Fish-Habitat Relationships & Effectiveness of Habitat Restoration

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Introduction

A major underpinning of recovery efforts for Pacific salmon listed under the Endangered Species Act (ESA) is that there is a strong relationship between freshwater habitat quantity and quality and salmon abundance, survival, and productivity in the fresh water environment. This is a major component of ESA recovery plans for salmon and steelhead and of the 2008 Biological Opinion (BiOp) for the continued operation of the Federal Columbia River Power System (FCRPS). The Reasonable and Prudent Alternative (RPA) for the 2008 FCRPS BiOp takes a comprehensive approach that includes, in general, a 10-year operations and configuration plan for the FCRPS facilities as well as for mainstem effects of other hydropower projects on Columbia River tributaries operated for irrigation purposes. The BiOp sets performance standards for per-dam survival for migrating juvenile fish and includes habitat, hatchery, and predation management actions to mitigate for the adverse effects of the hydro system, in addition to research, monitoring, and evaluation actions to support and inform adaptive management.

With regard to habitat, the 2008 BiOp RPA includes an expanded habitat program to protect and improve tributary and estuary environments and reduce limiting factors, based on the biological needs of listed fish. The tributary habitat program requires implementation of habitat improvement actions, including actions to protect and improve mainstem and side-channel habitat for fish migration, spawning and rearing, and to restore floodplain function. These actions are intended to meet performance targets for 56 salmon and steelhead populations. The targets, which correspond to survival improvements, are incorporated into the RPA (2008 BiOp).

Given that restoration of tributary habitat in the Columbia River Basin is a key underpinning of the FCRPS BiOp, it is important to (1) document our understanding of the relationship between habitat quantity and quality and salmon production; (2) quantify the improvements in salmon production and survival that can be expected with different restoration actions; and (3) use models to help identify habitat factors limiting production and quantify population level responses to restoration. This document provides a synthesis of scientific literature and our current level of knowledge on these three topics. We begin with a summary of basic salmonid-habitat relationships then discuss human impacts to habitat, restoration effectiveness, and the use of fish-habitat models to estimate population responses to habitat.

Fish-Habitat Relationships

The relationship between a species and the habitats utilized is fundamental to its persistence over time. Fish such as salmonids depend upon a suite of habitat types and associated environmental conditions over the course of their life cycle that is necessary for the survival of individuals and ultimately population sustainability (Bjornn and Reiser 1991). The habitat requirements for salmonids thus include the physical features (i.e. habitat area, instream cover, etc.), and environmental conditions associated with those features (i.e. streamflow, temperature, etc.). Habitat requirements also include biological factors (i.e. predation, competition, food etc.) that can strongly influence and modify habitat requirements at any salmonid life stage (Southwood 1977, Rosenfeld 2003). Thus knowing the habitat type, amount, and optimal environmental conditions for each life stage typically defines the habitat requirements for salmonids (Rosenfeld 2003).

Salmonids are perhaps the most thoroughly studied of all fishes, and decades of research have documented considerable information on the habitat quantity and quality requirements for Pacific salmonids by life stage and species (Groot and Margolis 1991, Bjornn and Resier 1991, Quinn 2005). Rather than a detailed review of all this literature, in this section we provide a brief overview of habitat requirements for major freshwater life stages from upstream migration of adults to downstream migration of juveniles and smolts. Upstream migration of returning adult salmonids from the ocean requires access, adequate flow, and a specified range of temperature and turbidity levels that do not delay migration (Bjornn and Resier 1991). Once on their spawning grounds, Pacific salmonids are affected by multiple variables at the regional (climate, elevation, topography, and geology), watershed (stream channel gradient, stream channel size, stream channel type), stream reach (stream temperature, channel hydraulics), and site scale (depth, velocity, substrate size), which determine the amount and condition of salmonid spawning habitat (Beechie et al 2008).

Regional variables influence the spatial timing and life history strategies of salmonids (Beechie et al. 2008). For example Chinook salmon typically spawn earlier at colder, higher elevation sites than Chinook salmon spawning at warmer low-elevation sites (Beechie et al. 2006). Incubation takes longer in colder sites, thus the need for earlier spawn timing (Beechie et al. 2008). Distance to sea and hydrologic regime can also determine the dominant life history strategies for Chinook salmon (Taylor 1990, Beechie et al. 2006). Spawning location and to a lesser extent timing are controlled by variables at the watershed scale such as the size and steepness of the stream channel. Larger species or individuals within a population are unlikely to access the smallest tributaries, thus instream flow requirements increase as stream size decreases towards the headwaters (Baxter 1961, Fukushima 1994, Beechie et al 2008). Stream channel pattern associated with specific stream reach types (i.e. pool-riffle channel types) located in specific parts of a watershed can determine the relative density patterns of Chinook salmon, coho salmon, and Atlantic salmon (Montgomery et al. 1999, Moir et al. 2004). Reach and site specific variables that control the location of suitable holding and spawning habitats as well as areas of groundwater upwelling, helping to determine a subset of preferred spawning sites relative to the total available area (Bjornn and Reiser 1991, Groot and Margolis 1991).

Once in the gravels, the egg-to-fry life stage for salmonids requires adequate dissolved oxygen levels and water temperature so as eggs can develop into alevins, move through the gravels, and up into the stream or lake environment. Fine organic material and sediment must be at low levels (typically < 15 to 20%) so that they do not entomb salmon redds or suffocate or reduce development of embryos (Jensen et al. 2009). In addition, streamflow and sediment transport must not exceed levels that mobilize the streambed to the point that it scours gravel to the depth that incubating eggs and embryos are injured or killed (Montgomery et al. 1995, 1999).

The freshwater rearing of juvenile salmonids also has habitat quantity and quality parameters at the watershed, reach, and site scale that are critical to the survival of juvenile salmonids. At the watershed scale juvenile salmonids use, move, and grow in main stem, tributary, and floodplain habitats throughout their time in freshwater (Quinn and Petersen 1996; Kahler et al. 2001; Jeffres et al. 2008). The connectivity between these habitats is critical, particularly for species which overwinter, such as coho salmon, stream-type Chinook salmon, and steelhead, because summer growth and fish size at the onset of winter are important predictors of survival, particularly in streams with limited winter growth opportunities (Bustard and Narver 1975; Reeves et al. 1989; Nickelson et al. 1992; Brakensiek and Hankin 2007). This is consistent with previous studies that have demonstrated higher overwinter survival of larger juvenile salmon (Ebersole et al. 2006; Jefferes et al. 2008; Brakensiek and Hankin 2007; Roni et al. 2012). This is important because factors which decrease growth of juvenile salmonids during freshwater rearing also have the potential to reduce juvenile survival to the smolt stage, as smolt size within a given cohort is positively correlated with marine survival (Holtby et al. 1990; Quinn and Peterson 1996; Connor and Tiffan 2012). At the reach and site scale, the amount of available slow water habitat, cooler temperature regimes in the summer and warmer temperature regimes in the winter, available cover from predators, and adequate food resources all play a key role in determine optimal juvenile salmonid habitat (Everest and Chapman 1972; Hillman et al. 1987; Sommer et al. 2001; Rosenfeld et al. 2005; Jeffres et al. 2008).

Estuarine habitats are also important for anadromous salmonids, as many rely on the estuary for migration, transition to the ocean environment, rearing, and refuge (Healey 1982, Thorpe 1994, Bottom et al. 2005; Rice et al. 2005). Juvenile salmonids may spend anywhere from a few days to months in the estuary depending upon the species and life history type. For example, subyearling migrant Chinook salmon, can reside in estuarine environments for months, initially utilizing tidal creeks and other shallow, near-shore habitats before moving to deeper water as they increase in size and move downstream (Healey 1982, 1991; Bottom et al. 2005). Other salmonids, such as steelhead or yearling Chinook smolts, may migrate quickly through the estuary to the marine environment. However unlike the freshwater environment, in the estuary salmonids must adjust physiologically to salt water, as well as feed, and orient for their return migration (Simenstad et al. 1982, Thorpe 1994). Habitat quality in these estuarine environments (i.e. available habitats, food resources and water temperatures) affect the growth rates of juvenile salmonids (Neilson et al. 1985). Habitat quantity in estuaries has also been shown to be critical to the survival of juvenile salmonids. For example, the amount of estuarine area in naturally functioning condition has been correlated to survival from the smolt to adult stage for Chinook salmon (Magnusson and Hilborn 2003).

Impacts of Management Actions on Fish Habitat

Anthropogenic actions can disrupt natural watershed processes (e.g., delivery of water, sediment, nutrients, wood), alter riparian and floodplain functions, or block fish access to habitats, all of which can have deleterious effects on aquatic ecosystems and salmonid populations (Pess et al. 2002; Karr 2006; Beechie et al 2010). First and foremost, habitat loss or isolation has greatly reduced the amount of available salmon habitat in the Columbia Basin and elsewhere. Habitat loss can result from direct manipulations such as blockages to fish migration (McClure et al. 2008), disconnection of main stem river and floodplain habitats through the construction of levees or bank revetments (Collins et al. 2002), and filling of floodplain channels through the conversion of lands to agriculture or urbanized areas (Beechie et al. 1994). Simplifying habitat in such a manner can result in the elimination or disconnection of salmonid spawning and rearing habitats, dramatically reducing salmonid habitat carrying capacity in river ecosystems (Beechie et al. 2012a). A loss in habitat carrying capacity through these and other actions not only can result in a decrease in salmonid abundance, but also can have deleterious effects on other aspects of salmonid populations such as decrease in genetic diversity (Bottom et al. 2005, Ozerov et al. 2012).

The degradation of habitat quality from human actions such as logging, urban development, mining, road building, and agriculture activities has also been well documented (see Meehan 1991 for detailed reviews). For example, logging and timber harvest and associated road building have led to increased sediment supply, removal of riparian vegetation, filling of pools, changes in peak and high flows, loss of in-channel wood, reduced pool spacing, and simplification of instream habitat (Salo and Cundy 1987; Holtby 1988; Murphy 1995; Spence et al. 1996), all of which can negatively impact salmon populations and reduce survival at various life stages. For example the loss of pools and loss of wood can result in spawning areas no longer being utilized by adult Chinook salmon and coho salmon due to the loss of holding habitat prior to spawning (Montgomery et al. 1999). The loss of such habitats in Washington State's Puget Sound has reduced the amount of spawnable habitat by almost 33% (Pess et al. 2002). In addition the loss of these features can result in loss of preferred juvenile coho salmon and steelhead habitat (Beechie et al. 2004). Even if pools are available utilization may not occur due to other factors such as stream temperature. Torgerson et al. 1999) found that highest reach density of large pools (depth >0.7 m) in both the North Fork and Middle Fork of the John Day occurred downstream of the reached occupied by adult Chinook salmon. Stream temperatures in the downstream reaches of both streams exceed the tolerance level for spring Chinook salmon, thus rendering numerous downstream pool habitats inaccessible (Torgerson et al. 1999). This indicates that trade-offs between pool availability and stream temperature play important roles in determining the longitudinal extent and carrying capacity of Spring Chinook salmon holding habitat (Torgerson et al. 1999).

Similarly, habitat degradation from removal of water from a stream (abstraction) during key life stages can result in reduced freshwater salmon productivity (Arthaud et al. 2010, Grantham et al. 2012). The loss of tributary streamflow due to water use during the early life stages of spring Chinook in the Salmon River basin, Idaho was an important predictor of adult return rates (Arthaud et al, 2010). Juvenile steelhead survival is affected by the magnitude of summer flow and the duration of low-flow conditions in Coastal California watersheds and is considered a limiting factor to steelhead productivity (Grantham et al. 2012). Conversely increases in the frequency or magnitude of flood flows due to natural (increased precipitation) and anthropogenic factors (increases in stream runoff due to impervious surfaces, loss of vegetation, and increased road density) (Booth and Jackson 1997) can have deleterious effects of specific life stages that leads to reduced survival and productivity of salmonids (Greene et al. 2005, Waples et al. 2008). Greene et al. (2005) found that as magnitude of flood events increased productivity declined in a Puget Sound Chinook salmon population. Waples et al. (2008) identified reduced potential survivorship at the egg to fry life stage of a Chinook salmon population in Puget Sound due to substantial increases in the magnitude and timing of flood flows since the late 1920s. Bigger floods have predictable effects on salmonids (more extensive scouring of redds, entombment of eggs by sediment, reduced oxygen in redds because of higher levels of organic matter, and downstream displacement of recently emerged fry), leading to generally reduced survival in early life stages (Quinn 2005). Thus anthropogenic actions that alter, reduce, or simplify aquatic habitats, regardless of effects on habitat capacity or survival, can have negative impacts on salmonid populations.

Freshwater habitat restoration efforts attempt to reverse the trajectory of a reduction in habitat quantity and quality from a variety of human activities (NRC 1996, Roni et al. 2002, Bernhardt et al. 2005; Roni and Beechie 2013). Understanding what and where to restore processes or habitats requires analysis of watershed processes and how they have been disrupted, assessment of habitat losses resulting from human actions, and modeling how those changes impact salmon populations (Beechie et al. 2013). The purpose of these analyses is to understand (1) which habitat losses have been most important for a salmon population, and (2) the causes of those habitat changes. Once these are known it is possible to develop a restoration strategy that will focus restoration effort on the most important factors that limit recovery of a salmon population. Ultimately, the most successful restoration efforts will be those that address the root causes of habitat and population declines, so that natural processes sustain habitats over time and continued management intervention is not needed.

Habitat restoration efforts focused on reconnecting “lost” main stem and tributary habitats include dam removal or breach, culvert replacement, and the development of fish passage structures (Pess et al. 2005). Levee setbacks and removals, and the reconnection of freshwater sloughs, wetlands, and lake environments are used to reconnect floodplain and estuarine environments (Pess et al. 2005). Quality-oriented aquatic habitat restoration efforts can include the re-establishment of native riparian vegetation, the reduction of unnatural sediment supply from roads and bank erosion due to land use impacts, the reintroduction of wood, nutrients, and mammals such as beavers in stream channels. Many of these efforts attempt to restore the natural watershed processes that salmonids evolved and persisted under for tens of thousands of years (Beechie et al. 2010). In the following section, we discuss in detail what is known about the effectiveness of multiple restoration action types that are implemented in the Columbia Basin and beyond to increase the quantity and quality of salmon habitat.

Effectiveness of Common Restoration Techniques

Several different types of restoration (habitat improvement) actions are being implemented across the Basin to improve tributary habitat and recover salmon and steelhead populations. These include but are not limited to fish passage, instream structures, floodplain restoration or improvement, riparian improvement, sediment reduction, land acquisition and flow augmentation (instream flows) (see Table 1 for project categories used by Action Agencies).

These actions are designed to address specific limiting factors[1] that have been identified for each population and/or subbasin. Obviously the investment in these projects is large, and improvements in survival in tributaries based on these actions are one of the underpinnings of the Biological Opinion. Several long-term studies including intensively monitored watersheds (IMW)[2] are underway within the Basin to evaluate the effects of different actions on limiting factors, and more importantly the effects of these actions on salmon and steelhead survival. However, these efforts are early in the implementation process and only very preliminary information on the effects of actions on survival and production is available. Fortunately, numerous studies reporting on the physical and biological effectiveness of restoration actions in other parts of the Northwest or world are available. In this section we summarize the published literature documenting the effectiveness of each major action category outlined in Table 1. We then discuss limiting factors addressed by these actions and general findings that are useful for project implementation and design.

Literature reviewed

Two comprehensive reviews of the published literature on effectiveness of habitat improvement have been completed in the last decade. The first, Roni et al. (2002), focused primarily on regional literature, while the second, Roni et al. (2008), reviewed literature published throughout North America, Europe, and elsewhere. The latter review examined 350 papers that reported the results of effectiveness monitoring of various habitat improvement techniques. In this paper, we supplemented these two reviews with any other papers or readily available technical reports that have been published since 2008. As a result, we examined an additional 61 published studies, a total of more than 411 papers or reports. While many of these papers examine restoration efforts outside of the Columbia River Basin and the Pacific Northwest, the techniques used in other countries are similar to those used in the Columbia River basin, and in many cases focus on salmonid fishes. For some action types, such as remeandering of stream channels, much of the existing literature is from European studies (except see Utz et al. 2012); however, the vast majority of published evaluations of habitat improvement techniques are from North America (70%), with most studies from the western United States and Canada. Much of the information on fish response to restoration is on coho salmon and steelhead in coastal streams rather than in the Interior Columbia, though

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[1] In the context of the BiOp and salmon recovery plans, a "limiting factor" is a problem or degraded habitat that is thought to reduce survival or population productivity. There may be several in any given watershed or population and typically a detailed analysis has not been conducted to determine what habitat or life stage is actually limiting the population.

[2] Intensive monitoring in one or more catchments to determine watershed-level or population-level fish and habitat responses to restoration treatments.

Table 1. The BPA Fish and Wildlife Program habitat improvement project categories and subcategories and the number of published studies that examined this type of restoration. Most of these studies occurred outside of the Columbia Basin; little published literature on effectiveness of actions implemented in the Basin are yet available.

Project Action Category	Sub Categories	Existing literature (no. of studies located)
Fish Passage*	Barriers* Entrainment/Screens*	19 (mostly dam removal)
Instream Structures	Complexity Stabilization Large Engineered Structures Beaver Introductions	211
Off-Channel/Floodplain Habitat	Side Channel Floodplain Wetland Restoration Confinement	84
Riparian Improvement	Fencing Planting Removal	52
Sediment Reduction/Addition	Roads Agricultural Spawning gravel addition	29
Acquisition and Protection	Acquisitions and Protections	1
Flow Augmentation	Water Quality Barriers	15 (flood rest.)

many of the results are applicable to Chinook and coho salmon and steelhead in Columbia basin. Rather than provide an exhaustive summary of each paper here, we provide a concise synthesis of studies and their general findings. Where appropriate we refer to key studies that support our points. In many instances, rather than reference all the papers referenced in the two aforementioned literature reviews, we reference the reviews themselves. A complete list of all the literature examined and a brief summary of key findings from each of those studies is provided in Appendix 1.

Fish passage

Studies evaluating the effectiveness of projects that have removed impassible culverts/dams or installed fish passage structures in North America and elsewhere have consistently shown rapid colonization by fishes, with colonization time positively related to distance to nearby source populations (Burdick & Hightower 2006; Stanley et al. 2007; Roni et al. 2008; Zitek et al. 2008; Nakamura & Komiyama 2010; Pess et al. 2012; Roni et al. 2013). Success of fish passage through culverts and fish passage structures depends on appropriate design and installation (slope, width, length, percent the culvert is countersunk), as well as regular maintenance (Price et al. 2010).

The benefits to fish populations of removal of culverts, small dams, and other migration barriers have been well documented in North America, Europe, and Asia. Studies show that fish typically migrate upstream and colonize new habitats rapidly (Burdick & Hightower 2006; Stanley et al. 2007; Kiffney et al. 2008, Nakamura & Komiyama 2010; Pess et al. 2012a, Roni et al. 2013). For example, the installation of a fish passage structure on a water diversion dam on the Cedar River in Washington State resulted in the recolonization of newly accessible habitat by both juvenile and adult salmon and steelhead within five years (Kiffney et al. 2008, Pess et al. 2011). Martens and Connelly (2010) demonstrated movement and recolonization of Chinook salmon, steelhead, and other fishes after improved passage at irrigation diversions in the Methow Basin. Similarly, evaluation of culvert removal projects in Washington State indicated increased fish numbers within two years of culvert removal or replacement (Tetra Tech 2010). Most studies, however, have focused on removal of complete barriers to migration, while many culverts may only be partial barriers to migration – that is barriers only during some flows, seasons, or years or for some life stages. Replacing partial barriers can be successful as well (Tetra Tech 2010), but such projects are more difficult to evaluate and thus are less frequently evaluated.

Reviews of the effectiveness of habitat improvement have consistently reported removal of barriers or installation of fish passage as one of the most effective at increasing fish numbers and highest priority habitat improvement measures for salmon, steelhead and other stream fishes (Roni et al. 2002; Roni et al. 2008). The rate at which salmon and trout recolonize these habitats is, however, highly dependent upon the amount and quality of habitat upstream of the barrier, and the size of the downstream or nearby source population (number of salmon or trout returning that could colonize habitat) (Pess et al. 2008, Pess et al. 2012). Therefore, compliance monitoring and periodic maintenance are often used to ensure that fish passage structures or new culverts function properly and meet original design criteria.

Entrainment
Most monitoring of screening projects is compliance rather than effectiveness monitoring focusing on whether installation or upgrading screens has reduced "entrainment" of fish into irrigation or water withdrawal systems. One of the few studies on diversion-screen effectiveness in the Pacific Northwest found that projects sampled exceeded most (80%) of the NOAA criteria for screening projects (Tetra Tech 2010). They recommended continued compliance monitoring of these projects, as screens need periodic cleaning and maintenance to maintain their efficiency. Walters et al. (2012) modeled the estimated cumulative effect of the unscreened diversions in the Lemhi River could be a loss of 71.1% of out-migrating Chinook salmon smolts due to entrainment. The Lemhi has undergone an extensive screening program and most diversions encountered by Chinook have been screened. The modeling by Walters et al. (2012) suggest that this screening program has potentially reduced Chinook mortality due to entrainment to 1.9%.

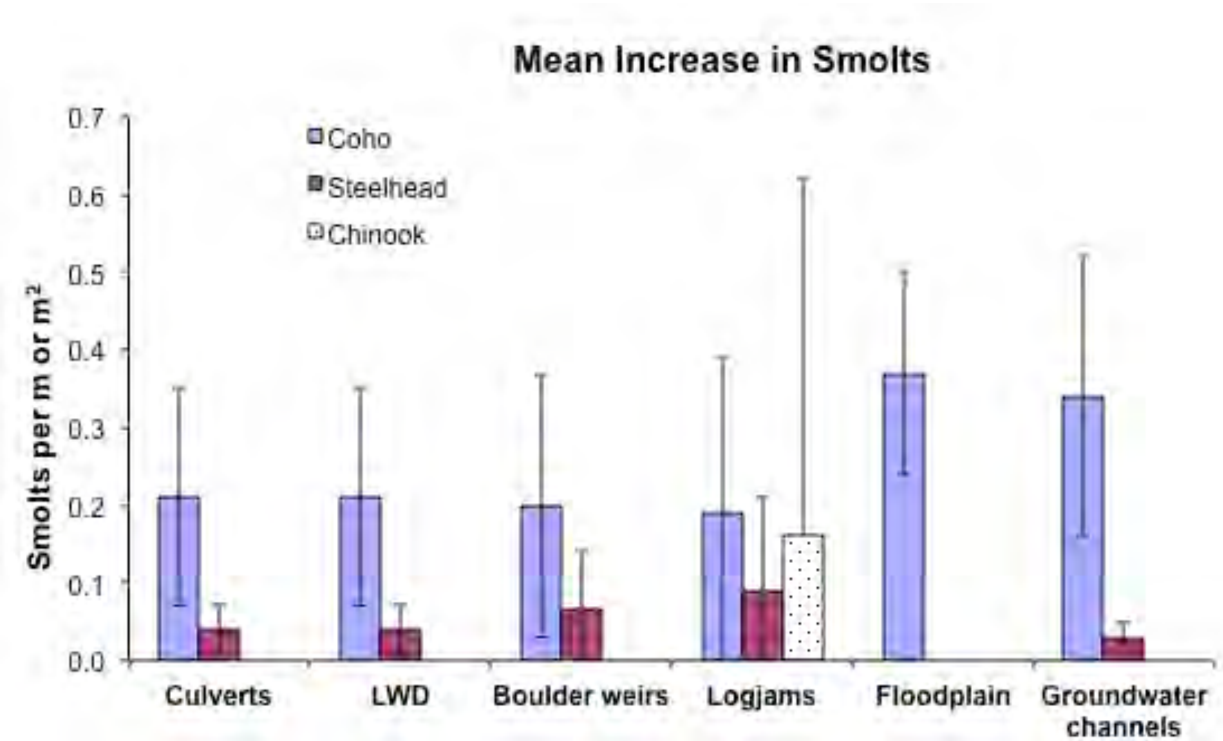

Figure 1. Mean increase in coho, steelhead and Chinook smolts reported from different types of habitat improvement examined by Roni et al. (2010). Note: Data are largely from coastal streams in Western Washington and Oregon not inhabited by Chinook salmon. Chinook data were only available for constructed logjams.

Instream structures
The placement of instream structures such as logs, logjams, cover structures or boulders and gravel addition are some of the oldest and most common methods of increasing pool area, habitat complexity and spawning habitat (Roni et al. 2013). In fact, the vast majority of published studies on effectiveness of habitat improvement have examined instream structures (Roni et al. 2002; Roni et al. 2008). For example, 229 of

the 376 published evaluations of effectiveness we reviewed examined placement of instream structures or logs. Most of these studies have focused on the effects of such actions on salmonid fishes (particularly coho salmon, steelhead/rainbow trout, or other trout species). The vast majority of these have shown a positive response (increased abundance) for juvenile salmonids (Figure 1 & 2). The lack of response or small decrease reported in some studies is largely because watershed processes (e.g., sediment, water quality etc.) were not addressed, monitoring had not occurred long enough to show results, or the treatments resulted in little change in physical habitat (Roni et al. 2013). This emphasizes the need for restoring processes (process-based restoration) prior to or in conjunction with habitat improvement (Roni et al. 2002, 2008; Beechie et al. 2010; Roni and Beechie 2013).

Placement of single logs or log structures has been shown to effective for juvenile coho salmon, and to a lesser extent steelhead and cutthroat trout and other species that rear in freshwater for several months (Roni and Quinn 2001; Roni et al. 2002; 2008). This was confirmed by recent meta-analysis of published studies on large wood placement by Whiteway et al. (2010). Constructed logjams have also shown to be useful for creating habitat for juvenile Chinook, coho, steelhead and other fishes (Abbe et al. 2002; Roni et al. 2002; Roni et al. 2008; Pess et al. 2012b). For example, ongoing monitoring of constructed logjams in the Grays River (a Lower Columbia tributary) reported improvements in pool area, habitat complexity and fish numbers following logjam construction (Hanrahan and Vernon 2011). In addition to improvements in physical habitat, the structures themselves have been shown to trap organic material and boost production of aquatic insects thus not only providing habitat, but food source (Coe et al. 2006, 2009). Less research has focused on adult salmon use of instream structures (Figure 2), but several studies have shown benefits for spawning Chinook salmon and steelhead (Merz and Setka 2004; 2008; Senter and Pasternack 2011), as well as to juvenile Chinook salmon growth (Utz et al. 2012). While a few studies have examined juvenile Chinook and steelhead response to placement of instream structures, most studies have focused on coho salmon and in coastal streams. Thus additional information is needed on effectiveness of these action types for steelhead and Chinook in the Columbia Basin.

Several factors appear to limit the success of in-channel projects; the most important appear to be assuring that upstream and watershed processes, including sediment and water quality, have been addressed, whether habitat complexity or pool area is limiting fish production, and the intensity of habitat improvement (Roni et al. 2013). Moreover, the vast majority of these studies have focused on smaller streams (<20 m bank full width), and on local or reach-scale effectiveness. While some work has been recently published (Utz et al. 2012), additional work is needed to examine response of techniques used in larger rivers, response of Chinook salmon, and watershed scale or population level responses. The total amount or extent of restoration is also an important factor as recent modeling suggests that monitoring to detect population level responses to restoration may require restoring 20% or more of habitat in a watershed.

