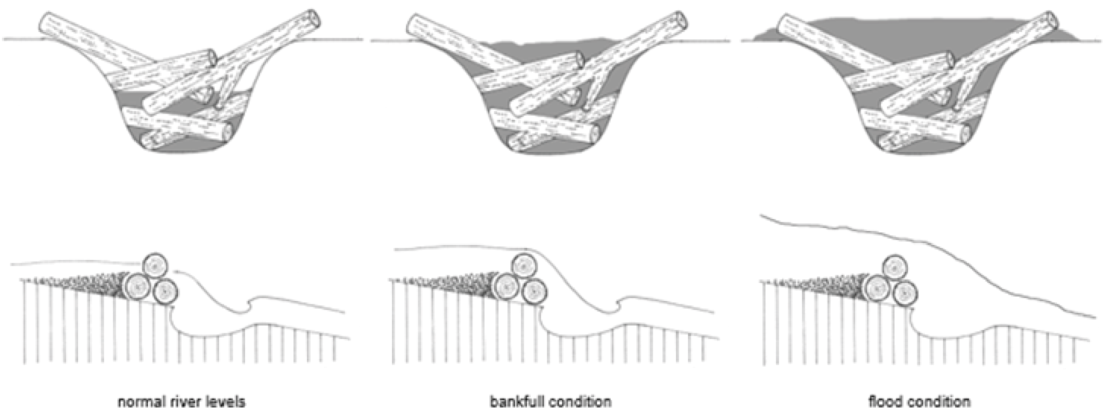


Category B type placement: man-made log jam

Photographs



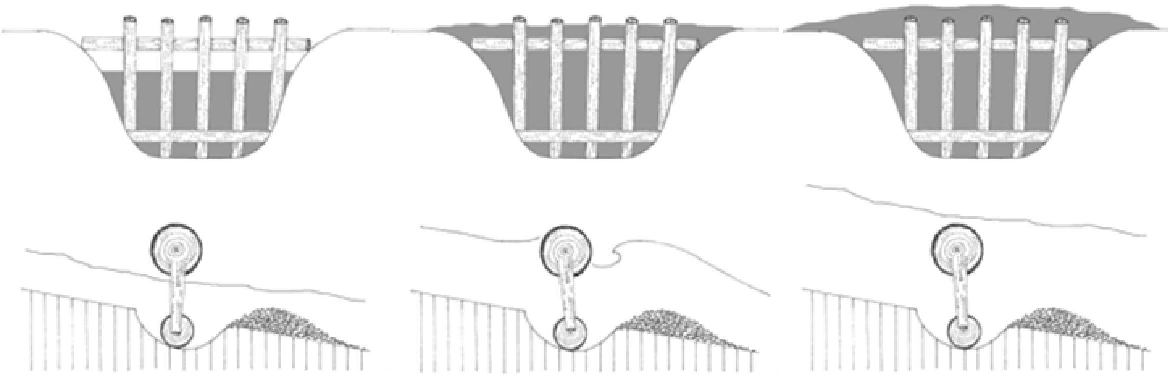
Schematics



Category B type placement: watergate

Photographs

Schematics

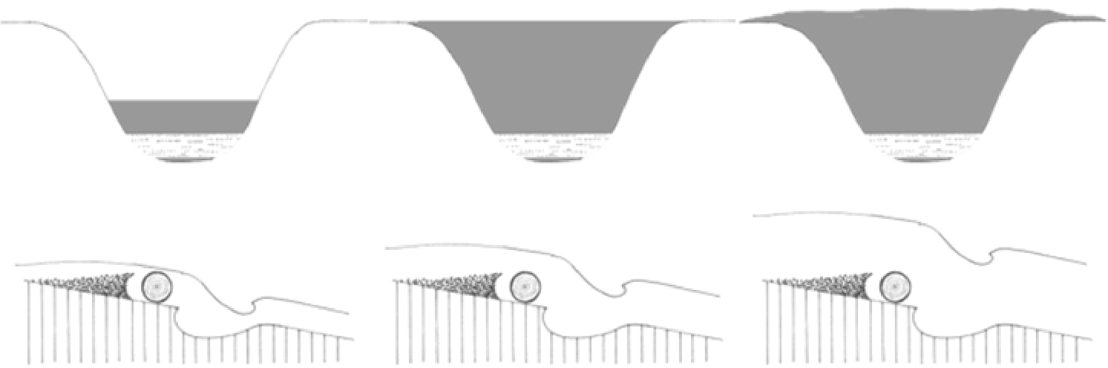


normal river levels | bankfull condition | flood condition

Category B type placement: grade control

Photographs

Schematics

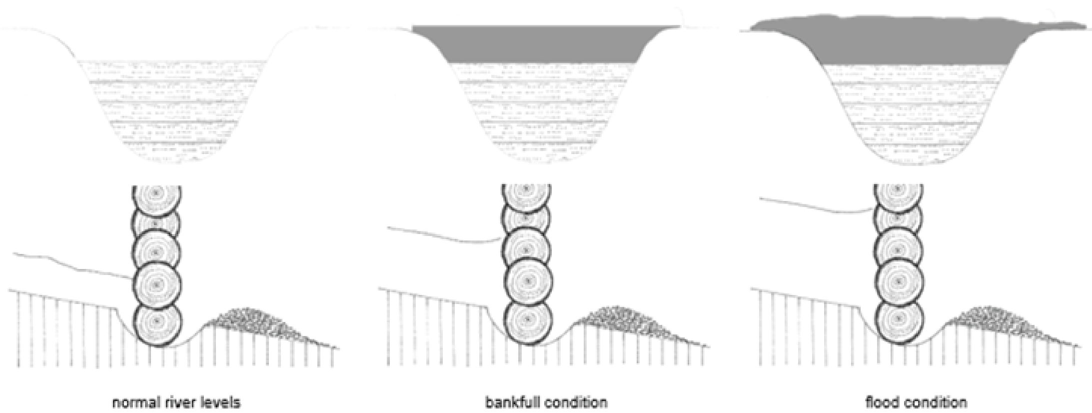


normal river levels | bankfull condition | flood condition

Category B type placement: ditch barrier

Photographs

Schematics



Category C type placement: Sidebar woody placements

Photographs

Category C type placement: Hinging trees

Photographs

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