CENTRE FOR EVIDENCE-BASED CONSERVATION

SYSTEMATIC REVIEW No. 12

DOES THE USE OF IN-STREAM STRUCTURES AND WOODY DEBRIS INCREASE THE ABUNDANCE OF SALMONIDS?

REVIEW REPORT

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COVER SHEET

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SYSTEMATIC REVIEW SUMMARY

Background

In-stream structures (such as flow deflectors, weirs and woody debris) have been in widespread use for the last eighty years to increase the production of fish stocks, primarily salmonids, but also species of conservation concern such as European Bullhead *Cottus gobio*. A large number of studies, of variable quality, have been undertaken to assess the effectiveness of in-stream structures, often with conflicting results. It has therefore been hard to develop a consensus regarding the utility of in-stream structures despite their continued use. This systematic review formally synthesises empirical evidence regarding the effectiveness of in-stream structures in terms of impact on abundance of salmonid fish and *C. gobio* using a documented *a priori* protocol.

Objectives

To assess the impact of in-stream structures on the abundance of salmonids and *Cottus gobio.*

To assess the impact of hydrological and ecological variables on the effectiveness of in-stream structures.

Search strategy

Electronic searching of ISI Web of Knowledge, Science Direct, Directory of Open Access Journals, Copac, Scirus, Scopus, Index to Theses Online, Digital Dissertations Online, Agricola, Europa, Wildlink, JSTOR. Publication searches of Canadian Wildlife Service, Countryside Council of Wales, Department of Agriculture and Rural Development, Department of Environment, Food and Rural Affairs, English Nature, Environment Agency, Food & Agriculture Organisation of the United Nations, Fisheries Management Science Programme, Fisheries and Oceans Canada, FRS Freshwater Laboratory (formerly Freshwater Fisheries Laboratory), Joint Nature Conservancy Council, United States National Parks and Wildlife Service, Scottish Natural Heritage. Searched Fishbase.org, BiologyBrowser.org, Graylit.osti.gov, Librarian's Internet Index, Google Scholar, Scirus and Google. Hand-searches of bibliographies of accepted articles. Personal contact with researchers.

Selection criteria

Any studies examining the impact of in-stream structures on the abundance of salmonids or *Cottus gobio*. Appropriate spatial or temporal controls were a prerequisite for studies to be included in quantitative analysis.

Main results

A total of 137 studies fulfilled the inclusion criteria of which 38 provided quantitative data regarding the impact of in-stream structures on salmonids or *Cottus gobio,* suitable for meta-analysis. Fifty four independent data points

provided evidence regarding the impact of engineered in-stream devices on salmonids, with a further 30 data points regarding woody debris and nine concerning *Cottus gobio.*

Meta-analytical synthesis results in a weakly significant positive impact of engineered in-stream habitat structures on salmonid populations. No ecologically significant impact on salmonid population size or habitat preference was evident. There are no significant relationships between the effectiveness of engineered in-stream structures and hydrological or ecological variables at a population level, although there is limited evidence that in-stream structures provide preferential habitat at higher discharges.

Woody debris has a significant impact on salmonids resulting in increased population abundance. This is especially pronounced for Brook Trout *Salvelinus fontinalis.* There is a lesser, but still significant, positive impact on microhabitat preference. Woody debris provides more preferential habitat at longer timescales and higher discharges, but appears to be less effective for Coho salmon *Oncorhynchus kisutch* than other salmonid species.

Riffles increase local abundance of *Cottus gobio* but deflectors do not.

Reviewers' conclusions

Implications for conservation

Available evidence does not demonstrate an ecologically significant impact of engineered in-stream structures on populations of salmonids, although they may provide preferential habitat where discharge is high ($>6m^3s^{-1}$).

Available evidence suggests that woody debris does increase the population abundance of salmonids, especially the brook trout *Salvelinus fontinalis*. It may also provide more preferential habitat over time (>4years) where discharge is high ($>1m^3s^{-1}$) but does not appear to provide preferential habitat for *Oncorhynchus kisutch*.

Cottus gobio populations are not increased by deflectors but riffles may provide preferential habitat.

Implications for further research

Further long term work is required to corroborate the evidence presented in this systematic review. Much currently available data is of inadequate duration and assesses habitat preference rather than long-term population change. Reach and water-shed scale studies are also rare in comparison to habitat unit studies. The use of independent treatments and controls, replication, and rigorous parameters of abundance is advocated.

Numerous confounding variables operate in riverine systems and sample sizes are currently too small to assess the impact of many factors in a robust manner. Further monitoring is required to fully evaluate the potential impact of time, discharge and species. Other hydrological and ecological factors such as stream gradient, proportion of cobbles in the substrate, degree of existing modification, water quality and canopy cover are insufficiently reported and studied, although they are known to impact fish populations.

1. BACKGROUND

In-stream structures have been widely adopted as a form of river restoration since the early 20th Century (Bayley 2002; Thompson 2006), although the type of work carried out and any associated monitoring varies widely (Bash & Ryan 2002; Holmes 1998). The earliest examples of in-stream structures were hard, engineered solutions (Bayley 2002), whereas the trend towards the later part of the century was toward more natural structures, which are believed to be more effective (Schmetterling 2001). The current paradigm embraces a holistic watershed approach, including land use management and catchment area planning along with the use of in-stream structures (Hendry *et al.* 2003; Kauffman *et al.* 1997; Opperman 2004).

In-stream habitat structures are used in an attempt to redress habitat degradation and enhance salmonid (and other fish) stocks, in streams and rivers. A wide range of techniques are employed, often in combination during restoration work. The interventions fall into two broad categories: structures designed to change flow patterns, water velocities and turbulence (deflectors, weirs, riffles); or structures which stabilize banks by reducing erosion and sediment inputs (riprap, rock revetments, gabions, livestock fencing). Woody debris, such as fallen trees, logs and root wads, is also considered here, independently of engineered structures, because it can act as a deflector or weir, changing flow patterns and potentially increasing the amount of pool habitat (Rosenfeld & Huato, 2003). Woody debris is now often deliberately introduced into rivers to influence flow and scour, and to create favourable habitat for many species, although it had previously been cleared from many salmonid rivers as it was thought to form a barrier to migration (Kauffman et al, 1997; Opperman et al, 2006). Both engineered in-stream structures and woody debris are sometimes used in combination with wider catchment management (e.g. contour ploughing to reduce sediment input, provision of bank-side cover). Other interventions, designed to improve habitat such as the provision of gravel for spawning may be important elements in restoration but are not the focus of this review.

A large number of studies, of variable quality, have been undertaken to assess the effectiveness of in-stream structures, often with conflicting results (Bayley, 2002; Roni et al, 2002, 2005; Thompson, 2006). Studies have shown that confounding variables such as fishing pressures have not been taken into account, and may be responsible for changes in salmonid abundance (Thompson 2006). There is also concern that some studies report positive outcomes which are not supported by the underlying statistics (Roni, 2002). It has therefore been hard to develop a consensus regarding the utility of in-stream structures despite their widespread and continued use. This systematic review formally synthesises empirical evidence regarding the effectiveness of both engineered in-stream structures and woody debris using a documented *a priori* protocol. The effectiveness of in-stream structures may be affected by local gradient and valley confinement, proportion of cobbles in the substrate, degree of existing modification, distance from source, water quality, flow, stream size and canopy cover. The impact of these potential effect modifiers was also investigated.

2. OBJECTIVES

To assess the impact of in-stream structures on the abundance of salmonids and *Cottus gobio.*

To assess the impact of hydrological and ecological variables on the effectiveness of in-stream structures.

3. METHODS

3.1 Question formulation

The Environment Agency identified the need for a systematic review to evaluate the effectiveness of in-stream devices. The review question and review protocol were developed by dialogue between CEBC and the Environment Agency. The need to differentiate between increasing carrying capacity (population change) and redistribution of the population (habitat preference) was highlighted.

3.2 Search strategy

Relevant studies were identified through computerised searches of the following electronic databases: ISI Web of Knowledge, Science Direct, Directory of Open Access Journals (DOAJ), Copac, Scirus, Scopus, Index to Theses Online (1970-present), Digital Dissertations Online, Agricola, Europa, English Nature's "Wildlink", JSTOR.

The search terms used to search the databases were: Trout*, Salmo*, Bullhead*, Cottus AND gobio, River* AND flow*, Stream* AND flow*, Deflector* AND flow*, Grazing AND fish*

* Denotes the use of a wildcard e.g. Salmo* is used in order to pick up salmon, salmo, salmonids etc.

These search terms yield huge quantities of results, and in order to make the web and organisational searches more specific and efficient, and to address the more limited search functionality of these sites, the search terms were revised to reflect the terminology used in the relevant papers already retrieved.

The search terms used for web and organisation searches were: river restor* AND (salmo* OR trout), in-stream structures AND (salmo* OR trout), woody debris OR large woody debris OR lwd, river restoration habitat improvement.

Publication searches were undertaken on conservation and statutory organisation websites (Canadian Wildlife Service, Countryside Council of Wales, Department of Agriculture and Rural Development, Department of Environment, Food and Rural Affairs, English Nature, EA, FAO, Fisheries Management Science Programme, Fisheries and Oceans Canada, FRS Freshwater Laboratory (formerly Freshwater Fisheries Laboratory), Joint Nature Conservancy Council, US National Parks and Wildlife Service, Scottish Natural Heritage). In addition bibliographies of articles viewed at full text were searched. Authors, experts and practitioners were also contacted for further recommendations and for provision of any unpublished material or missing data that may be relevant.

Web searching was undertaken using the same terms as used for the organisational searches. Sites searched were Wiley InterScience E-Journals Interface, Fishbase.org, BiologyBrowser.org, Graylit.osti.gov, Librarian's Internet Index, Google Scholar, SOSIG Environmental Science, Scirus, Exalead and Google. Exalead and Google were also searched specifically for spreadsheet files. The first 50 hits were checked for relevance, and then any that appeared relevant in the next 50.

Foreign language searches were not conducted for this review. However, the search identified studies on a global scale (e.g. studies from North America and Japan) all of which were included in the systematic review process, irrespective of geographical location.

3.3 Study inclusion criteria

Studies were initially filtered by title and any obviously irrelevant articles were excluded. Subsequently, the abstracts of the remaining studies were examined with regard to possible relevance to the systematic review question. A random subset of these articles (n = 152) were assessed for relevance by a second independent reviewer; agreement on inclusion between the reviewers was deemed to be "substantially good" (Cohen's Kappa test: K = 0.745). Studies were accepted for viewing at full text if it appeared that they contained information pertinent to the review question, or if the abstract was ambiguous and did not allow inferences to be drawn about the content of the article. The criteria, which studies had to meet for inclusion into the final stage of the systematic review, were:

1. *Subject*: rivers and streams containing trout, salmon and/or *Cottus gobio* populations.
2. *Intervention*: In-stream habitat structures e.g. flow deflectors, riffles, revetments, weirs, woody debris, riprap and other bank-stabilisation.
3. *Outcome*: the primary outcome was change in abundance of trout, salmon or *C. gobio.* However, studies were not rejected on the basis of outcome.
4. *Type of study*: any empirical study. Only studies with appropriate spatial or temporal controls and (pseudo) replication were included in quantitative analysis.

Studies which were not included:

1. Data regarding fish steps and other fish passage devices have not been included in this review as they are not a form of in-stream improvement.
2. Data regarding comparisons of natural vs. rivers altered away from natural habitat have not been included as this was not an intentional attempt to improve fish habitat, rather degradation.
3. Data regarding spawning behaviour and gravel were not included unless either as part of confounded habitat changes, or as a specific attempt to improve in-stream habitat.
4. Data about non-salmonids (except *Cottus gobio*) was not included in meta-analysis (other fish or species or habitat quality data was summarised due to lack of rigour and small sample sizes).

3.4 Study quality assessment

Reviewers considered articles viewed at full text excluding or admitting them to different categories of information quality, Qualitative data and quantitative data without comparators or variance measures were summarised in qualitative tables with a summary of methodology in lieu of study quality assessment. Quantitative data regarding change in salmonid or *Cottus gobio* stocks with comparators were subject to more rigorous critical appraisal.

Details of the methodology (e.g. study design, timescale), were recorded on data extraction forms. The biases resulting from study design were considered and an explicit statement regarding the source, and where possible, magnitude and likely impact was included.

The difference between population change and habitat preference has been referred to in the literature (Johnson 2005), and this distinction was made based on scale and methodology. Where data were collected over a number of years at a reach or sub-reach scale using a robust replicated assessment of abundance (electrofishing or mark-recapture), they were classified as population change data. Where data were collected over short timescales and/or at a micro-habitat level with little replication they were considered more likely to represent habitat preference than population change. The criteria used to distinguish these groups are included in Appendix 4.

Study quality assessment was undertaken by one reviewer with reference to a second in cases of uncertainty.

3.5 Data extraction

The details of study methodology and outcome were summarised in tables where qualitative data, data without comparators or variance, and data regarding outcomes other than change in the abundance of salmonids or bullhead were presented. Quantitative data regarding engineered in-stream structures was considered separately to data regarding woody debris. Engineered woody structures such as log weirs and dams were included as engineered in-stream structures. The quantitative data regarding salmonid and *Cottus gobio* populations were extracted using *a priori* rules to minimise bias, and standardised tables (Appendix 1) to increase transparency.

The site conditions (reasons for heterogeneity) identified in the protocol were extracted where presented, and recorded in a spreadsheet. These were not always extractable, for example where studies covered a range of streams with different characteristics. The characteristics of interest include local gradient, valley confinement, proportion of cobbles in the substrate, degree of existing modification, distance from source, water quality, flow, stream size and canopy cover.

Mean abundance data were extracted as a continuous outcome. Change in mean difference at treatment and control sites was extracted when Before-After, Control-Intervention (BACI) data were presented, but mean difference was extracted from site comparisons (treatment and reference) and time-series (before and after treatment) when other data were unavailable. Data were extracted from the longest time range where there was a choice to maximise predictive power. Independent data points were extracted, although different species in the same river were considered independent and where habitat manipulation occurred, data from different conditions were treated independently.

Data were extracted preferentially at the reach scale, with variance derived from within-reach replication. However, some manuscripts presented data at the reach scale with genuine replication. These authors were contacted, and asked to provide raw data to allow extraction of variance from within-reach measures. Data points based on between reach variance were included where authors did not respond as it was deemed better practice to include data across scales with down-weighting than to exclude it altogether. Likewise, when change in mean difference was extractable but change in variance was not, pooled variance was included resulting in down-weighting rather than exclusion. Variance was also imputed where p values were presented, and from summary data where no other measures were available. Sensitivity analyses were performed to examine the impact of these data extraction techniques where sample size allowed.

Data extraction was undertaken by one reviewer with a second reviewer checking data hygiene and verifying the robustness of the data extraction.

3.6 Data synthesis

The impact of the in-stream structures was explored using meta-analysis and meta-regression (Cooper and Hedges 1994, Scheiner and Gurevich 2001, Deeks *et al* 2001); these analyses were performed on fish abundance estimates (primarily counts and densities). Cohen's D effect sizes (Deeks *et al.* 2001) were derived from the treatment and control means, standard deviations and sample sizes. This effect size is generated by dividing the mean difference by pooled standard deviation (Cooper and Hedges 1994, Deeks *et al.* 2001) expressing the magnitude of the effect in relation to its variance. Data were pooled and combined across studies using DerSimonian and Laird random effects meta-analysis based on standardised mean difference (SMD) (DerSimonian and Laird 1986; Cooper and Hedges 1994). The random effects model anticipates that the true effect size differs among studies and the aim of the analysis is to quantify such variation in the effect parameters; it is therefore appropriate for ecological questions where the true effect is likely to vary between studies (Gurevitch and Hedges 1999). The standardised mean difference method expresses the size of the treatment effect in each study relative to the variability observed in that study (Deeks *et al*. 2001) allowing combination of the different fish abundance parameters reported in the primary studies.

Separate analyses were performed on in-stream structures, woody debris and *Cottus gobio*. Small sample sizes and the widespread use of combinations of in-stream structures in restoration projects precluded further comparison of types of in-stream-structure. The data was further split into population change and habitat preference (for salmonids), and the impact of riffles and deflectors were analysed separately for *Cottus gobio*. The impact of the in-stream structures or woody debris was examined by inspection of Forrest plots of the estimated treatment effects from the studies along with their 95% confidence intervals, and by formal tests of homogeneity undertaken prior to each meta-analysis (Thompson and Sharp 1999). Publication bias was investigated by examination of funnel plot asymmetry (Egger *et al* 1997).

The relationship between the impact of in-stream-structures or woody debris and explanatory variables was tested by examining the associations of treatment effects with time, discharge and stream width, using random effects SMD meta-regression in Stata version 8.2 (Stata Corporation, USA, 2003) using the program Metareg (Sharp 1998). Sub-group analysis was used to explore variation in impact amongst different species where sample size was sufficient. Other hydrological and ecological factors such as stream gradient, proportion of cobbles in the substrate, degree of existing modification, water quality and canopy cover were insufficiently reported for robust analysis.

4. RESULTS

4.1 Description of studies

Searching was completed in June 2006. 181 studies remained in the systematic review after the abstract stage filter stage (Table 1); 89 were captured using electronic database searches and 92 were found via other sources including Google Scholar. 18 studies selected at the abstract stage have not been obtained at full text for further examination, as they were unavailable from the British Library or other sources. Another 3 relevant studies were gathered through communication and feedback with authors and subject experts.

Table 1: Number of studies included during each of the systematic review filtering stages.

Systematic review stage	**No. of studies**
Studies captured using search terms in electronic databases (excluding duplicates)	*33,500
Studies captured using search terms in electronic databases remaining after title filter	152
Studies from web and organisational searches after title filter	171
Studies remaining after abstract filter	181
Studies remaining after full text filter	134
Relevant studies retrieved through correspondence at draft stage	3
Studies used in meta-analysis	38
Studies summarised in qualitative tables	99

*Approximate figure only

The review included 137 studies. Of these, 99 studies were assessed as non-meta-analysable. 27 were reviews or of broad interest and have been summarised in Appendix 2. 72 studies were qualitative or did not have comparators or variance measures. These have been broadly classed by intervention and are summarised in Appendix 3. Twenty six studies compared multiple interventions, either through multiple in-stream structure types, other interventions such as riparian management or by combining data from multiple sites that had been subjected to different restoration works. Six studies were concerned with land use management and catchment scale works such as riparian cover, grazing and logging. Seven studies compared microhabitat characteristics, which provided correlative data rather than control-intervention. 9 studies were concerned with flow modification and in-stream devices- either with regards to altered flow levels or rechannelisation. 16 studies have been summarised that focus on woody debris. The other studies look at various other types of in-stream devices.

Thirty-eight studies provided quantitative measurements of salmonid or *Cottus gobio* abundance data associated with in-stream structures or woody debris, with a comparator and variance measures. In total 54 independent data points were extracted regarding the impact of engineered in-stream structures on salmonids, with a further 30 data points regarding woody debris and nine concerning *Cottus gobio*. These include additional data points supplied by authors.

There is considerable variation in the key characteristics of quantitative studies (Tables 3-6).

Table 2: Characteristics of studies included in meta-analysis – in-stream structures and population studies

Key:

?	Value unclear or not presented
(x)	Shown after author names, this denotes the number of data points extracted from the paper if more than one.