The importance of beaver for creating habitat for coho salmon has been well documented (Reeves et al. 1989; Roni et al. 2008). Recent work in Bridge Creek, a tributary to the John Day River, has demonstrated the importance of beaver in restoring floodplain habitat and creating habitat for steelhead and Chinook in interior Columbia River tributaries (Pollock et al. 2007, Pollock et al. 2012). Projects that reintroduce beaver, install instream structures, or add food to entice beaver to construct dams or colonize a stream reach have gained popularity in the last decade (DeVries et al. 2012). Studies in both North America and Europe have shown that where beaver are reintroduced and protected from harvest or predators, and where a suitable beaver food source exists, the beaver rapidly recolonize and modify stream habitats. Recent studies have also shown that “beaver support structures”, such as those constructed on Bridge Creek in the John Day watershed, can lead to construction of beaver dams and aggradation of incised channels (Pollock et al. 2012; DeVries et al. 2012). Unpublished evidence from Bridge Creek also indicates improvements in juvenile steelhead abundance and survival following placement of beaver enhancement structures (NOAA NWFSC unpublished data).

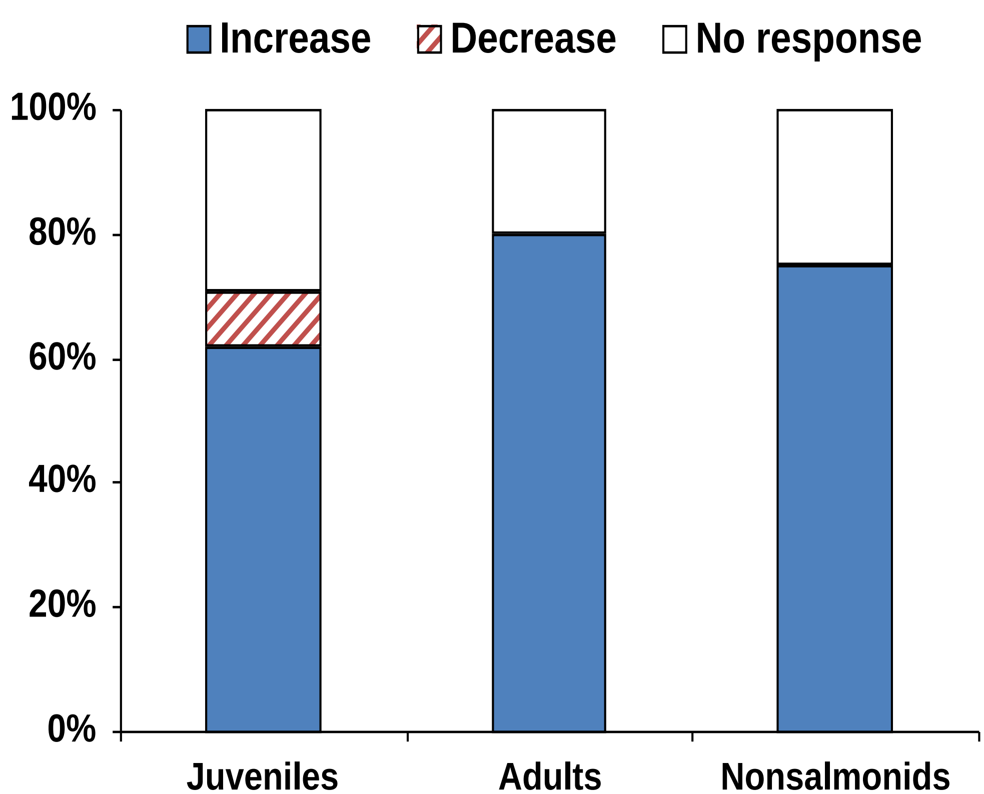

Figure 2. Percent of published studies evaluating instream habitat improvement that have shown an increase, small decrease, or no response of juvenile and adult salmon to placement of instream structures. Data from Roni et al. (2008). Overall, 99 studies reported information on juvenile salmonids, 14 on adult salmonids, and 24 on non-salmonids. No response or decrease were typically due to short-term monitoring, instream treatments that had little effect on physical habitat or water quality, other processes not being restored prior to instream treatments, or improvement in habitat for one life stage leading to a reduction in habitat for another.

Off-channel/floodplain habitat

Three major categories of floodplain or off-channel habitat restoration are discussed including reconnecting existing habitats (ponds, side channels or wetlands), removing levees or setting back levees to allow remeandering of channel or reconnection with floodplain, and construction of ponds, wetlands or side channels.

Reconnection – Similar to studies examining dam or culvert removal, studies on effectiveness of floodplain habitat reconnection, have consistently shown rapid recolonization of newly accessible habitats by salmonids and other fishes (Sommer et al. 2001; Roni et al. 2008). Reconnected floodplain ponds, side channels, and wetlands have proven to be effective at providing habitat for juvenile salmonids such as coho (Figure 1) and Chinook salmon (Richards et al. 1992; Henning et al. 2006; Roni et al. 2008). Which salmonid species benefit the most largely depends upon the stream flow, depth, morphology, and water source, with ponds and wetlands with little flow being used mostly by coho salmon, while surface-water fed side channels were generally more effective for Chinook and various trout species (Pess et al. 2008).

Levee removal/setback – Levee removal or modification is an increasingly common approach for restoring floodplain habitat. Published studies in both the United States and Europe demonstrate that these techniques can re-establish connectivity between a river and its floodplain and lead to a wider, active floodplain. The techniques can improve exchange between surface and subsurface flow, water residence time, overbank fine sediment deposition, organic matter retention, and can increase sinuosity, riparian and aquatic habitat diversity, and complexity (Jungwirth et al. 2002; Muhar et al. 2004; Konrad et al. 2008). This can lead to increased primary productivity in newly established or reconnected habitat, thus providing valuable food resources (Schemel et al. 2004; Ahearn et al. 2006). Fish rearing in floodplain habitats created or reconnected following levee removal or setbacks often have higher growth rates than those in the mainstem (Sommer et al. 2001; Jeffres et al. 2008). Most studies on the effectiveness of levee modification and setbacks have focused on physical aspects and hydrologic connectivity of habitats. Depending upon stream power and cohesiveness of bank material, channels can begin to move laterally and begin to recover their sinuosity fairly rapidly following removal of bank armoring (Bolton and Shellberg 2001; Jungwirth et al. 2002; Muhar et al. 2004; Roni et al. 2008).

Side channel and pond construction – Most of our information on the fish response to floodplain improvement is derived from studies on fish response to constructed ponds and side channels (Morley et al. 2005). Constructed floodplain habitats have consistently been shown to provide habitat for juvenile salmonids and, in some cases, to improve overwinter survival (Solazzi et al. 2000; Giannico and Hinch 2003; Morley et al. 2005, Roni et al. 2006a). Construction of groundwater-fed side channels can be an effective strategy for creating spawning and rearing habitat for salmon and trout (Bonnell 1991; Cowan 1991; Roni et al. 2008). For example, monitoring of a recently constructed spawning/side channel in Duncan Creek (Lower Columbia tributary) showed high levels of chum egg-to-fry survival (50 to 85%) and ideal spawning and incubation conditions (Hilton 2010). Similar to reconnected floodplain habitats, juvenile and adult salmon, trout and other fishes, rapidly colonize newly created habitats. The success of these projects depends largely on their connection with the main channel and their morphology and depth.

Restoring Meanders (Constrained Channels) – Restoring the sinuosity or remeandering straightened and confined channels is a common technique to restore constrained or channelized streams (Pess et al. 2005; Vought & Locoursiere 2010). Channel remeandering also typically includes the placement of boulders, wood, and other instream structures to create habitat complexity and cover, as well as riparian replanting to restore the riparian area and protect and stabilize soil exposed during construction. Most of the information on effectiveness of channel remeandering comes from European studies. Remeandering straightened or incised channels leads to dramatic increases in total stream length and habitat areas sometimes by as much as 60% (Iversen et al. 1990). European studies on remeandering have demonstrated improvement in habitat complexity and channel morphology, flood frequency, amount of water passing onto the floodplain, and nutrient retention as well as an increase in sediment deposition, sediment-associated phosphorous, and a decrease in erosion (Kronvang et al. 1998; Sear et al. 1998; Pedersen et al. 2007). Improvements in physical habitat, fish species diversity, and growth have also been demonstrated in some remeandered stream segments (Jungwirth et al. 1995; Baldigo et al. 2010). Most notably Utz et al. (2012) found increased growth of juvenile Chinook following remeandering of a California river. In contrast, other studies have reported little fish response to remeandering (Moerke & Lamberti 2003; Cowx & Van Zyll De Jong 2004; Pedersen et al. 2007). The lack of response of fish and some other biota has largely been attributed to water quality and other broader or upstream problems that had not been addressed (Cowx & Van Zyll De Jong 2004), the stocking of fish, continuation of other management activities (Pedersen et al. 2007), or attempting to design a static meandering channel in a highly dynamic stream reach (Miller & Kochel 2010). Despite these less than consistent findings on fish response, remeandering of streams in the Columbia Basin and elsewhere in the Northwest shows great promise to increase total habitat, restore floodplain habitats and increase fish numbers. While it appears to be successful restoration strategy, additional fish data monitoring of these projects is needed in the Columbia Basin.

Riparian improvement

Riparian habitat improvements fall into three general categories: 1) planting and other silviculture treatments, 2) fencing, and 3) invasive species removal. Riparian treatments often include a combination of these habitat improvement approaches.

Riparian planting and silviculture treatment – Because of the long lag time needed to measure a response for riparian planting, monitoring of most riparian planting has focused on the short-term survival of the planted species (Pollock et al. 2005; Roni et al. 2008). Several BPA-funded habitat improvement projects have been monitoring survival of plantings (e.g. Project #s 1987-100-01. 1997-056-00, 2003-011-00, 2007-231-00). These projects have generally shown relatively high survival rates of plantings (>60%) and increases in shade in the first few years following planting. Depth of planting, browse protection, exposure, and other site-specific conditions can dramatically affect survival.

Few studies have examined the response of instream habitat or fish to riparian planting or thinning, in part because of the long lag time between tree growth and any change in channel conditions or delivery of large woody debris. In fact, only a few short-term studies have examined the response of fish or other instream biota to various riparian silviculture treatments; these studies have produced variable results depending on the region and treatment (Penczak 1995; Parkyn et al. 2003). Moreover, most riparian silviculture treatments influence reach-scale conditions and processes, while in-channel conditions are often more affected by upstream or watershed-scale features, which may limit the physical and biological response in the project area. However, riparian treatments and restoration of the riparian zone are often critical to the success of other project types (e.g., instream, floodplain). For example, planting and grazing removal lead to increased shade, bank stability, reduction of fine sediment, reduce temperatures and improvement of water quality: all factors which can influence the success of instream habitat improvement projects.

Riparian fencing and grazing – The effectiveness of riparian fencing (livestock exclusion) and rest-rotation grazing have been the subject of several studies in the last 30 years (Platts 1991; Roni et al. 2002, 2008; and Medina et al. 2005). Improvements in riparian vegetation, bank erosion, channel width, depth, width: depth ratios, and fine sediment levels have been well documented in most studies both in the Pacific Northwest and elsewhere (see Medina et al. 2005 or Roni et al. 2008 for a review; Tetratech 2009), particularly for complete livestock exclusion. Rest-rotation grazing systems are generally less successful than complete livestock exclusion and results depend upon livestock densities, period of rest, and the ability to actively manage livestock. Fish response to rest-rotation grazing systems has been highly variable, with a few studies showing positive response for rainbow and other trout (e.g. Keller and Burnham 1982; Li et al. 1994; Kauffman et al. 2002). Similarly, ongoing work in the John Day Basin as part of a BPA-funded project shows increases in habitat improvement and juvenile steelhead numbers (Bouwes 2012). Overall, however, the vast majority of studies have not detected a measureable fish response to elimination or reduction of grazing (Rinne 1999; Medina et al. 2005; Roni et al. 2002; 2008). Rather than lack of project effectiveness, the lack of fish response in most grazing studies has been partly attributed to the short duration of monitoring, the small size of grazing exclosures, and to broader-scale processes occurring upstream (Medina et al. 2005).

Invasive species removal – Similar to riparian planting, studies examining the removal of invasive vegetation have focused on the short-term response of vegetation changes. We found no published studies that examined effects on channel conditions or fish and aquatic biota. The success of projects that remove invasive species is highly dependent upon the species in question, local site conditions, and the periodic maintenance or follow up conducted to assure that the species have been eradicated.

Sediment reduction/addition

Efforts to reduce sediment delivery to streams fall into two major categories: road restoration and agricultural treatments. Road restoration or modifications include road decommissioning, removal, or upgrades (e.g. stabilization, resurfacing, increasing stream crossings). Agricultural treatments include changes in crop rotation, planting, terracing and conservation tillage, creation of buffer strips, and other agriculture practices that reduce erosion and transport of fine sediment.

Several studies have reviewed the effectiveness of forest road restoration or modification efforts. Roni et al. (2008) examined 26 evaluations of various road treatments. They found that most published monitoring and evaluation on the effects of road treatments to restore streams have focused almost exclusively on physical monitoring of land slides, fine sediment, and runoff (Roni et al. 2008). Apart from studies that looked at fish recolonization after removing impassive road culverts, little monitoring and evaluation has been done to examine fish or other biota response to road treatments.

Less information exists on the impacts of different agricultural practices on salmon. While the impacts of agriculture practices on streams and water quality have been well documented, relatively little information exists on the effectiveness of different agriculture practices in reducing fine sediment and improving salmon habitat.

Habitat improvement efforts also include adding gravel to a stream reach. The addition of gravel, or placement of structures to trap gravel, can lead to the creation of suitable salmon spawning habitat. Several studies have shown increased number of salmon or steelhead redds or spawners following gravel addition (e.g., Merz et al. 2004; Roni et al. 2008; McManamay et al. 2010). Studies on gravel additions below dams suggest that salmon successfully reproduce in placed gravels, and macroinvertebrates quickly colonize new gravels (Merz et al. 2004; Merz and Chan 2005). Gravel additions are less likely to lead to improvements in spawning habitat, spawning numbers, and reproductive success of salmonids in areas with low velocities and high levels of fine sediment (Iversen et al. 1993; Roni et al. 2013). Other methods to create or improve spawning habitat (e.g. fine sediment traps, gravel cleaning) have met with only short-lived improvements or little success because high levels of fines sediment often overwhelm them (Roni et al. 2013).

Acquisition and protection

Monitoring and evaluation of land acquisition, conservation easements, and other protection measures are difficult because they are protection measures rather than active restoration. However, protection of existing high quality habitat through acquisition or conservation is a critical part of most habitat improvement, and may be needed to implement riparian, instream or other habitat improvement techniques. Further, the protection of existing high quality functioning habitats is considered one of the most effective strategies for habitat conservation It is cheaper and more effective to protect high quality habitat and properly functioning ecosystem processes than it is to restore or recreate it after it is lost or degraded. As discussed above, improvement and recovery of some degraded processes can take decades.

In the absence of other habitat improvement measures, monitoring of acquisition and protection efforts is typically limited to status and trend monitoring to assure that a habitat recovers or does not further degrade, or that degraded areas improve once the habitat is protected from further disturbance. Published studies have generally focused on the protection of riparian buffers (Roni et al. 2013). These studies have generally indicated that riparian protection through acquisition, easements or other methods can maintain riparian vegetation, lead to reduced sediment, nutrient, and pesticide concentrations delivered to streams and to improved bank stability and water quality (e.g., Osborne & Kovacic 1993; Barling & Moore 1994; Dosskey et al. 2005; Mayer et al. 2005; Puckett & Hughes 2005; Vought & Loucosiere 2010; Tetratech 2012).

Flow augmentation

Flow augmentation generally includes two major project types or goals – increases in instream or base flows and restoration of more natural flood flows or flood pulses. The later is not common in the Columbia River basin to date, but may become more common as we learn more about appropriate environmental flows to sustain healthy salmon populations and aquatic ecosystems. The former is, however, a key habitat improvement strategy in many rivers and streams in the interior Columbia.

There is an obvious and clear relationship between minimum instream flows for salmonids and other fishes: they require water of adequate temperature and flow to live. Moreover, the literature has shown that increases in base flow lead to increases in fish and macroinvertebrate production (e.g. Weisberg and Burton 1993; Gore et al. 2001; Lamouroux et al. 2006). The response is most dramatic in stream reaches that were previously dewatered or too warm to support fish due to water withdrawals (Sabaton et al. 2008; Roni et al. 2013). For example, while still underway and data are not published, ongoing studies in the Lemhi River show increased spawner and juvenile fish numbers following restoration of instream flows in tributaries (Chris Jordan, NOAA unpublished data).

Numerous methods exist to set instream flows, base flows, or environmental flows, including the Tennant Method (Tennant 1976), Instream Flow Incremental Methodology (IFIM) (Stalnaker et al. 1995), and Demonstraton Flow Assessment (Railsback and Kadvany 2008). However, determining the optimal flow for fish production or the minimum flow needed to sustain healthy salmon, trout, and other fish populations remains difficult (Poff and Zimmerman 2010). This is because it depends on many factors specific to a given stream or subbasin, such as gradient, aspect, climatic zone, channel width, condition of riparian zone, ground water sources, substrate and geology, and elevation. Obviously, the ideal instream flows would most likely be near those that were found historically in a stream before water abstraction and lead to highest species and habitat diversity. However, very stable flow and temperature can lead to high primary and secondary production and benefit some fish species. Regardless, the restoration of more natural flows, whether they are base flows or flood pulses, is critical for the success of many habitat improvement techniques such as riparian plantings, floodplain reconnection, and instream habitat improvement.

Studies examining survival

As noted previously, most studies that evaluated fish response to restoration reported changes in abundance (density or number), size or growth and few examined changes in fish survival. Of the nearly 400 studies on restoration we examined, 19 reported on changes in survival (Appendix 2). These studies mainly focused on floodplain habitats (created or reconnected ponds or side channels) and instream habitat improvement (LWD placement, gravel addition) and reported results from a variety of species including brown trout, brook trout, Atlantic salmon, coho salmon, Chinook salmon and steelhead. Of these 19 studies, about 13 suggested that survival improved post-restoration or was equivalent to that found in high quality reference sites. Because of the variety of treatments and species examined and small number of studies drawing firm conclusions is difficult. In general; however, it appears that floodplain creation or reconnection projects lead to survival rates for coho and Chinook that are equivalent to that found in natural floodplain habitats. Placement of LWD and instream structures can lead to increased survival for salmon and trout, with most of the evidence being for coho salmon (Rogers et al. 1993; Lonzarich and Quinn 1995; Solazzi et al 2000; Giannico and Hinch 2003). Improvement of spawning habitat through gravel addition, cleaning or gravel retention structures appears to lead to some improvements in egg-to-fry survival for salmon or trout (Overton et al. 1981; Klassen and Northcote 1988; Merz et al. 2004). A few other studies did modeling or correlation analysis to examine restoration (e.g. Paulsen and Fisher 2005; Budy and Schaller 2007). For example, the analysis by Paulsen and Fisher (2005) found that the number of habitat improvement actions in a watershed was positively correlated with Chinook parr to smolt survival in the Snake River basin.

Survival, growth, and movement are all processes or factors that ultimately influence population size or total abundance. While survival would seem an appropriate measure of restoration effectiveness, it is very difficult and costly to measure in the field. In fact, many of the studies that reported survival where very small scale, though a few, like Solazzi et al. (2000) and Rogers et al. (1993) reported watershed scale response to restoration. It is much easier, and therefore much more common, to measure changes in fish number or density, which also provide direct information on abundance or population size.

Restoration and limiting factors

Because most evaluations of different types of restoration actions are from outside the Columbia Basin, they have not directly evaluated factors identified as limiting for salmon and steelhead populations within the basin (Table 2.) Thus it is difficult to quantify the effects of specific actions on most limiting factors. However, based on the literature we can make a qualitative assessment as to the amount of evidence that exists that a particular action addresses or eliminates a specific limiting factor, which we summarize in Table 2 below. This also emphasizes that we have considerable info for some actions and limiting factors and little for others. For example, restoration actions such as diversion screens, removal of barriers and culverts, placement of instream structures have considerable evidence that they address limiting factors (Table 2). While other restoration techniques such as increases instream flows, may clearly address limiting factors related to flow or temperature, there is less information available on how they affect limiting factors related other water quality factors. Again, that is not to say that they don’t, but that there is little information published on the topic or those studies that exist do not produce consistent results.

The question then becomes do management actions that increase habitat quantity and quality lead to increased abundance and recovery of salmonid populations? Roni et al. (2010) found that, due to the variation in fish response to aquatic habitat restoration projects, almost an entire modeled watershed would need to be “restored” in order to detect a 25% increase in either coho salmon or steelhead smolts. Conversely, if the variation in fish response to these restoration actions were reduced, then a 25% increase in smolts could be quantified with only 20% of the floodplain and in-channel habitat restoration actions implemented in a modeled watershed (Roni et al. 2010). There is evidence to suggest that actions to improve longitudinal (i.e. among tributaries, main stem habitats) and lateral (i.e. floodplain channels, blind tidal channels in an estuarine environment) connectivity do increase habitat quantity and can increase salmonid condition (e.g., size, growth) and survival in the short-term (Roni et al 2006a, Sommer et al. 2001, Jeffres et al. 2008) and overall population size in the long-term (Pess et al. 2012). Increases in habitat quality from in-channel restoration actions can also have positive effects on salmonid survival and populations (Solazzi et al. 2000, Johnson et al. 2005, Roni et al. 2006b).

Table 2. Limiting factors addressed[3] by each restoration action type and subtype and the strength of evidence in published literature that a particular action sub-category addresses limiting factor or habitat impairment. High = many studies have confirmed this, Medium = some studies have documented this, Low = little to no information is available, ? = no information reported, NA = not applicable (limiting factor not typically measured or addressed by this action type. List of action categories and limiting factors provided by Bonneville Power Administration August 2012. Acquisitions were not included in table because little info exists on their effects on limiting factors and they often focus on protecting habitat.

Actions Sub-Categories	Limiting Factor/Habitat Impairments	Evidence From Literature
Barriers - passage	Migration Barriers (Road Crossings)	High
Barriers - screens	Entrainment	High
Habitat Complexity	Habitat Diversity/Complexity	High
	Habitat Quality	High
	Habitat Quantity	High
	Large Woody Debris	High
	Pool Quality	High
	Pool Quantity	High
	Side-Channel Connectivity	Low
Bank stabilization	Habitat Quality	Medium
Engineered Structures	Large Woody Debris	High
Beaver Introductions	Fine Sediment	Low
	Large Woody Debris	Low
	Pool Quality	High
	Pool Quantity	High
Confinement/remeandering	Channel Alteration and Confinement	High
	Channel Complexity	High
	Channel Morphology	High
	Streambank Condition/Erosion	Low
	Streambed Instability	Low
Side Channel	Floodplain Connectivity	Med
Floodplain	Riparian Condition and Function	Med
	Floodplain Connectivity	Med
	Wetland Structure and Function	Low
Riparian Fencing	Streambank Condition/Erosion	High
	Riparian Condition and Function	High

[3] By addressing limiting factor, we mean that one of the benefits of that action is an improvement in that limiting factor. For example, if fine sediment is a limiting factor, then forest road removal, would reduce the levels of fine sediment.

Riparian Planting	Streambank Condition/Erosion	High
	Riparian Condition and Function	Med
Invasive Plant Removal	Streambank Condition/Erosion	?
	Riparian Condition and Function	?
Roads (Forest)	Water Quality (Chemical Pollution)	NA
	Water Quality (Dissolved Oxygen)	NA
	Water Quality (Heavy Metal Contamination)	NA
	Water Quality (High Turbidity)	High
	Water Quality (pH)	NA
	Water Temperature	NA
	Fine Sediment	High
Agricultural	Water Quality (Chemical Pollution)	High
	Water Quality (Excess Nutrients)	High
	Water Quality (Low Nutrients)	NA
	Water Quality (pH)	NA
	Water Temperature	NA
	Fine Sediment	High
Flow -Water Quality	Water Quality (Chemical Pollution)	?
	Water Quality (Dissolved Oxygen)	Med
	Water Quality (Excess Nutrients)	?
	Water Quality (Heavy Metal Contamination)	>
	Water Quality (High Turbidity)	?
	Water Quality (Low Nutrients)	?
	Water Quality (pH)	?
	Water Temperature	Med
	Instream Flows/Water Quantity	High
Flow - Barriers	Passage or Migration Barriers (Diversions)	Med

Project implementation and design

Our review of the existing literature suggests that most restoration techniques lead to improvements in physical habitat when implemented properly and in the proper ecological context. Considerably less information exists on fish response, particularly for Chinook salmon. The best evidence of projects that successfully improve habitat or increase fish numbers is for those techniques that directly modify habitat (barrier removal, floodplain restoration, instream habitat improvement), in part because physical and biological responses are rapid and relatively easily detected. Other techniques that restore reach- or watershed-scale processes (riparian restoration, sediment reduction) often require very long-term monitoring (decades) to document improvements, but these techniques are often critical to the success of techniques that focus on improving instream habitat. The review also suggests a number of implementation and design factors that influence project success, which we summarize in Table 3 below.

Restoration Effectiveness at the Population Level

Population- or watershed-scale assessments of the effectiveness of restoration actions are quite rare, although a number of them are currently underway in the Pacific Northwest (e.g., ongoing basin-scale studies in the Entiat River, Potlatch River, Asotin Creek, Lemhi River, Bridge Creek, and lower Columbia River (Anderson, Mill and Abernathy creeks). The earliest efforts to link habitat conditions to population-level fish response were in

Table 3. Common factors to consider during project planning and design to increase project success or effectiveness. Modified from Roni et al. (2008).

Category	Common factors to consider during project planning and design to increase effectiveness
Fish Passage/Barrier removal	Project type (e.g., culvert type, bridge, fish ladder, dam removal), project design (slope, width, length, percent the culvert is countersunk), amount and quality of habitat above barrier, numbers of fish below barrier, width of stream crossing relative to floodplain
Instream structures	Instream flow, water quality, riparian shade, sediment sources, structure design, channel erosion, structure type, previous level of instream structure, upstream processes (wood, water, sediment), intensity and magnitude of habitat improvement (number of structures and length of stream treated)
Off-channel/Floodplain habitat	Level of connectivity (perennial vs. seasonal), water quality, instream flows, level of channel incision, restoration of natural flood regime, contaminants, upstream sediment, wood sources (riparian conditions), type of culvert or stream crossing
Riparian Improvement	Riparian silviculture - Soil treatment, herbivore control, plant species, hydrology and instream flows, floodplain connection, water quality, invasive species Grazing - Livestock levels, width of buffer (fencing), upstream riparian shade and sediment, duration of grazing, season on grazing
Sediment Reduction/Augmentation	Forest roads - Surface material, soil treatment, replanting (road removal projects), number of cross drain structures, stream crossing type, traffic levels and tire pressure, soil treatment and level of replanting (road removal projects) Urban roads - water quality, level of impervious surface area, size of area treated, riparian conditions Gravel addition – amount and size of substrate added, frequency of addition, location of additions, instream flows; natural sediment supply, delivery and transport

Acquisition and Protection	Quality and quantity of habitat prior to acquisition, protection of habitat from other uses, invasive species, land-use upstream and adjacent to site, inadequate assessment prior to purchase or protection
Flow Augmentation	Amount and timing of flows including minimum instream flow and flood flows, inadequate increase in instream flows, sediment and other water quality issues, length of stream reach impacted by flows, ability to control withdrawal by downstream users or plan for future water demands

basin-scale forestry experiments, in which various logging practices were tested and their effects on salmon populations measured in subsequent years (e.g., Moring and Lantz 1975, Holtby and Scrivener 1989). These studies tended to show that population-scale effects were relatively small, although in cases where habitat effects were severe (e.g., debris flows and dramatic increases in sediment supply) population declines were also significant (Hogan et al. 1998). We are aware of only a few studies reporting results of population scale-effects of habitat restoration on salmon, although there are several projects where the post-restoration monitoring period is just beginning and definitive results may not be available for a number of years. Among previous studies, the simplest actions are barrier removals, and a number of recolonization studies show dramatic population-level responses to re-opening access to large amounts of habitat (Roni et al. 2008; Pess et al. 2012). These studies clearly indicate that where habitat capacity has been reduced, restoring lost capacity results in relatively large and rapid population increases.