		Outcome		**Methodological**		**Ecological**		**Hydrological**	
Study Authors	**Intervention(s)**	**Mean difference**	**Abundance measure**	**Design**	**Time (months)**	**Species**	**Age class (yrs)**	**Discharge (m^3s^{-1})**	**Stream Width (m)**
Hartzler 1983	Half-log covers	4.38	Change in mean number over time (from a 380m reach)	BACI	36	Salmo trutta	>1	0.5	7
House 1996 (3)	Multiple devices	1037	Change in total number (from a 1.7Km reach)	BACI (variance pooled and imputed)	96	*Oncorhynchus kisutch*	Juvenile	0.04	8
		26				*Oncorhynchus mykiss*			
		-0.03	Change in density m^2			*Oncorhynchus clarki clarki*			
Linløkken 1997	Four rock weirs, deflectors	-6	Change in number per100 m	BACI (variance pooled and imputed)	96	*Salmo trutta*	Mostly >2	0.95	?
Wang *et al.*2002 (4)	Riprap, fencing, watershed management	-55.85	Change in annual catch	BACI (variance derived from independent reaches)	120	*Salvelinus fontinalis*	?	?	?
		-19.75							
		-82.15				*Salmo trutta*			
		-16.875							
Wu *et al.*	Stream bank cover	0.43	Number m^3	Site	?	*Oncorhynchus*	?	0.05	3.09

2000 (2)		0.32		comparison		*mykiss*		0.59	8.18
Binns 2004	Multiple devices	-600	Numbers per mile	Site comparison across 35 Wyoming rivers	Presumed variable	*Oncorhyncus, Salmo, & Salvelinus* trout genera	Presumed variable		
Binns & Remmick 1994	Multiple devices, fencing	135	Numbers per mile	Pre and post impact	132	*Oncorhynchus clarki utah*	Variable	2	5
Fjellheim *et al*. 2003	Weir creation, boulders	56	Density 100m^2	Pre and post impact (variance derived from t test and imputed)	72	*Salmo trutta*	Mostly <1	?	?
Gargan *et al.* 2002 (2)	Revetments, weirs, rubble mats, lateral scour pools.	-0.00057 0.083486	Change in minimum density (m^2?)	BACI	?	*Salmo trutta* *Salmo salar*	<2 <1	?	?
Hunt 1974	Bank cover, deflectors	0.275	Annual production g/ m^2/yr	Pre and post impact	84	*Salvelinus fontinalis*	Mostly <2	?	9.7
Hvidsten & Johnsen 1992 (2)	Weirs, revetments, bouldering	30 -5	Density (m^2?)	Site comparison	72	Salmo salar Salmo trutta	<1	?	20
Langford *et al.* 2001 (2)	Bouldering, fencing, bank alteration	0.2167 6.927	Density 100 m^2	Site comparison	24	*Salmo trutta* *Salmo salar*	? Parr	?	?
Mesick 1995	Pool creation	0.5	survival index	Site comparison	12	*Salmo trutta*	0-3	6.7	8
Quinn & Kwak 2000 (4)	Revetments, planting stabilization, in-stream structures	-310 700	Change in density (fish/ha)	BACI (variance pooled and	24	*Salmo trutta* *Oncorhynchus mykiss*	At least some >2+	86	?

		940		imputed)		*Salvelinus fontinalis*			
		20				*Oncorhynchus clarki clarki*			
Scruton *et al.*1998	Rewatering and dam removal	-2.57	Density 100 m^2	Pre and post impact	72	*Salvelinus fontinalis, Salmo salar*	Mostly >0+	?	?

Table 3: Characteristics of studies included in meta-analysis – in-stream structures and habitat preference studies

Study Authors	Intervention(s)		**Outcome**	**Methodological**		**Ecological**		**Hydrological**	
		Mean difference	**Abundance measure**	**Design**	**Time (months)**	**Species**	**Age class (yrs)**	**Discharge (m^3s^{-1})**	**Stream Width (m)**
Knudsen & Dilley 1987 (15)	Riprap	148	Petersen & Seber population estimates	BACI (variance pooled and imputed)	0.75	*Oncorhynchus kisutch*	>1	6.4	?
	Streambank relocation, riprap, streambed alteration	-722						0.64	
	Riprap	-19						0.4	
	Streambank relocation, riprap, streambed alteration	35.1						4.9	
	Riprap	-333						2.4	
	Streambank relocation, riprap, streambed alteration	333				*Oncorhynchus mykiss*		6.4	
	Riprap	-57						0.64	
	Streambank relocation, riprap, streambed alteration	-4						0.4	

	Riprap	401						4.9	
	Streambank relocation, riprap, streambed alteration	-119						2.4	
	Riprap	13				*Oncorhynchus clarki*		6.4	
	Streambank relocation, riprap, streambed alteration	17						0.64	
	Riprap	-1.1						0.4	
	Streambank relocation, riprap, streambed alteration	22						4.9	
	Riprap	-17						2.4	
Bjornn *et al* 1991	Riparian cover	2	Change in number of salmon in >26.1m^2 (reach mean)	BACI (variance derived from independent reaches)	0.36	*Oncorhynchus kisutch*	Mostly age 0+	0.03	3
	Undercut bank cover-	-3.1							
	Large boulder cover	3.3							
Brusven *et al* 1986	Artificial cover simulating undercut bank	17	Mean number per 7.6m x 2.5m section	Site comparison	0.06	*Oncorhynchus tshawytscha*	Juvenile	0.05	2.5
Jones *et al* 2003	Ramps, v-weirs, vanes and groins in an artificial stream	-8.9	Change in density m^3	BACI (variance pooled and imputed)	30	*Thymallus arcticus*	Adults	?	?
Mitchell *et al.*1998	Bank devices	-0.5	Numbers (100 m^2?)	Experimental site comparison	1.25	*Salmo salar*	Variable?	0.032	3
	Mid-channel devices	-1							
	Bank devices	0.2						0.063	
	Mid-channel devices	-0.7							
	Bank devices	0.2						0.13	
	Mid-channel devices	-0.7							
Moerke & Lamberti	Remeandering, riparian growth, gravel, riffles	-26.92	Fish per 100m^{-1}	Site comparison	36	*Oncorhynchus kisutch*	Mostly <2	0.03	3

2003	creation. (LWD also included).

Table 4: Characteristics of studies included in meta-analysis – woody debris and population studies

		Outcome		Methodological		Ecological		Hydrological	
Study Authors	**Intervention(s)**	**Mean difference**	**Abundance measure**	**Design**	**Time (months)**	**Species**	**Age class (yrs)**	**Discharge (m^3s^{-1})**	**Stream Width (m)**
Mossop & Bradford 2004	Large wood debris	119	Number per 100m	Site comparison (variance imputed from summary statistics)	72	*Oncorhynchus tshawytscha*	Juvenile	0.1m3s	4.4
Gowan & Fausch 2006 (8)	Large woody debris (structures)	130	Change in number per 250m section	BACI (variance pooled and imputed)	72	*Salvelinus fontinalis*	Adults and Juveniles	?	4.4
		75							
		13							
		63							
		44							
		-25				*Salmo trutta*			
		48				*Oncorhynchus mykiss*			
		5.80			na	*Salmo trutta*			?
Inoue & Nakano 1998	Large and fine woody debris	1000	Density N $100m^{-2}$	Site comparison	60	*Oncorhynchus masou*	Juveniles	?	15.6
Johnson *et al.* 2005	Large woody debris	1950	Population (thousands) in a 25.5 km treatment	Pre and post impact	60	*Oncorhynchus mykiss*	Age 0+	?	15.6

(3)		-150	stretch			*Oncorhynchus clarki clarki*	Adult	?	15.6
		119				*Oncorhynchus kisutch*	Age 0+	0.1m3s	4.4

Table 5: Characteristics of studies included in meta-analysis – woody debris and habitat preference studies

			Outcome	**Methodological**		**Ecological**		**Hydrological**	
Study Authors	**Intervention(s)**	**Mean difference**	**Abundance measure**	**Design**	**Time (months)**	**Species**	**Age class (yrs)**	**Discharge (m^3s^{-1})**	**Stream Width (m)**
Giannico & Hinch 2003	Large Woody debris	-0.1	Fish density (unspecified units)	Experimental site comparison (variance imputed from summary statistics)	12	*Oncorhynchus kisutch*	Juveniles	0.09	5.9
		1.4							
		-0.0375							6.18
		0.62							
Nickelson *et al.*1992		0.29	Change in density m^2	BACI (variance pooled and imputed)	24	*Oncorhynchus kisutch*	Juveniles	?	?
Cederholm *et al.*1997		263.2267	Number (unspecified units)	Pre and post impact (variance imputed from summary statistics)	36	*Oncorhynchus kisutch*	Smolt	1m	10
		95.9							

Culp *et al* 1996		0.9	Change in density m^2	BACI (variance pooled and imputed)	3	*Oncorhynchus mykiss*	Fry	1.43	23
Flebbe 1999		-1.62	Trout numbers per sampling unit (md is equivalent to -0.05 fish m^2)	Site comparison (variance derived from KW test and imputed)	?	*Oncorhynchus mykiss*	Juveniles?	?	3.5
Sweka & Hartman 2006		1.42	Change in density 100 m^2	BACI (variance pooled and imputed)	48	*Salvelinus fontinalis*	Age 1+	?	small
Zika and Peter 2002		49	Number per 100m stream	Site comparison (variance imputed from summary statistics)	36	*Salmo trutta*	Mostly <2	?	4
Giannico 2000		-0.08	proportional distribution	Site comparison	1	*Oncorhynchus kisutch*	Fry	0.04	2
Lehane *et al.* 2002		21.8	Change in numbers per 25m segment	BACI	21	*Salmo trutta*	Variable	0.45	4.7
Horan *et al*		6.4	Fish/100 m^2	Correlative-site comparison	-	*Oncorhynchus clarki pleuriticus*	All	0.4-0.6	-
Bjornn *et al* 1991		-6.4	Change in number of salmon in >26.1m^2 (reach mean)	BACI (variance derived from independent reaches)	0.36	*Oncorhynchus kisutch*	Mostly age 0+	0.03	3

4.2 Meta-analysis

In-stream structures population abundance

Engineered in-stream structures resulted in a small, statistically significant increase in salmonid population abundance (DL SMD 0.566, z 2.01, *p* 0.044) when considering all available data (Figure 1). Exclusion of data with imputed variance resulted in a larger but non-significant effect size (DL SMD 0.823, z 1.66, *p* 0.096). The range of variation in characteristics of the studies resulted in significant heterogeneity in effect size (chi-squared 209.53, df 26, *p*>0.001). Seven individual data points had significant positive effects whilst three had a significant negative effect (Figure 1). This was not related to time (coef -0.007, z -0.92, *p* 0.359), discharge (coef -0.001, z -0.16, *p* 0.872) or stream width (coef-0.07, z -0.78, *p* 0.438). Analysis by species was not possible due to small sample sizes.

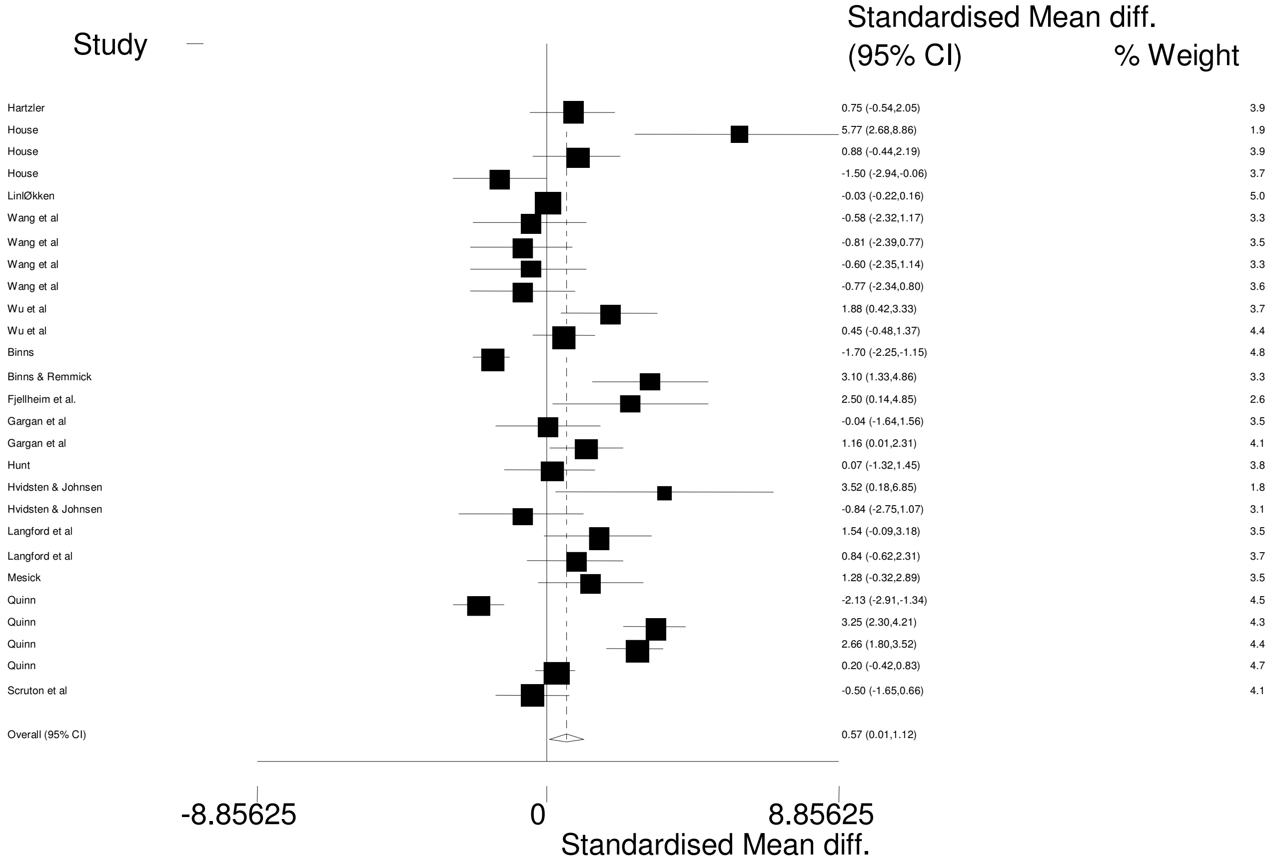


Figure 1: Forrest plot of in-stream structure population study effect sizes. Solid boxes represent the effect size of individual studies; box size is related to sample size; error bars are 95% confidence intervals; the open diamond is the pooled effect size generated using standardized mean difference random effects meta analysis. Note different axis scales when comparing Forrest plots.

In-stream structures-habitat preference

Engineered in-stream structures had no detectable effect on local salmonid abundance, indicating no habitat preference for in-stream structures (DL SMD -0.47, z 1.26, *p* 0.206; DL SMD excluding imputed variance data, -0.41, z 0.96, *p* 0.337) (Figure 2). The range of variation in characteristics of the studies resulted in significant heterogeneity in effect size (chi-squared 169.92, df 26, *p*<0.001). Six individual data points had significant positive effects whilst eight had a significant negative effect (Figure 2). This was not related to time (coef -1.789, z -1.60, *p* 0.111) but there was a small significant relationship with discharge, indicating that in-stream structures may provide preferential habitat at higher discharges (coef 0.437, z 3.15, *p* 0.002). Analysis by species was not possible due to small sample sizes.

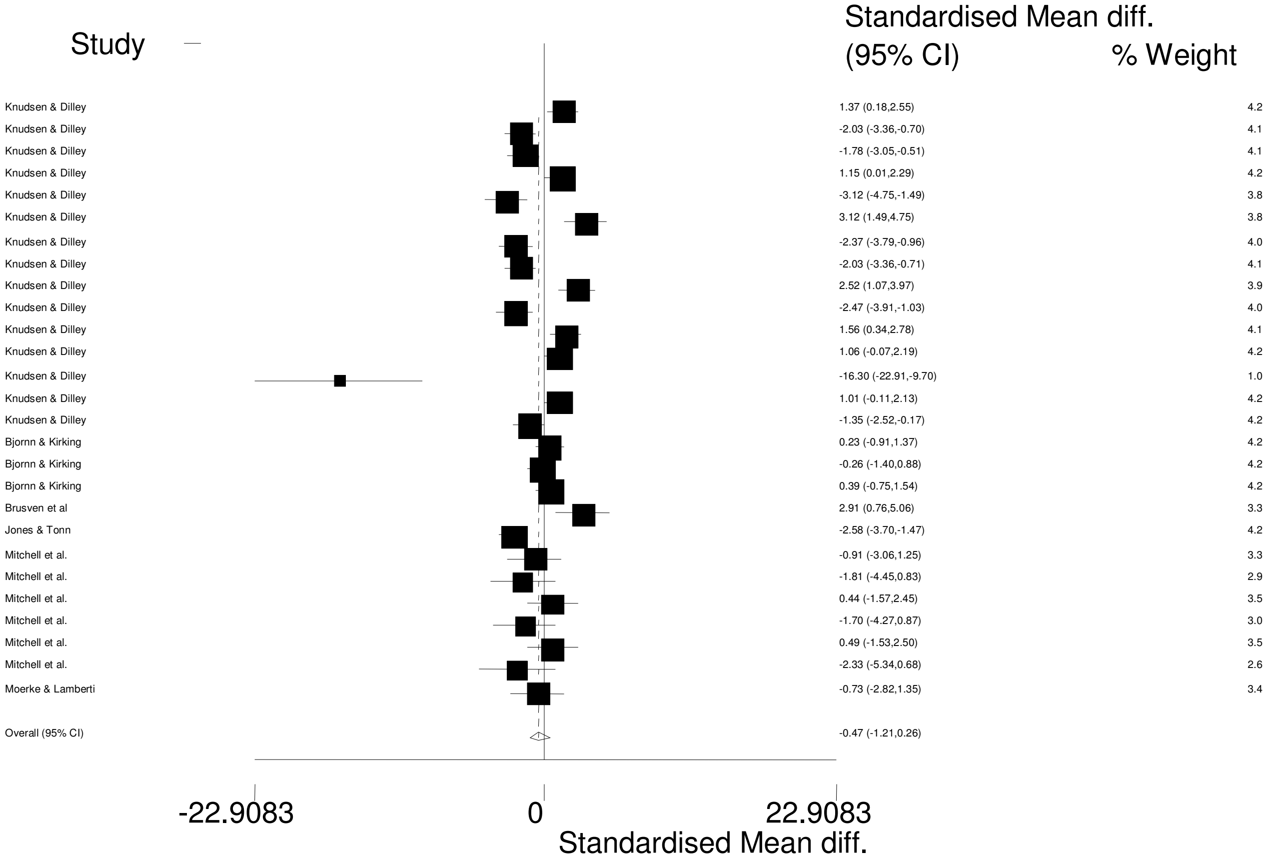


Figure 2: Forrest plot of in-stream structure habitat preference study effect sizes. Solid boxes represent the effect size of individual studies; box size is related to sample size; error bars are 95% confidence intervals; the open diamond is the pooled effect size generated using standardized mean difference random effects meta analysis. Note different axis scales when comparing Forrest plots.

Funnel plot asymmetry and the Egger test suggest that there is no significant publication bias in the in-stream data set (Egger bias 0.262, *p* 0.658) (Figure 3).