For other types of restoration actions, we are aware only four published population-scale studies examining responses of coho salmon or steelhead populations to physical manipulation of habitats (Reeves et al. 1997; Solazzi et al. 2000; Nickelson et al. 1992; Slaney et al. 2003). Reeves et al. (1997) and Nickelson et al. (1992) produced inconclusive results, though large flood events and design issues appear to have limited the ability of the studies to detect a significant response. Slaney et al. (2003), which focused on nutrient additions, was never fully completed though initial results were mixed showing increased juvenile steelhead growth, but no improvement in survival or adult returns. In contrast, the Solazzi et al. (2000) study, perhaps the most robust and ambitious of the existing studies, demonstrated that creation of winter rearing habitat increased winter survival for coho salmon as well as the number of smolts leaving the stream in spring. In these experiments, winter rearing area was increased by roughly 700% by construction of wood-formed pools and excavated alcoves, and overwinter survival and number of smolts increased by about 200%. Notably, the summer population increased by only 30-50%, indicating the importance of understanding which habitat/life-stage is limiting and addressing that life stage through targeted restoration actions. For the Solazzi study, basin wide habitat analysis had indicated that winter-rearing habitat was limiting, restoration actions were designed to increase winter-rearing habitat capacity, and the largest coho salmon response was in overwinter survival. In the Strait of Juan de Fuca IMW in northwestern Washington, the population abundance analyses have not yet been completed, but early results showed that increased pool area due to restoration activities may have increased coho salmon survival in the treated watershed (Roni et al. unpublished).

Six ongoing IMWs in the Columbia basin have experimental designs that appear to be suitable for answering population-level questions (Entiat, Potlatch, Asotin, Lemhi, Bridge Creek, and Lower Columbia) (Figure 3). All six of these ongoing IMWs use some variation of the Before-After/Control-Impact (BACI) design, in which treatment and control watersheds are monitored before and after restoration. This design helps to control for natural variation in fish abundance and survival, and improves ability to detect a salmon population response to restoration. Five of these basins appear to have sufficient pre-treatment monitoring (Entiat, Asotin, Bridge Creek, Lower Columbia, Potlatch), but most of the restoration actions in the Lemhi River were completed prior to monitoring, which means that most of the data collection will be post-treatment only. To date, these IMWs do not have sufficient post-treatment monitoring to determine the effectiveness of suites of habitat restoration actions at the population or sub-population scale, and most restoration actions were planned for implementation in 2012. Hence, it is likely that changes in either habitat or fish populations at the watershed or population scale will not be statistically detectable until 2017 or later in most cases, assuming significant restoration effort in 2012. However, some early results at the project or reach scale indicate that restoration efforts to increase abundance and longevity of beaver dams, increase pools by constructing log jams, or reconnecting isolated habitats (Bridge Creek, Entiat River, and Lemhi River, respectively) can locally increase salmonid abundance as expected. While each of these results appears promising, all of these studies require more years of monitoring to determine whether the restoration actions produce a population level increase in abundance or productivity.

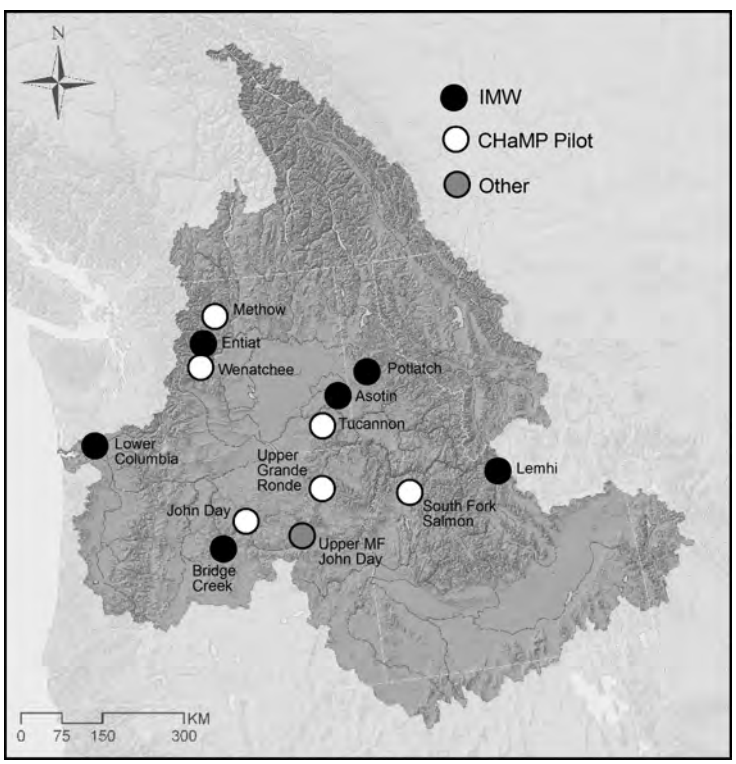

Figure 3. Map of IMWs and CHaMP pilot watersheds in the Columbia River basin.

What Can Models Tell Us About Population Responses?

In the absence of empirical data showing population-level effects of restoration actions on salmon, there are model approaches that can be used. For this purpose, modeling approaches require density and survival information specific to habitat types, and that information must be linked to information on habitat quality or quantity. That is, such models must be able to use estimated changes in habitat quantity and quality as a result of restoration actions, future land use, or climate change as inputs, and to use the habitat-specific density and survival information to estimate the cumulative effect of multiple actions on the population. Here we describe two general model forms that can be used (stage-specific capacity models and life-cycle models), and three broad types of analyses that have been done using these models (evaluation of restoration scenarios, evaluation of restoration scenarios and climate change, and evaluation of restoration scenarios, climate change, and future land use). While none of these models or analyses can substitute for measuring population responses, they can all help to set realistic expectations for restoration outcomes and help managers choose among alternative restoration scenarios.

Stage-specific capacity models

Stage-specific capacity models and life-cycle models differ primarily in how they link one life stage to the next. Stage-specific capacity models generally do not link life stages to each other or to adult returns. Rather, they estimate the spawning or rearing capacity of habitats at each life stage, and then use uniform survival numbers from that life stage to the smolt stage to compare capacities among life stages (e.g., Reeves et al. 1989). These models can therefore be used to estimate which life stage limits population size, as well as how different types of restoration actions might influence population size (Beechie et al. 1994). However, stage-specific capacity models generally cannot be used to estimate survival improvements because survival numbers are held constant in order to evaluate the effects of changing habitat capacity. By contrast, life-cycle models mechanistically link life stages so that fish surviving one life stage enter the next life stage or else move downstream to alternative habitats (e.g., Mousalli and Hilborn 1986, Greene and Beechie 2004). Hence these models more realistically represent the sequence of life stages a population must experience, and also allow variation in life history types to influence the outcomes of model runs. For example, if summer rearing habitats in mainstem rivers are at capacity, then some fish may simply migrate to the delta for summer rearing. Therefore, modeling of changes in one habitat may also influence density or survival in other habitats by altering the number of fish migrating into that habitat type.

Stage-specific capacity models are typically simple in form but very detailed in data needs. For example, the coho salmon stage-specific capacity model developed in the 1980s for estimating production potential of river basins produces a simple comparison of habitat capacities at four life stages, but it requires summing the areas of all individual habitat units (e.g., pools or riffles) measured or estimated throughout a river basin. Each habitat type has an associated density of juveniles it can support, and an estimated survival from that stage to the smolt stage. Life stages and habitats incorporated into the model can include spawning, early rearing (spring), summer rearing, and winter rearing (Reeves et al. 1989). For each life stage, the area of each habitat type must be estimated in all channels and summed across the basin, and then multiplied by density and survival to estimate the smolt production capacity of each habitat type. These estimates can then be compared among life stages to estimate which life stage limits the population.

These types of stage-specific capacity models can also be used to estimate habitat capacities for historical conditions to approximate the maximum potential smolt production of a basin, or to estimate habitat capacities for alternative restoration scenarios to tell managers which restoration options will likely yield the greatest improvement in a population. For instance, in the Skagit and Stillaguamish River basins in Washington State, assessments of both historical and current habitat capacities illustrated that winter-rearing habitats were likely limiting both historically and at present, but that in both basins the potential smolt production has been reduced by about 50% due to land uses (Beechie et al. 1994, 2001). Both assessments also illustrated that restoring overwintering habitats in floodplains and in beaver ponds were likely to be the most beneficial actions, and that restoring habitats impacted solely by forestry activities would likely yield a relatively small cumulative benefit even if all forestry impacts were corrected.

The stage-specific capacity model has also been used to evaluate the relative potential effectiveness of alternative restoration scenarios, as in the recent analysis of potential Chinook and steelhead rearing-capacity improvements that might be achieved by various restoration options in the Trinity River, California (Beechie et al. 2012b). In that analysis, three types of restoration options were considered: in-channel restoration actions that improved rearing habitat quality and survival, increasing sinuosity of the main channel to increase rearing habitat quantity and capacity, and constructing off-channel habitats to increase rearing habitat quantity and capacity. That analysis illustrated that potential increases in Chinook and steelhead carrying capacity range from 39% for a relatively realistic estimate of increasing habitat quality (more low velocity areas with cover) to 67% for a more optimistic scenario that increases both sinuosity and habitat quality (Figure 4). The most optimistic scenario, which increases habitat quality, increases sinuosity, and constructs tens of kilometers of side channels, more than doubles potential juvenile salmonid production. These types of quantitative predictions provide a frame of reference for benefits from restoration effort and can be used to inform measureable restoration goals.

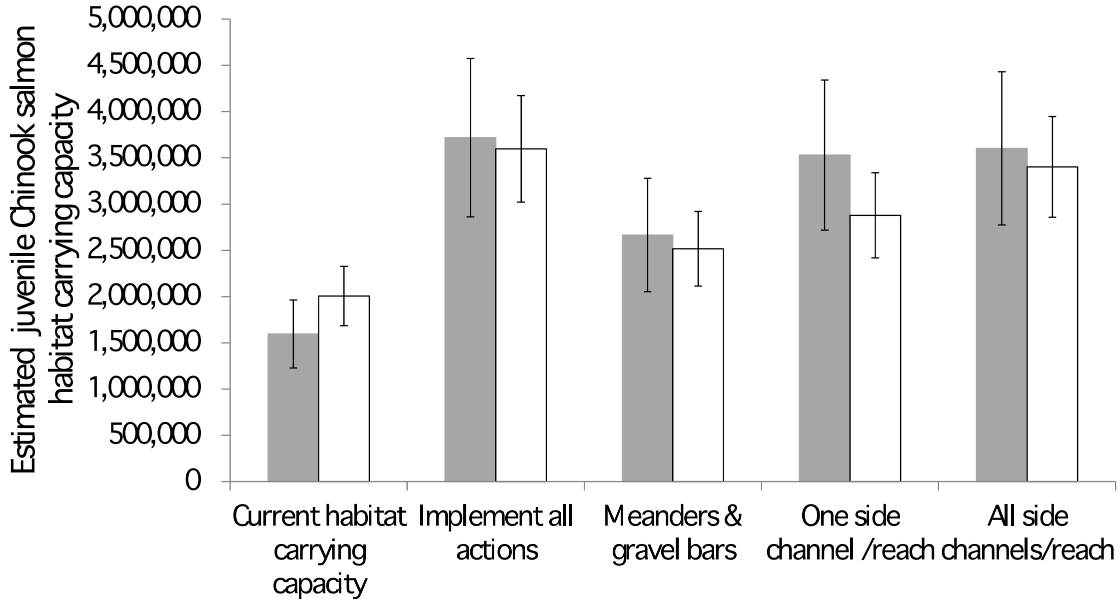

Figure 4. Estimated increases in juvenile Chinook salmon habitat carrying capacity, assuming an increase in habitat area and habitat quality, by rehabilitation action in all reaches of the 64km of the Trinity from Lewiston Dam to the confluence of the North Fork Trinity River. Gray bars are juvenile steelhead <50 mm. Clear bars are juvenile steelhead 50—200 mm. Solid black bars with perpendicular lines at top and bottom of bars is representative of one standard deviation of the estimate. From Beechie et al. (2012).

Life cycle models

Life cycle models may take a number of forms, including statistical life-cycle models, Leslie matrix models, and linked stock-recruit models. For the purposes of evaluating population scale effects of habitat restoration, the latter two are potentially the most useful, as the statistical life-cycle model is less suitable for incorporating restoration actions or scenarios into the model. That is, statistical life-cycle models relate habitat variables at different life stages directly to a performance measure such as the return rate, but it does not model habitat capacity at each life stage or survival between life stages, and therefore is less able to incorporate restoration actions. By contrast, both Leslie matrix and linked stock-recruit models can use habitat data to drive estimates of capacities and survivals by life stage. However, the resolution of habitat data is typically much lower than in stage-specific capacity models, with habitat data typically being estimated at the scale of reaches or sub-basins rather than habitat units (e.g., Bartz et al. 2006, Crozier et al. 2008). On the other hand, more types of habitat impacts and restoration actions have been incorporated into life-cycle models, typically by evaluating functional relationships between land use, habitat conditions, and life-stage capacity or survival outside of the life-cycle model (e.g., Bartz et al. 2006), and then using those capacity and survival data to drive the life cycle model (e.g., Scheuerell et al. 2006). For example, analyses of land use effects on habitat characteristics in the Snohomish basin indicated that fine sediment levels in spawning gravels are a function of forest road density, whereas pre-spawning temperatures are function of riparian forest cover (Bartz et al. 2006). Hence, modeling restoration scenarios that involve reduction of forest roads or increasing riparian forest cover produce changes in habitat characteristics (fine sediment or stream temperature). These habitat characteristics are then related to life-stage survivals via a second set of functional relationships in which pre-spawning temperature influences fecundity (the number of eggs a female salmon produces) and fine sediment levels affect survival of eggs in the gravel (Scheuerell et al. 2006). Thus, restoration actions are linked to salmon population responses via a series of linked functional relationships, and modeling a restoration action produces a change salmon population performance.

Regardless of model form, the utility of life-cycle models is in their ability to predict outcomes of restoration. Some modeling efforts ignore the effects of climate change or future land use, and simply evaluate the effects of restoration actions. Such analyses may examine a complex suite of land use impacts on habitat conditions, such as the effects of erosion on the quantity of fine sediments in spawning gravels, the effect of riparian conditions on stream temperature or wood and pool abundance, the impacts of unscreened water diversions, or land cover influences on peak flows (e.g., Bartz et al. 2006, Walters et al. 2012). Each of the response variables are known to affect capacity or survival of salmon. Fine sediments affect egg incubation and survival to emergence from spawning gravels, wood and pool abundance affect spawning or rearing capacity, and stream temperature can influence egg incubation, summer rearing survival, or spawning or emergence timing. Each of these effects requires a functional relationship (i.e., a mathematical equation representing the relationship between the habitat variable and salmon capacity or survival) in order to influence the life-cycle model outcome and relate habitat or restoration actions to habitat response, and habitat response to fish response (Scheuerell et al. 2006). Once all of these relationships have been assembled, the model can be constructed and then used to evaluate alternative restoration scenarios. For example, Scheuerell et al. (2006) compared restoring spawning habitat, rearing habitat, or both in the estuary, mainstem, lowland tributaries, or headwaters, and found that restoring rearing habitats in the estuary and mainstem would yield the largest improvement in spawner abundance. Such analyses can help prioritize restoration actions, and set realistic expectations for restoration outcomes (Beechie et al. 2010).

Life-cycle models are also useful for evaluating the potential effects of climate change on salmon population performance, as well as the effects of future land uses. Examples of using life-cycle models to analyze potential effects of climate change on salmonids include predicting effects of climate change on multiple populations to show that populations occupying different streams will likely respond differently to climate change (Crozier et al. 2006, 2008), or to show that population level effects of restoration actions are partially negated by climate change (e.g., Battin et al. 2007) (Figure 5). Finally, life-cycle models have also incorporated future land use effects into analyses restoration effectiveness, showing that while land use trends and climate change my tend to decrease population size in some areas, restoration actions can still overcome those negative effects and result in population increases into the future (Figure 5) (Battin et al. 2007).

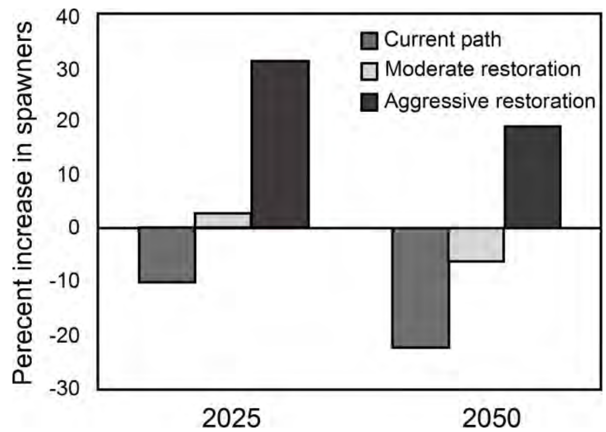

Figure 5. Estimated change in Chinook salmon population size with varying restoration scenarios and climate change. “Current path” represents limited restoration plus continued land use change into the future. The climate change scenario is the moderate A1B emissions scenario. Adapted from Battin et al. 2007.

Summary and Conclusions

Decades of fish-habitat research has demonstrated the importance of freshwater and estuarine habitat for various life stages of Pacific salmon. Moreover, research has shown the negative impacts of human actions on habitat quality and localized salmon carrying capacity, growth, and life history diversity. More recently, efforts have been quantifying effectiveness of different restoration techniques. Many studies have reported improvements in physical habitat particularly at a reach scale for various techniques. Fewer studies have quantified biological responses, but several studies have shown localized (reach scale) increases in fish abundance for placement of instream structures and reconnection of both tributary and floodplain habitat. Moreover, few of these studies have explicitly examined changes in salmon or steelhead survival. Less information exists for other techniques and additional research is needed to quantify changes in fish survival and abundance due to restoration at both a reach and watershed scale.

Scaling these reach-scale effects up to the watershed or population-scale requires either watershed or population evaluation or life-cycle modeling. Several IMW studies are currently underway to quantify population level responses to restoration and quantify the effects of multiple restoration techniques throughout a watershed on salmon survival and production. Initial results from these studies are promising; however, results will not be available for most of these studies for 5 or more years and results may not be directly transferable to other populations and watersheds. Until these studies are completed, predicting population level responses to habitat change can be estimated with statistical/computer models. These include two general categories: 1) limiting-factors models based on habitat capacity, and 2) life-cycle models that account for survival and abundance at each life stage. While modeling approaches are useful, there is much uncertainty in all models, and quantifying this uncertainty with Monte Carlo simulations and sensitivity analysis can provide useful information to managers.

No one model will address all needs for estimating restoration benefits and priorities and multiple models are needed. Models are population specific due to unique characteristics of each watershed and population and applying findings from one watershed or population to another should be done with caution and account for differences in habitat and population characteristics between basins. Moreover, models that directly incorporate data from the subject watershed or population should generally be given more weight than models based on extrapolations from other basins.

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Appendix 1.

Key findings of 411 published studies located that report effectiveness of different restoration techniques. Studies are sorted by major restoration action and year published.

Restoration Type	Reference	Key Quantitative Findings
Dam Removal	Born et al., 1998	Financial and social survey, no physical data just "opinion survey" on impacts and benefits
Dam Removal	Bushaw-Newton et al.	Channel changes in former impoundment = 0.5 m decrease in elevation above dam, WQ = no change, Inverts = dominant assemblage changed from lentic to lotic but no other changes, channel changes downstream of dam = 0.5m aggradation, fish assemblage = none downstream of dam, fish assemblage in former reservoir = change before and after
Dam Removal	Doyle et al., 2003a	Physical = total suspended solids increased downstream of dam following removal, 7.8% and 15.4% of sediment eroded from reservoirs in first year (they looked at two dams removals), change in channel cross sections above and below dams, increased fine sediment below dams
Dam Removal	DVWK 2002	Provides only general info on success of different fish passes - no specific numbers
Dam Removal	Grzybkowska et al., 1990	Actually this is not dam removal, but a recently constructed dam - no difference in density or production of macroinverts, but % collectors higher above dam than below (25.1% vs. 1% below)
Dam Removal	Hart et al., 2002	Review article with large table summarizing results of 20 dam removals and 30 papers - generalizations without specifics. In general increased fish migration, sediment transport, changes in nutrients and WQ (typically initial decrease) and change in fish and macroinvert community
Dam Removal	Hill et al., 1994	Hill et al. 1994: Increase in LM bass, WQ and species diversity

Dam Removal	Kanehl et al., 1997	Increased SM bass abundance and biomass, "good" fish IBI and decrease in carp upstream of dam. But initial decrease in SM bass and lower quality fish IBI downstream of dam, but rebounded to preproject levels by 5 years after dam removal
Dam removal	Kiffney et al. 2009	Coho, Chinook, cutthroat, rainbow. Before the ladder, late summer total salmonid (trout only) density increased with distance from the dam. This pattern was reversed after the ladder was opened, as total salmonid density (salmon and trout) approximately doubled in the three reaches closest to the dam. A nearby source population, dispersal by adults and juveniles, low density of resident trout and high quality habitat above the barrier likely promoted rapid colonization.
Dam Removal	Lenhart, C. F., 2003	Looked at 18 NOAA community based restoration program dam removals. Only reported general results - increased passage for river herring (Alosa spp.) and salmonids Oncorhynchus species.
Dam removal	Martens and Connolly 2010	Juvenile Chinook, juvenile coho, juvenile steelhead, rainbow and mountain whitefish. Dam-style water diversions were replaced with rock weirs allowing fish passage. There was a new appearance of Chinook, coho and mountain whitefish upstream of the weirs. Using PIT tags, 109 upstream passage events by small salmonids were recorded. 81% of those events were rainbow or steelhead. Small rainbow or steelhead ranging from 86-238mm were able to pass .
Dam Removal	Nelson and Pajak 1990	Hab. Suit. Index (HIS) values for SM bass increased following dam removal and channel restoration. On average H.S.I. increased by 0.29 or a 39.5% increase
Dam removal	Pearson et al. 2012	No fish. After dam removal, initial channel development and sediment erosion occurs rapidly (weeks to months) in sand-filled impoundments, but excavation of the remaining sediment occurs more slowly depending on vegetation feedbacks and flood events.
Dam Removal	Sethi et al. 2004	Density of mussels downstream of dam decreased by 1.2 mussels/m2 and silt and sand increased from 17.9 to 46.3% of total area sampled

Dam Removal	Shafroth et al., 2002	This is a review article discussing potential changes in riparian veg following dam removal. No specifics provided.
Dam Removal	Smith et al., 2000	Mostly review of sociological aspects including stakeholder input and expectations, though they report increased fish passage, but provide no data
Dam Removal	Stanley et al. 2007	Brook trout. Abstract only. No numbers. No new species colonized the creek in the two years after dam removal. CPUE was lower and YOY CPUE was higher in 2005 than in 2001 in all reaches, but the magnitude of the changes was substantially larger in the two dam-affected sample reaches relative to an upstream ref reach, indicating a localized effect of the removal. Total length of adults and YOY and the adult body condition did not vary between years or among reaches.
Dam Removal	Stanley et al., 2002	Physical - decrease in cross sectional area above dam (59 m2 to 11 m2), macroinvertebrate assemblage changed to lotic taxa, but following removal no difference in taxa between upstream and downstream reaches
Dam removal	Walters et al. 2012	Chinook. Under median-streamflow conditions with unscreened diversions, the estimated cumulative effect of the diversions was a loss of 71.1% of out-migrating smolts due to entrainment. Estimated mortality was reduced to 1.9% when all diversions were screened. Mortality dropped to between 1% and 4% for screened diversions for all streamflow conditions. If resources are limited, targeting the diversions that remove a large amount of water and diversions in locations with high fish encounter rates is most effective.
Floodplain/Off-Channel	Akita et al., 2006	Remeander. Radiotagged chum held in deep, slow current near bottom near the banks in canalized river. In restored area, chum swam in more shallow areas against stronger currents.
Floodplain/Off-Channel	Albert and Trimble 2000	Beaver reintroduction. With new dams water flow slowed, stream bed raised, improved hydrology, reduction of salt cedar infestation, increase in willows. Problems were farmland flooding and destruction of many large trees.

Floodplain/Off-Channel	Apple, L. L., 1985	No concrete numbers. Beavers built three major dam complexes which developed subirrigated meadow areas. Mud bars formed behind the dams, water tables were elevated and full riparian recovery was underway.
Floodplain/Off-Channel	Baattrup-Pedersen et al., 2000	Effects of stream restoration (remeandering) on plant communities. No. species decreased 25% in the stream and 9% on the banks; increased 15% in the stream valley. On the bank, dominance changed from non-riparian species to more diverse communities. Little change to plant communities in the valley.
Floodplain/Off-Channel	Biggs et al., 1998	No fish. Inverts and aquatic veg. Wetland macrophyte species richness quickly reached pre-restoration levels relative to control sections. Emergent plant species richness remained the same, or increased, after restoration. 1 year after restoration, the mean emergent plant species richness increased from 27 to 38 species/500m survey length. There was a highly significant increase in species richness between years but no interaction between location and year. Number of aquatic plant species went from 7.5 species pre-restoration to 7.0 species within a month of restoration and 8.0 species 1 yr. post restoration. The abundance of inverts generally recovered less rapidly than species richness. Downstream of the restored area showed a relative decline in invert species richness 1-2 months after restoration.
Floodplain/Off-Channel	Blackwell et al. 1999	4 restored and 3 natural off-channel habitats monitored during smolt migration. No difference in coho smolt production from natural vs. restored habitats. Major benefits will be quantity, not quality of available habitat. Juvenile steelhead utilized off-channel areas in low densities (<1 smolt/100 m2). Coho smolt abundance varied from <2/100m2 to >50/100m2
Floodplain/Off-Channel	Boedeltje et al., 2001	Constructed shallow side channels and studied vegetation. Although submerged aquatic macrophytes persist for a relatively short time, shallow zones function as habitat for helophyte communities and contribute to a higher aquatic biodiversity.

Floodplain/Off-Channel	Boussu, M. F. 1954	Rainbow, eastern brook and brown trout. The increase in total pounds of fish following application of brush cover amounted 258.1%. The 3 sections which were unaltered increased an average of 22.5%. There was an average increase in legally catchable fish of 0.62 pounds per inventory per 100 square feet of cover applied. The total pounds decreased 40.5% in the sections where cover was removed. Legal fish decreased an average of 0.95 pounds per inventory per 100 square feet of brush cover removed.
Floodplain/Off-Channel	Bryant, M. D., 1988	Abstract only - no numbers. Gravel pits flooded and connected to rivers. The ponds were found to support coho throughout the winter. Number of coho fluctuated, but was high 2,000 throughout study
Floodplain/Off-Channel	Carl, J., 2001	Abstract only. Abundance results indicate restoration measures (remeandering and discontinuance of stream maintenance) can improve the overall stream environment and increase total abundance of trout - but its not clear what habitat types are beneficial to improving abundance.
Floodplain/Off-Channel	Caruso , B. 2006	Evaluates the effectiveness of a river recovery project. No numbers. Lists recommended elements and restoration components with no specifics.
Floodplain/Off-Channel	Cederholm and Peterson 1989	Constructed pond - winter survival rate increased from .11 to .56. Mean length increased from 13 to 41mm and mean weight increased from 3 to 13 g. Constructed braided channel - significant increase in winter survival (rate = .57) and growth (post-construction 20mm length and 5.6 g weight - no pre-construction data.)
Floodplain/Off-Channel	Cederholm et al., 1988	Constructed habitat. Overwinter survival and growth of coho increased significantly post construction (survival .11 to .56; mean change in length from 13 to 41g; mean change in weight from 3 to 13 g)
Floodplain/Off-Channel	Childers et al., 1999	Abstract only. No fish. No numbers. Measured sawgrass in marsh following levee removal.

Floodplain/Off-Channel	Childers et al., 1999	Abstract only. No fish. Nutrient concentrations more than doubled immediately after levee removal, from about 0.2 to 0.4 mu M TP and from about 45 to 140 mu M TN. However, the sawgrass marsh quickly took up this nutrient load. Flume sampling showed ammonium and DOC update, and TOC release. The periphyton zone imported TN, while nitrate-nitrite flux was dominated by marsh dynamics.
Floodplain/Off-Channel	Chovanec et al., 2002	Levee removal - fish species richness increased with connectivity. No numbers. Colonization of structures by dragonflies (28 species). Amphibians 12 out of 20 potential species colonized island
Floodplain/Off-Channel	Clarke and Wharton 2000	Evaluated marginal habitat and macrophyte community 5 years after bank re-profiling and planting program. Enhanced reaches were floristically distinct and had higher values of wetland species diversity, % of wetland species, bank width, soil moisture and lower bank angles.
Floodplain/Off-Channel	Clayton, S. R., 2002	Remeander. Following restoration, reach-median max depths at baseflow increased 56% to 0.43m and velocities decreased 24% to 0.28 m/s - at bankfull discharge =, reach-median max depths increased 30% to 1.5m and velocities decreased 17% to 0.85 m/s. Pool frequency increased by 50%, resulting in an even pool:riffle ratio.
Floodplain/Off-Channel	Cooperman, Hinch et al. 2006	Coho. Ten studies - not a lot of numbers. Eight of ten off-channel projects appear to be functioning as designed, although 5 of those have conditions that could compromise their utility to young coho (beaver dams and/or extensive aquatic macrophyte growth to limit connectivity to parent system or impair water quality. Effectiveness would improve by providing upwelling groundwater and by routine project maintenance.
Floodplain/Off-Channel	Cott, P.A., 2004	Abstract only. Constructed ponds and channels connected to river. Yielded successful spawning and utilization of nursery habitat by northern pike. Spottail shiners and invertebrates used the new area as well. Area re-vegetated itself. Ultimate habitat gain was calculated to be over 11:1.

Floodplain/Off-Channel	Cowx and Van Zyll de Jong 2004	Case study #1: Boulder treatments caused significant +0 and +1 salmon density increase, V-dam treatment significantly increased +0 salmon in 2nd PT year, half-log cover increased +0 salmon density for both PT years. Trout densities did not change significantly for any age class. Case study #2: Remeander and creation of pool and riffle habitat - upper reaches had reasonable good brown trout populations reaching 46 per 100m-2, middle and lower reaches had low density of absence of mixed coarse fish assemblage or had an impoverished coarse fish community. In general, there was a weak response of the fish populations to the improvement measures.
Floodplain/Off-Channel	Decker and Lightly 2004	Constructed 3 side channels. Mean density of outmigrating coho smolts was 2.3 times greater in the side channels than in the mainstem (4,857 vs. 2,117 smolts km-1). Smolts outmigrants from side channels represented 13% (+-1.3%) of the estimated total smolt production for the river though only 6% of the total habitat by stream length.
Floodplain/Off-Channel	Florsheim and Mount 2002	Levees breached and subsequent study of sand-splay complexes. Rapid vertical accretion and scour occurred. Max deposition measured on the splay surface was 0.36 m/yr. and max scour in channels was 0.27 m/yr.
Floodplain/Off-Channel	Friberg et al., 1998	Remeandering. Created a physically stable environment in <3 years with an improved density and diversity of macroinvertebrates.
Floodplain/Off-Channel	Grift et al., 2001	Reconnection of off-channel habitats. Presence and abundance of rheophilic cyprinids increased from isolated oxbow lake to connected oxbow lake and secondary channels. Water flow and connectivity are important factors driving the structure of the YOY fish community. Secondary channels provide suitable nursery habitat for rheophilic cyprinids.

Floodplain/Off-Channel	Grift et al., 2003	Constructed side channels. Total fish density increased along a gradient of decreasing water flow whereas the proportion of rheophilic species decreased. Flow velocity and water depth were most important factors determining habitat utilization. During floods, inundated terrestrial veg was important habitat for the larvae of all species. Floodplain water bodies should have complex shorelines and a high variability of flow velocities.
Floodplain/Off-Channel	Grift, R.E., 2001	Abstract only. Constructed side channels had a beneficial value for the riverine fish community. They serve as nursery areas for all rheophilic cyprinids and spawning areas for a couple of those species.
Floodplain/Off-Channel	Habersack and Nachtnebel 1995	Constructed side channel. Study showed higher growth of algae, higher numbers of species of macroinvertebrates and greater densities of fish species.
Floodplain/Off-Channel	Hammersmark et al. 2008	No fish. Model simulations yielded three general hydrological responses to the meadow restoration effort: 1) increased groundwater levels and volume of subsurface storage, 2) increased frequency/duration of floodplain inundation and decreased magnitude of flood peaks and 3) decreased annual runoff and duration of baseflow. 'Pond and plug' type stream restoration has the capacity to re-establish hydrological processes necessary to sustain riparian systems.
Floodplain/Off-Channel	Hansen, H. O., 1998	Remeander, raised stream water level, added coarse substrate for spawning. At 2 years pretreatment (PT), only terrestrial plants had recovered. Fish and inverts had not reached expected levels, however, the number of brown trout caught PT approached expected levels. No numbers.
Floodplain/Off-Channel	Hein et al., 1999	Reconnection. No numbers. Lotic conditions led to higher phytoplankton biomass. Heterotrophic compartments dominated plankton under lentic conditions. The biomass ratio of phyto-to bacterioplankton declined as hydrological connectivity decreased.

Floodplain/Off-Channel	Henning et al. 2006	Reconnect. Added water-control structures to emergent wetlands to provide an outlet for fish emigration. Resulted in higher abundance of age-1 coho in enhanced wetlands. Yearling coho had comparable specific growth rate and minimum estimates of survival (1.43%/d by weight and 30%; 1.37%/d and 57%) to other side-channel rearing studies.
Floodplain/Off-Channel	Hoffmann et al., 1998	Remeander. 92 kg ha-1 year -1 of nitrate was removed during passage through the river valley. Iron leaked from the floodplain to the river at 400 kg ha-1 year-1. Enhanced removal of nitrate along the restored reach during a 2-month period of flooding right after restoration.
Floodplain/Off-Channel	Holubova and Lisicky 2001	Meander reconnection. Abundance of limnophilous fish species lowered in favor of both reophilous and eurytopic species but the number of species did not change. Species diversity of water macrophytes decreased from 13 to 5. Inverts showed a shift from stagnicolous to semireophilous species composition. A large gravel-sand bank formed creating a new habitat used in the 1st year by terrestrial annual plants.
Floodplain/Off-Channel	Iversen et al., 1993	Remeander. Inverts increased to 75 species In restored reached compared with 62 in control reach. Harmful effects of the project on downstream reaches was negligible, and a stable abiotic and biotic stream environment was established within 2 years.
Floodplain/Off-Channel	Jahnig et al. 2009	Rebraiding. No. of floodplain mesohabitats was significantly higher in restored sections, but there was no significant effect on the number of aquatic microhabitats. Mean length of mesohabitats increased by a factor of 3 to 0 (terrestrial) 1 to 4 (aquatic) and 5 to 9 (transient parts). Plants: the median species richness was 60 in the non restored and 125 in the restored sections. Median number of genera increased from 62 to 86 and median number of families from 28 to 35. Ground beetles: proportion of riparian species was 75 - 2% in the restored sections and 29-5% in non-restored sections. 169 benthic invert taxa were recorded. Values of metrics were always slightly higher in restored sections.

Floodplain/Off-Channel	Jeffres et al. 2008	Juvenile Chinook. There were significant differences in growth rates between salmon rearing in floodplain and river sites. Salmon reared in seasonally inundated habitats with annual terrestrial vegetation showed higher growth rates than those reared in a perennial pond on the floodplain. Growth of fish in the river upstream of the floodplain varied with flow and turbidity. When flows and turbidity were high, there was little growth and high mortality, but when flows were low and clear, the fish grew rapidly. Fish in tidal river habitat below the floodplain showed very poor growth rates. Ephemeral floodplain habitats supported higher growth rates for juvenile Chinook than more permanent habitats in either the floodplain or river.
Floodplain/Off-Channel	Jungwirth et al., 1995	Remeander. Number of fish species increased from 10 in straightened sections to 19 in restructured sites.
Floodplain/Off-Channel	Jungwirth et al., 2002	Reconnection. Overall evaluation of ecological integrity of three reaches was 0.22, 0.54 and 0.37. Includes physical habitat conditions, vegetation, and fish fauna.
Floodplain/Off-Channel	Jutagate et al. 2005	Flooding - sluice gates open on dam. CPUE ranged from 038 to 1.70 and 0.61 to 2.71 kg fisherman-1 night -1, downstream and upstream of the dam, respectively. Month % index of relative importance of the fish species caught varied between months.

Floodplain/Off-Channel	Klein, Clayton et al. 2007	Channel length increased 60%, resulting in a 60% increase in sinuosity; median bankfull velocity was significantly slower immediately following restoration but not 3 yrs. later; model simulation showed an average increase in post-restoration hydroperiod by more than 25 days or 200%; mean native plant cover increased from 32% in 1997 to 57% in 2001, then 65% in 2003; mean native greenline plant cover decreased fro 49 to 43%; total number of habitat units increased by 52% from 48 to 73 then increased to 102 in 20003; proportion of fines decreased significantly; temperatures exhibited significant increasing temporal trends; salmonid densities fluctuated and ranged from 7.1 fish/100 m2 in 2003 to 27.8 fish/100 m2 in 2001 - no significant increasing trend in salmonid density or % composition was detected in the restored reach; Annual Chinook redd density fluctuated - no significant increase; bird numbers increased significantly from 52 in 1996 to 91 in 2003.
Floodplain/Off-Channel	Kronvang et al., 1998	No fish. Reducing the bankfull capacity, raising the bed level and lowering the bank level allowed an increase in flooding frequency and in the amount of water passing onto the floodplain in all three rivers. In the river Brede, restoration of the natural hydrological contact between the river and its floodplain resulted in high deposition of sediment (189 t year -1) and sediment associated phosphorus (770 kg P year-1). Construction caused excessive downstream loss of sediment and phosphorus.
Floodplain/Off-Channel	Langler and Smith 2001	Construction of off-channel habitats. Abundance (t=3.94. df=61, p<0.001) and diversity (t=6.48, df=50, p=<0.001) of 0-group fishes (non-salmonid) was significantly higher in treatment areas.
Floodplain/Off-Channel	Lister and Bengeyfield 1998	Constructed ponds. No clear numbers. At 4 of 5 study sites the compensatory habitat was functioning to effectively offset the original impacts. Natural colonization appeared capable of revegetating disturbed marshes and riparian areas in a relatively short time.

Floodplain/Off-Channel	Marshall et al. 2008	Brown trout. Effects of planting cool- or warm-season grass cover on highly erodible croplands along stream corridors. Pre-planting fish communities had a relatively high diversity of eurythermal species and low coldwater IBI scores. They found significant increases in coldwater IBI scores over time in streams within the high planting area relative to streams within the low planting area. Fish populations in the high planting area shifted from eurythermal and tolerant species before planting to stenothermal, cool- and coldwater species. Ecological responses within the high planting streams also included a reduction in species richness. IBI scores and species richness were correlated with phosphorus loading estimates and predicted phosphorus reductions were greater with the high planting area.
Floodplain/Off-Channel	Martin et al. 2010	Juvenile coho. Biofilm chlorophyll-a concentrations were 4-10 times higher in analog-enriched treatments than in the control and wood treatments. No treatment effects were detected in benthic invertebrate density; however, treatment differences were detected in coho diets, with nearly twice the amount in invert abundance and biomass in the analog and analog plus wood treatments. Juvenile coho density and biomass were significantly higher in the wood treatment than in the analog plus wood treatment. Body condition of coho was highest in the two analog-enriched treatments - juveniles in these habitats showed nearly two times the condition increase of fish in control and wood treatments.
Floodplain/Off-Channel	Marttin and Graaf 2002	Mortality rate (% of total larvae recaptured) of carp hatchlings (+-SE) for under and overshot operations of the sluice gates. Overshot = 11.8 +- 3.6; undershot = 44.0 +- 5.6.
Floodplain/Off-Channel	McKinstry and Anderson 2002	Beaver reintroduction. Lost 30% of beaver to mortality and 51% to emigration 6 months after release. Survival estimates were 0.49 (SE=0.068) for 180 days and 0.433 (SE=0.084) for 360 days. 2-3.5 year old beaver had higher average success than older or younger beaver.

Floodplain/Off-Channel	McKinstry et al., 2001	Beaver reintroduction. Survey of land managers found that beaver had been removed from 23% of streams managers knew of; there are over 3,500 km of streams where beaver could improve habitat; riparian width in streams with beaver ponds averaged 33.9 m compared to 10.5m without. There are more ducks in in areas with beaver ponds. Waterfowl is quick to respond to creation of beaver-created wetlands.
Floodplain/Off-Channel	Moerke and Lamberti 2004	No fish. No good numbers. Restored reaches had significantly lower stream widths and greater depths than did upstream unrestored reaches, but riparian canopy cover often was lower in restored than in unrestored reaches.
Floodplain/Off-Channel	Moerke and Lamberti, 2003	Abstract only. Remeander. Increase in size distribution and # of redds for trout. Fish community changed from rheophilic species to highly tolerant, slow-water species.
Floodplain/Off-Channel	Moerke et al., 2004	Remeander. One year PT, periphyton, inverts and fish recovered or exceeded levels in the control reach but 5 years PT, invert diversity and fish abundance in restored reaches were similar to or below levels in the control reach.
Floodplain/Off-Channel	Moerke, A.H., 2004	Abstract only. Remeander. Upstream sediment is limiting factor so restoration should target the scale at which degradation occurs. Anthropogenic factors explained most variation in stream conditions. Forested streams were least degraded in terms of water quality, habitat, and fish. Agricultural streams without buffers were the most degraded and urban and agricultural streams with buffers were intermediate.

Floodplain/Off-Channel	Morley et al. 2005	Juvenile salmonid use of constructed vs. natural side channels. Total salmonid density (fish x m-2) in summer was 2.14 (+-1.60) and 0.11 (+-0.89) for constructed and reference sites, respectively; in winter it was 0.81 (+- 0.87) and 0.81 (+-0.96), respectively. Coho densities were higher in constructed channels and trout densities were higher in reference channels during winter. Both channel types supported high densities of juvenile coho during summer and winter. Constructed channels were deeper and warmer in winter and cooler in the summer than natural channels but had lower physical habitat diversity, wood density and canopy coverage.
Floodplain/Off-Channel	Muhar et al. 2008	Not a lot of good numbers. Results showed improvements of the habitat and fish ecological situation in rehabilitated sites. Juvenile grayling benefitted from increased areas of shallow habitats; the ecological status improved between 0.2 and 0.9 ecological classes, depending on the spatial extent of the measures. Both brown and rainbow trout showed higher values in the channelized sections.
Floodplain/Off-Channel	Muhar et al., 2004	Levee removal and constructed side channel. Aquatic area increased by 67% initiating 5 additional aquatic habitat types; riparian and floodplain vegetation restoration was successful in terms of characteristic plant species and associations; new shallow water areas in restored areas were utilized by juvenile graylings of 70-140mm more than twice as often as in unrestored stretches.
Floodplain/Off-Channel	Nagayama et al. 2008	Remeander and LWD. No numbers. Before wood placement, few small masu salmon were observed in lateral scour pools - 1 year after wood placement juvenile and adults were abundant, and some lentic and benthic fish species were found around the wood structures. In winter after wood placement, some salmonids (chum) returned from the ocean. No fish were observed in lateral scour pools without wood, and wood structures tended to be used by more fish species compared to areas without wood.

Floodplain/Off-Channel	Nakano and Makamura 2008	No fish. No good numbers. Macroinverebrate response to remeander. The natural meandering and restored meandering reaches showed higher cross-sectional diversity in physical variables and total taxon richness across a reach than did the channelized reach. Almost all taxa observed in the natural and restored reaches were concentrated in the shallowest marginal habitats near the banks. Shear velocity increasing with water depth had a negative association with invert density and richness.
Floodplain/Off-Channel	Nakano and Nakamura 2006	No fish. The shear stress of the river edge in reconstructed meanders and groyne reaches was lower than that in a channelized reach. The edge habitat near the stream bank created by the reconstructed meander and groyne reaches had higher total density and taxon richness of inverts than those in channelized reaches.
Floodplain/Off-Channel	Neilsen, M., 2002	Remeander, improve hydraulic interaction between river and meadows, restore wetlands. Water storage increased; improved natural habitat for plants and animals, including salmon; water quality increased. No numbers.
Floodplain/Off-Channel	Payne and Cowan, 1998	Carp and catfish. Yields increased from 1863 kg/ha to 11.384 kg/ha, which partly resulted from improved access to fishing and no. of fishing days increased from 396 to 810 over a year. The percentage of the catch due to major carps and large catfishes increased from 2% to 24% indicating that immigration and recruitment had increased substantially.
Floodplain/Off-Channel	Pedersen et al, 2006	Compared macrophyte communities in natural streams, restored streams (remeandered) and channelized streams. Macrophyte communities were similar in restored and natural streams (30 and 33 species in restored and natural vs. 16 in channelized, shannon diversity 2.7 and 2.8 vs. 1.4). Bank morphology and management and bed depth strongly influence macrophyte communities.

Floodplain/Off-Channel	Pedersen et al. 2007	Remeander. River valley changed from ag. fields into meadows with a rapid succession in plant species. The new river was rapidly colonized with plants and inverts from upstream reaches. New shallow lakes and meadows caused a minor increase in predation of brown trout and Atlantic salmon due to the increased populations of fish-eating birds. Lampreys were found at 75% of the investigated locations both before and after restoration; Soft rush community increased from 2% to 12%; number of plant species associated with humid soils increased from 3 to 7 and wetland species increased from 1 to 23. Area became an important feeding and roosting site for migratory birds; Breeding possibilities and general survival possibilities improved for the Common frog and Moor frog. Otters were spotted in 12 of 19 sites visited before the project and 18 of 20 sites after; floating water plantain coverage had a slight decrease in occurrence after restoration.
Floodplain/Off-Channel	Raastad et al. 1993	Abstract only. Built a rearing channel where water flow and substrate can be controlled. Physical habitat improved with the density of benthic animals. Survival of age 1+ salmon was 30%. Addition of 115g wheat/sq m resulted in a three-fold increase in benthic fauna compared to control area. Largest increase was in Chironomidae in Aug-Sept.
Floodplain/Off-Channel	Rahman et al. 1999	Abstract only. Canal rehabilitation to re-establish fish migration, fish conservation and create fish sanctuaries. Catch in beel and floodplain increased from 2481kg to 12 222 kg and from 1451 kg to 5181 kg in pagars. Major carps catch increased from 29 kg to 1221 kg in pagars; species recorded increased from 46 to 59.
Floodplain/Off-Channel	Richards et al., 1992	Excavated channels to reconnect ponds to river. Highest juvenile Chinook density (5.2/m2) was in the new channel habitat with cover, low water velocity and moderate depths.
Floodplain/Off-Channel	Richardson et al. 2005	Abstract only. No numbers. Reflooded mash area shows rapid reestablishment, high productivity, and reproduction of native flora and fauna.

Floodplain/Off-Channel	Rohde et al., 2005	Abstract only. No numbers. River widening, in general were found to increase the instream habitat heterogeneity and enhance the establishment of pioneer habitats and riparian plants. Ability of widenings to host typical riparian species and to increase local plant diversity depends strongly on the distance to near-natural stretches.
Floodplain/Off-Channel	Roni et al., 2006	Analyzed smolt trap data from 30 constructed and natural floodplain (FP) habitats. Constructed FP habitats produced coho salmon smolts of similar size and density as those in natural FP habitats. Mean coho smolt densities and lengths from restored FP habitats were similar to or higher than those in natural FP habitats. Variation in smolt production among sites generally increased as wetted area increased. Shoreline irregularity was positively correlated with smolt density but negatively with smolt size.
Floodplain/Off-Channel	Rosenfeld 2005	Stream off-channel habitats produce higher numbers and biomass of juvenile parr during summer and fall than pond off-channels (mostly coho data). Parr abundance in channels was approximately 4 times higher than in other habitat types and total biomass was also higher in channels (8.01 g/m2 in channels compared to 2.37 g/m2 in ponds) Average parr size tended to be higher in ponds than in channels (5.98g vs. 3.14g); small ponds appear to be more productive per m2 than large ponds; smolt production per unit area in the spring is not statistically different between ponds and stream off-channels. Biomass of drifting inverts in inlet enclosures were 10 x higher than drifting biomass in enclosure outlets.

Floodplain/Off-Channel	Rosenfeld et al. 2008	Juvenile coho. Review of studies. Avg. density and biomass of coho parr were significantly higher in stream-type side channels (3.4 parr/m2 and 8.01 g/m2, respectively) than in pond-type side channels (0.8 parr/m2 and 2.37 g/m2). Although total parr biomass was 3 times higher in stream-type side channels, average parr weight was 47% lower. Parr abundance declined from late summer to early spring in both side channel types but appeared to decrease more quickly in stream-type side channels. Fish density in a single off-channel or main-stem complex that contained both stream and pond habitats was also higher in stream habitats, although fish were significantly larger in pond habitats than in stream habitats. Parr density in stream-type side channels was constant with increasing channel size, whereas density in pond-type side channels was a decreasing function of side channel area. Smolt density was also a decreasing function of total side channel area.
Floodplain/Off-Channel	Schmutz et al., 1994	Abstract only. Constructed side channel. After 1 year, 40 fish species occurred in the system but densities were very low. Colonization of the canal is mainly a result of drift of larval and YOY fish.
Floodplain/Off-Channel	Schmutz et al., 1998	Reconnection via bypass channel. Although more than 57,000 fish of 35 species passed the bypass channel, pike-perch were under-represented. Bypass not successful for all species - it represents a bottleneck for the immigration of pike-perch.
Floodplain/Off-Channel	Sear et al., 1998	No fish. Channel sinuosity was increased, with the creation of 21 new bends. Bed levels were raised by 0.75m throughout the length of the downstream restored reach. Bed slope was marginally increased in the upstream restored reach, and significantly increased in the downstream restored reach.

Floodplain/Off-Channel	Sheng et al. 1990	Constructed/excavated to create groundwater-fed channels. Recruited annually between 50-250 coho spawners in 1st three years. Channels appear to be fully seeded each year. Channels can produce up to 3 coho smolts/m2. Rip-rap armoring can increase smolt productivity over ten fold (crevices provide sanctuary for presmolts). Cover availability is closely related to coho smolt abundance in groundwater-fed channels.
Floodplain/Off-Channel	Simons et al. 2001	Abstract only. No numbers. Constructed secondary channels functioned as a biotope for riverine species. The density and number of rheophilic species are influenced by the water level and frequent inundation from the high hydrological connectivity.
Floodplain/Off-Channel	Sommer et al. 2001a	Floodplain rearing. Juvenile Chinook. Salmon increased in size substantially faster in the seasonally inundated floodplain than in the river. Juveniles released in the floodplain were significantly larger at recapture and had higher apparent growth rates than those released in the river. Hydrology affects the quality of floodplain rearing habitat. Fork length in 1998 was 93.7 +-2 mm in floodplain and 85.7 +-1.4 in river, in 1999, 89.0 +- 2.6 in FP and 82.1+- 1.7 in river; Apparent growth rate (mm x day -1) in 1998 was .80 +-.06 in FP vs. 0.52 +-.02 in river, in 1999 0.55 +- .06 in FP and .42 +- .03 in river.
Floodplain/Off-Channel	Sommer et al. 2001b	References many results from Sommer et al. 2001a. No good numbers. Floodplain is a valuable spawning and rearing habitat for splittail and young Chinook. Year-class strength is strongly correlated with the duration of floodplain inundation.. Salmon are most abundant in areas with velocity refuges such as trees, shoals, and the downstream portions of levees. Mean salmon size increased significantly faster in the floodplain than in the river suggesting better growth rates.

Floodplain/Off-Channel	Stroh et al. 2005	Redeveloping pasture. Areas were inoculated with diaspores. After two vegetation periods, the plant species composition at the inoculated plots develop in the desired direction in contrast to non-inoculated plots. The rehabilitated area now has high diversity and even includes threatened species. Inoculated plots have a significantly higher number of species per plot than non-inoculated plots.
Floodplain/Off-Channel	Sudduth et al. 2011	No fish. Stream metabolism did not differ between stream types in either season and that nitrate uptake kinetics were not different between stream types in winter. During the summer, restored stream reaches had substantially higher rates of nitrate uptake than unrestored or forested steam reaches; however, we found that variation in stream temperature and canopy cover explained 80% of the variation across streams in nitrate uptake.
Floodplain/Off-Channel	Thompson and Hossain, 1998	Carp and 'small fish'. After restoration, catch from the beel and floodplain increased by about 6 times (part of this increase was due to greater flood extent in the 2nd year), while in the floodplain the catch from fish aggregating devices (ditches or pagars) increased 3.6 times.
Floodplain/Off-Channel	Van Liefferinge et al. 2003	12 Belgian species. Pre-restoration evaluation of fish assemblage and the macroinvertebrate communities mainly on the population level. Used species composition, diversity and IBI for fish and the Belgian Biotic Index (BBI) for inverts. In one case, the pre-evaluation showed that restoration at the present state would probably not result in a higher ecological value - restoring a good water quality would be of higher priority than restoring meanders. Meander restoration of 4 other sites would result in a higher ecological value.