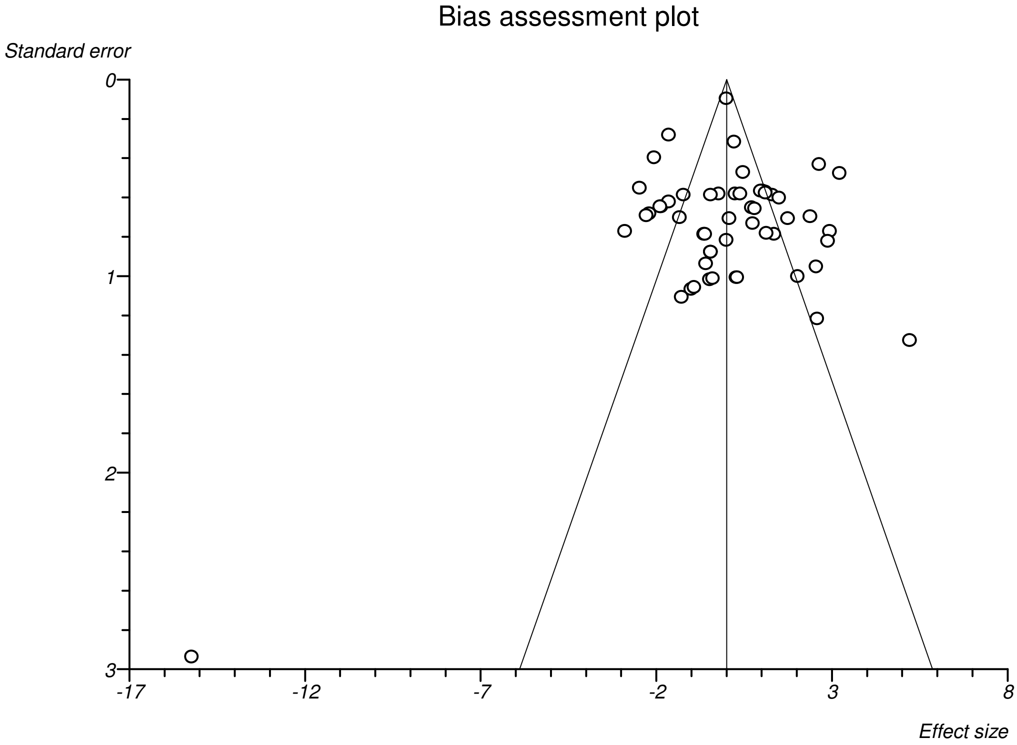


Figure 3: Funnel plot of in-stream structure effect size - standard error relationship. The line perpendicular to the x axis represents pooled effect size, with studies outwith the triangle illustrating positive or negative bias.

Woody debris and population abundance

Presence of woody debris resulted in the largest increase in salmonid population (DL SMD 5.32, z 4.31, p<0.001) when considering all data, including those with imputed variance. (Figure 4). The range of variation in characteristics of the studies resulted in significant heterogeneity in effect size (chi-squared 127.56, df 12, p<0.001). Six individual data points had significant positive effects whilst none had a significant negative effect (Figure 4). Some variation is due to species as *Salvelinus fontinalis* has a bigger significant effect size than data combined across species (DL SMD 17.29, z 3.53, p<0.001) indicating that woody debris has a bigger impact on *Salvelinus fontinalis* than salmonids in general. Analyses of other species were not possible due to small sample sizes.

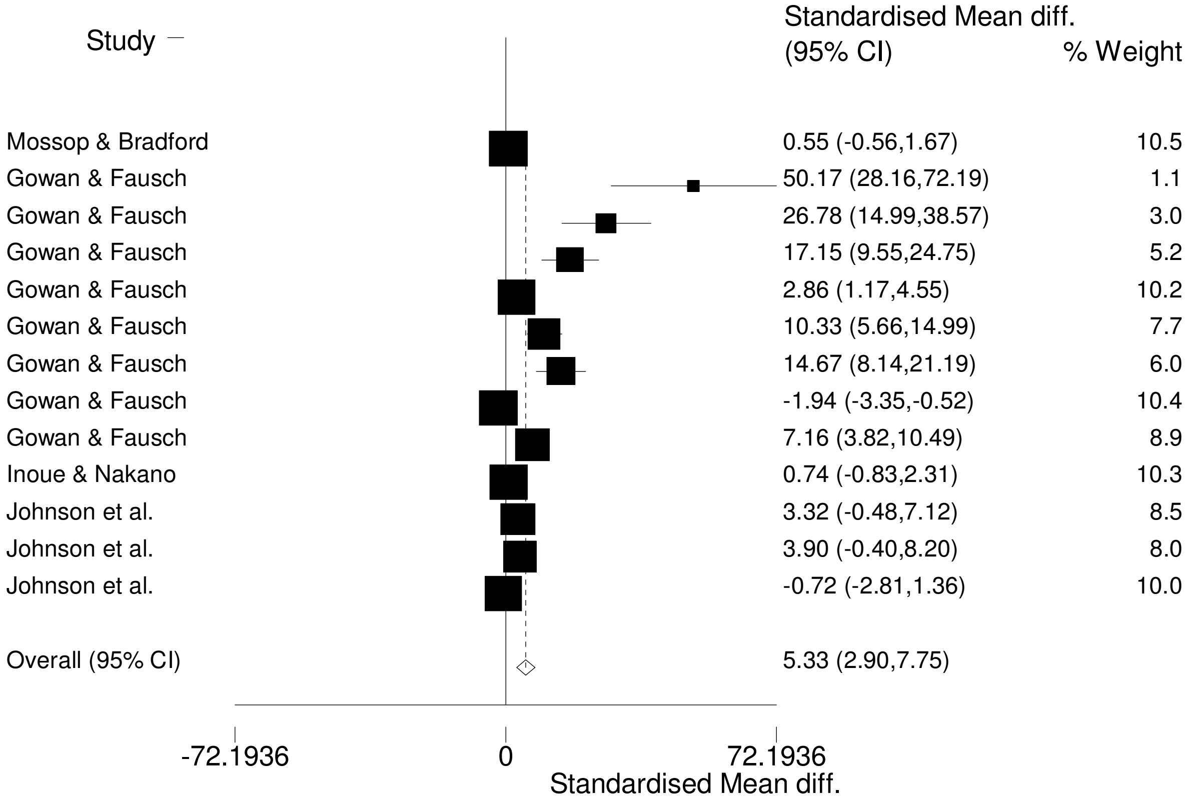


Figure 4: Forrest plot of woody debris population study effect sizes. Solid boxes represent the effect size of individual studies; box size is related to sample size; error bars are 95% confidence intervals; the open diamond is the pooled effect size generated using standardized mean difference random effects meta analysis. Note different axis scales when comparing Forrest plots.

Woody debris and habitat preference

Presence of woody debris resulted in an increase in local salmonid abundance, indicating some habitat preference for woody debris (DL SMD 0.936827 (z= 2.79 p = 0.005) (Figure 5). Exclusion of data with imputed variance resulted in a smaller non-significant effect size (DL SMD 0.49706 (z= 1.46 p = 0.146). The range of variation in characteristics of the studies resulted in significant heterogeneity in effect size (chi-squared 99.83, df 13, p<0.001). Six individual data points had significant positive effects whilst none had a significant negative effect (Figure 5). This was weakly related to time (coef 0.08, z 2.93, p 0.003) and discharge (coef 1.85, z 3.32, p 0.001), but not stream width (coef 0.104, z 1.65, p 0.1) indicating that woody debris may provide preferential habitat over longer time periods and at higher discharges. Further heterogeneity was accounted for by species. Sub-group analysis indicated that *Oncorhyncus kisutch* local abundance did not increase significantly in response to woody debris although salmonids in general did (DL SMD 0.899, z 1.59, p 0.111). Small sample sizes precluded investigation of other species..

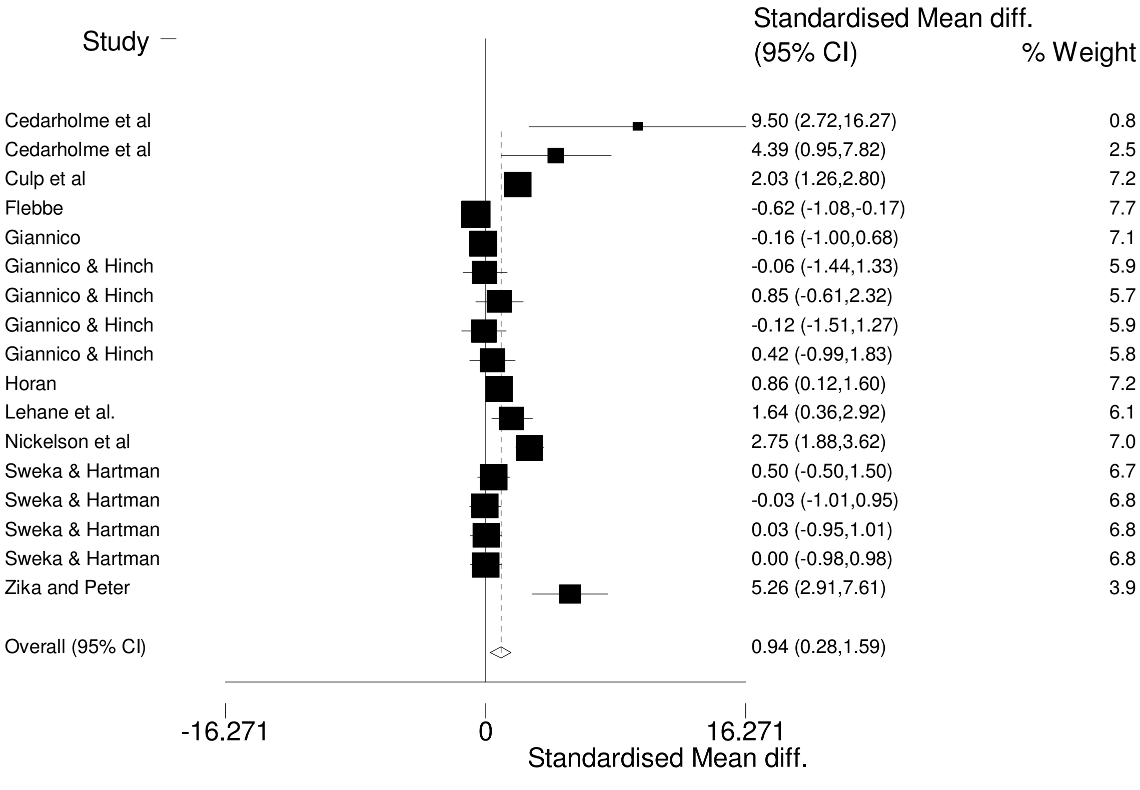


Figure 5: Forrest plot of woody debris habitat preference study effect sizes. Solid boxes represent the effect size of individual studies; box size is related to sample size; error bars are 95% confidence intervals; the open diamond is the pooled effect size generated using standardized mean difference random effects meta-analysis. Note different axis scales when comparing Forrest plots.

Funnel plot asymmetry and the Egger test suggest that there is considerable bias in the woody-debris data set as there are fewer small negative studies than one would expect (Egger bias 3.847427 , $p < 0.0001$) (Figure 6).

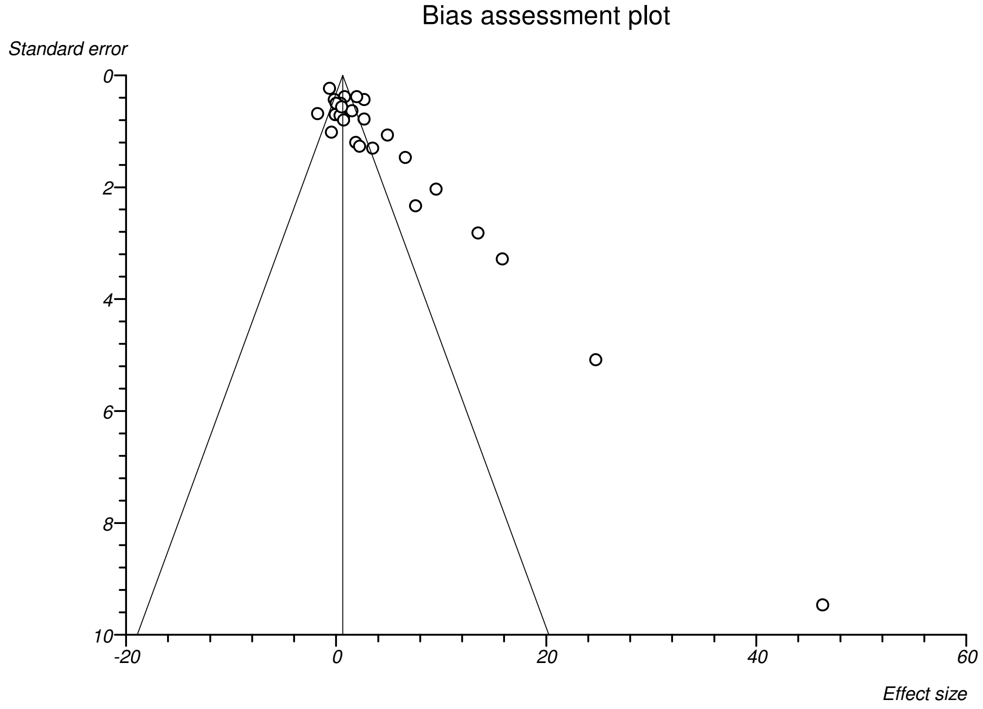


Figure 6: Funnel plot of woody debris effect size - standard error relationship. The line perpendicular to the x axis represents pooled effect size, with studies outwith the triangle illustrating positive or negative bias.

The following table (Table 5) summarises the results of the meta-analyses.

Table 5: Summary of statistical significance of meta-analyses

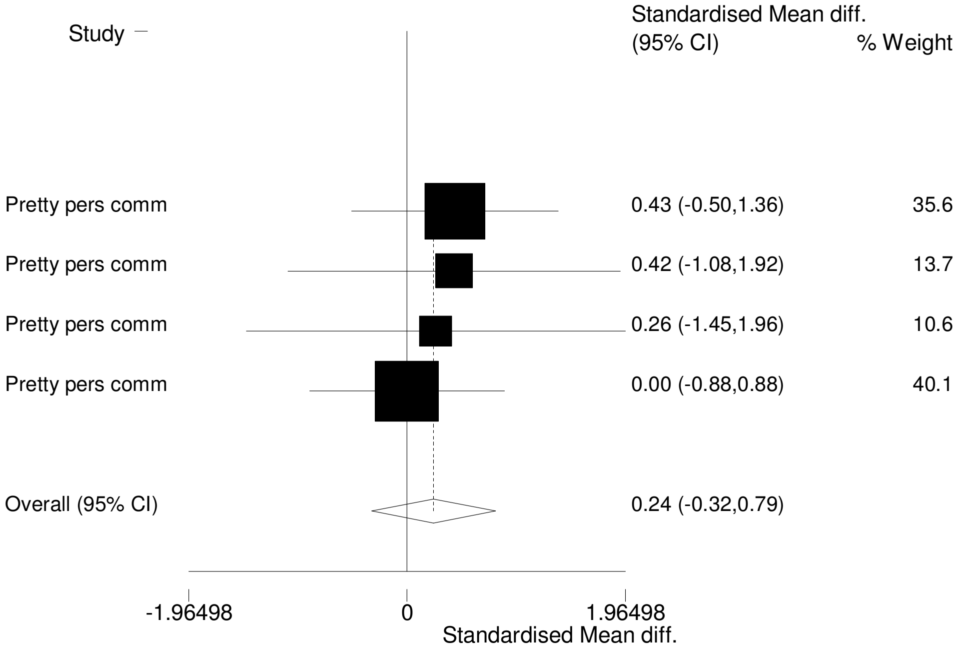
Meta-analysis	Statistical significance	Ecological significance
In-stream structures- population abundance	s (0.566) *p*<0.05	ns
In-stream structures- habitat preference	ns (-0.47) *p*>0.05	ns
Woody debris- population abundance	s (5.32) *p*<0.001	s
Woody debris- habitat preference	s (0.936827) *p*<0.001	ns

ns = not statistically significant
s = statistically significant
( ) = DL SMD

Statistical significance does not mean that an outcome is ecologically significant.

Cottus gobio

Raw data were provided by Pretty to enhance those provided in Pretty *et al* 2003 allowing comparison of the effects of specific in-stream devices, namely deflectors and riffles, on the bullhead, *Cottus gobio*. Deflectors resulted in no significant change in abundance (DL SMD 0.238, z 0.84, *p* 0.4) with no significant heterogeneity between data points (.chi-squared 0.51, df 3, *p* 0.918) (Figure 7a). Riffles resulted in a significant increase in local abundance (DL SMD 0.804, z 2.01, *p* 0.044) with significant heterogeneity between data points (chi-squared 13.32, df 4, *p* 0.01) due to the Knapkens *et al* (2002) data point showing a significant positive impact, whereas the Pretty *et al* data points showed no significant impact (Figure 7b).



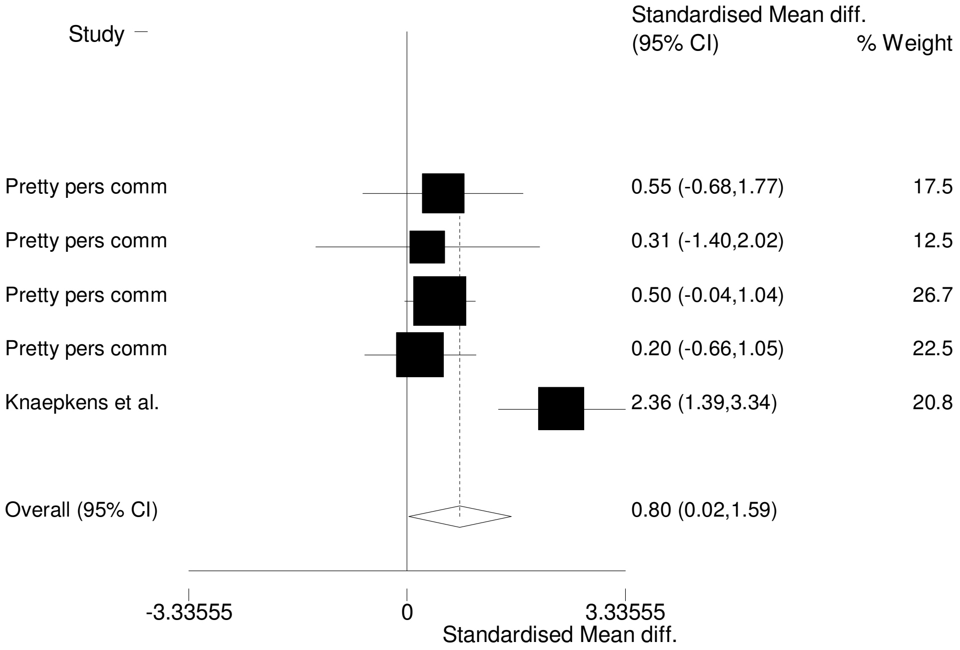


Figure 7: Forrest plot of *Cottus gobio* study effect sizes. The upper plot (a) = deflectors, the lower plot (b) = riffles; Solid boxes represent the effect size of individual studies; box size is related to sample size; error bars are 95% confidence intervals; the open diamond is the pooled effect size generated using standardized mean difference random effects meta analysis. Note different axis scales when comparing Forrest plots.

5. DISCUSSION

5.1 Evidence of effectiveness

This systematic review provides substantial evidence that engineered in-stream structures have little or no ecologically significant impact on salmonid population size, and do not provide a preferred habitat. The overall population analysis for engineered in-stream structures is statistically significant but the effect size is small, reflecting both the small mean differences of the included studies and high variance. Other analyses lack statistical significance. Much of the variance cannot be explained by covariates with the limited data presented (see below).