Floodplain/Off-Channel	Weber et al. (2009)	20 species. No good numbers. River widenings vs. canalized reaches. Habitat diversity (depth, flow, velocity, cover availability) was considerable greater in the 2 longer widenings (>900m length) than in the canalized reaches and in the shortest widening (300m), with higher proportions of shallow or deep areas of different flow velocities. Rehabilitated reaches showed consistently longer shorelines than canalized reaches (32-200% of historic values). No overall significant relationship was found between reach type and the no. of species or total fish abundance. Highest winter abundance were observed in deep, well-structured backwaters of rehabilitated reaches. Assemblage structure and composition were similar in both reaches.
Floodplain/Off-Channel	Zurowski and Kasperczyk 1988	Reintroduced 168 beavers. In first year they set up 64 sites. Loss of beaver was 15% in first year after reintroduction. 44 new colonies were eventually created. A high birth rate of 1.9 young per litter was observed. Beavers raised in a farm for reintroduction are suitable.
Flow	Bednarek and Hart 2005	DO increased from 4.7 to 7.1 mg/l (34%), temp dec. from 16.1 to 13.3, velocity 1.5x or (59%), discharge increased 528%, invert family richness increased 36%, % pollution tolerant taxa 13%, and total abundance increased 163% when flow increased, but decreased 60% with DO modifications. (Note there were two treatments: increase in flow, and increase in DO following flow increase.
Flow	Dominick and O'Neill 1998	Comparison of streams where they augmented flow above natural vs. natural streams: increase in BFW and w/d ratio in augmented streams, median particle size in augmented streams ranged from 38 to 56mm, while it was 15 to 26mm in natural basins. Augmented basins saw a decrease in riparian cover of up to 10% (note this study differs from others in that flow was diverted into streams to increase flows above natural)

Flow	Dyer and Thoms 2006	Examined variety of flows releases in Australian river -results are not clear cut because of long reaches surveyed and multiple scales. "The diversity of flow types or hydraulic patches changed with discharge, but changes observed did not follow a predictable or expected relationship" - Note results probably not applicable to other streams.
Flow	Galat et al., 1998	Examines use of reconnected floodplain habitats following series of large floods in Missouri River. Not a lot of quantitative results: twice as many fish species in reconnected habitats and more diverse riverine fish assemblages, differences in turtle species using connected vs. isolated habitats.
Flow	Hill and Platts 1998	Restoration of flows and flood pulsed to dewatered reach. Increased pulse and base flows led to establishment and rapid growth of riparian veg. and good quality microhabitat (pools, runs, depth and wetted width). Brown trout numbers increased 40% and catch rates increased from 0/hr. to 5.8 to 7.1 fish/hr.
Flow	Johansson and Nilsson 2002	Compared riparian veg on free flowing and regulated rivers. Growth rates of *Betula pubescens* and *Filipendula ulmaira* were higher in free flowing, while no difference was found for *Carex acuta* and *Leontodon autumnalis*. (Abstract only)
Flow	Jurajda et al. 2004	managed flooding of former borrow pits to examine effect on species diversity. Species richness was higher in flooded than non-flooded borrow pits (14.7 vs. 11). Adult fish abundance (CPUE) was 3 to 14 times higher in flooded vs. nonflooded pits and juvenile abundance was nearly 2X higher in flooded vs. non-flooded.
Flow	Rood and Mahoney 2000	Recruitment of cottonwood in regulated river following natural and restored floods. High cottonwood recruitment following 1995 flood (seedling density 200/m2), but uncertain if full recovery as imposed based and flood flows may not reach those seen in natural floods (1995)

Flow	Rood et al., 2003	Restoration of flows to Truckee River - led to recovery of cottonwood and sandbar willow, also lead to return of 10 of 19 bird species that had been extirpated (abstract only)
Flow	Sabaton et al. 2008	Brown trout. Flow manipulation. On average, the potential habitat in bypass sections increased by 39% (a factor of 1.4 between the 2 flow levels). Average weighted usable area was 68% of the max before enhancement, and rose to 87% post-enhancement. For all bypass section sites, there was a 22.8% mean increase in the numbers of adults in the post-enhancement period, as opposed to pre-increase.
Flow	Scruton et al., 1998	Restoration of flows to dewatered stream - before an after monitoring indicated an increase in fluvial habitat to 450 units a 62% increase. Salmonid production (Atlantic salmon and brook trout) was estimated to increase 18 fold. Biomass increased from 68.4 g/unit to 281g/unit or total production from 18 kg to 330 kg.
Flow	Speierl et al., 2002	Restored reaches vs. regulated reaches. More species and individuals were caught in restored vs. regulated for larvae, juvenile and adult fishes. (abstract only - no details)
Flow	Stevens et al., 2001	Test flood in Colorado River - restored sandbars, 10.7% of endangered snail habitat and 7% of population was lost, buried riparian veg under >1m of sand
Flow	Theiling et al., 1999	Studied response of reclaimed river wetland to flooding; 26 species found after flood vs. 26 species afterward. 33 species were found the following June, but only 16 in subsequent collections in August suggesting temporary or seasonal increases in diversity due to flood.
Flow	Weisberg and Burton 1993	Diversity of consumed prey increased for white perch from 143 to 186 species for white perch, but not channel catfish or yellow perch. Growth rate of white perch increased by as much as 38%. Condition factor of all three species was greater post treatment

Instream	Aitken, W. W., 1935	Log structures. No numbers. Tree planting hinders and eventually practically eliminates bank erosion, shade will be produced, vegetation will take hold, cover will be provided, food organisms will increase and benefit fish, and water temp will be more stable. The log and rock crib deflectors are effective if located in streams where current will be forced against ledge rocks or boulder-strewn banks. Reforestation and erosion control should come first, then bank protection by plantings and by mechanical means, and finally actually installation of stream improvement devices.
Instream	Albertson et al. 2011	Invertebrate abundance and biomass were lower in the restored reach and there was a shift from dominance by filter-feeding caddis flies to grazing mayflies. Avg. densities declined 19%. Species richness and evenness were higher in the restored reach. Abundance declined nearly 50% in heterogeneous substrate treatments compared to homogeneous treatments. Biomass declined 65% from heterogeneous treatments to homogeneous treatments.
Instream	Aldridge et al. 2009	Reintroduction of coarse particulate organic matter in the form of leaf litter. Before addition, there was no difference in community respiration by control reaches retained 6.8% more filterable reactive phosphorus than treatment reaches. After addition, community respiration was greater in the treatment reaches and 7.7% more filterable reactive phosphorus was retained than in control reaches.
Instream	Anderson, J. W., 1981	No numbers. Constructed gabions function well and have been used extensively by anadromous fish for spawning. Chinook, coho, winter steelhead, cutthroat and Pacific lamprey use the structures which have trapped spawning gravels and created rearing pools. Scour pools have developed while extensive beds of gravel for aquatic organism production and adult salmonid spawning have been deposited.

Instream	Angermeier and Karr 1984	Wood addition. Fish and benthic invertebrates were usually more abundant on the side with debris. Artificial debris was colonized by many invertebrates. Inverts were 3.9 times more abundant on the debris side in July and 5.7 times more abundant on debris side in September. Most large fish (age 2+) avoided reaches without debris, whereas some smaller fish preferred them. Fish's association with woody debris appeared more closely related to camouflage than those of increased food availability or protection from strong currents.
Instream	Armantrout, N. B., 1991	Added lwd, rock and gabions. Of the 396 structures, 85% were completely or partially intact and in place and improving aquatic habitat. Where most structures are located, pool habitat increased from 40% to 48%, riffles decreased by 5.5% and glides by 5.3%.The percentage of substrate as exposed bedrock decreased from 33% to 20%; rubble, sand and silt showed the greatest percentage increase. Beavers built dams on top of 22 structures. Measurements of existing fish communities were limited. Preliminary results showed that juvenile fish used structures for overwintering. During the summer, juvenile salmonids are visible in pools, glides, and other quieter waters or shallow riffles. Juvenile populations increased where pools and other habitats increased. Coho, steelhead and cutthroat used undercut banks, root masses, and woody debris in pools behind structures for winter habitat.
Instream	Avery, E. L., 1996	Riffle construction and sediment trap installation. The amount of gravel substrate did not increase significantly in any treatment streams, although the sand dunes appeared to decline in all streams. No evidence that installation of sediment traps and gravel riffle solve deficiencies in juvenile trout recruitment where sand is the natural and prevailing parent material and there is no prior record of successful spawning.

Instream	Avery, E. L., 2004	LWD, boulders, beaver and brush removal. The success of each project was judged on the basis of the percent change within a treatment zone for 4 categories (or population variable): 1) total number of trout, 2)number of trout >=6 inches, 3) number of legal size trout, and 4) total biomass (pounds per mile). Standardization was at a "per mile" basis. Two levels of success were determined: Level 1 = post-development increases in the population variable of 25% or more and Level 2 = increases in the population variable of 50% or more. Approximately 59% of the changes in 140 population variables analyzed had Level 1 success after habitat development; 50% had Level 2 success. Total abundance of trout met Level 1 success in 43% of the treatment zones. Success rate at Level 2 was found in 31% of the treatment zones. Abundance of legal size trout achieved success rates of 65% and 62% at Levels 1 and 2, respectively. In treatment zones with allopatric populations of brook trout or brown trout, success rates were similar. In sympatric populations, brown trout responded much more positively than brook trout did to habitat development. Average empirical post-development changes for populations in trout in 58 treatment zones included a 13% decline in total abundance of trout (from 1,323 per mile to 1,125 per mile), a 65% increase in trout >= 6 inches (from 208 per mile to 344 per mile), a 25% increase in legal size trout (from 291 per mile to 363 per mile), and a 63% increase in biomass (from 100 lbs. trout per mile to 163 lbs. trout per mile).
Instream	Baldigo et al. 2008	The habitat suitability indexes for all salmonid species increased by 15% on average (brook, brown and rainbow trout). The net increase in the number of species was significant (34%) after restoration. Net increase in density of fish averaged 0.16 fish/m2 (a 253% increase) after restoration. Net increase in biomass was significant and averaged 3.65 g/m2 (a 239% increase) after restoration. Brown trout density increased 206% and biomass 253%

Instream	Baldigo et al. 2008	Relative fish species richness, total biomass, and biomass equitability increased significantly after restoration. The relative response of fish-community density at treatment reaches was slight negative. Biomass differentials increased significantly on average by 5.32 g/m2 after restoration, mean biomass differentials differed slightly among the streams, and the response of biomass to restoration differed across the three streams.
Instream	Baldigo et al. 2010	Significant increases in community richness (30%), diversity (40%), species or biomass equitability (32%) and total biomass (up to 52%) was found in at least four of the six restored reaches. Bank stability, stream habitat , and trout habitat suitability indices generally improved significantly at the restored reaches, but key habitat features and trout habitat suitability indices did not change or decreased at two of the sites.
Instream	Banchetti et al. 2004	Abstract only (paper is in Italian). No good numbers. Reclamation of the chemical and hygienical quality of the water (via stopping waste waters from marble cutting) is a necessary but not sufficient to recover the biological quality and the colonies of macro-invertebrates.
Instream	Barrineau et al., 2005	Pools associated with instream structures provided habitat for trout in the fall, but ice processes from fall through winter affected habitat in many of the polls. The forming, dissipation, and reforming of ice features, such as hanging dams, anchor ice, and surface ice, affected the volume of pool habitat available Trout were observed in these pools in the fall but tended to abandon polls with variation in ice formations as winter progresses. Small influxes of groundwater in the study reach affected both the magnitude and frequency of ice formations and pool habitat.
Instream	Bates et al., 1997	Poster abstract. Rock weirs built to duplicate natural riffles and polls. Result has been the collection of spawning gravel on the upstream edge of riffles and increased areas in pools for rearing. The restored areas are stabilizing, providing a significant increase in rearing habitat for both coho and cutthroat.

Instream	Beschta et al., 1994	Wood and rock. Several case studies. Despite large restoration effort, no species of salmon had a significantly increase trend. # of coho produced in the creek was the lowest since smolt trapping began. No Chinook were observed despite better fish passage. The habitat manipulation had not significantly increased the production of anadromous fish; In some situations, the presence of in-channel structures continued to maintain factors limiting habitat productivity; Despite seeding and passage over falls, the project was unsuccessful since adult Chinook salmon still have not migrated beyond the falls. Channel realignment, bank modification and planting of riparian veg produced no benefits as Chinook salmon and steelhead trout parr densities were 1/10th to 1/5th those of the control streams; log structures, rock structures, boulder placement and current deflectors resulted in no significant differences between treatments and controls of parr densities for any class of steelhead or Chinook; ungrazed stream reaches inside exclosure were narrower and deeper than the grazed stream reaches and pool quality was consistently higher within the ungrazed reach but rainbow and cutthroat populations did not reflect difference in habitat conditions between the two reaches; heavy channel and bank alterations shows no y-o-y trout response to additions of large amounts of gravel; juvenile and adult age groups did not respond to channel alterations that supposedly provided deep water habitat and object cover.
Instream	Binns, N. A., 1994	LWD and boulders. Stream developed a narrower channel with deep pools that helped brook trout survive low flows. After 7 years, brook trout 6 inches and longer had increased 1.814%, brook trout less than 6" increased 1.462%, and the total population density had reached 2,074/mi (268 lb./acre). This dropped to 222/mi (41lb/acre) after an extended drought but this level was 90% better than before habitat development.

Instream	Binns, N. A., 1999	Compendium - 60+ case studies. For the 89 trout population indices analyzed at the 30 projects containing only wild trout, statewide trout population response after habitat improvement was positive. Funds invested in habitat development gave a satisfactory return (wild trout and streams with a mix of wild and stocked). 81% of the 89 wild trout abundance and biomass indices had a percent change increase of 25% or greater (level 1). Rate of success was 50%, or greater (level 2) for 74% of the indices. Rate of success for 139 population indices at projects containing both wild and stocked trout was 83% at level 1, and no less than 72% for level 2. Success rates for wild trout/mile were generally less at streams of higher order. Averaged over all projects, post treatment abundance of wild trout of all sizes increased 310% and biomass 271%. Catchable (6 inches, or greater) wild trout numbers increased 192% and their biomass was up 146%. For instream structures, best trout response was at plunges (363% gain), but revetments (129% gain), tree jams (69% gain) and rock weirs (66% gain) also increased trout numbers. Both log and timber plunges exceeded minimum residual pool depth criteria (RPD), but log plunges (RPD 1.85 ft.) were better than either timber plunges (RPD 1.6 ft.) or rock plunges (RPD 1.35 ft.).
Instream	Binns, N. A., 2004	Boulders, LWD. Summary of 30+ projects. Abundance and biomass of trout increased following habitat manipulation among most of the projects. Both mean abundance (105%) and biomass (124%) for total trout increased post-treatment and were significantly higher than pre-treatment levels. Mean catchable trout numbers (77%) and biomass (62%) also increased significantly. Cover for trout and residual pool depth significantly increased following projects, where as eroding banks significantly decreased. Both timber and log check dams consistently produced good pools, but rock check dams did not.

Instream	Biron et al., 2004	Compared various deflectors. Results showed a 26-30% smaller scour depth resulting from 45° deflectors than from 90° deflectors. The volume of scour and the potential for bank erosion were greater when flow was under the height of the deflectors rather than over topping and when the length of deflector was increased. When flow was under the deflector height, 135° deflectors had the highest amount of bank erosion; whereas during overtopping flow conditions, 90° deflectors had the greatest bank erosion potential.
Instream	Black and Crowl 1995	Abstract only - conference proceedings. LWD. No numbers. Manipulated woody debris resulting in significant changes in trout densities and physical characteristics. Trout prey electivity (Chesson's) and capture efficiency were directly related to habitat complexity. Macroinvert densities did not respond as significantly to changes in habitat complexity as trout densities. the inverts appeared to be limited by primary productivity rather than habitat complexity. Habitat complexity was subsequently decreased by a high spring runoff which lowered significance of responses.
Instream	Blakely et al., 2006	Boulder placement. Adult caddisfly diversity and abundance was greater downstream than upstream. Numbers of caddisflies caught declines upstream and about 2.5 times more individuals were taken in traps immediately below than above five culverts. Bridges had no significant effect on the size of catches made above or below them.
Instream	Bond and Lake 2005	Added wood due to sediment. Observed short-term increases in the abundance of Mountain galaxias at the 4- structure sites, while both the four-structure and the one-structures treatments appeared to buffer against drought-induced declines in two other species. Drought eventually caused the loss of all fish. Beneficial wood is contingent upon permanency of flow.

Instream	Bond et al. 2006	Added LWD. Colonization of algae was rapid with distinct changes in the assemblages over the first 4 weeks. Thereafter changes were less marked. There were differences in nutrient concentrations and some measures of algal abundance. Inverts colonized the wood extremely rapidly, peaking in abundance and richness inweeks.8. Invert abundances closely tracked changes in abundance of algae. By 20 weeks, there were sharp decreases in invert and algal abundances and invert species richness. The added timber quickly created habitat with high levels of primary production in an otherwise heterotrophic stream system.
Instream	Boreman, J., 1974	Log structures. There was no difference in biomass, average weight, or no. of rainbow trout between structured and control sections. No differences existed among biomass, avg. weight or numbers of sculpin or minnows in bank crib and control sections. However, sculpin in pool digger sections were smaller in biomass, avg. weight and number in the above-pool sections. Sculpin biomass and number were greater in pool subsections of the pool diggers when compared to the above-pool subsections. Trout comprised a significantly greater % of the total biomass in the crib sections than pool digger sections (66% vs. 48%).
Instream	Brittain et al. 1993	Addition of rocks and stones to channelized river increased brown trout densities, especially in areas in contact with the river banks. The new areas of rock addition provided cover for fish as well as a greater variations in depth and flow conditions. Although there was no significant difference between the unmodified river banks with the artificial areas under the bridges, densities were over twice as high along the modified river banks than under and around the bridges. Increased density of the young grout at the stony areas is probably the result of redistribution of fish in the river.

Instream	Brock, W.A., 1986	Boulder placement. The estimated age 1+ steelhead population increased 300% in the section where boulder clusters were not lost or transported by a large flood event, while the estimated population in the control reach decreased 35%. Biomass of steelhead age 1+ in the section with boulder clusters increased 256%/m2 and 143%/m3. Biomass in the control reach decreased 41%/m2 and 22%/m3
Instream	Brooks et al., 2002	Created 'high' and 'low' heterogeneity treatments in riffles by altering the variability of streambed particle sizes. The initial disturbance and riffle construction significantly reduced invert abundance by 67% in both high and low heterogeneity riffles, but invert abundance and species richness did not differ between treatments. Results support idea that changes in community structure may be poor indicators if environmental change in highly variable environments inhabited by mobile, fugitive taxa.
Instream	Brooks et al., 2004	Created ELJs. After 12 months, the major geomorphologic changes in the test reach included an increase in pool and riffle area and pool depth; the addition of a pool-riffle sequence; and increase by 0.5-1 m pool-riffle amplitude; a net gain of 40 m3 of sediment storage per 1000m2 of channel area (while the control reach experienced a net loss of 15 m3/1000m2 over the same period); and a substantial increase in the spatial complexity of bed-material distribution. fish assemblages in the test reach showed an increase in species richness and abundance, and reduced temporal variability compared to the ref reach. 8 species were recorded in the control reach for a total of 545 fish, while 12 species were in the test reach for a total of 2340 fish.
Instream	Broussu, M. F., 1954	Eastern brook trout, rainbow and brown trout. After brush cover addition, the increase in total pounds per inventory averaged 1.6 vs. 0.23 in control sections. Brush removal resulted in a decrease of 1.71 pounds per inventory - and control increased 0.18 pounds per inventory. Removal of undercut banks caused a decrease in total pounds per inventory of 0.25. Control section increased an avg. of 0.28 per inventory. Aquatic veg was of value as cover when rooted to the stream bottom and also while free-floating.

Instream	Burgess and Bider 1980	Habitat improvement resulted in brook trout population and biomass increases of 208% and 179%, respectively, after 2 years. Crayfish biomass was 220% greater in the improved section. Mink did not respond to the trout biomass increase.
Instream	Carlson and Quinn 2005	Videos of winter use of v-weirs by salmonids. There were no significant interaction effects between habitat and ice cover. There were no significant differences in the number of fish observed between the ice-covered and open-water pools or between treatment and control pools. There were no statistically significant differences in the number of fish observed at control and V-weir pools in the open water sites but there were significantly more fish observed at V-weirs than control sites in the ice-covered pool.

Instream	Cederholm et al., 1997	LWD addition. Amount of LWD in the engineered site was 8.9 times the pretreatment level, while at the logger's choice site it was 3.6 times. The number of LWD pieces increased 2.3-fold in the ref. site. Increased piece length and abundance resulted in a 11.5-fold increase in total weed volume in the engineered site and a 3.0-fold increase in the logger's choice site. Proportion of pools in the engineered site increased from 33%, 38% and 38% in spring, fall and winter to 59%, 74% and 56%; logger's choice site's pools increased from 7% to 12%; fast-water habitats decreased at the two enhanced sites; abundance of coho during spring and fall showed no response to enhancement but juvenile coho responded in the winter - prior to enhancement, the ref site supported nearly 10 x the # of presmolt coho as the two treatment sites. After enhancement, coho abundance increased 20-fold in the engineered site and 6-fold in the logger's choice site. There was no significant differences in age-0 steelhead abundance during spring among the sites prior to enhancement and no change after enhancement in the spring; however, age-0 steelhead abundance declined significantly in the logger's choice site. The number of coho smolts migrating from the engineered and logger's choice sites increased following enhancement - prior to enhancement, an avg. of 117 smolts/year emigrated from the engineered site and 55 smolts/year from the logger's choice site. After enhancement, avg. annual yield increased to 370 smolts/year fro engineered site and 142 smolts/year from logger's choice. Winter population levels of juvenile coho salmon and age-0 steelhead were related to mean winter discharge and maximum winter discharge. Coho salmon populations decreased more rapidly with increasing mean winter discharge than did age-0 steelhead.

Instream	Champoux et al., 2003	Bank-cover deflectors, large boulders and woody debris. Fish habitat in 1999 was better than in 1963, but has deteriorated substantially since 1966. Pool area increased from 267 m2 to 625 m2 between 1963 and 1966, but has decreased to 488 m2 since then. Most of this deterioration is in the morainic section. In the outwash plain, the area occupied by pools has remained constant since 1966; in the morainic section, most structures are no longer efficient an the channel is unstable due to high bed-shear stress values, which entrain bed and bank erosion. In 1963, the mean depth was 0.12m - after improvements, the mean depth increased to 0.21m in 1966 then decreased to 0.17 in 1999. there is a clear difference in the frequency of the fluctuations in elevation between the morainic and outwash sections which indicates a greater variability of aquatic habitat in the outwash section.

Instream	Chapman, D. W., 1996	Summary of many projects. Instream structures: There was no significant difference in preference for the treatments tested between trout and salmon. Under natural densities, young salmon preferred the stream bank treatment while at higher densities (1.5 x natural) fish were displaced into the less preferred treatments. Hydrologic conditions are important to the success of instream structures. Wing deflectors did not produce the anticipated habitat features - there was limited increased velocity and scouring. The results that the projects had any direct effect on productive capacity due to structure placement would be difficult to verify; Nutrient additions - increased benthic invert abundance which subsequently resulted in an increase of salmonid biomass. Barrier removal - post removal activities did not show any increase in salmonid biomass in the upper stations. biomass remained low and the length frequency distributions offish in the two areas were dissimilar. Spawning gravel additions - the number and proportion of fry increased in all stations. newly placed gravel was selected for and used by spawning salmon. One site had 4 redds in 1995 and 23 in 1996 and had the highest success of gravel retention, >90% as compared to approx. 50% in other sites. Major restoration/re-watering - avg. salmonid biomass was always higher in the affected section than that observed in the control site and the majority of biomass in both areas was derived from brook trout 1+ and older. The difference between the avg. biomass observed in the new habitat compared to the control sites increased 1.8 times in 1991, 2.1 times in 1993, and 3.6 times in 1999. Pools with lunkers had on avg. 2.6 times the biomass of large brook trout than those without lunkers. The avg. fish biomass and available habitat in 1992, years after restoration, indicated a potential production of 51.46 kg - a 2.9 fold increase. The estimate for potential production in1996 was 263.94 kg, a 14.7 fold increase from pre-restoration levels. The site had a habitat gain of 215 units (30% increase) and increase in potential production of 246 kg from 1990 - 1996.

Instream	Clarke and Scruton 2002	Summarized several habitat improvement projects evaluated in Newfoundland. (Noel Paul's Brook & Joe Farrell Brook instream structures, Great Gull River - barrier removal, Placentia River - gravel placement, Cole Pond -nutrient addition, Seal Cover River, Pamehac Brook - rewatering/reconnection). Most projects successful in meeting objectives, but results varied by project - see publication.
Instream	Crispell and Endreny 2009	No fish - no good numbers. Study of constructed in-channel structure controls on hyporheic exchange flow (HEF) was conducted using stream and hyporheic temperature amplitude analysis and computational fluid dynamics (CFD) hydraulic simulations. Results indicate a pattern consistent with natural riffle pool sequences and analysis agreed with the direction of flow simulated with CFD at 80% of the locations. CFD simulation demonstrated that increasing stream flows result in changes in HEF spatial patterns and magnitude at each structure.
Instream	Crispin et al., 1993	LWD. Restructuring caused substantial changes favoring suitable habitat for coho; meanwhile, the untreated reach became less favorable for rearing coho. Stream surface area and water volume, respectively, increased 74 and 168% in the treated reach, and 8 and 37% in the untreated reach. Surface area of pool and suitable off-channel habitat increased nearly 5 fold in the treated reach at summer low flow. In the treated reach, newly recruited LWD was 52% greater in mean length and 60% greater in mean diameter than in the untreated reach. In the treated reach, suitable summer habitat for coho increased 5 fold and suitable winter habitat increased 6 fold, in the untreated reach suitable summer habitat decreased by half and no winter habitat was available.
Instream	D'Aoust and Millar 2000	Stability of placed LWD structures. The stability of single-LWD and single-LWD with root wad structures can be successfully predicted by theory. The stability of the multiple-LWD structures proved to be more complex to predict.

Instream	Dauwalter et al. 2004 (In warm streams symposiumII)	Rock vanes. Installation changed stream habitat. Substrate distributions did not change at the control site among dates, but included bedrock, boulders, and more silts at the project site. Abundance of submergent vegetation increased more at the project site. Water depth and velocity heterogeneity among transects did not change. Relative weights of smallmouth and shadow bass decreased after rock vane installation. Fish assemblage stability did not differ between sites. Shadow bass abundance appeared to respond negatively at first to the project, but then showed an increase, whereas as abundance in the control site decreased. Smallmouth bass abundance did not appear to change at the project site.
Instream	Devries et al. 2012	No fish. Constructed log flow-choke structures that mimic the hydraulic function of a natural beaver dam during flooding. Monitoring showed that within 1-2 years, beaver built more persistent dams in close proximity to installed structures. Increased hydraulic connectivity with the floodplain was observed.
Instream	Dewberry et al., 1998	Flood effects on salmonid production varied among species and depended on the life-history stage of the species. Steelhead and cutthroat over one year old appeared to be the least affected by the floods and their smolt numbers were higher after the flood than before. Chinook outmigrants dropped from 247,000 in 1995 to 50,000 in 1996.

Instream	Ebrahimnezhad and Harper 1997	Artificial riffles. Mean diversity of inverts in the natural riffle and two shallower artificial riffles were highest, while those of the other deeper, artificial riffle and the channelized runs were lowest. There was a significant negative correlation between diversity and depth; significant positive correlation between diversity and velocity. Hydropsychidae, Simuliidae, Baetidae, Elmidae and Hydracarina were the abundant taxa of artificial riffles (all are typical of faster-flowing riffles) Chironomidae were slightly more abundant in run sites (64.7%) than the artificial riffle site (59.2%). There were small differences between the natural riffle site and the artificial riffle sites: a greater relative abundance of Hydropsychidae and Tubificidae in the latter (9.3%, 5.9%) compared with the natural site (38%, 0.7%), and greater relative abundance of Hydracarina, Baetidae and Elmidae in the natural site (7.3%, 5.7%, 4.2%) than the artificial ones (2.4%, 3.1%, 2.9%).
Instream	Ehlers, R., 1956	LWD and rock dams. No numbers. Of the 67 pools developed by the 41 dams and deflectors built in 1935, only 15 remained in 1953. Log dams are superior and generally more durable than rock dams on streams of slight gradient. Pools formed below the structures are more permanent than pools above.
Instream	Ernst et al. 2010	Rainbow, brook and brown trout. On average, stream stability increased at treatment sites for 2-5 years after restoration. Mean channel depth, thalweg depth, and the pool-riffle ration generally increased, whereas mean channel width, percent streambank coverage by trees, and shade decreased. Habitat suitability indices for salmonids increased at 4 or 6 reaches after restoration.

Instream	Filoso and Palmer 2011	No fish. Evaluation of whether stream restoration to improve water quality is effective at reducing the export of N in stream flow to downstream waters. During low discharge, lowland streams that receive minor N inputs from groundwater or bank seepage reduced instream N fluxes. Lowland streams with the highest N concentrations and lowest discharge were the most effective. During high low, only those restoration projects that converted lowland streams to stream-wetland complexes seemed effective at reducing N fluxes. The observed N-removal rates were relatively high for stream ecosystems, and on the order of 5% of the inputs to the watershed.
Instream	Floyd et al. 2009	Atlantic salmon. LWD structures were effective in creating complex habitat. Structures narrowed the channel, scoured pools and undercut banks. They created habitat that parr used for refuge and spawners used for cover and resting. Gravel accumulated. Treatment reaches had higher spawning densities than those without them.
Instream	Frimpong et al., 2006	Abstract only. Logs/LWD. Cost effectiveness ratios for vegetative filter strips decreased from $387 to $277 per 100m for a 1% increase in IBI scores from first- to fifth-order streams with 3% discount and 30-year recovery. This cost weighted by proportion of stream orders was $360. The ratio decreased with decreasing time of recovery and discount rate. Based on installation costs and an assumption of equal recovery rates, half-logs were 2/3 to 1/2 as cost-effective as vegetative filter strips.

Instream	Frissell and Nawa 1992	LWD fish habitat structures. The incidence of functional impairment and outright failure varied widely among streams; the median failure rate was 18.5% and the median damage rate (impairment plus failure) was 60%. Modes of failure were diverse and bore no simple relationship to structure design. Damage was frequent in low-gradient stream segments and widespread in streams with signs of recent watershed disturbance, high sediment loads, and unstable channels. Rates of damage were higher in larger and wider streams. Projects in streams with active channel widths wider than 15m had a median damage rate of 79%, while those narrower were highly variable and had a median damage rate of 50%. High gradient streams had higher failure rates than those in gently sloping streams.
Instream	Fuller and Lind 1991	Boulder deflectors. Steelhead utilization of instream structures was found to vary depending on season and streamflow. Thirteen fish were counted in the study reach before placement and 14 fish were counted after. eight fish were counted in the control reach before placement and 10 fish were counted after. Foothill yellow-legged frogs utilized the 30m reach for breeding during the three years prior to deflector placement, but not during the three years after. the diet of the western aquatic garter snake appeared to differ after placement.

Instream	Gard, R., 1961	Dams of rock and wood. Greatly reduced current resulted in ponds with an avg. deposition of 3.3 in. of silt, organic material, and gravel after 1 year and 4.8 in. after 3 years. Holes were created by the digging action of the water passing over the dams. An avg. water depth of 4.5 in. increased to 17.2 in. after damming but fell to 5.8 in. by 1960. During the 3 summers following dam installation, the numbers of introduced brook trout were counted. 49 trout were collected the 2nd summer giving a 1-year survival rate of 38%. 73% of the fish surviving to the 2nd summer were collected the 3rd summer and 39% of those surviving to the 3rd summer lived to the 4th.The introduced trout spawning successfully. Avg. weights of bottom organisms per unit area at the pond sites in 1958 and 1959 were 5 and 8 times heavier than the avg. weight per unit area at the same site before ponding. Avg. # of grams per sq. ft. of summer standing crops of bottom organisms was 0.67 before dams, 5.12 one year after and 3.48 two years after.
Instream	Gard, R., 1972	Headwater check dams. After 12 years, about 1/2 of the dams were in good to excellent condition. Log dams help up better than rock dams for the 1st 3 years but rock dams were generally in better condition after 12 yrs. Avg. depth of the ponds decreased from 16 to 10 inches, but holes 9-13 inches deep were created below the dams. The standing crop of trout of catchable sizes (>= 100mm) was estimated to be 93 trout weighing 9.6 pounds (= 394 trout per acre weighing 41 pounds). Cost of dams and trout introduction was $154, or $12.80 per year over the 12 years.
Instream	Gargan et al., 2002	Examined response of juvenile salmon and trout to variety of instream treatments (revetments, weirs, rubble mats, lateral scour pools etc.) at paired treatment and control sites in 13 tributaries before and after treatment. Significantly high levels of Atlantic salmon parr ((0.19 vs. 0.06 fish/m) and brown trout parr (0.127 fish/m difference), but no differences for salmon fry, or brown trout fry in Lough Corrib catchment. Similar results were found in for brown trout in the5 sites in Lough Carra-Lough Mask catchment streams (0.32 vs. 0.07 fish/m) (salmon are not present in these watersheds).

Instream	Gerhard and Reich 2000	LWD. The addition of wood improved the channel morphology within 4 yrs. The variation in channel width and depth was considerably larger than in a regulated section. The extension of the riparian zone, especially of the semi-aquatic gravel and sand bars was strongly correlated with the amount of large wood that accumulated in a single section. The # of microhabitats and their patchiness on the stream bottom was higher in restored sections, as well as the density of inverts and the species #. The number of discrete microhabitat patches increased from 7 to 14 patches/m stream course in the restored sections, compared to 4 patches /m in the regulated section.
Instream	Giannico and Hinch 2003	Wood addition increased juvenile coho winter carrying capacity and spring smolt output only in the 'colder' surface-fed side-channel. In contrast, the groundwater-fed side-channel, with relatively higher water temps, the wood treatment slightly reduced the channel's carrying capacity and the spring output of coho smolts. In the warmer groundwater-fed area, the control and wood-treated halves showed similar declines in fish densities whereas in the colder surface-fed area, the decrease in densities was 50-60% greater in the control half than in the wood-treated half between Jan and May. Although the values of the relative index of survival for juvenile coho salmon varied widely between both side-channels and from year to year, they were consistently higher in the wood-treated side.. for each year, juvenile coho growth rates between fall and spring were consistently higher in the wood-treated halves of the side channels.
Instream	Gidley et al. 2012	Bank stabilization. 17 species. Fish relative abundance was significantly higher at stabilized sites. There was a possible correlation between relative abundance and diameter of rock at stabilized sites. Brown bullhead, northern pike and pumpkinseed were captured more readily at stabilized shoreline sites. stabilized structures provide stable habitat year-round. Overall, stabilized shorelines were not found to be adversely affecting overall fish relative abundance, diversity and species composition under the existing low fraction (2.5%) of bank stabilization.

Instream	Gore and Hamilton 1996	Abstract only. Wood weirs. Simulation using PHABSIM (physical habitat simulation) demonstrated that benthic inverts habitat can be dramatically increased at low flows (up to five times higher) after placement of structures that improve hydraulic conditions to sustain maximum diversity of the benthic community. These low-head structures augment habitat under high flow conditions.
Instream	Gore et al., 1998	Artificial riffles. The simulation predicted that this reach contained significantly higher amounts of available benthic habitat at low flows (more than tripled), and over 40% of the total wetted area should support high benthic community diversity at optimal flows. The presence of artificial riffles contributed most of this habitat enhancement. A plot of cell-by-cell composite habitat and suitability and sample diversity from these cells revealed a significant correlation between PHABSIM predictions and actual community diversity.
Instream	Gortz, P., 1998	Restoration using gavel, boulders and stream concentrators. Results were a deeper and narrower stream with a higher flow velocity near the bottom and a coarser substrate compared with the ref. section. The fauna showed higher similarity to the fauna found on the stony bottom sections due to immigration of taxa preferring stony substrate. SI (saprobic index) and DFI (Danish fauna index) generally improved from II to/towards I-II. Clean-water species such as Agapetus ochripes and Limnius volckmari, were found in significantly higher numbers in the restored sections compared with the ref. section. Five times as many trout spawning redds occurred in the restored sections than in the non-restored. However, electrofishing revealed few y-o-y trout and did not reflect spawning success.

Instream	Gowan and Fausch 1996a	Log weirs. Mean depth, pool volume, total cover, and the proportion of the fine substrate particles in the stream bed increased in treatment sections within 1 to 2 years, whereas habitat in adjacent controls remained unchanged. Abundance and biomass of adult fish, but not juveniles, increased in treatments relative to controls in all streams. Recaptures of trout that were tagged and others that were batch marked revealed that immigration was primarily responsible for increased adult abundance and biomass, whereas no biologically significant differences occurred for recruitment, survival, or growth. Trout biomass increased in treatment sections because fish immigrated, not because growth rates increased.
Instream	Gowan and Fausch 1996b	Wood weirs. Brook trout movement was most common in the upstream direction during summer, and about equal upstream and downstream between summers. Highest rates of movement occurred during and just after runoff, and before spawning, but substantial numbers of fish moved throughout the summer. Fish captured moving through weirs tended to be longer but in poorer condition than fish captured during electrofishing between weirs. On the basis of capture histories for individual fish, 59 and 66% in the two streams moved at least 50m (up to 3380m), even though most could be tracked only for several months. Long-range movements were relatively common which is contrary to most literature on resident stream salmonids.
Instream	Haapala et al., 2003	Boulders and leaf retention. Streambed complexity increased, stream channel widened, water velocity lowered, and decreased moss cover. Leaf retention was 25% before restoration and 75% after. Leaf biomass was 28 times higher in retention than in random sites. Densities in retention sites were roughly twice as high as in random sites, both before and after restoration.

Instream	Hale, J. G., 1969	Artificial deflectors and shelters. Avg. depth of cross section profiles increased 1.74". Greatest physical change was change in composition of bottom soil type from 26% silt and 14% gravel before to 17% silt and 24% gravel after. 57 log shelters increased surface cover by 3.8% of total surface area. Abundance of y-o-y brook trout increased 894% and older trout 223%. Total standing crop of brook trout increased 356% while in ref area the increase was only 65%. Anglers increased by 219 vs. 46 in ref area. Post alteration there was a 362% increase in avg. annual harvest vs. 51% in ref area. Catch rate of native brook trout rose from 0.58 before to 0.89 after wile ref. sector dropped from 0.82 to 0.75 fish per man hour. Avg. annual harvest of native brook trout increased by 807 fish at an annual cost of $745 vs. $968 for annual cost of providing the same number of hatchery brook trout.
Instream	Hamilton, J. B., 1989	Deflectors in a high gradient stream. After winter flows only 14% of structures were intact. Changes in steelhead fry and parr numbers, densities, biomass and standing crop in treated sections were not significantly different from changes in control sections. Condition of parr was significantly reduced in treated sections after winter flows. A significantly lower percentage of marked parr remained in the treatment sections after alteration. A review of other studies showed that habitat improvement projects that increase populations have usually been on lower gradient (mean=1.0%) reaches.
Instream	Harper and Quigley	Development activities that resulted in the greatest % of HADDs (harmful alteration, disruption, and destruction of fish habitat) included urban development, roads and highways, and forestry (33%, 20% and 18% respectively). Not assessing particular projects.

Instream	Harper et al., 1998	Artificial riffles. 20 of 26 riffles retained their original physical character while 6 were deep, slow flowing and covered with sand or silt. Shallow riffles retained their coarse particle dominance and caused the scouring between themselves of deeper pools than were found elsewhere in the stretch. Shallow riffles had high flow velocities which resulted in richness of functional habitats not found elsewhere. Invert colonization showed a clear distinction between communities of shallow, fast-flowing riffles and deeper slow-flowing runs and silted riffles. Riffle reinstatement in lowland rivers of low energy will produce desirable geomorphological and ecological changes if the riffles are spaced according to geomorphological 'first principles' and are shallow (<30 cm depth) under low-flow conditions.
Instream	Harrison et al. 2004	Abstract only. Artificial riffles and flow deflectors. Artificial riffle benthos had a faster current, a coarser substratum and was shallower than ref. area. Depth and substratum particle size differed little between flow deflector and ref area, although velocity downstream of the deflector tip was great , and velocity in the lee of the deflector lower, than ref. area. At a habitat scale, the benthos of artificial riffles, but not flow deflectors, had higher abundance, taxon richness and diversity than ref. area. the impact of artificial riffles was most marked for benthic rheophilic taxa. Invert diversity was highest in marginal macrophytes and abundance highest in instream macrophytes. Neither artificial riffles nor flow deflectors had any significant impact on the taxon richness of the benthos or of the rehabilitated stretch of the river as a whole. Local rehabilitation structures appeared to have minor biological effects in lowland rivers.
Instream	Hartzler, J. R., 1983	Installed half-log covers. Anglers caught 10% more trout in treated sections and brown rout harvest declined 11% in untreated sections. Number and weight of larger trout collected by e-fishing rose by 12% and 14% respectively, but those increases were not statistically significant. Response of 'catchable size" brown trout to cover enhancement was poor.

Instream	Hester et al. 2009	No fish. Varied the height of an experimental weir and monitored the hydraulic and thermal response of surface and subsurface water. The presence of the structure altered stream temperature patterns, increasing thermal heterogeneity in surface water and shallow sediments by up to 1.0 degree C. Streambed hydraulic conductivity appears to be the overriding factor determining the magnitude of weir-induced hyporheic influence on surface and subsurface water temperatures.
Instream	Hilderbrand et al., 1997	LWD addition. Pool area increased 146% in the systematic placement and 32% in the random placement sections of the low-gradient stream. High-gradient stream changed very little after LWD addition. Logs oriented as dams were responsible for all pools created regardless of method of placement. Multiple log additions created only 2 pols while the other 7 were created by single LWD pieces. Debris-formed pools increased from 6 to 14 (61%) 1 year after additions. Total invert abundance did not change as a result of LWD additions in either stream but net abundances of Plecoptera, Coleoptera, Trichoptera, and Oligochaeta decreased, while Ephemeroptera increased significantly with the proportional increase in pool area in the low-gradient stream.
Instream	Hilderbrand et al., 1998	Log length exerted a critical influence in stabilizing LWD pieces . Logs longer than the average bank-full channel width (5.5 m) were significantly less likely to be displaced than logs shorter than this width. The longest log in stable log groups was significantly longer than the longest log in unstable groups. Longer logs moved less often, but they moved farther when entrained in the current than the majority of mobile smaller logs. Log stability did not differ between a treatment section with randomized placement of LWD and a section in which LWD was placed systematically. Channel scouring typically occurred around LWD oriented as ramps and as dams perpendicular to stream flow; aggradation occurred above and below pieces oriented as dams angled to the current. Microscale channel responses to LWD additions varied.

Instream	House and Boehne 1985	Abst. only. Stream enhancement structures installed were successful and functional after two winters with usual freshets. The structures dramatically increased the diversity of the stream bed, trapped gravel, and created shallow gravel bars and deep, covered pools. Also, the number, size, and quality of the pools increased in areas with structures. Coho salmon (Oncorhynchus kisutch) and steelhead (Salmo gairdneri) spawning increased substantially, as well as the numbers of rearing coho, steelhead fry, and steelhead and cutthroat trout (*Salmo clarki*) parr.
Instream	House and Boehne 1986	LWD caused the development of secondary channels, meanders, pools, and undercut banks in an unlogged, mature-conifers, stream section. These were absent in the young-alder section. The mature conifer section had more than twice as many pools and 10 times the amount of spawning gravel compared to the young alder section. Salmonid biomass was significantly greater in the mature conifer than the young alder section prior to enhancement; after enhancement, no significant difference was found. Prior to enhancement, 3 times as many coho and trout fry were living in the mature conifer section. there was a positive correlation between coho numbers and the presence of LWD. Structure is most likely a more important factor than shade in a stream's capacity for producing salmonids.
Instream	House and Boehne 1986	LWD caused the development of secondary channels, meanders, pools, and undercut banks in an unlogged, mature-conifers, stream section. These were absent in the young-alder section. The mature conifer section had more than twice as many pools and 10 times the amount of spawning gravel. Prior to enhancement, three times as many coho and trout fry were living in the mature-conifer stream section. Available water in pools was 126% greater in the stream section above the culvert. At treated sites, the gravel substrate increased by 233%, useable spawning gravel areas increased 25-fold. The section above the culvert was supporting 12 times as many coho than below the culvert. Trout were about three times more abundant above the culvert than below.

Instream	House et al., 1989	Case studies. Narrow riffle areas were converted into long, wide pool habitat. Work more than doubled the surface area, with the low flow wetted perimeter increasing an average of 22 ft2 for each 3 ft. of treated stream. The potential increase in populations was an estimated 92,140 juvenile coho, 14,170 trout fry, 6,780 yearling steelhead, and 2,560 sea-fun and resident yearling cutthroat. Generally the greatest increase occurred in channels over 39 ft. in width and treated with many full-spanning wood structures. Structures also substantially increased spawning areas and use by adult spawners in treated reaches. Long-term monitoring on one project has shown a fourfold increase in juvenile coho and a thirteen fold increase in adult coho with an avg. annual ocean catch of 181 fish attributed to the project. Stream rehabilitation work seems to have achieved structural, habitat, biological, and economic success. The best and probably least costly method of rehabilitating streams in through a riparian management policy that provides optimum numbers of all sizes of conifers along all streams used by salmonids. Recommendations are to install large full-spanning structures made of natural material in large tribs and upper mainstem rivers; manage riparian zones to produce optimum numbers of mature conifers; continue rehab work in key reaches of coastal streams; and continue long-term evaluations to determine accurate project benefits.
Instream	House, R., 1984	Chinook, pink, chum, coho and steelhead. Gabions increased the useable spawning area, trapping an avg. of 15.9 m2 in one creek and 8.3 m2 in another creek of high quality gravels at each structure. Most treated areas showed a disproportionately high use by spawning salmonids compared to untreated areas.

Instream	House, R., 1996	Abstract only. Treated with mostly full-spanning, rock-filled gabions in 1981 and boulder structures in 1987. Freshets in the winter of 1981–1982 filled all gabion structures with large gravel; the surface area of pool and low-gradient riffle habitats increased but area of high-gradient riffle habitat decreased. From 1985 through 1993, the average number of coho salmon spawners increased 2.5 times compared with returns during 1981–1984. Treated areas supported significantly more juvenile coho salmon and cutthroat trout and had higher overall salmonid biomass than control areas, whereas age-0 trout (cutthroat trout plus steelhead) and juvenile steelhead showed no increases. For the entire 1.7-km reach receiving treatment, the number of coho salmon juveniles was higher after than before treatment, whereas numbers of steelhead and cutthroat trout fry and juveniles remained constant. Between 1981 and 1992, over 50% of the coho salmon and steelhead spawned on newly deposited, higher-quality gravels associated with 15 gabion structures that fully spanned the bank-full channel width. Quality of gravels impounded by gabions equaled or exceeded the quality of gravels in unmodified areas of the creek. Habitats, primarily pools, created by gabion structures lasted 10 years; however, disintegration of wire mesh tops starting in 1989 caused a slow reduction in pool habitat and gravel riffles at treated sites.
Instream	Hunt, R. L., 1969	Bank covers and current deflectors reduced surface area by 50%, increased avg. depth by 60%, increased pools by 52% and increased permanent overhanging bank cover for trout by 416%. Sand substrate was reduced by 40%, silty bottom was reduced by 70%, but gravel area was increased by 11%. Avg. # of legal-sized trout (8-in plus) increased by 156%; annual production increased by 17%; mean standing crop of trout increased by 40%. Age 1+ trout accounted for 78% of avg. standing crop before alteration, but 87% after; yield increased by 196%; food consumption increased by 28%.

Instream	Hunt, R. L., 1976	LWD. Mean annual biomass of trout, mean annual number of trout over 15 cm, and annual production increased significantly during the 3 yrs. following development, but even more so during the 2nd 3 years. Max number and biomass and number of legal trout did not occur until 5 yrs. after completion of the development. Peak number of brook trout over 20 cm was reached the 6th year post development.
Instream	Hunt, R. L., 1988	45 case studies. Success was judged on the basis of percentage changes within treatment zones for each of 6 possible variables standardized to "per mile": total # of trout, # 6" or larger (legal size), # 10" or larger (quality size), total biomass, angler hours and angler harvest. Level 1 success was post development variable increases of 25% or more, level 2 = increases of 50% or more. Approx. 60% of the quantified changes in the 6 standard variables exceeded success level 1 after habitat development; 43% exceeded success level 2. At least one trout population variable improved after development in 93% of wild trout in 41 treatment zones containing wild trout. Approx. 72% of the 185 measurements of change among the 4 standardized population variables in these zones were positive, 26% were negative, and 2% showed no avg. change. Avg. empirical post development changes for the populations wild trout in 41 treatment zones included a 21% increase in # trout (to 1,940/mile), a 35% increase in legal-sized trout (to 828/mile), a 56% increase in quality-size trout (to 156/mile) and a 49% increase in biomass (to 242 lbs./mile).
Instream	Huusko and Yrjana 1997	Boulder structures. Results showed that the availability of potential physical trout habitat can be increased at simulated low and moderate flow conditions by reconstruction of the river bed and placing instream boulder structures. The resulting diversity of depth and velocity conditions created a spatially more complex microhabitat structure. Water depth and velocity median values decreased owing to the enhancement at all study sites and at all simulated discharges, but the highest depths and velocities were almost always found among the post-rehabilitation areas. Improved habitat conditions were able to sustain a larger trout population.

Instream	Huusko and Yrjana, 1995	Abstract only. No numbers. Boulder dams increased the diversity and patchiness of available depths, velocities, and dominant substrate size classes making the rapids spatially more complex.. The restoration procedure seems to favor 1+ or older trout.
Instream	Hvidsten and Johnsen 1992	Boulder placement. Restoration of the river bottom with blasted stones provided salmon with more substrate spaces. Densities of trout increased after the river bank was covered with stones. Sediments transported downstream from the canalized river stretch decreased the densities of juvenile salmon and trout. Density estimates ere 7 fish per 100m2 prior to draining. After restoration, densities of juvenile salmon varied from 25 to 125 fish per 100m2.
Instream	Jahnig et al. 2010	Hydromorphology and inverts. Mean SWIs (Shannon-Wiener Indices) for both mesohabitats (1-1 non-restored, 1-7 restored) and microhabitats (1-0 non-restored, 1-3 restored), while SWIs for invert communities were not significantly different (2-4 non-restored, 2-3 restored).
Instream	Jester and McKirdy 1966	Logs and boulders. A mean increase of 3.5 feet in width provided 36 additional acres of water. Increase of approx. 3" in mean depth, volume has almost doubled from 639 to 1,226 acre feet. Minor changes in water temp occurred. Silt caused significant decreases in depth of pools on the upstream side of structures in 6 of 32 streams observed. Increases of inverts were found at 14 stations, no change at two, and decreases at two. 36 additional acres of water have provided habitat for stocking increase of 6,840 pounds or 34,200 rainbow trout annually. Overwinter survival was enhanced by presence of structures. 97 of 122 tagged fish were recaptured at the release sites, 19 moved past one structure, 5 moved past two structures, and 1 moved past 3 structures. Total spread from this movement was approx. 300 ft. Mean catch rate in all 11 streams and sections has increased from .79 to .89 trout per man hour. Water temp increased at 6 of 16 stations and remained stable or decreased at 10 stations in 8 streams. Mean temp in all 8 streams decreased 2 degrees F. No change in chemical composition.

Instream	Johnson et al., 2005	Abstract only. LWD. Steelhead smolt abundance, steelhead freshwater survival, and coho salmon freshwater survival increased in one creek after the input of wood. Steelhead age 0+ summer populations ad steelhead smolt populations increased in the ref stream, although steelhead freshwater survival did not. Coho populations remained unchanged in the ref. stream. Results illustrate the potential shortcomings of the BACI design under field conditions and the potential for misinterpreting results.
Instream	Jones and Tonn 2004	Boulders. Structures attracted significantly higher densities of Arctic grayling than did nearby reference sections, yet age-0 Arctic grayling at the structures did not experience any density-dependent reduction in growth, suggesting that structures provided energetically favorable microhabitats. Relative to reference streams and prestructure conditions, the addition of these physical structures did not increase the density, biomass, or growth rates of age-0 Arctic grayling in the artificial stream as a whole.
Instream	Kasahara and Hill 2006a	Abstract only. The effect of constructed riffles and a step on hyporheic exchange flow and chemistry in restored reaches of several N-rich agricultural and urban streams. Hydrometric data collected from a network of piezometers and conservative tracer releases indicated that the constructed riffles and steps were effective in inducing hyporheic exchange. However, despite the use of cobbles and boulders in the riffle construction, high stream dissolved oxygen (DO) concentrations were depleted rapidly with depth into the hyporheic zones. Differences between observed and predicted nitrate concentrations based on conservative ion concentration patterns indicated that these hyporheic zones were also nitrate sinks. Zones of low hydraulic conductivity and the occurrence of interstitial fines in the restored cobble-boulder layers suggest that siltation and clogging of the streambed may reduce the downwelling of oxygen- and nitrate-rich stream water. Increases in streambed DO levels and enhancement of habitat for hyporheic fauna that result from riffle step construction projects may only be temporary in streams that receive increased sediment and nutrient inputs from

		urban areas and croplands.
Instream	Kasahara and Hill 2006b	Abstract only. Riffle construction. The constructed riffles studied induced more extensive hyporheic exchange than the natural riffles because of their steeper longitudinal hydraulic head gradients and coarser streambed sediments. The depth of > 10% stream water zone in a small and a large constructed riffle extended to > 0·2 m and > 1·4 m depths respectively. Flux and residence time distribution of hyporheic exchange were simulated in constructed riffles. Hyporheic flux and residence time distribution varied along the riffles, and the exchange occurring upstream from the riffle crest was small in flux and had a long residence time. In contrast, hyporheic exchange occurring downstream from the riffle crest had a relatively short residence time and accounted for 83% and 70% of total hyporheic exchange flow in a small and large riffle respectively. Although stream restoration projects have not considered the hyporheic zone, data indicate that constructed riffles and steps can promote vertical hydrologic exchange and increase the groundwater–surface water linkage in degraded lowland

		streams.
Instream	Keim et al., 2000	Coarse woody debris. Treatment immediately increased CWD by 86% to 155%. Although there was more CWD during the 3 years after treatment then there had been before, rates of movement were high. Aggregation of CWD increased in all 3 streams for at least 1 yr. and accumulations associated with key pieces were larger after 3 yrs. than immediately after treatment. Pulled-over alders were more stable and more effective in forming accumulations than bucked conifers, but were subject to rapid decay.