Some practitioner experience suggests that engineered structures are successful in otherwise healthy waterways (O'Grady, 2006). Water quality and degree of existing modification are considered critical limiting factors which may mask any impact of in-stream habitat remediation (Roni, Cowx and O'Grady pers comm.).

Insufficient and inconsistent reporting of water quality precludes robust investigation but studies reporting high water quality (i.e. Linløkken 1997) do not demonstrate increased effectiveness. This may reflect confounding by other variables such as degree of existing modification.

Studies with a high degree of existing modification (Linløkken 1997, Scruton 1998, Wang 2002 and Quinn & Kwak 2000) demonstrate lower effectiveness than studies with a lesser degree of modification (Binns and Remick 1994; Langford 2001). Thus, engineered in-stream devices are less effective where existing habitat modification is high. As with water quality, lack of standardized reporting and small sample sizes prevent formal analysis. Support for the effectiveness of in-stream structures in otherwise healthy waterways therefore remains speculative.

Available evidence suggests that woody debris has a significant impact on salmonids resulting in increased population abundance. The effect size is large (>5) reflecting the large mean differences and low variance of most studies. There is a lesser, but still significant, positive impact on habitat preference, although exclusion of imputed variance data reduces statistical significance below the 0.05 threshold, probably explained by lack of power (n=6).

Sample sizes are small for analyses of *Cottus gobio,* with only two studies providing four data points for deflectors and five for riffles. The available evidence suggests that riffles provide *C. gobio* with preferential habitat but deflectors do not appear to increase population size. However, the generality of these conclusions is clearly open to question, given the limited work available.

Comparisons between the relative effectiveness of in-stream structures and woody debris can only be made indirectly. Given the lack of direct head to head comparisons, results must be interpreted carefully. Available evidence suggest that woody debris is effective at increasing salmonid populations and provides preferential habitat, whereas engineered in-stream structures are much less effective. Furthermore the effect size for change in salmonid abundance is an order of magnitude higher for woody debris than for engineered in-stream structures. It is possible that the different context of woody debris (generally found in low order, high gradient, mountain streams) and engineered in-stream structures (all streams) may be responsible for the perceived variation in impact; although investigation of reasons for variation suggests otherwise (see below).

5.2 Reasons for variation in effectiveness

There are no significant relationships between the effectiveness of in-stream structures and measured hydrological or ecological variables at a population level, although there is limited evidence that engineered in-stream structures provide preferential habitat at higher discharges. However, the impact of many variables was not investigated because of lack of reporting and small sample sizes. It is interesting to note that other authors have suggested that in-stream structures are more effective at higher discharges (Mitchell *et al* 1998) and lower gradients (Hamilton 1989).

The positive impact of woody debris is especially pronounced for *Salvelinus fontinalis*. Woody debris provides more preferential habitat at longer timescales and higher discharges, but is less effective for *Oncorhynchus kisutch* than other salmonid species. As with in-stream structures, lack of reporting and small sample sizes precluded investigation of all variables of interest, including analysis of other species. It must also be recognised that some of these correlations may be misleading, as numerous study characteristics could account for the differences in effect size. Nevertheless, the results are consistent with other workers who suggest that woody debris is most effective as a habitat refuge at high flow (Bunt *et al* 1999) and over long timescales (Opperman 2004). The apparent variations between salmonid species may be related to differences in age groups. For example, the data for *Oncorhynchus kisutch* were taken from juvenile or smolt counts, and research suggests that salmonids use different habitat types at different stages of their life cycle (APEM Ltd. 1996).

5.3 Concurrence with excluded literature

Literature excluded from the meta-analysis suggests that engineered structures have variable impacts on salmonids whereas literature regarding the physical habitat suggests that favourable habitat conditions should be increased. The former is consistent with the meta-analysis but the latter indicates a discrepancy between biological and physical outcome measures. This suggests that either the beneficial effects of the engineered in-stream structures are being countered by other variables or that the conditions do not improve as expected.

Literature regarding the use of woody debris does suggest that it increases salmonid abundance at both a population, and, especially during some life stages, at a micro-habitat scale. This concurs with the findings of the meta-analyses.

Literature also reports some detrimental effects of woody debris, as it can act as a barrier to migration, provide habitat for predators, and alters hydrological flow. Managers must balance these conflicting trade-offs to achieve suitable outcomes for their site.

5.3 Methodological limitations

There are three possible methodological limitations to this overview that need to be borne in mind: limitations of the original research, extraction of data and publication bias.

The original research synthesised in the analyses is of variable quality. Much currently available data is of inadequate duration, poorly replicated and reported. This problem is exacerbated by the combination of BACI designs, time series data and site comparisons. Numerous methodological factors vary along with ecological and hydrological modifiers, presenting intractable complexity given the sample sizes available.

Data extraction introduces bias where variance is imputed, particularly if the variance is calculated from summary statistics. The method is defensible provided the bias does not overweight the study, but the combination of large numbers of studies with imputed variances remains problematic. We tried to partly address any shortcomings using sensitivity analysis to clarify areas of uncertainty but were hampered by sample size and could not run sensitivity analysis for woody debris population data as only four points from two studies did not have imputed variance.

Although steps were taken to minimize publication bias by searching grey literature, we are aware of literature that exists that has not been captured. It is therefore possible that there are some studies that we have not identified despite our systematic efforts to do so. The Egger Test (Egger *et al.* 1997) uses a regression method to assess the symmetry of funnel plots, and shows evidence of asymmetry, with less favourable results unreported (hence possible publication bias) for woody debris The practical effect of this is that the magnitude of the effectiveness of woody debris may be smaller than our estimates suggest.

6. REVIEWERS' CONCLUSIONS

6.1 Implications for conservation

Available evidence suggests that engineered in-stream structures do not have an ecologically significant impact on the populations of salmonids, although they may provide preferential habitat where discharge is high (>6m^3s^{-1}). High levels of heterogeneity between studies suggests that conservation managers may need to consider other underlying environmental factors when considering the most appropriate action for each site.

Woody debris can increase the population abundance of salmonids, especially *Salvelinus fontinalis*. It may also provide more preferential habitat over time (>4 years) where discharge is high (>$1 m^3 s^{-1}$) but does not appear to provide habitat for *Oncorhynchus kisutch*. Managers need to consider the wider role of woody debris within their sites to assess whether it acts as a barrier to migration or may offer more beneficial effects.

Cottus gobio populations are not increased by deflectors but riffles may provide preferential habitat.

6.2 Implications for research

Much currently available data is of inadequate duration and assesses habitat preference rather than long-term population change. Reach and water-shed scale studies are also rare in comparison to habitat unit studies. The use of independent treatment and controls, replication, and rigorous parameters of abundance should be encouraged.

Numerous confounding variables operate in riverine systems and sample sizes are currently too small to assess the impact of many factors in a robust manner. Further monitoring is required to fully evaluate the potential impact of time, discharge and species. Other hydrological and ecological factors such as stream gradient, proportion of cobbles in the substrate, degree of existing modification, water quality and canopy cover are insufficiently reported and studied, although they are known to impact fish populations.

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8. POTENTIAL CONFLICTS OF INTEREST AND SOURCES OF SUPPORT

No potential conflicts if interest reported. Financial support from NERC Knowledge-transfer/ Environment Agency funding

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10. APPENDICES

APPENDIX 1 – DATA EXTRACTION FORMS FOR STUDIES INCLUDED IN META ANALYSIS

Reference	**Binns**
Location	Wyoming, USA
Subject	Oncorhynchus, Salmo, & Salvelinus trout genera
Intervention	revetments, check dams, deflectors, rock weirs, boulders, wooden bank cover, trash-catcher, livestock exclusion, LWD, rock funnels, pool excavation, flow modification
Methodology	Site comparisons were combined from 35 reaches where one or more interventions had occurred to assess the overall impact of in-stream improvement in Wyoming.
Sources of bias	This is effectively a multi-site comparison so variation between sites could impact the results. Additional bias stems from generation of mean values which were combined across studies with no weighting (e.g. inverse variance). This also means the impact of variation in in-stream improvement intervention cannot be assessed (hence no reasons for heterogeneity).

Outcomes	treatment			control		
	n	m	sd	n	m	sd
Trout numbers per mile	35	600	300	35	1200	400

Reasons for heterogeneity	time (no information on age of in-stream devices), mean flow (unknown), stream gradient (6), proportion of cobbles in substrate (dominant cf 75%?),degree of existing modification (unknown assumed low?), distance from source (3km), water quality (unknown), size of stream (3.5), canopy cover (hard wood forest assumed high cf 20%?).
Pop/pref	population due to catchment wide scale
Extraction	data were abstracted from Figure 1 with associated reading error.
Notes	The author was contacted and asked to provide the raw data which would provide 35 data points rather than a single (albeit heavily weighted) effect size

Reference	**Binns & Remmick**
Location	Huff Creek, Idaho, USA
Subject	Oncorhynchus clarki utah (Bonneville cutthroat trout)
Intervention	in-stream habitat structures (36 wooden dams, 9 rock plunges, wooden double deflector, rock deflector, 14 small rock grade controls) rock riprap, fencing of banks

Methodology	Before and after monitoring
Sources of bias	Confounding impacts concurrent with the habitat improvement are probably the most important sources of bias. Post improvement droughts occurred resulting in a likely under-estimate of effectiveness.

Outcomes	post intervention			pre intervention		
	n	m	sd	n	m	sd
Habitat quality index (HQI)	6	38	2	6	30	2
Trout numbers	6	170	59	6	35	18

Reasons for heterogeneity	Monitoring time 11 years. Discharge is extremely variable with a mean of 6ft3/s, stream gradient (1%), proportion of cobbles in substrate (common in half of river, estimated at 25%),degree of existing modification (heavy grazing but river unmodified- low), distance from source (6km), water quality (no information), size of stream (small stream >5m), canopy cover (low >5%).
Pop/pref	population
Extraction	habitat quality pre and post treatment, from text and figure 6. trout numbers from text and table 2. n is the number of sites. Maximum time range was used for post treatment assessment (11 years). Some data is presented for individual sites which allows some separation of features. This was not extracted i) to maintain independence, ii) because no pre treatment assessments are available at a site level
Notes	HQI was evaluated for cutthroat trout. population sizes were estimated using electrofishing (Armour et al. 1983) with degree of population fluctuation assessed as in Platts and Nelson (1988). Much other data regarding both physical habitat and trout was presented but not extracted.
References	Armour, C.L., Burnham, K.P., and Platts, W.S. (1983) Field methods and statistical analysis for monitoring small salmonid streams. U.S. Fish and Wildlife Service FWS/OBS 83/33. Platts, W.S. and Nelson, R.L. (1988) Fluctuations in Trout populations and their implications for land-use evaluation. North American Journal of Fisheries Management 8. 333-345.

Reference	**Bjornn *et al*.**
Location	Staney/Shaheen Creeks, Prince of Wales Island, Alaska
Subject	Oncorhynchus kisutch (Coho salmon)
Intervention	addition of riparian cover, woody debris cover, undercut bank cover and large boulder cover
Methodology	BACI Design with four treatments
Sources of bias	BACI design minimizes bias but only one control is used for four comparisons. However use of genuine replication rather than pseudoreplicated points minimizes bias by reducing the number of comparisons sixfold.

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd

riparian cover- change in number of salmon	6	0.8	11.5	6	-1.2	4.5
LWD- change in number of salmon	6	-7.6	12.2	6	-1.2	4.5
undercut bank cover- change in number of salmon	6	-4.3	16.1	6	-1.2	4.5
large boulder cover- change in number of salmon	6	2.1	11	6	-1.2	4.5

Reasons for heterogeneity time (11 days), mean flow (0.03m3/s1), stream gradient (unknown), proportion of cobbles in substrate (unknown),degree of existing modification (previously logged-high), distance from source (unknown), water quality (unknown), size of stream (3m), canopy cover (alder cover but unquantified-medium).

Population/Preference Assessment of fish number was made only 11 days after cover addition therefore the study is concerned with habitat preference

Extraction Data was extracted from Table 3. Theoretically pseudoreplicated data could have been used to provide six effect sizes for each treatment rather than one (although only means were presented) but genuine replication was used as i) this downweights the number of points extracted from this study minimizing potential bias derived by comparing four treatments to one control and ii) SDs for change over time were calculable.

Notes Other data is presented regarding the response of fish to removal of cover and the recolonization rate when fish were removed. The change over time SDs are much smaller than pooled SDs substituted in other studies when they are incalculable resulting in downweighting of studies where all data is not presented

Reference **Brusven *et al*.**

Location South Fork Salmon River, Idaho, U.S.A

Subject Oncorhynchus tshawytscha (Chinook Salmon)

Intervention artificial cover simulating undercut bank

Methodology randomized block design (but data presented is essentially a site comparison)

Sources of bias Fish distribution is not reported prior to the experiment therefore it is not clear if treatment and control sites were similar prior to treatment

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Chinook Salmon mean number per section	4	22.125	7.5	4	5.125	3.49

Reasons for heterogeneity time (48 hours), mean flow (0.05m3/s), stream gradient (unknown), proportion of cobbles in substrate (removed by hand-0),degree of existing modification (artificial channel-high), distance from source (unknown), water quality (unknown), size of stream (2.5m), canopy cover (riparian vegetation cut-0).

Population/Preference small scale experimentation to determine habitat preference

Extraction Data was extracted from Table 2. Data from 1980 was extracted in preference to data from 1981 as 1981 experimentation involved stocking. July and August data were averaged rather than selecting one month or the other.

Reference	**Cederholm *et al***
Location	North Fork Porter Creek, Washington, USA
Subject	Oncorhynchus kisutch (Coho Salmon)
Intervention	LWD
Methodology	BACI design but only time series data presented. Two methods for the addition of LWD were used in this study- one used an engineered approach where imported logs were anchored using a variety of methods- a second approach (the "logger's choice") used chain to tether felled trees to their stumps.
Sources of bias	It is not clear if the change in population is due to the addition of LWD or some other factor (control data not presented with n). The post treatment data is entered twice resulting in problems of independence. LWD naturally entered reference stretch as a result of storms etc during the experimental period, fish were stocked in pre-treatment years. SDs were extracted temporally (sensitivity analysis).

Outcomes	Treatment or Post-Intervention			Control or Pre-Intervention		
	n	m	sd	n	m	sd
ENGINEERED - Change over time treatment and control	3	252.6466667	31.36426417	3	-10.58	23.50514063
LOGGER'S CHOICE - Change over time treatment and control	3	85.32	20.0756237	3	-10.58	23.50514063

Reasons for heterogeneity	time (3 years pre- and post treatment), mean flow (discharge (av annual) 1m3/s, low summer flow of 0.05m3/s), stream gradient (2%), proportion of cobbles in substrate (),degree of existing modification (), distance from source (), water quality (), size of stream (width 10m av), canopy cover (post logging regrowth).
Population/Preference	population assessed using electrofishing
Extraction	Data extracted from Figure 6- each year pre-treatment and each post is treated as a replicate as no SD presented- can not extract from fig 5 etc as sample size not known.
Notes	Additional BACI data broken down into fish species not extractable as n is unreported.

Reference	**Culp *et al***
Location	Jumping Pound Creek, Alberta, Canada
Subject	Oncorhynchus mykiss (Rainbow Trout)
Intervention	LWD - but FINE woody debris
Methodology	BACI type design monitoring change over time in treatment and control- 40 sites selected, 20 had FWD added, 20 were controls, min 4m apart within stream reach. Surrounded instalments by minnow nets before triple-pass electrofishing.
Sources of bias	Design minimizes bias. Data read from graph, SDs pooled resulting in underweighting of the study (sensitivity analysis).

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Change in density of Rainbow Trout fry (no/m2)	20	1.05	0.55	20	0.15	0.3

Reasons for heterogeneity time (3 months), mean flow (mean discharge at confluence is 1.43m3/s), stream gradient (?), proportion of cobbles in substrate (sand, gravel and cobble-),degree of existing modification (), distance from source (?), water quality (assumed to be quite good as provides rich habitat for invertebrate microfauna and other fish species), size of stream (width 23m, depth 0.5m), canopy cover (open meadow with aspen, willow and poplar).

Population/Preference Preference - short term, small spatial scale (within reach) and deals with fry.

Extraction Density of fry (no/m2) extracted from Fig 4 p475. Data read from graph, and includes control and intervention data for longest time range available (I.e. day 220 and day 300 for with and without FWD). SEs also read from graph and SDs calculated from this. Calibration of graph reading: 2mm = 0.1 of a fish. SDs before and after intervention were pooled

Notes Experimental design aimed to reduce effects of sampling methods by moving upstream, and electrofishing should impact fry at both control sites and interventions equally.

Reference De Jong *et al*.

Location Joe Farrell's Brook, Newfoundland, Canada

Subject Salmo salar (Atlantic Salmon), Salvelinus fontinalis (Brook trout)

Intervention boulder clusters, V-dams, half-log covers v no devices

Methodology Before and after monitoring (a reference control is mentioned in the methods but no data are presented regarding it)

Sources of bias Confounding impacts concurrent with the habitat improvement are probably the most important sources of bias.

Outcomes	post intervention			pre intervention			
	n	m	sd	n	m	sd	
trout density boulder cluster	4	0.02	?	4	0.014	?	sig
trout density v dam	4	0.05	?	4	0.026	?	ns
trout density half-log cover	2	0.04	?	2	0.035	?	ns
salmon density boulder cluster	4	0.19	?	4	0.06	?	sig
salmon density v dam	4	0.3	?	4	0.06	?	sig
salmon density half-log cover	2	0.056	?	2	0.03	?	sig

Reasons for heterogeneity time (24months), mean flow (0.49ms), stream gradient (0.19%), proportion of cobbles in substrate (unknown),degree of existing modification (clear cutting of forest, channelisation and removal of in-stream substrate and creation of dams result in heavily modified river), distance from source (<18.4km), water quality (unknown), size of stream (9.3), canopy cover (47.6).

Pop/pref	
Extraction	Data were extracted from figure 2 although this necessitated extracting before and after data rather than the BACI data which the methods infer exist. Data extraction is problematic as results were read off a graph with associated transcription error. furthermore fish densities were averaged across age classes assuming equal numbers of fish in each age class. Standard deviations could not be extracted from the data presented. Habitat attributes are means across all measurements presented. Before data (1993), after data (1995).
Notes	The author's general conclusion was that restoration techniques increased habitat heterogeneity and degree of complexity in channelised sections therefore reducing competition and increasing production of salmonids.
Reference	**Fjellheim *et al*.**
Location	River Teigdalselva, Western Norway
Subject	Salmo salar L. (Atlantic Salmon) and Salmo trutta L. (Brown Trout)
Intervention	Construction of 4 weir basins and bouldering on substrate in one inlet to facilitate spawning
Methodology	Before-after; site comparison mentioned but non-extractable
Sources of bias	Confounding caused by stocking of both Salmo salar and S. trutta in the river from 1990-1996
Outcomes	

	Post Treatment			Pre-treatment		
	n	m	sd	n	m	sd
Trout density individuals (100m2)-1	3	65	21	3	9	23.8

Reasons for heterogeneity	time (1991-1997), mean flow (100+ to less than 0.2m3s-1), stream gradient (?), proportion of cobbles in substrate (in experimental weir basin went from low (very fine substrate) to higher (greater proportion of boulder clusters)),degree of existing modification (weir pools created), distance from source (unknown), water quality (was acidic, containing labile aluminium and ANC quantities, later shells and added to increase pH.), size of stream (wide), canopy cover (surrounded by farmland and mixed forest, cover not apparent).
Extraction	Before and after data extracted from Fig.6 (p.21), showing Brown Trout densities at area of experimental substrate manipulation, pre-treatment sd estimated using reverse t-test, assuming variables for both are the same.
Notes	Paper suggests habitat improvement more effective than stocking on fish numbers, but confounded as both occurred during the test reaches- also does not present weir information in an extractable way.
Reference	**Flebbe**
Location	Wine spring Creek, North Carolina, U.S.A
Subject	Oncorhynchus mykiss (Rainbow trout)
Intervention	23 LWD engineered structures and naturally occurring LWD compared to no woody debris

Methodology	Site comparison
Sources of bias	The primary source of bias associated with this site comparison is potential confounding e.g. the Lower Creek is dominated by boulders rather than cobbles and has a higher gradient. Lack of independence of treatment and control may also bias results. Data extraction makes assumptions regarding sample size and variance.