Instream	Kelly and Bracken 1998	Boulders. There was little change in the overall mean brown trout density (all ages excluding 0+) and standing crop in the enhancement section. There was a mean decrease in density of 18% in the control sections compared with a mean increase of 21% in the experimental sections, and a mean increase in biomass of 11% in control and increase of 23% in experimental. This mean increase in density and biomass in the enhancement sections was due to an increase in the number of 2+ and 3+ brown trout and a decrease in 1+ fish. there was a significant overall mean increase of 152% in salmon density in the experimental sections compared to a mean increase of 36% in the control. Percentage increase in salmon density ranged from 25% to 300%. There was an overall mean increase of 219% in salmon biomass in the experimental sections compared to an increase of 88% in the control. Increase in biomass in experimental sites ranged from 75 to 390%. Drought affected physical variables, but mean water depths were lower at 7 sites post-works. Results indicate that the channel became deeper at six of nine sites due to increase in the # of pools. Velocity and discharge values were lower at all cross sections, while max depth increased at all sites.
Instream	Kennedy and Johnston 1986	Not found. Book section "Proceedings of the 17th Annual Study Course - Institute of fisheries Management, University of Ulster at Coleraine.
Instream	Klassen and Northcote 1988	Gabions. Improvement of intragravel dissolved oxygen depression was significant (5.4 mg/L before to 2.5 mg/L after). Intragravel permeability also improved significantly in the low-gradient (1%) reaches, from 870-cm/h to 2,400 cm/hr after installation. Pink salmon egg survival at one site in its first year did not differ significantly from two nearby ref. sites.

Instream	Klassen, H. D., 1991	Abstract only. LWD. No significant changes in stream width. # of pools in the thalweg increased from 4 before rehab to 18 after, and to 13 pools 7 months later. Several sediment lobes dispersed with rehab, resulting in a more constant streambed slope gradient of 2.9% vs. 2.0-4.7% before. There was a 23% reduction in wetted area but pool area more than doubled after rehab. There was a reduction of the majority of overhanging veg. Critical overwinter rearing habitat tripled and habitat diversity more than doubled. 50% of the logs were underscoured, reducing avg. pool depths but also adding diversity. Sediment storage areas averaging approx. 14m2 per log developed over the winter. Streambank erosion from rehab averaged 1m per log.
Instream	Knaepkens et al. 2004	Abstract only. Tiles as artificial spawning substrate. Tiles were successfully used by bullhead for spawning . In the meandering parts of the river, the number of egg deposits was significantly positively correlated with water depth, while in canalized areas, water depth and velocity were of no importance for tile usage.
Instream	Koljonen et al. 2012	Brown trout. Channelized vs. semi-natural streams. Fish of both age classes (age-0 and age-1) lost mass early in the winter but age-0 fish in the channelized streams lost more of their initial mass than did the restored stream fish (10% vs. 2.5% on average, respectively). By early spring they caught up for their greater initial mass loss. The shortage of suitable sheltering sites in channelized streams apparently intensified competition and caused greater initial mass loss in age-0 trout. Growth compensation may have negative impacts on the long-term fitness of juvenile trout.
Instream	Kondolf et al., 1996	Riffle reconstruction with gravel. In planning phase, there was no consideration to geomorphic context or erosion and sediment transport. Hence, the gravel placed in the channel was scoured and transported with a return period of 1.5 years. The project design greatly simplified the physical habitat need of spawning salmon. Estimated mean annual redds over its expected 15-year life was 120 - actual counts from 1990-1994 were 16, 8, 41, 46, and 56 respectively.

Instream	Korsu, K., 2004	Boulders. Response of inverts to disturbance. Restoration procedure destroyed nearly half of the bryophytes present in study reach and invert densities decreased sharply immediately after restoration (total number reduced by 50% on day one and 83% of day 4). Within 2 weeks, inverts had recolonized the disturbed reach and within 1 month, peak numbers were attained. Inverts showed a clear association with bryophytes, especially after restoration.
Instream	Laasonen et al., 1998	Boulder dams/flow deflectors. Water depth and current velocity were lower, and relative bed roughness higher in restored than in dredged channels. Moss cover was negligibly low in recently restored streams, but mosses had recovered well within three years of restoration. The standing stock of leaf litter was lower than in natural streams, but mostly higher than in channelized streams. Abundances of all inverts were highest in natural streams and lowest in streams restored 1 month before sampling. All other restored streams had abundances comparable to, or slightly lower than, those in channelized streams. There was a tendency toward higher abundances of shredders with a long recovery period, but streams restored 8 or 16 years ago still contained relatively sparse shredder populations. Enhanced litter retention increases the capacity of restored streams to support high abundances of detritivorous invertebrates. Abundances of shredders, as well as other detritivores, were indeed higher in streams restored a few years ago than in recently restored streams.
Instream	Lacey and Millar 2004	Abstract only. LWD and rock groyne. 2-d flow model velocity and depth predictions compare favorable to measured field values with mean standard errors of 24% and 6%, while areas of predicted high shear coincide with the newly formed pool locations. At high flows, the fish habitat index used (weighted usable area) increased by 150% to 210%.

Instream	Laitung et al., 2002	LWD. The avg. concentration of fungal spores in ref sections was nearly 10x greater in French streams than in English. No. of hyphomycete species was also higher in French streams. Difference were probably because of the much lower standing stock and diversity of leaf litter in the English streams. The treatment had a clear effect in all streams. Detrital standing stocks were enhanced in treated sections by up to 90% in French and 70% in English streams. Mean spore density below treated sections increased by 1.8-14.8% in French and 10.2-28.9% in English. LWD can increase detritus retention and enhance hyphomycete diversity and productivity.
Instream	Larson et al., 2001	LWD. Pool spacing narrowed after LWD installation. All project sites exhibited fewer pools for a given LWD loading, however, than has been reported for forested streams. . Only limited success was observed controlling downstream sedimentation. None of the sites had any detectable improvement in biological conditions due to the addition of LWD. In all but one stream, sediment storage associated with LWD increased by 50-100% where LWD frequently increased. Added LWD contributed most to grade control (11-23%) on the highest gradient streams where wood spanned the full width of the channel, but contributed little to grade control and low-gradient streams.
Instream	Latta, W. C., 1972	LWD. An assessment of movement indicated little interchange of trout with the water outside the experimental area, but substantial interchange between sections. There was a consistent increase of brook trout when the structures were in the stream. For brown trout, there appeared to be a steady increase before, during and after, independent of the addition or removal of structures. For brook trout, a statistically significant increase occurred in numerical catch, in fall standing crop, in fall standing crop plus catch, and in numbers of age -1 and older fish. There was a decline in the area of water over 3 ft. deep and decline in the amount of cover, but little or no change in bottom soil types.

Instream	Lawrence et al. 2012	Fish response not reported. Natural vs. engineered large wood loading. The amount of large wood in the bankfull channel and the amount available for recruitment from the 10-year floodplain were highly variable among and within reaches and largely dependent on the local geomorphic setting. Reaches with engineered wood structures had elevated pool frequencies suggesting a higher capacity to support salmonids during critical life stages. Among wood pieces that had a strong influence on pool formation, 23% had an attached root wad and 66% were part of a cluster. All reaches had lower volumes of large wood in their bankfull channels than similar stream types with natural wood-loading levels.
Instream	Lehane et al. 2002	LWD. Brown trout. Wood created more suitable habitat for trout through development of additional pools in which beds of fine sediment developed and constraining the current, increasing the amount of eddies and slack water areas. There were significant increases in trout density and biomass in the debris segments relative to controls although trout condition was not modified by the addition of LWD. Pool habitat increased from 16% of total surface area to 35%; riffles decreased from 31% to 25%. Pre-installation (March 1998) fish survey had 664 trout in two reaches - post surveys captured 1170 (Sept. 1998), then 670 (1999), then finally 523 (2000). Recap rates suggest that loss rates over time appear to be lower in debris segments.
Instream	Lehane et al. 2002	Brown trout. Surveys over 2-years following LWD installation showed a change in stream architecture. This created more suitable habitat for trout through development of additional pools in which beds of fine sediment developed, and constrained the main current, increasing eddies and slack water areas. There were significant increases in trout density and biomass in the debris segments relative to control segments 1 and 2 years after LWD addition, although trout condition was not modified by the addition of LWD. Prior to installation, pool habitat was 16% of total surface area and riffles were 31%. 1 year post installation, pools increased to 35% and riffles decreased to 25%. 2 years post installation, pool area was 33% and riffle area 21%.

Instream	Lemly and Hilderbrand 2000	LWD. After LWD additions, total area occupied by pools more than doubled (from 222 m2 to 546 m2) concurrent with a 42% decrease in riffle area (from 768 m2 to 443 m2) Pools contained significantly more benthic detritus than riffles but showed no post-treatment response of LWD relative to the ref. section. Net benthic detritus in riffles decreased by 14.3 kg after LWD additions, dropping from 71.6 in 1993 down to 57.3 kg in post-treatment 1994. Community structure based on functional feeding groups was similar both spatially and temporally between treatment sections for pools, and was spatially similar for riffles in 1993, but differed significantly between years in riffles.
Instream	Lepori et al., 2005a	Boulders. At both the reach and patch scale, structural heterogeneity was substantially higher at restored than at channelized sites, although differences in between-patch variation were not significant. Restored sites had higher total fish biomass relative to channelized sites. Higher total biomass at restored sites reflected higher numbers of individuals due to more habitat availability rather than increased fish density or individual fish biomass. The components of diversity assessed for inverts were comparable between restored and channelized sites. Despite substantial differences in heterogeneity across different spatial scales, most components of fish and invert diversity were similar between restored and channelized sites.
Instream	Lepori et al., 2005b	Boulders. Coarse particulate organic matter (CPOM) retentiveness reflected most strongly the density of boulders and submerged woody debris at the study sites. Restored sites were on average twice as retentive as channelized sites and significantly more retentive than ref. sites when discharge was controlled. Current velocity at bankfull flow was the single most important predictor of CPOM mass loss. Other apparent controls of CPOM breakdown included water temp and shredder abundance. CPOM mass loss was similar between restored and ref. sites. However, breakdown was slightly faster at most channelized sites.

Instream	Lester and Wright 2009	No fish. Reintroducing wood in streams to measure velocity profile, stage and erosion rates. There was no clear evidence of longer-term rates of erosion or flooding associated with the introduction of wood to streams over the study period. There was a lack of adverse effects on stream morphology and increased variability of the instream environment suggesting improved habitat diversity.
Instream	Linlokken, A. 1997	Weirs. The mean density of brown trout in the experimental section was 18.3 per 100m prior to enhancement, and increased by 200% after weir construction. The increase was due to increased # of specimens >10cm, whereas number of fish <10cm decreased.
Instream	Lonzarich and Quinn 1995	LWD. Mortality (likely due to bird predation) of water-column species using the simplest habitat type was a much as 50% greater than in other treatments. Coastrange sculpin used deep pools more frequently than shallow pools by a ratio of nearly 3 to 1. Yearling cutthroat and steelhead were almost never collected in shallow pools - 100% of cutthroat and 83% of steelhead were found in two deep-water treatments. habitat selection by age-0 trout was strongly associated with structure, as fish were 3 x more abundant in structure (75%) than in unstructured treatments (25%). Age-1+ cutthroat and coastrange sculpin were positively associated with deep-water habitat, age-0 rout were associated with structure, and age-1+ steelhead and coho were associated with both. Coho (16%) and age-0 steelhead (21.5%) showed the greatest gains in growth; coastrange sculpin were next (10.8%) followed by age-1+ steelhead (9.9%). Coho survival was greatest in the deep and structured treatment (89%) nearly twice that in the shallow, no structure treatment (47%). Both age-0 and age 1+ steelhead showed higher survival in the deep-structure treatment (71 and 89%) than in the shallow-non-structures treatment (29 and 33% respectively). Water depth appeared to be more important than structure in determining the distribution of large age-1+ cutthroat and steelhead trout, while structure alone (age-0 trout) or both structure and depth (coho) were important for the small salmonids.

Instream	Louhi et al. 2011	Following treatment, invert densities decreased in all treatments, but less so in the controls. Taxonomic richness also decreased; in the long-term comparative study, invert species richness show no difference between the channel types; community composition differed significantly between the restored and natural streams, but not between restored and channelized streams. Overall, restoration measures increased stream habitat diversity but did not enhance benthic biodiversity.
Instream	Lyons and Courtney 1990	Case studies. Little specific info. Five recommendations for habitat improvements. LWD and boulders. Some studies showed increases in fish, some with no change and a few with decreases.
Instream	MacInnis et al, 2008	Atlantic salmon. Redd counts increased for the first 4 years post restoration from 43 in 1992 to 592 in 1996. After that, red counts remained high (502-605) but no longer increased. In 2004, reaches with structures had significantly more redds (366) than reaches without (280). In reaches with artificial structures, 48% of redds were associated with gravel pool tails or the heads of riffles, 44% were near artificial structures and 7% were near natural large woody debris. In reaches without artificial structures, almost 89% of the redds were associated with pool tails and the remainder were associated with natural large woody debris.
Instream	McCubbing and Ward 1997	LWD, boulders, nutrients. Complex lateral debris jams had highest coho fry densities (x bar = 80 fry per 100 m2), while bolder clusters had greatest steelhead parr abundance (x bar = 6 parr per 100 m2) or avg. of one parr per boulder. However, results were not significantly different statistically among habitat structures. Riffles were associated with higher steelhead parr numbers and shallow pools with higher coho fry numbers. Growth data, in summer and early fall size, indicated improved length (5 to 10 cm) and weight (greater than 30%) of both coho fry and steelhead fry in fertilized areas compared to untreated areas.

Instream	McCubbing and Ward 2000	LWD, nutrients, boulders. Significant increases were found in steelhead parr and fry abundance and coho fry abundance overall at the watershed level and in reaches treated with structures, compared to untreated controls both within and between watersheds, despite low levels of adult escapement. A diversity of structural types appears to provide an optimum strategy for habitat rehabilitation, rather than singular types. Significantly larger salmonids were found in fertilized sections. Relative steelhead parr abundance was higher in 1998 than in 1997 by an avg. increase of 20 parr per 100m within reaches of the Keogh, a mean increase of 110%. In contrast, 3 of 4 sample reaches on the Waukwaas River showed reductions in parr abundance (a mean of 30% reduction for all reaches), to levels which were not significantly different that those in the Keogh. Coho fry densities were lower in both watersheds compared to 1997 data, except in the upper-most reaches of both watersheds. Coho fry were most abundant in pool and complex LWD habitat while steelhead fry were associated with run and flat habitat, regardless of LWD presence. Steelhead and coho parr were found in low numbers in pool habitat and some flats, particularly when LWD was present.
Instream	Merz and Chan 2005	Abstract only. Gravel. Placement of cleaned floodplain gravel decreased depths and increased stream velocities. Benthic organisms colonized new gravels quickly, equaling densities and biomass of unenhanced spawning sites within 4 weeks. Macroinvertebrate species richness equaled that of unenhanced sites within 4 weeks and diversity within 2 weeks. Standing crop, as indicated by densities and dry biomass, was significantly higher in enhancement sites after 12 weeks than in unenhanced sites and remained so over the following 10 weeks. Although mobile collector/browsers initially dominated new gravels, sedentary collectors were the most common feeding category after 4 weeks, similar to unenhanced sites.

Instream	Merz and Setka 2004	Gravel. The project significantly increased channel water velocities, intergravel permeability, and dissolved oxygen; reduced channel depths; and equilibrated intergravel and ambient river temperatures. The benefits remained throughout the 30-month monitoring period. adult Chinook began spawning at the previously unused site within 2 months after gravel placement and continued to use the site during the 3 spawning seasons encompassed by the study. Avg. bed elevation increased by .12m; avg. velocities increased by .24m/s.
Instream	Merz et al., 2004	Abstract only. Gravel. Salmon embryos planted in enhanced gravels had higher rates of survival to the swim-up stage than embryos planted in unenhanced spawning gravels. No significant increase in growth was observed. Intergravel temperature and substrate size were strongly correlated with distance downstream from the lowest nonpassable dam. Intergravel turbidity and total suspended and volatile solids were also strongly correlated. Survival models accounted for 87% of the variation around the mean for salmon and 82% for steelhead. Growth models accounted for 95% of the variation around the mean for salmon and 89% for steelhead.
Instream	Miller and Kochel 2009	Summary of 26 studies. Not a lot of good numbers. Decrease in bank cohesion and increase in stream power makes for a high risk of erosion given a moderate sediment supply. Change in channel capacity is highly variable from site to site, but more than 60% of projects on average, underwent a 20% change in channel capacity.
Instream	Miller et al. 2010	No fish. Meta-analysis of 24 separate studies. Increasing habitat heterogeneity had significant, positive effects on macroinvertebrate richness, although density increases were negligible. LWD produced the largest and most consistent responses, where as responses to boulder additions and channel reconfigurations were positive, yet highly variable. On average, richness estimates in restored reaches were 14.2% greater than unrestored control reaches and density estimates were 28% greater. On average, richness and density increases were, respectively, 83 and 75% greater for LWD than boulder additions.

Instream	Mitchell et al. 1998	Boulders. Results showed that the mid-channel treatment (boulder cluster and a low-head barrier dam) did not serve its purpose at lower discharges. However, as the discharge increased, more salmon took up residence in this treatment. In all experiments, greater depths were selected in the stream bank treatment, and salmon parr in the mid-channel treatment consistently selected positions closer to cover. Large parr preferred greater depths and were found closer to the improvement structures. Funneling effects of the drift were created near structures. The average number of fish counted decreased as the discharge increased. There were no significant differences found in the densities of benthic invertebrates in each replicate or treatment. The drift in the channel was significantly different that the drift in the reference site.
Instream	Moore and Gregory 1988	LWD. An increase in lateral habitat area of 2.4 times the area observed in control reaches resulted in a 2.2-times great density of age-0 cutthroat. Y-o-y fish were virtually eliminated from stream sections with reduced area of lateral habitat. In the first census following emergence the average numbers of age-0 fish per 15.m section were 26.7 in the increased-lateral-habitat treatment, 13.3 in the control treatment, and 3.0 in the reduced-lateral-habitat treatment. The difference between treatments was highly significant at each observation date. In the increased-lateral-habitat sections, a 2.4-fold increase in area of lateral habitat resulted in a 2.2-fold increase in the avg. # of age-0 fish. Straightening stream sections reduced the area of later habitat 86% and resulted in an 83% reduction in avg. number of age-0 cutthroat.
Instream	Moreau, J. K., 1984	Steelhead and Chinook. Population estimates for steelhead parr increased by 100% two years after boulder placement in one stream section while estimates in 2 control sections declined by 56% and 61%; large areas of spawning travel were create; increases in both steelhead parr habitat and gravel spawning areas were attained; costs ranged from $41 to $77 m3.

Instream	Morley et al. 2012	14 fish species. Mean substrate temperatures were significantly warmer at armored sites, but water temperature was similar to unarmored habitats. Epibenthic invertebrate densities were over 10 times great on unarmored shorelines and taxa richness double that of armored locations. Taxa richness of neuston invertebrates was also higher at unarmored sites, but abundance similar. There was no difference in Chinook diet, but observed a higher proportion of benthic prey for chum from unarmored sites.
Instream	Mueller and Liston 1994	Abstract only. Low-profile artificial reefs. Fish and invert data indicated reefs significantly benefitted aquatic organisms. Fish species diversity increased by 120% and abundance was 20 times greater than control sites. No species named.
Instream	Muotka and Laasonen 2002	Boulders. Leaf retention. Substrate heterogeneity increased by moss cover decreased dramatically. Retention efficiency in restored streams was higher than in channelized, but lover than in natural streams. Algae-feeding scrapers were the only macroinvert whose density increased significantly -3 x higher in restored than in channelized.
Instream	Muotka et al., 2002	Boulders/gravel. Invert communities in unmodified streams changed little, whereas those in restored streams had undergone considerable changes.
Instream	Nagayama et al. 2012	Masu salmon, lamprey, stone loach, goby and sticklebacks most dominant fish in study. Abundance of Masu was highest at the log jam sites but lowest at site with no wood. Goby abundance was higher at the log jam sites that at sites with no wood and simple wood structure sites. Lamprey abundance was higher at the logjam sites than at the no wood sites. In the autumn, current variability at the simple wood structure site and the log jam sites was higher than that at the no wood sites, and the proportion of coarse bed material at the simple wood structure site and the log jam sites was significantly lower than that at the no wood site. Depth and proportion of fine bed material were significantly higher at the log jam sites than the no wood sites. The abundance of masu was positively related to the current variability.

Instream	Nagayama et al. 2012	12 fish species including rainbow, chum, masu and white-spotted charr. No good numbers. Fish diversity was higher at the simple wood structure (SWS) and the log-jam (LJ) sites than in the no wood (NW) sites during both seasons (autumn and winter). Diversity at the LJ sites was higher than at the SWS sites during the winter. The abundance of the four dominant fish species was generally higher at the LJ sites than at the NW sites during both seasons. The SWS and LJ sites had greater depths, finer bed material and more diver flow conditions during autumn. During the winter, the LJ sites had slower currents and finer bed materials.
Instream	Naslund, I., 1989	Boulders and logs. Boulder dams increased brown trout densities by up to 3 times and standing crop by up to 5 times. Log deflectors gave similar effects on standing crop while boulder groupings and boulder deflectors seemed to be inefficient.
Instream	Negishi and Richardson 2003	Boulder clusters. Mean velocity and its coefficient of variation increased 140 and 115% respectively. Enhanced particulate organic matter storage (550%) was accompanied by increased total invert abundance (280%). Effect of boulder clusters on taxonomic richness was negligible.
Instream	Newbury and Gaboury 1988	Riffles and boulders. Based on egg density measurements, more walleye spawned on the paired riffles (3.6 eggs/sq. m) than on the single riffles (1.1 eggs/sq. m). The number of newly hatched walleye larvae caught below paired riffles was significantly greater than the number caught below any single riffles.
Instream	Newbury and Gaboury 1993	Riffles and boulders. Inconclusive results. Walleye, brook trout and rainbow.
Instream	Nickelson et al., 1992	Log, gabion and rock. When placed across the full stream width, structures provided good summer habitat but poor winter habitat for juvenile coho. No numbers.

Instream	Nicol et al., 2004	Abstract only. LWD. Carp and native fish. Little support that competition for LWD habitat as population level effects; There was a significantly significant relationship between native fish, LWD and location within a meander and curvature of the meander. Carp response to LWD placement was inconclusive.
Instream	O'Grady et al., 1991	Rubble and brush removal. Velocity increased (7.5 cm/sec in control to 46.2 cm/sec in treatment). Depth decreased from 176.7 cm in control location to 34 cm in treatment with rubble mats.
Instream	O'Grady, M., 1995	Boulders and brush removal. All numbers were estimates. Enhancement costs were estimated as being £0.34-2.13 per fish caught on a rod and line. Shrub-pruning salmon production was estimated at being >= £0.24 per adult salmon returning to the river or >= £1.5 per adult salmon caught on rod and line. Atlantic salmon and brown trout.
Instream	Overton et al., 1981	Boulders. Steelhead and Chinook. Project resulted in a two-fold and a four-fold increase in juvenile steelhead numbers in the boulder-only section and the boulder-log section, respectively. There was a marked increase in age 1+ steelhead trout in the treated section. Treatment reach increased 19% in surface area and streamflow volume increased 75% were boulders were placed in clusters. The increase in pool stilling area averaged 1.10 m3 per boulder. The increase in absolute biomass of 315% in treatment reach parr, boulder cluster section, was greater than the 256% and 143% increase in relative biomass per surface area and volume respectively. Steelhead egg- to-fry survival ranged from 71% to 98%

Instream	Palm et al.2007	Boulders. Brown trout. After restoration, density of age 0+ trout increased significantly in the boulder+ gravel section and was positively correlated with the area of reconstructed gravel beds. Percentage of age 0+ in the population increased from 36% to 51.5% after gravel bed restoration .The density of age 0+ trout did not change in the boulder only treatment, where as this same percentage declined from 27.9% to 23.4% in the boulder only section. Egg-to-fry survival was significantly higher in the boulder + gravel section compared to the boulder only section. (10.3% +-2.6% vs. 1.7% +-1.1%)
Instream	Paulsen and Fisher 2005	Logs, boulders, etc. Model estimates only. There was a positive, significant correlation between actions and parr-to-smolt survival; however, there were also numerous significant correlations between survival, actions, and many of the potential independent variables.
Instream	Pess et al. 2012	Chinook, coho and trout. Juvenile salmonid density was higher in ELJ units for all control-treatment pairs except one in 2002 and 2003. Positive mean differences in juvenile densities between ELJ and non-ELJ unities were observed in 2 of 4 years for all juvenile salmon, trout greater than 100mm and juvenile Chinook. Positive mean differences occurred in one of four years for juvenile coho salmon and trout less than 100mm.
Instream	Peters et al., 1998	Summary of studies. No specific numbers.
Instream	Pierce et al. 2013	Study of 18 projects and various techniques. Wild trout. At pretreatment conditions, average trout abundance was significantly lower in treatment vs. reference sites (0.19 vs. 0.62 trout/m). By 3 years post treatment, trout abundance had increased significantly to an average of 0.47 trout/m and was no longer significantly different from the reference average. These initial rapid increases were sustained over 5-21 years in 15 streams. Although long-term (12 yrs.) average response trends were positive, trends varied spatially and native trout responded more strongly in the upper portion of the basin.

Instream	Poulg et al. 2013	Brown trout. Both gravel addition and gravel cleaning proved to be suitable for creating spawning grounds. Fish reproduced successfully at all test sites. The relative number of y-o-y brown trout increased clearly after restoration. Sediment on the test sites colmated during the 4 years of the study. In the first 2 years, highly suitable conditions were maintained, with a potential egg survival of more than 50%. Afterwards, the sites offered moderate conditions - egg survival less than 50%. Conditions unsuitable for reproduction were expected to be reached in 5-6 years post restoration.
Instream	Poulin, V. A., and Associates Ltd., 1991	LWD, gabion. Coho, rainbow, Dolly Varden. Juvenile salmonid response to large organic debris structures was positive, with substantially increased densities after construction in two creeks (from 1.0 to 210% and from 13 to 194% of control reaches. Juvenile densities in blast pool sections of one trib increased substantially after construction (from 61 to 485%).
Instream	Pretty and Dobson 2001	LWD. No numbers. Increases in detritus levels were slight, standing stocks remained very low and the invert fauna was unaffected.
Instream	Pretty et al., 2003	Boulders and riffles. No numbers. There was little evidence that treatments substantially improved the conservation value of the fish assemblage, in terms of abundance, species richness, diversity and equitability. Bullhead and stone loach.
Instream	Price and Birge 2005	Rip rap, veg. Non salmonid (bass, sunfish, darters). No good numbers. A decrease in total habitat assessment scores was observed at the remediated sector in each stream. However, the IBI fish assemblage scores were similar for upstream and remediated sectors, indicating that habitat impact resulted in limited effects on assemblages.
Instream	Purcell et al., 2002	No numbers. Both biological and habitat quality improved in the restored compared with the unrestored section, but restored area was of lower quality that a stream restored 12 years before.