Outcomes	Upper Wine Spring Creek (LWD + structures)			Lower Wine Spring Creek (no LWD)		
	n	m	sd	n	m	sd
Trout numbers per sampling unit	42	1.85	3.73	42	3.47	3.73

Reasons for heterogeneity	time (~20 years), mean flow (unknown), stream gradient (6), proportion of cobbles in substrate (dominant cf 75%?),degree of existing modification (unknown assumed low?), distance from source (3km), water quality (unknown), size of stream (3.5), canopy cover (hard wood forest assumed high cf 20%?).
Pop/pref	habitat preference (assessed by counts using snorkelling fish surveyors)
Extraction	The data presented in this paper is mostly concerned with occupancy. Table 3 provides estimates of trout numbers at different parts of the catchment. Lower Wine Spring Creek was selected as a control because it contains no woody debris and Upper Wine Spring Creek was originally selected as a treatment because it contains 23 wooden engineered structures with an additional 87 pieces of LWD/km. Following communication with the author, Lower and Mid Wine Spring Creek were used, and standard errors were provided.

Reference	**Gargan *et al***
Location	Lough Corrib Catchment, W Ireland.
Subject	Salmo trutta (Brown Trout) Salmo salar (Atlantic salmon)
Intervention	revetments, weirs, rubble mats, lateral scour pools.
Methodology	BACI design
Sources of bias	BACI design minimizes bias

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
change in older brown trout minimum density	3	-0.001133333	0.021016739	3	-0.000566667	0.006867557
change in salmon parr minimum density	7	0.050757143	0.064161589	7	-0.032728571	0.079023851

Reasons for heterogeneity	time (unknown), mean flow (unknown), stream gradient (unknown), proportion of cobbles in substrate (unknown),degree of existing modification (unknown), distance from source (unknown), water quality (unknown), size of stream (unknown), canopy cover (unknown).
Population/Preference	although timescale is unknown fish populations were estimated over a number of years using electrofishing
Extraction	Data was extracted from appendices 2 and 3. Mean change over time was extracted before and after intervention in treatment and control

	sites. Where there were multiple measures for one site the average was taken. SDs were calculated based on change before and after treatment with n represented by the number of paired data points. Data was extracted from Salmon parr and old trout (older fish) preferentially over fry and young fish to maintain independence.
Reference	**Giannico**
Location	Spring Creek, British Columbia, Canada
Subject	Oncorhynchus kisutch (juvenile coho salmon)
Intervention	woody debris consisting of bundles of tree branches (FWD)
Methodology	site comparison between experimental treatments in two stretches of the creek
Sources of bias	Variation in site conditions could impact the result of the experiment (replication is temporal)
Outcomes	

	treatment			control		
	n	m	sd	n	m	sd
proportional distribution of salmon fry	11	0.12	0.5	11	0.2	0.5

Reasons for heterogeneity	time (1 month), mean flow (0.04m3s), stream gradient (?), proportion of cobbles in substrate (moderate cf 20%),degree of existing modification (golf course above experiment and in-stream structures -high), distance from source (unknown), water quality (unknown), size of stream (2), canopy cover (moderate in lower half of stream cf 10%).
Pop/pref	habitat preference measured by introducing experimental fish into the experimental set up 11 times
Extraction	Data was extracted from figure 5 (with associated reading error). The legend is erroneous therefore it is assumed that open bars represent an additional feeding experiment (as in the other figures). Data was only extracted for no cover-no food and dense fwd-no food treatments. This experiment was preferentially extracted to experiment 1 as food addition was not a split-plot treatment (both could not be extracted whilst maintaining independence).
notes	This paper demonstrates that food is important in determining habitat preference and as food supply varies seasonally, fish prefer pools with woody debris in summer but not in spring
Reference	**Giannico & Hinch**
Location	Squamish river, British Columbia, Canada
Subject	Oncorhynchus kisutch (juvenile coho salmon)
Intervention	LWD debris bundles
Methodology	2 independent experimental stretches with treatment and control
Sources of bias	Experimental design minimizes potential for bias but the extraction of data across seasons (and estimation of subsequent sd) may introduce bias and results in potential underweighting (sensitivity analysis required)

Outcomes	treatment				control	
	n	m	sd	n	m	sd
coho salmon density upper paradise low density (96/7)	4	2.375	1.670079838	4	2.475	1.819111505
coho salmon density upper paradise high density (97/8)	4	3.625	1.367174702	4	2.225	1.869714773
coho salmon density upper mamquam low density (97/8)	4	0.55	0.264575131	4	0.5875	0.3473111
coho salmon density upper mamquam high density (96/7)	4	2.52	1.252663828	4	1.9	1.669331203

Reasons for heterogeneity time (1 year), mean flow (0.09m3s), stream gradient (0), proportion of cobbles in substrate (low?),degree of existing modification (exacvated side channels with riprap-high), distance from source (unknown), water quality (water chemistry results presented- 0.444ppm nitrate-good), size of stream (up 5.9, um 6.18), canopy cover (?).

Pop/pref habitat preference

Extraction Data was extracted from figure 3 (with associated reading error). Data was averaged across seasons to prevent multiple extraction of points (maintenance of independence). However, this obscures the effectiveness of lwd at low fish densities in march and may. The standard deviations and n are also calculated across seasons resulting in potential downweighting although the sds are not dissimilar to those presented for monthly treatment effects.

Notes Subjective judgement was required to ascertain how to extract this data which presents results from two years (different fish densities each year) and seasonal variation. It was decided to extract 4 points as i) two sites were independent and ii) the experimental design meant the years were independent (2 years + 2 sites = 4 effect sizes). However, results were averaged across seasons.

Reference Gowan & Fausch

Location six streams, Colorada, U.S.A

Subject Salvelinus fontinalis (Brook trout) Salmo trutta (Brown Trout) Oncorhynchus mykiss (Rainbow Trout)

Intervention LWD 10 log drop structures (low log weirs)

Methodology BACI design with a complex (but rigorous) analysis (ANOVA used to confirm site similarity prior to treatment, MANOVA used for subsequent analysis with mean change imputed as a dependent variable)

Sources of bias Good experimental design limits bias but replication methods are unclear hence there is uncertainty regarding sample size (sensitivity analysis). Data extraction results in further bias as standard deviations (imputed from Confidence intervals) consist of pooled before and after values- probably resulting in underweighting and necessitating sensitivity analysis.

Outcomes	treatment				control	
abundance (no per 250m section)	n	m	sd	n	m	sd
Change in Brook trout abundance- Colorado Creek	6	95	3	6	-24	1.5
Change in Brook trout abundance- Walton Creek	6	165	1.5	6	35	6.7

Change in Brook trout abundance- North Fork Poudre	6	105	6	6	30	1.5
Change in Brook trout abundance- Jack Creek	6	75	2	6	62	6.1
Change in Brook trout abundance- South St Vrain Creek	6	80	6.1	6	17	6.1
Change in Brown trout abundance- South St Vrain Creek	6	52	3	6	8	3
Change in Rainbow trout abundance- South St Vrain Creek	6	-5	18	6	20	3
Change in Brown trout abundance- Little Beaver Creek	6	50	3	6	2	9

Reasons for heterogeneity time (6 years), mean flow (0.1m3s), stream gradient (1.9), proportion of cobbles in substrate (unknown),degree of existing modification (unknown), distance from source (unknown), water quality (unknown), size of stream (4.4), canopy cover (unknown).

Pop/pref population assessed using three pass electrofishing and implant tags with ML population estimates (White et al. 1982)

Extraction Adult trout abundance was extracted from figures 2,3 & 4 (with associated reading error) n=6 as there are six possible annual comparisons but the sample sizes used in the different analyses are not specified by the author. CIs were converted to Sds and pooled (CIs were assumed equal where one was missing). The down stream control was used for St Vrain Creek.

References White, G.C., Anderson, D.R., Burnham, K.P. & Otis, D.L. (1982) Capture-recapture and removal methods for sampling closed populations. Los Alamos national Laboratory LA-8787-NERP, Los Alamos, New Mexico, U.S.A.

Reference Harzler

Location McMichaels Creek, Pennsylvania, USA

Subject Salmo trutta (Brown Trout)

Intervention 68 half log covers providing 40m2 of supplemental shelter to 700m of the Creek

Methodology BACI

Sources of bias Lacking data from before in the control sections therefore study is effectively a site comparison and stocking is a confounding factor. (Sensitivity analysis required)

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Change in mean number of Brown Trout over time	5	1.48	4.551593128	5	-2.9	6.829348432

Reasons for heterogeneity time (3 years; 2 before, 3 after), mean flow (0.5m3/s during low flows in midsummer), stream gradient (7m/km), proportion of cobbles in substrate (rubble and gravel),degree of existing modification (medium- rock and log dams to create pools already constructed), distance from source (unclear but not far?), water quality (low alkalinity and low pH.), size of stream (7m width average), canopy cover (medium?- second growth deciduous forest shades most of length except for several open meadow sections.).

Population/Preference Population

Extraction	Pre-and post- data for control and intervention means and standard deviations collected as change over time from table 2, p231, n=5 as presented in table 2.
Notes	Other data presented for different age class fish in Tables 3 & 4. Angler harvests increased in the sections containing the half-log covers and decreased in those without (preference?) but were not statistically significant and had increased pre-treatment too. Mean no of harvested brown trout for 5 sites

Reference	**House**
Location	East Fork Lobster Creek, Oregon, USA
Subject	Oncorhynchus mykiss (Steelhead), Oncorhynchus clarki clarki (Cutthroat Trout), Oncorhynchus kisutch (juvenile Coho Salmon)
Intervention	15 full span gabions, 7 full span boulder structures, 10 partial span boulder groups and deflectors
Methodology	BACI design
Sources of bias	Experimental design minimizes bias but imputation of sds may lead to errors (coho and steelhead are likely to be underweighted while cutthroats may be overweighted- although not significant- sensitivity analysis).

Outcomes	treatment			control		
	n	m	sd	n	m	sd
Change in juvenile coho salmon total number	5	1235	223	5	198	122
Change in steelhead total number	5	46	33	5	20	26
Change in cutthroat trout m2	5	0	0.02	5	0.03	0.02

Reasons for heterogeneity	time (8 years), mean flow (0.04ms), stream gradient (3), proportion of cobbles in substrate (dominant cf 75%?),degree of existing modification (logged-medium), distance from source (not known but 5th order stream), water quality (unknown), size of stream (8), canopy cover (bank side alnus therefore assumed high cf 20%?).
Pop/pref	populations estimated using electrofishing over 8 year timescale
Extraction	Data was extracted from table 4. changes in time for treatment and control were extracted. Sds could not be calculated for rate of change but were pooled for preand post treatment as an estimate. Sds were imputed for cutthroat trout based on the fact that there was no significant difference (t test); p was therefore assumed to be 0.051 for calculation of t and hence sd.

Reference	**Horan *et al***
Location	Colorado River, Uinta Mountains, Utah/Wyoming, USA
Subject	Colorado River Cutthroat Trout *Oncorhynchus clarki pleuriticus*
Intervention	Habitat complexity- large woody debris
Methodology	Site comparisons

Sources of bias	Data extraction, averaged LWD numbers.					
Outcomes	Treatment			Control		
	n	m	se	n	m	se
CRCT/100m2	10	13.9	11.69	30	7.5	5.47
Pop/pref	Preference					
Extraction	WILL and BFBF were selected as highest and lowest levels of LWD densities. Fish numbers for adults and juveniles were combined to reflect population trends- data in fish/100m2 was extracted from table 3 p1255 for both sites, n and SEs were presented. Sds calculated from SEs.					
Reference	**Hunt**					
Location	Lawrence Creek					
Subject	Salvelinus fontinalis (Brook trout)					
Intervention	Bank cover and cover deflection devices					
Methodology	Before and After monitoring					
Sources of bias	There are no control sections in this work (although controls do exists for some of the sections that are treated as replicates in this analysis). Change concurrent with the intervention is therefore the major source of bias.					
Outcomes	after			before		
	n	m	sd	n	m	sd
annual production of brook trout gm2yr	4	12.9	5.5	4	12.625	1.7
Reasons for heterogeneity	time (7 years), mean flow (unknown), stream gradient (unknown), proportion of cobbles in substrate (unknown),degree of existing modification (unknown), distance from source (unknown), water quality (unknown), size of stream (9.7), canopy cover (unknown).					
Population/Preference	population assessed over 10 years using rigorous electrofishing methodology					
Extraction	Data was extracted from table 2. Mean production before intervention was extracted from 1960 with SD derived from the four sections. Post intervention data was extracted from 1970 to maximise time range.					
Notes	Data is available from four different publications regarding this site necessitating value judgment about which should be extracted. We decided to extract one point from the study (to maintain independence) over maximum timescale at the biggest spatial scale. The data is therefore robust but arguably underweighted in the analysis.					
Reference	**Hvidsten & Johnsen**					
Location	River Søya, Norway					

Subject Salmo salar (Atlantic salmon) and Salmo trutta (Brown Trout)
Intervention Weirs, revetments and bouldering using blasted stones
Methodology Site comparison comparing control/intervention
Sources of bias Effects confounded as drainage & channelisation of the stream occurred at the same time as bouldering.

Outcomes

	T			C		
	n	m	sd	n	m	sd
Atlantic salmon 100m2	2	35	14.5	3	5	2
Brown Trout 100m2	2	29	6.5	3	34	5.7

Reasons for heterogeneity time (1984-1990), mean flow (varies considerably), stream gradient (?), proportion of cobbles in substrate (5-10cm stones to fine substrate),degree of existing modification (none mentioned from before the draining, channelisation and weir/boulder installations), distance from source (?), water quality (?), size of stream (20m width in channelised areas), canopy cover (unknown, estimated low).
Population/Preference population estimates
Extraction Data taken from Figure 3 and Figure 5, widest time range for average of reference points 6,7 and 8 (upstream controls changed) and data for stream subsection with greatest alteration i.e. riprap across stream bottom and banks- 4b and 5a.

Reference Inoue & Nakano

Location Teshio River, N Hokkaido, Japan
Subject Oncorhynchus masou (Masu salmon)
Intervention LWD, FWD
Methodology Correlative study linking habitat features (including woody debris abundance) to salmon population in 48 study reaches
Sources of bias There is no information regarding baseline conditions or change from baseline. The authors state that there is considerable variation in stream characteristics within the study. This could account for the variation in salmon numbers rather than woody debris. Data extraction uses tributaries as replicates therefore the study is underweighted.

Outcomes

	Treatment (natural woody debris)			Control (no woody debris)		
	n	m	sd	n	m	sd
masu salmon density	9	6.555555556	8.314311624	2	0.75	0.212132034

Reasons for heterogeneity Each of the replicates has such different characteristics that overall means summarising the catchment characteristics would be misleading.
Population/Preference population estimates derived at the reach scale using electrofishing methodology
Extraction Data was extracted from table 1 using the 11 tributaries with salmonid data as replicates. The two containing no woody debris were used as control sites with the remainder being treatment sites from which means and standard deviations were calculated. Other data is presented

	comparing microhabitat preference but we only extracted the population measure to retain independence.
Notes	The authors use partial correlation analysis to examine the relative impact of LWD and hydraulic variables and found no relationship between salmonid density and LWD at the reach scale but habitat use by salmon in pools or riffles (non-pools) was affected by woody debris rather than hydraulic variables at the micro-habitat scale.

Reference	**Johnson *et al*.**
Location	Tenmile Creek, Oregon, U.S.A.
Subject	Oncorhynchus mykiss (Steelhead), Oncorhynchus clarki clarki (Cutthroat Trout), Oncorhynchus kisutch (Coho Salmon)
Intervention	Large Woody Debris (this was a planned intervention but additional woody debris entered the system naturally following a winter storm).
Methodology	Before and after monitoring (BACI treatment confounded)
Sources of bias	Confounding impacts concurrent with the habitat improvement are probably the most important sources of bias.
Outcomes	

	post intervention			pre intervention		
	n	m	sd	n	m	sd
Oncorhynchus mykiss population	2	9000	301	2	8000	301
Oncorhynchus clarki clarki smolt population	2	2200	500	2	250	500
Oncorhynchus kisutch population	2	5000	207	2	5150	207

Reasons for heterogeneity	time (60 months), mean flow (unknown), stream gradient (3), proportion of cobbles in substrate (unknown),degree of existing modification (low?), distance from source (4km), water quality (unknown), size of stream (15.6), canopy cover (coniferous catchments therefore moderate cover).
Pop/pref	population estimates derived for reaches using electrofishing
Extraction	Steel head, Coho and cuthtroat smolt population was extracted (figs 5, 6, 7). Data were extracted from the maximum time range 1991-2000 but the time range is considered as 5 years (5 years post intervention). Sds were calculated working back from the p values reported from T tests (note that our mean difference is calculated from the maximum time range not the mean of before and after, which may introduce a small error). n was downweighted to 2 because three non-independent points were extracted
Notes	The authors interpret the BACI data as confounded because the trends in the reference stream do not match those in the treatment- thus site differences are operating. Data has therefore been extracted as time-series data from before and after impact in the treatment.

Reference	**Jones *et al***
Location	Barrenlands, Northwest Territories, Canada
Subject	Thymallus arcticus (Artic grayling)
Intervention	ramps, v-weirs, vanes and groins in an artificial stream

Methodology BACI

Sources of bias extracted pooled standard deviation. Artificially created stream, different fish, weather conditions (sensitivity analysis)

Outcomes

	Treatment			Control			0
	n	m	sd	n	m	sd	
Fish number per m-3	14	-0.6	2.75	10	8.3	4.25	

Reasons for heterogeneity time (1998-2000-1), mean flow (?), stream gradient (?), proportion of cobbles in substrate (fine sediments equal 44% so cobbles estimated as low),degree of existing modification (entirely unnatural), distance from source (within a lake chain, estimate medium), water quality (?), size of stream (?), canopy cover (unvegetated, estimated low).

Population/Preference habitat preference

Extraction p1361- data read from Figure 6a. Standard deviations were pooled, this creates an additional source of bias but should lead to an underestimation.

Notes Although numbers decreased overall, fish showed a preference at a mesohabitat scale for the structures. LWD not naturally occurring in this tundra environment so not used. Climate conditions appear to reflect overall changes in fish numbers

Reference Knaepkens *et al*.

Location Witte Nete, Flanders, Belgium

Subject Cottus gobio (European bullhead)

Intervention artificial stones v no stones

Methodology Site comparisons from sampling by electrofishing at 40 random locations 7 of which contain stones

Sources of bias The primary source of bias associated with this multi-site comparison is potential confounding. The sites with stones are near bridges with offer cover and water velocities are also higher. Lack of independence of treatments could also impact the results

Outcomes

	treatment			control		
	n	m	sd	n	m	sd
bullhead numbers	7	6.7	6.849	33	0.2	0.442

Reasons for heterogeneity time (unknown), mean flow (0.16ms), stream gradient (lowland river with low gradient extracted as 0.1%), proportion of cobbles in substrate (30% on average in the treatment),degree of existing modification (channelised heavily modified lowland river-high), distance from source (unknown), water quality (unknown), size of stream (unknown), canopy cover (unknown).

Pop/pref habitat preference

Extraction Data was extracted from table 1. mean values were used across all sites for habitat variables except proportion of cobbles which was restricted to the treatment sites.

Reference	**Knudsen & Dilley**
Location	Five sites, Western Washington, U.S.A
Subject	Oncorhynchus kisutch (Coho salmon), Oncorhynchus mykiss (Steelhead), Oncorhynchus clarki (Cutthroat trout)
Intervention	Streambank relocation, riprap and streambed alteration
Methodology	BACI design
Sources of bias	BACI design minimizes bias but extraction involved pooling CIs and converting them to SDs (assuming normal distribution and n of 100!) potentially underweighting the study (sensitivity analysis). Population parameters were estimated when n>7 thus n is assumed conservatively to be 7.

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
change in coho numbers- Decker	7	158	145.744898	7	10	47.23214286
change in coho numbers- big Mission	7	-1167	410.9196429	7	-445	290.1403061
change in coho numbers- Beaver	7	-8	14.84438776	7	11	2.698979592
change in coho numbers- Lower Deschutes	7	0.1	0.06747449	7	-35	43.18367347
change in coho numbers- Upper Deschutes	7	-246	107.2844388	7	87	105.934949
change in steelhead numbers- Decker	7	417	142.3711735	7	84	50.60586735
change in steelhead numbers- Big Mission	7	-29	31.7130102	7	28	12.14540816
change in steelhead numbers- Beaver	7	8	0.674744898	7	12	2.698979592
change in steelhead numbers- Lower Deschutes	7	449	184.880102	7	48	128.2015306
change in steelhead numbers- Upper Deschutes	7	-67	52.63010204	7	52	43.18367347
change in cutthroat trout numbers- Decker	7	16	10.79591837	7	3	4.723214286
change in cutthroat trout numbers- Big Mission	7	7	11.47066327	7	-10	19.56760204
change in cutthroat trout numbers- Beaver	7	-1	0.06747449	7	0.1	0.06747449
change in cutthroat trout numbers- Lower Deschutes	7	24	14.84438776	7	2	26.98979592
change in cutthroat trout numbers- Upper Deschutes	7	-7	17.54336735	7	10	3.37372449

Reasons for heterogeneity	time (three weeks), mean flow (0.5-11m3/s), stream gradient (unknown), proportion of cobbles in substrate (unknown),degree of existing modification (unknown), distance from source (unknown), water quality (unknown), size of stream (unknown), canopy cover (forested catchment but unquantified).
Population/Preference	Although the authors used population estimation techniques the timescale is so short (maximum three weeks) that habitat preference rather than change in population is being studied.
Extraction	Data was extracted from Table 2. Individual fish species were extracted in preference to pooled species. Change over time was extracted for

treatment and control sites, n was assumed to be 7 (see methods), CIs were pooled and converted to SD assuming a large sample size and normal distribution by dividing the length of the confidence interval by 3.92, and then multiplying by the square root of the sample size. Where the mean or CI was zero it was substituted with 0.1 for inclusion in the analysis

Reference	**Koed *et al*.**
Location	River Skern, Denmark
Subject	Salmo salar (Atlantic Salmon) and Salmo trutta (Brown Trout)
Intervention	Dyke removal and re-meandering
Methodology	BA
Sources of bias	Large lake (250ha) developed due to bank collapse part way through experimental run leading to increased predation from bird colonies

Outcomes	After			Before		
	n	m	sd	n	m	sd
Atlantic Salmon Survival (% indiv)	1	49		1	54	
Brown Trout Survival (% indiv)	1	74		1	81	

Reasons for heterogeneity	time (24 months), mean flow (?), stream gradient (70m fall over 94km), proportion of cobbles in substrate (),degree of existing modification (), distance from source (? but to mouth), water quality (3-24% salinity in estuarine end), size of stream (?), canopy cover (?). Discharge (mean annual 36m3s-1)
Population/Preference	Population?
Extraction	Survival data (%) taken from Table II, p74, before and after. No Standard Deviation is extractable.

Reference	**Langford *et al***
Location	Wessex
Subject	Trout and Salmon
Intervention	Bouldering, some livestock fencing and bank alteration
Methodology	Site comparison
Sources of bias	Confounded interventions and potential error from extraction assumption of sample size (sensitivity analysis)

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Wild trout number 100m-2	4	0.25	0.197	4	0.0333	0.025
Salmon parr no 100m-2 4	10.26	11.28	4	3.333	2.95	

Reasons for heterogeneity	time (approx 2yrs), mean flow (?), stream gradient (?), proportion of cobbles in substrate (estimated as low although some),degree of existing modification (grazing and abstraction), distance from source (?), water quality (unknown), size of stream (?), canopy cover (estimated as low/medium).
Population/Preference	population (assumed given spatial scale and time)
Extraction	Data extracted from Fig 30 pXVII for wild trout and for salmon parr, read from graphs. N is given as 4 and this is assumed for both control and intervention. Calibration= (Wild trout: 9mm=0.1 fish/100-2 and Salmon parr: 1.95mm= I fish)
Notes	Other fish data included but not extracted, as well as for age class (0 and 1 trout)

Reference	**Lehane *et al***
Location	Douglas River, Cork, Ireland
Subject	Salmo trutta (Brown trout)
Intervention	large woody debris
Methodology	BACI type RCT design with pre and post treatment and control fish abundance estimated using electrofishing.
Sources of bias	The experimental design minimizes bias but the short timescale limits the predictive value of results. The control also incorporates "natural" levels of LWD therefore the treatment effect is likely to be underestimated in comparison to no woody debris. mean difference based on the extracted rate of change (21.8) is higher than mean difference based on treatment-control post intervention (17) or pre and post treatment (7.5).

Outcomes	treatment			control		
	n	m	sd	n	m	sd
Trout numbers	4	7.5	8.426	12	-14.3	14.342

Reasons for heterogeneity	time (21 months), mean flow (0.45ms), stream gradient (3%), proportion of cobbles in substrate (unknown),degree of existing modification (riparian plantation-medium), distance from source (<5Km), water quality (unknown), size of stream (4.7), canopy cover (surrounding plantation infers high cover, estimated at 20%).
Pop/pref	habitat preference- small scale measure of trout distribution
Extraction	Changes in total trout captures over time in treatment and control were extracted from table 1. pre installation figures March 1998, installation is June 1998, post installation was extracted from spring 2000. the 4 segments with dams were treated as four treatment replicates and the 12 segments without dams were treated as controls. The reaches were not deemed independent which is why they were combined to derive a single effect size for analysis.
Notes	Other data presenting both fish and habitat metrics was presented including ANOVAs, recapture data and a PCA. Mark recapture data suggested that the trout moved but they moved less when woody debris was present. The authors concluded that appropriate riparian management would provide an input of LWD. In the absence of this input, artificial intervention provides short to medium term stream

enhancement for trout.

Reference **Linløkken**

Location River Glomma, SE Norway

Subject Salmo trutta(Brown Trout)

Intervention Four rock weirs and deflectors

Methodology BACI type design

Sources of bias Although the BACI design minimizes bias, it is unclear how the work was replicated. Data extraction involved pooling CIs and converting them to SDs probably resulting in underweighting. This may have been counteracted by the use of fish numbers from figure 4 to derive sample sizes. A drought also resulted in low flow at the end of the experiment potentially confounding the results, thus there is considerable potential for bias in spite of the BACI design. (sensitivity analysis)

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Change in brown trout density	170	-5	255.3	287	1	215.5

Reasons for heterogeneity time (8 years), mean flow (0.95m3s1), stream gradient (1.75%), proportion of cobbles in substrate (high but not quantified),degree of existing modification (dredged for logging-high), distance from source (<68Km), water quality (high), size of stream (unknown), canopy cover (unknown).

Population/Preference Density estimated by electrofishing and mark recapture over long timescale- population

Extraction Data was extracted from figure 2 with before data 1986 and after data 1996. CIs were pooled and converted to SD assuming a large sample size and normal distribution by dividing the length of the confidence interval by 3.92, and then multiplying by the square root of the sample size. Sample size was taken from 1986 from figure 4. Graphical reading errors will decrease accuracy.

Reference **Mesick**

Location Rush Creek, California, USA

Subject Salmo trutta (Brown trout)

Intervention excavation of pools with woody debris or boulders added, side channels (to reduce flow) and spawning gravel added downstream of pools

Methodology Comparisons of different river sections were made with associated estimates of fish numbers assessed by electrofishing. Population estimates were computed using the maximum likelihood method (Platts et al. 1983). Survival rates were calculated standardized over a 12 month interval. Regression models were developed relating fish population parameters to habitat.

Sources of bias The primary source of bias associated with this multi-site comparison is potential confounding. Lack of independence of treatments could also impact the results, e.g. Immigration of fish resulted in survival indices of over 100% for some sites. It is difficult to assess whether these

	biases would over or underestimate the effect size.

Outcomes	treatment post intervention			control post intervention		
	n	m	sd	n	m	sd
survival index (1=100% survival)	3	0.732	0.646	5	0.246	0.141

Reasons for heterogeneity	time (1 year for survival indices), average stream flow 1985-1992 is 61cfs, stream gradient (2.1%), proportion of cobbles in substrate (unknown),degree of existing modification (heavy grazing impacts on riparian strip, flow controls from lake higher up the catchment-high), distance from source (unknown), water quality (unknown), size of stream (8m), canopy cover (low <5%).
Pop/pref	population
Extraction	This is a complex paper presenting many results. Raw fish number data is not presented in relation to sites or treatments (although the output of a regression model is). Data has been extracted from table 7 comparing survival indices from restoration sites with pools to control sites (main channel only). Extracted data has been averaged across age classes.
Notes	The overall regression model indicates that the number of pools, boulders and channel gradient do not have a significant impact on juvenile abundance or catchable biomass but maximum depth, area of vegetation and streambed complexity effect one or other outcome measure. High winter flows appear to be limiting the effectiveness of the habitat modification.
References	Platts, W.S., Megahan, W.F. and Minshall, G.W. (1983) Methods for evaluating streams, riparian and biotic conditions. Ogden, UT: U.S. Forest Service, Intermountain Forest and Range Experiment Station (General Technical Report INT-38).

Reference	**Mitchell *et al.***
Location	Noel Pauls Brook, Newfoundland, Canada
Subject	Salmo salar (Atlantic salmon parr)
Intervention	mid channel boulders and a low head barrier dam compared to two mini lunkers (artificial overhangs), wing deflectors and control without in-stream devices (Ripraps were present in all treatments).
Methodology	Site comparison data extracted. Three RCT experiments were run in an experimental streambed with six replicates. Experiment three consisted of stocking at natural density at three discharge rates and seeing which habitat (midstream devices, bank side devices, no devices) where preferred by fish. Invertebrates were also sampled
Sources of bias	Rigorous experimental design minimizes confounding bias's but the timescales are very short thus the experiment is concerned with local habitat preference rather than population change. The sampling methodology is also problematic as electrofishing gives radically different results to counting. Great care must be exercised to avoid "over weighting" this study as two treatments are compared to the same control at three flow rates creating problems of non-independence. (n has therefore been downweighted to two from six).

Outcomes	treatment post intervention			control post intervention		
count of fish numbers	n	m	sd	n	m	sd

lowdischarge mid-channel	2	6.9	0.5	2	7.9	0.6
lowdischarge bank	2	7.4	0.5	2	7.9	0.6
mediumdischarge mid-channel	2	6	0.3	2	6.7	0.5
mediumdischarge bank	2	6.9	0.4	2	6.7	0.5
highdischarge mid-channel	2	4.5	0.3	2	5.2	0.3
highdischarge bank	2	5.4	0.5	2	5.2	0.3

Reasons for heterogeneity	time (5 weeks) , discharge is 0.032m3s1 (low), 0.063m3s1 (medium), and 0.13m3s1 (high), stream gradient (0.41), proportion of cobbles in substrate (low <5%),degree of existing modification (experimental streambed-high), distance from source (unknown), water quality (unknown), size of stream (3m), canopy cover (unknown).
Pop/pref	habitat preference
Extraction	average number of fish and sd's were read off figure 4 (with associated recording error). Fish numbers were estimated by night counting. Electrofishing results are also presented at high discharge and are inconsistent with the count data which was extracted preferentially as it is standard across treatments. Other data is presented but it is of lesser relevance. N has been downweighted from 6 to 2 in an attempt to counteract overweighting resulting from multiple extraction of non-independent data (the same controls are used to compare two treatments, and the same experimental site is used to compare three discharge rates)

Reference	**Moerke & Lamberti**
Location	Indiana, USA
Subject	Fish, various
Intervention	Re-meandering, other (most) habitat improvements (riparian growth, in-stream LWD, gravel, riffle creation etc)
Methodology	CI (almost BACI but insufficient data)
Sources of bias	site comparison therefore variation in initial condition is major source of bias

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Fish per 100m-1 in Juday Creek	2	69.23	35.25	2	96.15	37.96

Reasons for heterogeneity	time (36 months), mean flow (?), stream gradient (?), proportion of cobbles in substrate ("gravel and cobble substrate"),degree of existing modification (completely new reaches), distance from source (?), water quality (?), size of stream (5.37m average width, 0.39m average depth), canopy cover (moderate (higher in control stretches)).
Population/Preference	small scale study of habitat preference
Extraction	Data read from Figure 2, p752, and the latest data sets only were extracted. Calibration= 0.13mm=1 fish.

Notes	Larger fishes with greater biomass were found in restored reaches compared to the control.
Reference	**Mossop & Bradford**
Location	Yukon River Basin, Canada
Subject	Oncorhynchus tshawytscha W. (Chinook Salmon)
Intervention	Large woody debris
Methodology	Multi-site analysis (some space-pseudoreplication)
Sources of bias	site comparison with potential for confounding due to variation in initial condition. Data extraction may have increased bias as we extracted an average over for five years of data (sensitivity analysis required).
Outcomes	

	Treatment			Control		
	n	m	sd	n	m	sd
Juvenile Chinook Salmon number per square metre	5	1.03	0.740236449	9	0.61	0.774754441

Reasons for heterogeneity	time (1998-2002 incomplete data), mean flow (unknown), stream gradient (various), proportion of cobbles in substrate (),degree of existing modification (low), distance from source (tributaries close to river confluence), water quality (?), size of stream (2nd to 4th order streams), canopy cover (boreal forest).
Population/Preference	Reach scale population estimates using petersen formulae
Extraction	Extracted as a Control/Intervention study, where LWD abundance was used to qualify: <30 per 100m = control, >30 per 100m = intervention, data extracted from Table 2 p1959 and Appendix 1. average excluding 2001- this was highlighted by the authors as 2001 appeared as an abnormality. Fish data is for juvenile Chinook salmon. 13 streams sampled are in three distinct regions with slight climatic variations, many may have been cleared (logged) in the past but no data is available.
Notes	Median diameter of pool forming debris was 17cm, age count estimated at 70-200 years. One stream discounted as no fish data available (Stoney).
Reference	**Nickelson *et al*.**
Location	(Pacific Northwest) Oregon, USA
Subject	Oncorhynchus kisutch (Coho Salmon)
Intervention	LWD (Brush bundle data)
Methodology	BACI
Sources of bias	Did not include "underseeded" streams in their analysis. Data read from graph and sds pooled (sensitivity analysis).
Outcomes	

	Treatment - brush bundles			Control- no brush bundles		
	n	m	sd	n	m	sd

Coho Salmon per m2	24	0.39	0.12	17	0.1	0.08

Reasons for heterogeneity	Time (assumed 2 yrs for extracted data), mean flow (?), stream gradient (?), proportion of cobbles in substrate (?),degree of existing modification (pools were formed by artificial means, either dammed or plunge pool.), distance from source (multiple, no data given), water quality (?), size of stream (?), canopy cover (?).
Population/Preference	habitat preference
Extraction	Took data from Figure 2 "pools combined" for both control and intervention- read from graph and pooled standard deviations. Assumed 0.44mm = 0.01 of a fish per meter2
Notes	Shows effects of brush bundles in both dammed and plunge pools

Reference	**Pretty *et al*.**
Location	New Cut, Evenlode, Little Ouse-Knettishall, Little Ouse-St Helens, Witham, Hiz (deflector sites); Lymn, Ivel, Lark, Great Eau (riffle sites), These are all lowland rivers, UK.
Subject	Cottus gobio (Bullhead)
Intervention	deflectors and riffles (sampled independently)
Methodology	Fish population abundance estimated in treatment and control reaches
Sources of bias	No population estimates exist prior to installation of devices therefore it is not clear if treatment and control sites were similar prior to treatment. Sampling within reaches was not random-20-50 "haphazardly chosen" points were sampled.

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Little Ouse @ St Helens-deflector	13	0.419354839	0.620440357	7	0.175	0.446496332
Evenlode-deflector	13	0.265306122	0.527218345	2	0.05	0.220721428
Hiz-deflector	4	0.2	0.410391341	2	0.1	0.307793506
Witham Deflector	10	0.333333333	0.758098044	10	0.333333333	0.546672274
Thame-riffle	20	0.350877193	0.550688792	3	0.06122449	0.242226071
Lark-riffle	4	0.125	0.336010753	2	0.03030303	0.174077656
Ivel-riffle	54	0.947368421	1.05933019	18	0.45	0.7493587
Witham-Riffle	13	0.433333333	0.727932042	9	0.3	0.595963433

Reasons for heterogeneity	time (Little Ouse @ St Helens-deflector-3,Evenlode-deflector-4, Hiz-deflector-5, Witham deflector-6, Thame riffle-5, Lark riffle-7, Ivel-riffle 8, witham-riffle 5 years), mean flow (unknown), stream gradient (unknown), proportion of cobbles in substrate (unquantified),degree of existing modification (medium), distance from source (unknown), water quality (good), size of stream (5-15m), canopy cover (unknown).

Population/Preference point abundance electrofishing and repeated depletion sampling used to assess population abundance

Extraction Raw data was used to provide eight independent data points (rather than two overall points which could have been extracted from the published manuscript) 2001 data was extracted preferentially over 2000 to maximise the timescale. Where data with zero cells occured in treatment or control effect sizes could not be estimated. Lark riffle control (n was made up to 2)

Notes The author provided raw data which has replaced that published in a Journal article as eight points can be included rather than two pooled points.

Reference Quinn & Kwak

Location Beaver Dam tailwater, Arkansas, U.S.A.

Subject Salmo trutta (Brown Trout) Oncorhynchus mykiss (Rainbow Trout) Salvelinus fontinalis (Brook trout) Oncorhynchus clarki clarki (Cutthroat Trout)

Intervention wood and rock revetments and planting vegetation to stabilize banks together with in-stream structures (boulders and logs)

Methodology BACI design

Sources of bias Experimental design minimizes bias but imputation of sds may lead to errors (pooling before and after Sds will overestimate sd of change and underweight the study) Additionally the study setting (Dam tailwater) and stocking may confound the results.

Outcomes	treatment			control		
fish/ha	n	m	sd	n	m	sd
Change in brown trout density	20	-430	200	20	-120	50
Change in rainbow trout density	20	800	300	20	100	50
Change in brook trout density	20	950	500	20	10	10
Change in cutthroat trout density	20	190	125	20	170	60

Reasons for heterogeneity time (2 years), mean flow (very variable- tailwater therefore flow is dependent upon number of turbines active in the dam-average cf 86m3s), stream gradient (unknown), proportion of cobbles in substrate (cf 70%),degree of existing modification (tailwater-high), distance from source (unknown), water quality (unknown), size of stream (unknown), canopy cover (cf 2%).

Pop/pref population change estimates were derived using electrofishing and mark recapture using a Petersen single-census, mark-recapture method (Kwak 1992).

Extraction Data was extracted from figure 5 (with associated reading error) Change in density before and after treatment was extracted for treatment and control sites and before and after sds were pooled in the absence of data to calculate rate of change sd. N=20 as 20 transects were sampled in treatment and control for microhabitat. As there is no mention of sample size for population estimates, it is assumed the same sampling points were used.

Notes	microhabitat preference was examined as well as population change
References	Kwak, T.J (1992) Modular microcomputer software to estimate fish population parameters, production rates and associated variance. Ecology of Freshwater Fresh 1, 73-75.

Reference	**Scruton *et al.***
Location	Pamehac Brook, Newfoundland, Canada
Subject	Salvelinus fontinalis (Brook Trout) and Salmo salar (Atlantic Salmon)
Intervention	Rewatering and dam removal (replaced with bridges and culverts)
Methodology	Before/After
Sources of bias	Data read from graph. Stocking occurred in 1992 although these fry are likely to have left the river as smolts by 1996. Primary source of bias is dewatering of the site prior to enhancement.

Outcomes	After			Before		
	n	m	sd	n	m	sd
Total salmonids density/100m2	6	8.97	4.49	6	11.54	5.77

Reasons for heterogeneity	Time (6 yrs (72months)), mean flow (?), stream gradient (?), proportion of cobbles and boulders etc in substrate (high),degree of existing modification (some- dams & culverts had been put in, stream course diverted, stream bed had been empty for 20 years), distance from source (?), water quality (?), size of stream (?), canopy cover (?). Data collected for some of these but not presented.
Population/Preference	population estimates from electrofishing
Extraction	Data extracted only for points below the diversion from 1990 and 1996, data from above not included as confounded control, so before after for downstream read from Figure 2, p151. Also, data for total salmonids was extracted as trout and salmon data was divided by age class.
Notes	Trout decline whereas salmon increase- biomass increases too.

Reference	**Sweka & Hartman**
Location	Middlefork River, Appalachians, West Virginia, USA
Subject	Salvelinus fontinalis (Brook Trout)
Intervention	Large woody debris
Methodology	BACI
Sources of bias	Sample reaches were over 8 tributary streams from the same river, control and treated stretches were 100m apart. Bias in calculation as pooled SD/SE (sensitivity analysis).

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd

mean trout density per 100m2	4	-0.83	1.21	8	-2.25	0.590434162

Reasons for heterogeneity time (4 years), mean flow (), stream gradient ("relatively high"), proportion of cobbles in substrate ("dominated by coarse substrate"),degree of existing modification (), distance from source (), water quality (), size of stream (small), canopy cover (70-80%).

Population/Preference habitat preference due to small spatial scales (treatments and controls separated by 100m)

Extraction Data extracted from figure 5 p373 for Age 1+ fish as longest time scale was presented, also more reflective of population not spawning. Within stream data was chosen as although smaller scale, offers control/intervention rather than degrees of intervention (as in "among stream"). SD was calculated using pooled SE for before and after for the control and intervention separately.

Notes LWD caused pool formation in lowest gradient streams. No overall effect of LWD in-stream, but among stream, those with greatest amounts of LWD had greatest brook trout densities.

Reference Wang *et al*.

Location Spring Creek and Joos/Eagle Creek, Wisconsin, U.S.A

Subject Salvelinus fontinalis (Brook trout) Salmo trutta (Brown Trout)

Intervention barnyard runoff controls, manure storage, contour ploughing, reduced tillage, stream bank fencing, sloping and rip rapping

Methodology Robust BACI design monitored over 10 years at watershed scale

Sources of bias BACI experimental design and watershed scale implementation minimize bias but prevents disassociation of individual interventions. Data extraction was undertaken across streams (rather than using pseudoreplicates) in the absence of within stream variance measures, resulting in potential underweighting of the study (sensitivity analysis).

Outcomes	Treatment			Control		
	n	m	sd	n	m	sd
Brook Trout annual catch Joos/Eagle Creek	2	0.3	0.424264069	4	56.15	112.1000297
Brook Trout annual catch Spring Creek	3	0	0.01	4	19.75	31.54113716
Brown Trout annual catch Joos/Eagle Creek	2	0.05	0.070710678	4	82.2	156.8198754
Brown Trout annual catch Spring Creek	3	1.8	1.2489996	4	18.675	28.19661623

Reasons for heterogeneity time (10 years), mean flow (unknown), stream gradient (unknown), proportion of cobbles in substrate (unknown),degree of existing modification (high), distance from source (unknown), water quality (unknown), size of stream (unknown), canopy cover (unknown).

Population/Preference population estimates given timescale and watershed level spatial scale

Extraction data was extracted as presented in Table 5 with n and sd calculated from the means presented (resulting in underweighting- see sources of bias- this may be counteracted by the extraction of four data points by one study).

Reference Wu *et al*

Location Middle Fork, John Day River, Oregon, U.S.A
Subject Oncorhynchus mykiss (Rainbow Trout)
Intervention stream bank cover
Methodology Site comparison
Sources of bias Factors other than bank cover could account for variation in fish number. Unwarranted statistical assumptions may have been made in data extraction (sensitivity analysis)
Outcomes

	Treatment			Control		
	n	m	sd	n	m	sd
camp creek-trout abundance	8	1.41	0.218	4	0.98	0.253
middle fork-trout abundance	19	0.32	0.75	6	0	0.589

Reasons for heterogeneity time (na-site comparison), mean flow (mean discharge cc 0.05, mf 0.59m3/s), stream gradient (cc 1.27, mf 0.69), proportion of cobbles in substrate (unknown),degree of existing modification (unknown), distance from source (unknown), water quality (unknown), size of stream (cc 3.09, mf 8.18), canopy cover (unknown).
Population/Preference data was collected over several years from 64 catchments and is probably therefore more representative of population than habitat preference.
Extraction Data was extracted from table 4. treatment = 4, control = 1 for both camp creek and middle fork. Sds and n were estimated from t values and p values using statistical tables (It is worth noting that these do not coincide with the number of observations reported by the authors in table 1 or the stated replication (n=64)).

Reference Zika & Peter

Location Furstentum Liechtenstein, W Europe
Subject Salmo trutta (Brown Trout)
Intervention Large woody debris
Methodology Site comparison
Sources of bias Variation in initial conditions could confound results. Imputation of sds could compound any bias (sensitivity analysis required). 70 000m3 of raw sewage entered system upstream during final year.
Outcomes

	Treatment			Control		
	n	m	sd	n	m	sd
Brown Trout abundance per 100m stream	7	151.67	6.99066861	7	102.67	11.16216334

Reasons for heterogeneity time (1995-1997), mean flow (?), stream gradient (0.06-0.18%), proportion of cobbles in substrate (),degree of existing modification (channelised, partially with conduits), distance from source (?), water quality (?- see note about sewage in s. of bias), size of

	stream (4m mean width), canopy cover (some trees along banks).
Population/Preference	habitat preference due to small spatial scale.
Extraction	Data extracted from Table II, p360. Took sum of observed and expected control and calculated (imputed) SD from the 7 sample data given. N=7 from data taken rather than true n.
Notes	mean water velocities decreased and no and vol of pools increased in treated sections.

APPENDIX 2 – REVIEWS (27)

Reference	**Topic**	**Summary Conclusions**
Allouche (2002)	The role of in-stream cover for riverine fishes.	This review looks at the role of in-stream cover and its effects on the distribution of fish, especially the importance at a habitat unit scale. States the three main reasons for the importance of in-stream cover are protection, shelter and isolation from competition.
Armstrong (2003)	Habitat requirements of Atlantic salmon and brown trout in rivers and streams	Review looks at factors affecting the distribution and abundance of salmon and trout. Suggests that habitat structures have greatest affect when populations are near carrying capacity, and as such concludes that it is important to understand population bottlenecks in order to determine whether habitat manipulation is appropriate. Author presently finds predictive models of the effects of most habitat modifications hard to derive.
Bash & Ryan (2002)	Monitoring of stream restoration projects.	Found that monitoring does not always occur, and that the type and quality of data collected varies widely for the projects that do monitor.
Bayley (2002)	The responses of salmon and trout to habitat changes.	A review of studies on fish responses of salmon and trout to habitat change through both restoration and environmental factors. The review was undertaken after a thorough journal literature search. Author reports that many studies were of a short time scale and used poor statistical analysis, and that confounding means that studies are often not able to clearly indicate which factor is responsible for changes.
Cowx & Welcomme (1998)	Rehabilitation of rivers for fish	Manual looks at the methods and projects undertaken for rehabilitation of rivers, and how biological value can be added to aesthetic restoration projects at little additional cost.

Cowx et al (2003)	The Bullhead (*Cottus gobio*)	Looks at the ecology, distribution and habitat preferences of the Bullhead, *Cottus gobio,* part of the Conserving Natura 2000 Rivers Series.
Finlayson et al. (2005)	Trout restoration in national forests.	Discusses the projects and work done so far which attempt to restore trout populations, and looking at this evidence debate whether they are being successful or otherwise.
Glen (2002)	Recovery of Salmon and Trout following habitat enhancement works	Reviews case studies of habitat enhancement, including removal of obstruction to migration, with both economic and ecological factors included. Findings suggest that habitat enhancement projects do work, and this can be seen within a short timescale, with removal of migration barriers giving the greatest results. Also finds other habitat enhancement projects are successful but acknowledges the need for monitoring over a longer timescale.
Hamilton (1989).	Response of Juvenile Steelhead to In-stream Deflectors in a High Gradient Stream	Found that there was little impact on fish populations from the installation of deflectors, which was attributed to the high gradient of the study reaches. Literature was found to reflect these findings- the most successful studies had been carried out in lower gradient streams.
Hendry et al. (2003)	Habitat management for rehabilitation of salmonids	Looks at the main areas to be taken into account in salmonid habitat management. Paper states that land-use regulation is required due to the high levels of degradation that have occurred, and that root causes of problems should be addressed in mitigation and enhancement works.
Holmes (1998).	A review of river rehabilitation in the UK, 1990-1996	Reports a lack of consistency in recording or reporting of habitat rehabilitation schemes. Found that the most commonly used methods were often the cheapest, such as restoration of riparian growth, or those river restoration projects targeted at a particular key species (often bird or mammal).
Keeley et al (1996)	Estimating production benefits of habitat improvement initiatives.	Summarised the findings of 30 studies that included control and intervention sites in order to calculate the potential production benefits of stream restoration initiatives on salmonids. Suggests off-channel habitat may increase numbers, and increases in spawning substrates should lead to great increases in numbers.
Kauffman & Krueger (1984)	The effects of riparian grazing	Looks at general effects of riparian grazing, includes studies regarding fish. Concludes that riparian grazing affects salmonid fish populations as a result of changes to water temperature and reduction of organic matter, and states that riparian management is an important part of fisheries management.

Kauffman et al (1997)	Restoration of riparian and stream habitat	Suggests that a holistic approach concerning both riparian and stream restoration needs to be used, and that often restoration efforts don't attempt to stop the processes causing degradation of the land.
Kauffman et al. (1993)	Fish habitat improvement projects and management recommendations	Reviewed habitat restoration projects over a number of sites. Report looks at the restricting factors that need to be taken into account and the implementation of these projects.
Kondolf, G. M., J. C. Vick, et al. (1996)	Salmon spawning habitat rehabilitation in the Merced, Tuolumne, and Stanislaus Rivers, California: An evaluation of project planning and performance	Found that projects did not always take into account features that modified the intended workings of modifications, such as upstream dams on riffle sequences. Also found that some of the projects actually increased suitable habitat for salmonid predators, negating positive outcomes of the improvement features.
McGrath, C. C. (2003)	Whitewater parks	Study looked at the effects of Whitewater parks on fish populations. Whitewater Parks commonly contain engineered versions of riffles and pools and therefore should provide a good habitat for fish, especially as shelter should protect them from recreational use of the habitat. Conclusions derived from comparisons with data from non-park locations as research in that area extremely limited.
McPhail and Baxter (1996).	A review of Bull Trout (Salvelinus confluentus) life history and habitat use in relation to compensation and improvement opportunities	This review looks at the biology and habitat use of fish at the different stages of their life cycle, and some of the habitat issues of concern which may impact on choice of habitat remediation.
Opperman et al (2006)	Large woody debris in streams	This guidance document discusses the role of LWD in stream and river habitats in relation to salmonids, and states the importance of both living and dead woody debris in the ecosystem.
Pusey and Arthington (2003).	Importance of the riparian zone to the conservation and management of freshwater fish: a review.	Although with an Australian bias, this review describes the role and interactions between stream and riparian zones, and concludes that attention to riparian zones are of key importance when planning restoration work.
Roni et al (2002)	The effects of habitat improvement studies.	A review of habitat improvement studies. Concludes that little is known about the effectiveness of in-stream habitat improvements.
Roni et al (2005).	Habitat rehabilitation for freshwater ecosystems.	This review discusses the effectiveness of habitat improvement projects and translates the findings into guidelines to help guide and improve future restoration and mitigation

		attempts.
Rosenfeld (2003)	The assessment of fish habitat requirements.	Looks at the different scales at which habitat assessment take place, and some of the factors that affect these. States the need for clearly defined habitat requirements to be understood to make habitat restoration and species management more effective. Review discusses the importance of understanding the optimal habitat configurations for fish species.
Schmetterling et al. (2001).	Effects of riprap bank reinforcement on stream salmonids	This review looks at the effects of using riprap to reinforce river and stream banks, and find that although it may provide some benefits on stream banks that have been severely degraded, the use of riprap goes against current restoration philosophy and impedes future attempts to restore the stream reach. Concludes that riprap does not provide an alternative to riparian cover and the benefits this offers to Salmonids, such as LWD, undercut banks and cover.
Summers et al (1996)	Restoration of Riverine Trout Habitats	This guidance manual describes the methods used for restoring riverine habitats, specifically for trout species.
Thompson (2006)	The pre-1980 use of in-stream structures to improve streams and fish populations.	This review looks at studies from pre-1980, which attempt to show the positive effects of in-stream structures. The review finds that little evidence exists to show that in-stream structures improve fish populations and concludes that their effectiveness to increase fish populations should not be presumed. The author also notes that many of the studies are confounded, as fishing pressures are not accounted for.
Ward & Ward (2004)	Hydroelectric development mitigation	Looks at habitat restoration initiatives aimed at mitigating the effects of hydroelectric operations within the Columbia River Basin using various methods.

APPENDIX 3 – QUALITATIVE REFERENCES (68)

Reference	Subject	Intervention	Outcome	Summary findings	Methodology
Bank cover deflectors					
Champoux et al (2003)	N/A	Bank-cover deflectors	N/A	Concludes that the siting of bank cover deflectors needs to be considered in relation to the different geomorphic contexts encountered in river reaches as effectiveness is dependent on other factors.	Looks at the long-term changes in river morphology, and as a by-product, fish habitat suitability, before and after installation of bank-cover deflectors. Data sets from 1963, 66 and 99.
Bouldering					
Huusko & Yrjäna¨ (1997).	Brown Trout	Channel modification and boulder structure placement	Habitat suitability	The effects of channel modification and boulder structure placement using PHABSIM suggests that increased diversity created conditions more likely to sustain a larger trout population.	PHABSIM based on before and after field site data
Maki-Petays et al (2000)	Brown Trout and Grayling	Heterogenous substrate and flow level	Location	Looked at microhabitat preference of age-0 brown trout and grayling in two artificial streambeds at high and low flow. Found that trout spatial patterns were different in flume types. Concludes that rehabilitation programmes should aim to provide a broad range of microhabitats, and restoration aimed at one particular species may not provide suitable environmental conditions for other species in the same habitat.	Laboratory conditions experiment of fish habitat preference in both an artificial channel and a "restored" channel, with highly heterogenous substrate
Smith et al (2005)	Rainbow Trout	Prismatoidal shapes (producing turbulence)	Fish occupancy	Paper concludes that the angular nature of in-stream devices could promote higher turbulence than natural objects, meaning potentially reduced habitat occupancy by drift-feeding salmonids.	Measured fish location and focal points in relation to flow turbulence in a laboratory flume.
Confounded – multiple factors					
Binns (1994)	Trout	Habitat management – riprap and	Population density	In-stream improvement structures were found to increase numbers of trout of different age classes over a long time period. The degraded habitat had	Triple-pass electrofishing using block nets at sampling sites. No variance measures are presented for fish parameters. Controls

		improvement devices		been restocked prior to works. Wooden plunges seemed to be easy to install and created good pool habitat.	established after treatment.
Connolly & Jezorek (2001)	Steelhead and other salmonids	Different Habitat sites-unclear as to what	Biomass of salmonids	Monitored fish abundance at a number of different habitat sites but do not state which samples relate to what habitat types	Electrofishing and PIT-tagging
De Jong et al (1997)	Atlantic salmon and brook trout	Boulder clusters, v-dams and half-log covers	Salmonid density	Suggests that the restoration techniques were successful although success is not solely attributed to the devices.	BACI with one control site. Multiple-pass electrofishing using nets. Population estimates made using MICROFISH 3.0.
Environment Agency (2003)	Salmon	Multiple-riparian, fish pass, water quality	Greater fish stocks through an Action Plan	Project to improve river habitat for salmonids included much riparian restoration- costed actions are presented	Assessment and creel data assembled and assessed to decide what steps to take next to restore the River Wye.
Everest et al (1986)	Chinook, Coho salmon and steelhead	Off-channel ponds, in-stream bouldering, berms (v-dams) and LWD, gravel	Population and smolt production	Several interventions used in an attempt to improve the habitat for salmonids in the river system, which was previously degraded and lacked suitable microhabitats for sheltering and smolting.	Data provided in other papers covered by the search with longer time-spans
Everest et al (1985)	Chinook, Coho salmon and steelhead	Off-channel ponds, in-stream bouldering, berms (v-dams) and LWD, gravel	Population and smolt production	Several interventions used in an attempt to improve the habitat for salmonids in the river system, which was previously degraded and lacked suitable microhabitats for sheltering and smolting.	Data provided by other papers covered in the search with longer time-spans
Goldberg et al (1995)	Chinook and sockeye salmon	Debris structures and channel modifications	Microhabitat preference	Use of in-stream devices to mitigate effects of flow alteration downstream of a hydroelectric dam showed that fish preferred debris structures to engineered in-stream structures and both over natural (comparator) sites.	Snorkeller observations and electrofishing surveys using stopnets around structures. Data not extracted as species figures presented as percentages of total fish counted.
Hale (1969)	Trout	Habitat improvement-artificial	Changes in angling and standing crop	Increase in fish abundance in treated sections after improvement work in YOY and older trout. Angling catch rate (fish per man hour) increased in treated	Electrofishing of control and altered sections and angling creel data collected.

		deflectors and log shelters		sections but decreased in the reference sections.	
Hubert & Joyce (2005)	Cutthroat Trout(Age-0)	Habitat type (artificially created)	Presence of trout	Stream modified with artificial pools and riffles and riparian (willow) planting is sampled for Cutthroat Trout (age-0) at riffle, riffle margin, pool margin and backwater. Stream margin habitats more popular with trout than riffles.	Field survey using electrofishing
Hunt (1976a)	Trout	Stream bank covers and current-deflector devices	Brook trout production	Studies showed habitat was degraded and so major renovation was undertaken, leading to changed morphology and an increase in fish numbers. Labour and equipment proved to be highly costly compared to the actual cost of the devices.	Semi-annual electrofishing surveys to measure the number of fish stock in the river. Data extracted from other papers by author.
Hunt (1969)	Trout (Brook trout)	Bank covers and current deflectors	Increased production	Increases in trout numbers attributed to higher overwinter survival than recruitment or growth.	Electrofishing to enable mark-recapture. Multiple papers by author cover experiment and so data extracted from another source.
Hunt (1976b)	Trout	Bank covers and current deflectors	Biomass, size and number	Paper shows that although increases were observed during the first few years after installation of devices, the greatest improvements in fish size and number became apparent after a longer time scale (after the initial three years).	Electrofishing to enable mark-recapture. Multiple papers by author cover experiment and so data extracted from another source.
Keith et al (1991)	Salmonids	Riparian and in-stream cover	Abundance	Findings showed that abundance decreased in all stream sections, but at a greater rate in the closed canopy cover sections. In streams with and without in-stream cover, the only noticeable result reported was greater abundance in Age-1 and older fish in streams with in-stream cover than without.	In-stream cover removed from pools. Alder brush bundles placed in sections and overhead alder cover removed from some sections. Some sections were stocked with fish to increase numbers. Electrofishing technique used for fish measurement.
Lacey & Millar (2004)	Salmonids-Coho salmon and steelhead	In-stream LWD and rock groyne structures	Modelled fish habitat increases	Paper reports that modeling simulations suggest greatest increase in the weighted useable area at periods of high flow.	Use of 2D monitoring software (River2D) based on field survey data.

Lamouroux and Capra (2002).	Fish	Habitat alteration	Modeled outcomes.	Simple predictions of in-stream habitat model outputs for target fish populations- suggest they should be used as part of the restoration planning process.	Use of habitat modeling software compared to real site derived data.
Mamorek et al (2004)	Salmonids	Multiple	Population increase	Report on multiple watersheds which have had restoration work carried out- Findings ask for more and better information on projects; hypotheses and monitoring were lacking; data retrieval requires significant effort; space & timing need more thought in experiments; scale of studies and comparative scale of inferences are not appropriate.	Data assembly and synthesis of projects carried out in the region to evaluate their successes.
O'Grady (1995)	Salmonid rivers	Enhancement works	Increased fish production	Looks at river enhancement in Ireland, including cost-benefit factors and the importance of monitoring. Concludes that in-stream and riparian-pruning methods are more effective than stocking or smolt ranching.	Reviews and discusses the costs and effects of a number of in-stream enhancement projects
Shields et al (1998)	Fish- mainly cyprinids and centrarchids.	Addition of spurs to stone toe- also included willow planting	Fish and fish habitat.	Found that the addition of the spurs to the stone toe created different habitat features that may be of preference to different fish species than the straight run sections present before- fish populations reflected this but in part was confounded by beaver dams.	Stone spurs added to toe and willow planted on opposite bank. Physical habitat characteristics and fish types and numbers monitored. Beaver dams affected fish populations.
Summers et al (1996)	Trout	Rehabilitation	Restoration of populations	Guidance manual on restoring rivers for trout populations. Discusses limitations of knowledge.	Contains further reading at each section on each type of habitat alteration intervention although no useable data
Swales & O'Hara (1983)	Dace, chub and other species	Low dams, current deflectors and artificial cover structures	Fish distribution and abundance	Paper found that fish populations increased after habitat improvement had taken place, but also that fish relocation had occurred, with large densities of fish being found around the improvement structures, especially the artificial cover devices and the pools associated with the low dams.	Boat electrofished using stopnets for each study section before and after the devices were installed.

Tarzwell (1938)	Trout	In-stream devices- unclear	Fish yield and creel counts	Stream improvement devices increase the food production, and the growth rate and number of trout compared to an unimproved stream.	Several studies carried out including invertebrates and creel counts but stocking had taken place in control reach at different levels.
Thompson (2002)	Channel Morphology	In-stream Habitat improvement structures	Long term changes in morphology and environment	Paper found over a long term many in-stream structures had lead to levels of unintended bank erosion and a loss of riparian vegetation and overhead cover in modified reaches.	Fieldwork involved site histories and measurement of 40 in-stream structures.
Vehanen et al (2003)	Grayling (*Thymallus thymallus*)	Constructed islands, reefs, and cobble and boulder structures	Habitat preference	Paper reported the importance of awareness of other factors operating on a river system that has been identified for restoration, as these may impact on any improvement attempts. High fishing pressures, and underlying issues such as nutrient load are two such factors mentioned.	2D hydraulic modeling used on data from echo sounder, Doppler device, tachometer and scuba surveys. Tagged grayling were monitored and tracked.
Wu et al. (2000).	Steelhead Trout	Stream Bank Improvements (Vegetation Stability Index)	Abundance	Looks at the economic effects of stream restoration projects in Oregon but also includes some data from case studies regarding vegetation cover and fish numbers.	Data sets used from other studies.
Yrjana et al (2002)	Salmon	Confounded habitat changes & stocking	Density of wild salmon fry	Stocking and wild fry densities in modified river channels undergoing restoration have limited success, wider work needs to be undertaken	Field surveys using electrofishing; catch data
Yrjana et al (2002)	Salmon	Spawning, habitat & nursery improvement measures and fishways.	Increase populations	Despite a number of measures to improve habitat and increase numbers, recovery of salmon numbers appears to be slow. Concludes that in-stream restoration and stocking are not enough, and wider schemes such as integrated river management are needed to increase salmon numbers.	Rod catch data, electrofishing for parr, smolt trapping and mark recapture have been used to measure fish numbers following habitat enhancement- rivers stocked heavily throughout.
Flow modification					
Biggs et al (1998)	Macrophytes and aquatic	River channel restoration e.g.	Species richness, rarity	Plant species showed recolonisation to at least pre-works levels during the survey time, whereas	BACI design with upstream control sections. Macroinvertebrates surveyed

	macroinvertebrates	remeandering	and abundance	macroinvertebrates took longer to recover. Abundance increased but species richness was slower to recover.	using kick and sweep sampling or core sampling.
Booker & Dunbar (2004)	Chub, roach and dace	Channel modification-straightening	Modelled habitat suitability	Models channelled urban rivers to measure impact of channelling on available habitat.	PHABSIM used based on data from two study sites using degrees of modification
Capra et al (2003)	Brown trout	Natural and bypassed stream reaches	Fish abundance	Software to predict trout populations in streams suggests discharge fluctuations effect populations positively as ease effects of high discharge	EVHA and MODYPOP modeling software used, compared with electrofishing data
Connor et al. (2003)	Chinook salmon	Summer flow augmentation	Survival	Measure survival of tagged salmon in a flow augmented river but control is hypothetical model-predicts summer flow augmentation enhances survival	Field sampling and PIT-tagging but using a modelled control
Connor & Pflug (2004)	Salmon – Pink, Chum and Chinook	Water flow	Distribution and density (abundance)	Measure abundance and spatial distribution of salmon in three reaches before and after flow management measures- suggests salmon numbers improved after implementation.	Field study for flow retrieval, fish data acquired from WDFW and compared for before and after
Covington & Hubert (2003)	Brown Trout	Summer flows	Abundance and biomass	Measure trout abundance at sites with natural flow and "less than natural" flow, suggestion higher and lower numbers and biomass of trout respectively.	Sites surveyed, fish abundance estimated for control and intervention
Hagen & Baxter (2004)	Rainbow Trout	Habitat types and channelisation	Population size	Investigate habitat use and abundance of trout in watershed system using radio telemetry- showed fish preferred deeper pools in low flow and didn’t like channelised sections.	Radio telemetry of angled catches and diver counts
Jutila et al (2001)	Brown Trout	In-stream and catchment characteristics in dredged streams	Density	Study of rivers with both dredged and non-dredged sample sites to assess abundance of trout, shows trout prefer the more complex habitats and pools	Field surveys using electrofishing at control and treated sites
Oscoz et al (2005)	Fish - various	Channelisation	Fish density and biomass	The effects of channeling a stretch of river during highway construction on fish populations upstream, downstream and in the channeled section.	Field sampling using electrofishing with control and treatment sections

				Compares channeled with natural, and finds lower density and biomass of fish in modified sections.	
Habitat characteristics					
Bryant et al (2005)	Anadromous salmonids	Habitat variables	Population estimates	Monitoring aquatic habitat for salmonids can give good estimates of population. Relationships between habitat features are not always clear but can be demonstrated with pools and LWD.	Used statistical models to calculate fish populations and compared to field data from correlative data from multiple sites.
Franco & Budy (2005)	Trout and salmon	Biotic and abiotic habitat components	Distribution, abundance and condition	Looks at trout and salmon populations along a river in relation to biotic and abiotic factors inc substrate size	Field sampling using electrofishing, dissection
Legalle et al. (2005).	Bullhead	Microhabitat features	Weighted useable area predictions	Compares stretches of reach with differing habitat characteristics with Bullhead distribution	Field sampling using electrofishing
Legalle et al. (2005)	Bullhead	Stream width, slope and substrate	Population density	Compares stretches of a river with differing habitat characteristics with Bullhead distribution	Field sampling using electrofishing
Rich et al (2003)	Bull Trout	Local habitat features	Fish occurrence	Bull trout were positively associated with presence of LWD and channel width, other associations detailed too.	Correlative data compiled on habitat conditions of 112 streams, which were single-pass electrofished to assess fish occurrence.
Roni (2002)	Oncorhynchus sp.	Habitat charicteristics	Fish density, size and weight	Greater numbers of often larger fish were found in pools compared with riffles. Suggests reach or watershed scale characteristics are better predictors of fish density than microhabitat characteristics.	Correlative study of 30 streams comparing habitat variables with fish and salamander densities using multiple-removal electrofishing.
Sharma & Hilborn (2001)	Coho salmon	Watershed characteristics	Smolt abundance	Study reports that pool and pond densities in streams act as an indicator of smolts and productivity.	Correlative study comparing watershed characteristics at different sites in relation to smolt abundance, ascertained from fish count studies.
Land management & catchment scale works					

Erman & Mahoney (1983)	Macro-invertebrates	Logging buffer strips	Macro-invertebrate diversity	Study observed a positive association between buffer width and macro-invertebrate diversity. Concludes that narrow buffers are no more effective than rivers without buffer strips in the recovery of logged ecosystems.	Water was sampled, river characteristics were recorded and macro invertebrate diversity measured using Surber sampling.
Knapp et al (1998)	Golden Trout	River width and bank vegetation	Age-0 trout and redd density	Compares stream morphology on trout spawning at both narrow, vegetated sites and grazed wider reaches- grazed areas had higher densities of smaller fish, and spawning habitat was the limiting factor.	Field survey using electrofishing on narrow and grazed river sections
Koed et al (2006)	Atlantic salmon and brown trout	Dyke removal and re-meandering	mortality	Restoration works caused development of a lake which led to increased threat of predation for migratory fish.	Tagging and tracking individuals, electrofishing for smolts suspected of being predated.
Opperman & Merenlender (2004)	Steelhead	Riparian restoration	Improved fish habitat	Paper finds that, when compared to in-stream devices, riparian restoration produces more comprehensive and sustainable benefits, as well as being more cost-effective.	Riparian restoration and use of exclusion fencing on treatment reaches- changes in habitat compared with those in control reaches. Compares cost and performance of in-stream v riparian restoration.
Rieman et al (2001)	Salmonids	Federal land management alternatives	Predicted status and distribution of salmonids	Findings from this study suggest that an active but cautious management plan would yield the best results, with an aggressive scheme providing the worst results, and the status quo falling somewhere in the middle.	Used Bayesian Belief Networks to estimate effects of different management schemes on salmonid populations over 100 years.
VanDusen et al. (2005).	Brook Trout	Logging	Density and biomass	Brook Trout habitat preferences at sites that have been subjected to logging shows recently logged areas have smaller populations than areas logged previously.	Field survey using electrofishing
Log Jams					
Pess et al (2005)	Salmonids	Engineered log jams	Fish density	Engineered log jams appear to increase number of juvenile salmonids and provide preferential habitat compared with control sites.	Control and treatment data collected, some before data available. Fish counts using snorkel lanes.

Revetments					
O’Grady et al (2002)	Salmon and trout	Log bank revetment (and minor debraiding)	Fish density	Log bank revetments were used along a degraded Irish river. Results indicate altered channel morphology and the beginnings of plant recolonisation. Increases of fish stocks were reported for the modified reaches compared to control sections.	Electrofishing data used to measure abundance. Not all sections monitored over same time period. Insufficient data presented for robust extraction.
Riffles					
Gore et al (1998)	Benthic (macro invertebrate) communities	Artificial riffles	Habitat suitability	Model effects of two artificial riffles put into a stream using PHABSIM, focuses on the benthic macro invertebrate populations suitable habitat	PHABSIM habitat simulation
Weirs					
Gowan (1995)	Trout	Low log weirs	Population	Found that abundance and biomass of adult fishes increased, but believed to be due to immigration rather than population increase.	Used mark-recapture to look at trout responses to low log weirs. Data not extracted as thesis abstract only obtained.
Woody Debris					
Bilby & Fransen (1992)	Fish inc Steelhead and dace	LWD	Fish density	Addition of LWD increased pool area in treatment sections. Fish numbers were found to increase at all sites. Dace increased most in the enhanced reach containing LWD.	Methodology not presented. Data gathered at three sites, one with added LWD, and two without. Of the two without, one had canopy cover and the other did not.
Brooks et al (2004)	Fish- Australian species	Woody Debris	Fish abundance, species richness	Engineered logjams appear to improve species richness and abundance in Australian fish species.	BACI field surveys using electrofishing
Bunt et al (1999)	Brown Trout	Flow (pulsed discharge), woody debris & pools	Fish movement	Looks at effects of high and low flow on Brown Trout populations by measuring fish movements to show microhabitat preference- pools and LWD most popular.	2D modeling of available habitat, fish radio-tagging
Coulston & Maughan (1983)	Salmonids	Removal of natural woody debris	Trout numbers	Looking at the effects of removal on trout populations, so the habitat restoration in this example is removal of woody debris	BACI experimental design whereby restoration is removal of LWD (degradation)

Fausch & Northcote (1992)	Coho salmon and cutthroat trout	LWD	Biomass	Individual and overall fish biomass was greater in the complex sections that contained LWD than those where the LWD had been removed.	Naturally occurring LWD was removed from sections of a stream and these were compared with reaches where LWD had not been removed. Not included for meta-analysis as LWD removal was a form of habitat degradation and so is not the same as addition or natural variation.
Gore & Hamilton (1996)	trout & benthic macroinvertebrate potential habitat	weirs	increase in potential habitat	Models effects of weirs in variable flow conditions on fish (trout) and benthic macroinvertebrate populations.	Comparison of PHABSIM and published data on a comparable water body.
Harvey (1998)	Cutthroat trout	Naturally occurring LWD	Retention and immigration	Measuring pairs of complex and simple ponds (complex ponds containing naturally occurring in-stream matter, usually LWD, tree roots and boulder) fish were tagged and measured over time to see which pools were preferred. Concludes that the presence of woody debris appeared to affect retention but not immigration or growth.	Multiple pass electrofishing used to collect fish, which were injected with a PIT tag into body cavity and monitored at river sites.
Keim et al (2002)	Salmonids	LWD	Increase in physical habitat	Paper looks at effects of LWD in creating physical habitat for salmonids when LWD source is from riparian alder rather than conifers.	Site surveys in stream sections before and after the addition of LWD to monitor changes in the channel morphology.
Larson et al (2001)	Streams	Large woody debris addition	Habitat condition and benthic macro-invertebrates	Looks at a number of projects within the Puget Sound Lowland urban basin in Washington, and the effects of LWD on benthic macro invertebrates and environmental conditions. Found less effectiveness of LWD addition in urban rivers than has been reported for forested rivers, and concluded that LWD did not improve the biological conditions.	Selected six restoration projects and measured characteristics. Used a Surber sampler to identify macro invertebrate populations.
Neumann & Wildman (2002)	Brook trout and brown trout	LWD	Habitat use	Findings indicate that both LWD and FWD correlate with trout density, and that woody debris is an important part of habitat.	Site inventories and fish counts by snorkel counts.

Nicol et al (2004)	Carp and Australian native species	Habitat restoration using LWD	Distribution and abundance	Findings showed that Carp were not strongly associated with habitat features, whereas native species were strongly associated with LWD.	Compared treatment and control reaches, fish measured using boat mounted electrofishing
Nislow et al. (1999)	Atlantic Salmon, Invertebrates	In-stream remediation e.g. large woody debris	Amount of potential habitat, fish retention	Suggests that addition of large woody debris increases the amount of potential habitat and foraging habitat, increasing salmon retention.	Mathematical modeling based on field and lab observations, compared with real findings.
Roni and Quinn (2001)	Oncorhynchus sp.	Large woody debris	Densities of fish	Suggests that woody debris placement leads to higher densities of salmonids, especially during winter.	Correlative study on amount of LWD and number of fish in treatment and reference sites using multiple-removal electrofishing.
Rosenfeld & Huato (2003)	Pool formation	Large Woody Debris	Pool frequency and quality	LWD with a diameter of >60cm is likeliest to cause pool formation, especially across wider channels.	Field survey and statistical analysis
Sundbaum & Naslund (1997)	Brown Trout	Woody debris	Growth and behaviour	Study found that although individual fish biomass decreased in both control and treatment streams, the biomass decrease was less in those streams with LWD. Concludes that the LWD decreases intraspecific competition through visual isolation.	Experiments comparing woody debris and non-LWD streams carried out outdoors with wild fish and also indoors with hatchery stock. No population density data measured.
Sundbaum, K. (2001)	Brown trout	woody debris	multiple	Study of effects of LWD on Brown Trout in both stream and artificial conditions- data not included but author contactable	Concludes that trout prefer WD as habitat, and addition of LWD increases the number of feeding sites and visual isolation.

APPENDIX 4 – POPULATION & PREFERENCE MEASURES

Study features such as timescale, repetition and spatial scale were determined, and methodological factors such as independence and study unit size were also extracted in order to inform the decision. The classification of all studies to either population or preference were agreed by two reviewers.

POPULATION

Timescale:	2-20 years
Repetition:	1-13 rivers, 1-48 units, often paired control reaches
Spatial Scale:	river-watershed
Author opion:	usually predict population
Methodological factors:	Usually using electrofishing & seining, often study adults, reach scale measurements

PREFERENCE

Timescale:	0-3 years
Repetition:	1-21 streams, 1-199 units, use paired control sites, maybe within same reach
Spatial Scale:	stream-basin
Author opion:	Both population and preference
Methodological factors:	Local counts, often juvenile life stages, often using backpack electrofishing or snorkel counts, often measure non-independent sites or habitat units.