Instream	Quinn and Kwak 2000	LWD and rocks. Brown, rainbow, brook and cutthroat. Rainbow and brown accounted for most of the total trout density (87%) and biomass(97%) in the ref reach and modified reach (76% density, 90% biomass). Mean total trout density was 463 fish/ha (103 kg/ha) in the ref reach and 1,854 fish/ha (252 kg/ha) in the modified reach.
Instream	Raborn and Schramm Jr. 2003	LWD/weirs. Although habitat variables changed, neither species richness, evenness, nor fish assemblage structure differed between mitigated and channelized segments with both exhibiting less richness and different assemblage structures than the unaltered segment. 85 species.
Instream	Reeves et al., 1997	LWD. Juvenile coho were 14.8% longer for the period following restoration. Smolts were 6.8% longer in the same period, but not significant. Mean estimated annual number of y-o-y steelhead declined by 53.2% for the period following restoration. The mean for age-1 steelhead increased 11.7% and that of smolts 27.7% following restoration - but not significant. Age-0 and 1 steelhead were on average 12.5% and 4.1% larger, respectively, in the period after restoration.
Instream	Reich et al., 2003	LWD. Synthesis of case studies. Gives project details but not results.
Instream	Riley and Fausch 1995	LWD. Abundance and biomass of age-2 and older trout (and often age-1 trout) increased but there was no evidence that trout were in better condition or grew to larger sizes. Installing 10 logs caused pool volume to increase from less than 40 m3 to 115-150 m3. Cover increased significantly. Abundance and biomass of adult trout (age 2 or older) and often juveniles (age 1), increased significantly.
Instream	Rinne, J. N., 1982	129 recaptured Gila trout moved <0.1 km and grew less, both in streams containing larger fish populations and log improvement structures. Those that moved traveled greater distances downstream. <2% moved upstream over structures, and such movement was limited by structures >= 0.5m high.

Instream	Rodgers et al., 1993	LWD/alcoves. Juvenile coho. Average overwinter survival increased from 11% in one creek to 51% the first year, and 40% the 2nd year after treatment. In another creek it increased from 14% to 63% in the 1st year. Fork length increased more in treatment reaches than in control streams.
Instream	Roni and Quinn 2001a	LWD. Juvenile coho densities were 1.8 and 3.2 times higher in treated reaches compared with references reaches during summer and winter, respectively. Densities of age 1+ cutthroat and steelhead did not differ between treatment and ref reaches during summer but were 1.7 times higher in treatment reaches during winter. Total pieces of LWD per 100m was significantly higher in treatment than in ref reaches during summer (20-80 vs. 8-63) and winter (16-78 vs. 4-64) and averaged 1.83 and 1.89 times greater in treatment reaches in summer and winter respectively. The total number of functional LWD was significantly higher in treatment than in ref reaches during both summer and winter and averaged 2.83 and 2.96 times greater in treatment than in ref reaches. Pool area in treatment reaches averaged 1.52 times that in ref reaches during summer and 1.51 during winter and total wetted area increased by a factor of 1.11 in summer and 1.08 in winter. Treated reaches had 1.31 times more pools than ref reaches in summer and 1.48 times ore in winter. Total number of habitat units was 1.11 and 1.22 times higher in treatment than in ref reaches during summer and winter, respectively.
Instream	Roni and Quinn 2001b	LWD. Juvenile coho, steelhead and cutthroat. 0-33% of marked trout or coho moved between restored and reference reach. There were indications of considerable migration to and from the study reaches. In artificial channels, fewer fish moved in the woodless channel than in the woody channel (22% vs. 37%), and the mean distance moved was shorter in the woody channel (4.4 vs. 6.7 habitat units). In the woodless channel, fish that moved grew faster than those that didn't.

Instream	Roni et al. 2008	Boulders. Coho and steelhead. No. of coho spawners and peak red counts were significantly higher in treatment reaches than in control reaches (avg. difference = 2.9 redds and 4.6 spawners). No differences existed in coho spawner counts or steelhead redd counts among reaches without weirs. Redd densities in trib reaches were higher than those in main-stem reaches either with or without boulder weirs. Spawner density and redd density were positively correlated with percent gravel. 43% of observed redds were located within 10m of a boulder weir. Of those redds, more than 80% were within 3m upstream of a boulder weir.
Instream	Roni et al., 2006	Boulders. Pool area, # boulders, total LWD and LWD forming pools were all significantly higher in treatment reaches. No differences in water chemistry or macroinvertebrate metrics were detected. Abundance of juvenile coho and trout were higher in treatment reaches, while dace were more abundant in control reaches.
Instream	Roni, P., 2003	LWD. Densities and mean lengths of giant salamanders, reticulate sculpins, torrent sculpins, and lampreys did not differ significantly between treatment and control reaches. Lampreys densities and length of age-1 and older reticulate sculpins among streams were positively correlated with LWD within the wetted channel. Lampreys length was also positively correlated with differences in % of pool area.
Instream	Roper et al., 1998	Logs, boulders. Less than 20% of 3,946 structures were removed following floods exceeding a 5-year return interval. Less than 15% of the structures were moved from the site of placement in floods with return intervals less than 65 years. Where floods exceeded a 64-year return interval, structures were almost 2 times as likely (25%0 to have been removed from original placement than those that experienced lower intensity floods. Structures made of logs or boulders were more likely to have remained in place (67%) than those made of a combo of logs and boulders (57%). Structures were less durable in the 20% of the sub-basins having the highest landslide frequencies.

Instream	Rosenfeld et al. 2011	Review of restoration. No fish. Land use impacts in geologically young landscapes with high sediment yields vs. areas with naturally low sediment yields caused by low relief, resistant bedrock, and abundant mainstem lakes that trap sediment. Contrasting restoration priorities illustrate the consequences of divergent regional land use impacts on sediment supply, and the utility of planning restoration activities within a mechanistic sediment supply-transport framework. No numbers
Instream	Rosi-Marshall et al., 2006	Abstract only. LWD and k-dams increased the relative abundance of harvestable trout (>25 cm) but not overall trout abundances. Both techniques increased max channel depth and organic matter retention but only k-dams increased overall habitat quality.
Instream	Rubin et al., 2004	Gravel addition. Sea trout. More than 60% of the eggs produced emerging fry in the artificial grounds compared with less than 45% in the natural habitats.
Instream	Saunders and Smith 1962	Boulders, lwd. Brook trout. In the year following alterations, the standing crop of fingerlings was above average. The numbers of age 1 and older trout were approximately doubled. The alterations had no noticeable effect on the growth of trout.
Instream	Schmetterling and Pierce 1999	LWD and rock. Of the original 66 structures, 55 (85%) were intact following the flood. The mean max depth of remaining pools decreased from 1.1 m in 1996 to 0.8 m in 1997. The length of the project area occupied by pools increased from 452 m (13.4%) in 1996 to 958 m (17.6%) in 1997.
Instream	Sear and Newson 2004	Abstract only. Riffle/gravel. The gravel bedforms display the hydraulic functionality associated with natural pool-riffle sequences. At bankfull discharge, water surface elevation is not significantly increased over those existing prior to installation, and physical habitat is shown to be more diverse following rehabilitation.

Instream	Senter and Pasternack 2011	Chinook. Spawners built 85% of redds within one average channel width (31m) of large wood. Spawners utilized large wood within a 10m radius 36% of the time in the upper 3 km rehabilitated reach, and 44% of the time in the lower 4.7 km marginal habitat reach. A greater percentage of large wood was utilized in riffles in the upper 3 km reach where 90% of redds were built, while a larger percentage of spawners used large wood in riffles in the lower 4.7 km reach. Large wood-redd interactions occurred at greater rates than by random chance alone in the lower 4.7 km reach.
Instream	Shetter et al., 1949	Log deflectors. Brook trout. Deflectors raised the number of good pools from 9 to 29, increased avg. pool depth by 6 inches, and exposed additional gravel without significantly changing the avg. stream depth over the entire section. There was a decrease in total number and volume of all organisms but an increase in forms found most frequently in trout stomachs. There were slight increases in the # of smaller trout present after deflector addition with a slight decrease in avg. size. Post-improvement showed an increase of 120% in the total catch and of 46% in pounds caught per hour with a 64% increase in angling pressure.
Instream	Shields and Alonso 2012	No fish. Testing flows on wood in artificial channel. For both simple and complex large wood, maximum lift and drag forces during the rising limb of unsteady flows were about 2-3 times greater than steady flow temporal mean values.
Instream	Shields et al. 1998a	LWD and stone. Species composition shifted away from small colonists toward larger centrarchids, catostomids, and ictalurids (50+ species). Fish density and species richness increased at one rehabilitated site by 72% and 27% at its degraded reference but remained stable at others. Pool habitat availability doubled. Mean depth increased 155% and velocity decreased 40%. Bed material became coarser. Volume of scour hole pools declined but was still about 14 times greater than before rehab.

Instream	Shields et al. 1998b	Abstract only. Rock (stone spurs). Spur addition resulted in modest increases in baseflow stony bankline, water width and pool habitat availability, but only local effects on depth. Fish species composition shifted away from a run-dwelling assemblage dominated by cyprinids and immature centrarchids toward containing fewer and larger centrarchids.
Instream	Shields et al. 2004	LWD. Structures reduced velocities and induced sediment deposition and retention. Construction costs per unit channel length were 23-58% of costs for recent stone bank stabilization projects. Mean water depth increased by 40-100%. Inverts showed a positive response to LWD both within treatment and downstream.
Instream	Shields et al., 1993	Plantings and boulders. No. of fish species and mean fish length increased by 90% and 60% respectively. Mean weight of fish catch increased by more than an order of magnitude. Weights of the largest bluegill, longear sunfish and spotted bass were 18,572 and 7255% larger than their pre-restoration counterparts. 12 species were captured post-restoration that were absent prior to restoration. Wood cover increased from 38 to 66%. Mean depth and mean scour hold depth corrected for stage variation increased 44 and 82% respectively. Mean scour hole width increased 130%.
Instream	Shields et al., 1995a	Abstract only. Boulders. Depth of scour holes increased from 32 cm to 72 cm, and pool habitat in the lower half of the study reach increased from 2.9% to 14% of water surface area. Median water depth at base flow increased from 9 cm to 15 cm. Woody veg cover on one side of the channel increased from 38% to 78%. fish numbers tripled, median fish size increased by 50%, and the number of species increased from 14 to 19.

Instream	Shields et al., 1995b	Abstract only. Boulders. Restoration increased pool habitat availability, overall physical heterogeneity, riparian veg, shade and woody debris density. After restoration, mean width, depth and velocity exhibited changes of +56%, +150% and -56% respectively, despite discharge levels that averaged 43% lower during data collection periods. Pool area increased to 72% of the water area. Before restoration cyprinids and centrarchids comprised 74 and 11% respectively, of the numerical catch, but 32 and 55% after restoration.
Instream	Shields et al., 2003	Abstract only. No numbers. LWD and plantings. Initially, structures reduced high flow velocities at concave bank toes; sand berms were created and there was a slight increase in base flow water width and depth. Fish assemblages were typical of incising streams, but minor initial responses to debris was evident. Structure failure and renewed erosion began during the 2nd year after rehab.
Instream	Shields et al., 2006	LWD and plantings. Long-term willow survival was less than 10%. Fish biomass increased and species richness approximately doubled. Fish numbers, biomass, and size increased after rehab, but biomass and size were the only statistically significant. 32 species.
Instream	Shuler et al., 1994	Boulders. On avg., 65% of the adult brown trout and 69% of the juveniles were holding positions near structures. They used primarily wingdams, midchannel boulder clusters, and natural bank cover and avoided single boulders and areas with no structures. 89% of juveniles were not associated with structures during the day, and 91% of those at night occupied positions near natural cover.
Instream	Slaney et al., 1994	LWD and fertilization. Juvenile Chinook highly colonized stream-side debris structures. Fry density was similar to that in natural woody cover. Adult rainbow also more extensively colonized debris structures than nonstructure sites.

Instream	Smokorowski and Pratt 2007	Meta-analysis of many studies. On the whole, decreases in structural habitat complexity are detrimental to fish diversity and can change species composition. In creases in structural complexity showed increases, decreases, or no measurable changes in species and (or) communities. the majority of the meta-analysis resulted in supporting a direct link between habitat and fish abundance and biomass, with fish biomass responding most strongly to habitat change.
Instream	Solazzi et al., 2000	LWD. Avg. winter rearing habitat increased 13 times over that in the previous year while the ref. area stayed the same. Fastwater habitat in the treatment stream decreased by about 6000m2 but remained relatively constant in the ref. stream. Mean summer population of juvenile coho increased by 50% while there was a 25% decrease in the ref. stream. Mean # of coho smolts increased by over 200% while the ref. stream stayed the same. Mean number of coho migrants doubled but decreased 75% in the ref. stream. Overwinter survival of coho increased from a mean of .13 to .38 (ref. was .17 to .20) In another stream, mean overwinter survival increased 250% from .11 to .39 but fell in the ref stream from .19 to .10. Mean # of steelhead migrants increased by over 800%. Cutthroat migrants in the treatment stream increased by 275% and decreased 75% in the ref. stream.
Instream	Spanhoff et al. 2006	LWD effects on inverts. No good numbers. Diversity in the wood-enriched section was distinctly lower compared to the control section the first year, but nearly equal in the 2nd sampling period.
Instream	Stewart et al. 2009	Review of 17 studies. Meta-analysis shows that evidence regarding the effectiveness of instream devices in equivocal. Heterogeneity is significant both for population size and local habitat preference. Heterogeneity is related to stream width, with instream devices being less effective in larger streams. Engineered structures show no detectable effect on local abundance, indicating no habitat preference. No numbers. Many species.

Instream	Sudduth and Meyer (2006)	Abstract only. No numbers. Amount of wood and root bank habitat was much higher at the ref site and 3 of 4 bioengineered sites than at the unrestored site or the 4th bioengineered site. Higher biomass and abundance were found on organic habitats vs. inorganic habitats across all sites. Percent organic bank habitat proved to be strongly positively correlated with invert taxon richness, total biomass, and shredder biomass.
Instream	Sundermann et al. 2011	No fish. Analyzed 24 restoration projects. On average, the restorations did not improve the benthic invertebrate community quality. Restoration success depends on the presence of source populations of desired taxa in the surrounding of restored sites. Only where source populations of additional desired taxa existed within a 0-5 km ring around the restored sites were invert assemblages improved by the restoration. Beyond the 5-km rings, the recolonization effect was no longer detected.
Instream	Tarzwell, C. M., 1937	LWD structures. Each deflector produced on avg. 82 sq. ft. of plant bed, 392 sq. ft. of mucky area, 965 sq. ft. of riffle and uncovered 144 sq. ft. of graveled area. Improved bottom avg. was 2,027 sq. ft. in one river and 1,418 in another. More legal trout were taken and the avg. size of the trout was greater after improvement. Before improvement, 71 legal trout were caught in 75.75 hours. After improvement, 250 were caught in 167.5 hours. The counts of organisms per unit area was from 3-5 times greater after improvements than before. 4.53 times as much food was found in the riffle areas produced by the barriers as before improvements.

Instream	Tarzwell, C. M., 1938	LWD structures. Rainbow, brook and brown trout and Yellowstone native. Creel census showed 25,150 fish caught in the treatment over 6 years and 46,190 in the control but almost twice as many trout were placed in the control. The yield in pounds per acre from the treatment creek was greater than from the treatment reach by 8.6 lbs. in one year, and by 16.6 lbs. in another. Riffles are richer than the natural pools but the artificial pools in the treatment creek are richer than the riffles due to the collection of debris and organic materials in them. The control creek yielded one pound of trout to 4.97 pounds of bottom organisms and the treatment creek had one pound of trout to 5.48 pounds of bottom organisms.
Instream	Thom, B. A., 1997	Examined physical effects of LWD placement in 9 streams with paired treatment and reference reaches using a BACI design. Positive treatment effects were observed for various LWD and habitat metrics (no. pieces, jams, habitat units, no. of pools, slackwater pools). Treatment reaches increased from 11.7 to 17.2 pieces of wood and to 21.1 to 25.1 m3 of wood per 100m. Key pieces increased on average 0.8 pieces per 100m and decreased in control reaches 0.50 pieces per 100m.Proportion of slackwater pools (alcoves, backwaters, dammed pools, etc.) in treatment reaches after treatment increased 4 fold in summer and 7 fold in winter.
Instream	Thompson, D. M., 2002	LWD. Cover structures have produced a 30% reduction in streamside vegetation with over 75% less overhead cover than unaltered reaches.
Instream	Thompson, D. M., 2006	Review of 79 pubs. Little evidence of the successful use of instream structures to improve fish populations exists prior to 1980.
Instream	Tikkanen et al., 1994	Boulders. The immediate effect of rehab was a slight decrease in the abundances of benthic insects and recolonization occurred rapidly (within 10 days). Disturbance of the rehabilitation work did not have a detectable effect on the invert community. The detection of effects was obscured by rapid life cycle phenomena taking place at the same time.

Instream	Van Zyll De Jong et al., 1997	Boulder/logs. Boulder clusters were the most effective structure, increasing densities of 0+, 1+ and 3+ juvenile Atlantic salmon. V dams were effective in increasing both the density of brook trout and Atlantic salmon through creation of more diverse pool habitat. Half-log covers increased the number of juvenile salmon age 0+ through an increase in instream cover. Boulder sites were the shallowest, fastest flowing reaches and boulders substantially increased the large substrate composition. Boulder clusters increased habitat diversity.
Instream	Vehanen et al. 2010	Brown trout. Treatments = LWD w/boulders, boulders alone, and unmodified. Restoration increased streambed complexity but did not have a detectable effect on brown trout stocks for LWD or boulders except for age 2+ and older fish which decreased in abundance compared to control reaches. Structures provided some safeguard against drought for age -2 and older, but not for the younger age classes.
Instream	Vehanen et al., 2003	Boulders. Grayling largely stayed in the restored area and avoided the unchanged channel. The range of daily movement was from stationary to 2700 m per day. Adult grayling preferred water velocities between 0.20 and 0.45 m s-1, depths between .20 and 1.55 m and coarse substrate.
Instream	Viola et al., 1991	Abstract only. LWD. There was a significant increase in the density and biomass of older aged wild rainbow/steelhead trout; the instream habitat structures concentrated hatchery fish and provided increased harvest within habitat altered river sections; the creation of aesthetically pleasing areas for anglers; and increased spawning use by steelhead and Chinook.

Instream	Voilin et al. 2011	No fish. Compared physical and biological structure of 4 urban degraded , 4 urban restored and 4 forested sites. Restored streams were indistinguishable from their degraded urban counterparts. Forested streams were shallower, had greater habitat complexity and median sediment size, and contained less-tolerant invert communities with higher sensitive taxa richness than streams in either urban category. Restored streams had less canopy cover. Channel habitat complexity and watershed impervious surface cover were the best predictors of sensitive taxa richness and biotic index at the reach and catchment scale, respectively. Invert communities in restored channels were compositionally similar to those in urban degraded channels and both were dissimilar to communities in forested streams. Reach-scale restoration is not successfully mitigating for factors causing physical and biological degradation.
Instream	Wallace et al., 1995	LWD. Sampled upstream of debris dams. Stream depth increased (20-30 cm), current velocity decreased, cobble was covered by sand and silt, and both coarse and fine particulate organic matter increased dramatically. Abundances and biomass of scrapers and filterers decreased; collectors and predators increased. Secondary production of scrapers and filterers decreased, whereas that of collectors and predators increased.
Instream	Ward and Slaney 1981	LWD. And boulders. The mean number of steelhead parr and coho fry in boulder groupings increased to 0.10 m2 and 0.27m2 respectively. Groupings ranked highest in salmonid standing crop. Gabions failed to increase steelhead parr abundance, but significantly increased juvenile coho. Steelhead significantly increased by around one parr per boulder. There was a 400% increase in number of steelhead parr/lineal m in the boulder clusters.
Instream	Warner and Porter 1960	Boulder structures. 63 deflectors had successfully narrowed the flow or created pools. Rock dams were largely unsuccessful. After 2 years, 37 deflectors were virtually unaffected by freshets. Spring holes created pools 6-30 inches deep. Y-o-y trout were moderately abundant where few had been seen previously.

Instream	Weber and Peter 2011	No specific fish. In 32 (80%) of the 40 studies, fish response was measured at the population level. Structural and compositional indicators dominated (31 and 24 studies, respectively), while functional indicators were underrepresented (5 studies). Eighteen studies used multiple indicator types for a given ecosystem attribute, a given hierarchical level, or both. Among these studies, they found only very limited evidence that project outcome differed among different indicator types (1 study). In contrast, highly heterogeneous results were found within the different indicator types at the level of the individual study. Such heterogeneity was related to the spatiotemporal variability of the results and species-specific responses to physical habitat rehabilitation. Most studies (73%; 29 studies) used a single type of reference, and the majority focused on degraded conditions. Among the 10 studies that applied multiple reference types, one-third (3 studies) showed inconsistent results.
Instream	West, J. P., 1984	Chinook, steelhead. Fine sediment was reduced about 18%. Use of treated areas rose from no use to approx. 29 redds/season. After boulder placement, steelhead juvenile rearing increased 10-fold. Salmon and steelhead spawner use increased 3-fold. Use of control area was relatively static.
Instream	Wheaton et al. 2004	Chinook. Hydrodynamic shear zones provide equally important refuge from predation and resting zones for energy conservation. The increased heterogeneity appeared highly effective in terms of redd utilization with 70 redds located in close proximity to 93% of the available structural cover, and 42 redds located in close proximity to 90% of the available shear zone refugia.

Instream	White et al 2011	Log weirs. Brook trout. Pool volume remained more than 3 x higher in treatment sections and mean depth was also greater. Adult trout abundance increased rapidly after installation and remained 53% higher in treatment sections than in controls 21 years later. Effects on juvenile trout were not detected. Of 53 logs installed, all were in place 21 years later and 98% were functioning to create dammed and plunge pools. Pool volume averaged 229% higher in treatment sections in 2009; treatment sections had a n average of 54% more adult trout in 2009.
Instream	White et al. 2011	Brook, brown, and rainbow. When streams were resampled decades after wood installation, none of the 53 logs had moved, and all but one were functioning properly. Pool volume remained more than 3x higher in treatment sections than in adjacent controls, and mean depth was also greater. Adult trout abundance increased rapidly after structures were installed and remained 53% higher in treatment sections than in controls 21 years later. Effects on juvenile trout abundance were not detected.
Instream	Whiteway et al.(2010)	Analysis of 211 projects using instream structures. 7 species. Showed significant increase in pool area (mean effect size = .65), average depth (mean effect = .29), lwd (mean effect size = .73), and % cover (mean effect size = 1.14) as well as a decrease in riffle area (mean effect size = -.52). There was a significant increase in salmonid density (mean effect size of .51 o 167%) and biomass (mean effect size of .48 or 162%). Large differences were observed between species, with rainbow showing the largest increases in density and biomass. Projects with multiple structures increased pool area more than those with only one type of structure.
Instream	Wilkins, L. P., 1960	Logs and boulders. Wild rainbow populations declined in the 2 yrs. after construction but this was associated with an increase in anglers. A significant increase in y-o-y trout occurred while the standing crop of age-group 1 trout has gradually increased despite greater fishing intensity.

Instream	Yrjana, T., 1998	Boulders and gravel. No good numbers. Restoration was immediately followed by a decrease in the number of benthic fauna but it returned to prior levels within 2 weeks. The biomass and density of trout yearlings was significantly greater in the restored areas. Boulder groups should be placed on spawning grounds to offer cover and increase local velocities.
Instream	Zika and Peter, 2002	LWD. Brown and rainbow trout. No good numbers. Abundance and biomass of brown and rainbow increased; max and standard deviation of fish total length increased in all sections during summer; the number of individuals and standard deviations of total lengths decreased in the control section in winter, but increased in the treatment section. Mean water velocities decreased and number and volume of pools increased in treatment section. Trout sought woody debris for cover.
Riparian/Grazing	Briggs, M. K., 1996	Book contains several case studies…only have summary…need entire text
Riparian/Grazing	Carline and Walsh 2007	No fish. Buffer strips and bank stabilization, fencing, rock-lined crossings in areas with grazing. Few changes were found in channel widths and depths due to a drought. Vegetation increased from <=50% to 100% in nearly all formerly grazed buffers. Proportion of fine sediment decreased in one of 2 treatment streams. Suspended sediments during base and storm flow decreased 47-87%. Invert densities increased in both treated streams.
Riparian/Grazing	Chen and Zhou (2005)	Abstract only. No numbers. Vegetation restoration on erosion-induced sediment yield.
Riparian/Grazing	Clary et al., 1996	Response of sagebrush steppe riparian to grazing control. Detailed study with numerous tables that are hard to quantify in a few statistics due to multiple measures and treatments. Herbaceous plant species increased in growth and vigor under reduced grazing. Significant improved stands of cottonwood and willow developed where they were artificially planted. No difference in nesting birds or small mammals 7 years after treatment. W/D ratio increased in all treatments except those not subjected to grazing.

Riparian/Grazing	Clary, W. P., 1999	10 year grazing study comparing high, medium and no grazing on Stanley Cr, ID. Stream channel narrowed (ratios of after/before .54, .52 and .29 for h, m and no grazing respectively), embeddedness decreases, stability increased. Height of willows increased .35, .28 and .4 meters for h, m and no grazing treatments). And willow cover increased by 29, 37 and 56% in three treatments, little change was detected in herbaceous cover.
Riparian/Grazing	Connin, S., 1991	Reviewed of 13 fencing and other similar riparian projects. Results varied by study, but overall studies reported increased spawning gravels, bank stability, decrease in channel width and erosion. 25 to 50% increase in streambank cover. One project reported increase in smolt production from 0 to 25 smolts per pool. Fecal coliform also decreased with fencing/livestock exclusion.
Riparian/Grazing	Cooperman, Hinch et al. 2007	Grading, plantings, rock deflectors and fencing. Invert abundance did not differ between treatment and control sites but was affected by channel gradient and river segment; sites didn't differ in multivariate space but treatment sites had narrower wetted widths and higher inside banks than control sites. All other in-channel response variables and channel gradient did not statistically differ between sites.
Riparian/Grazing	Dobkin et al., 1998	Examined recovery of livestock grazing on plots on small stream in Great Basin. Increase in forb and sedge cover. Increase in avian species richness (from 10 to 12) and abundance from ~15 to 30/plot)
Riparian/Grazing	Emmingham et al., 2000	Reviewed several conifer conversion projects along Oregon coast - provided only qualitative results. Relatively poor growth and survival due to shade, predation (beaver & deer) and competition. Provides recommendations for improving project success (control of predation, shade, competition)
Riparian/Grazing	Gladwin and Roelle 1998	Response of saltcedar and cottonwood to fall and spring flooding. Fall flooding survival of saltcedar 0.8% vs. 21% for cottonwood. Spring flooding survival was 94% vs. 99% for cottonwood. Fall flooding recommended to control saltcedar

Riparian/Grazing	Holmes et al., 2004	Economic evaluation of riparian restoration based on cost and survey of "values" or "benefits". Benefit cost ratio ranged from 4 to 15.7 demonstrating that riparian restoration was cost effective
Riparian/Grazing	Hook, P. B., 2003	Sediment retention on rangeland riparian buffers. Sediment retention ranged from 63 to 99% depending upon veg. type and buffer width. 94 to 99% retention in 6m wide buffers regardless of veg type or hill slope.
Riparian/Grazing	Humphrey and Patterson 2000	Scottish study looking at effects of grazing on plant species diversity. Grazing led to greater species richness, but decrease in veg height.
Riparian/Grazing	Kauffman et al., 2002	Examined control (grazed) and treatment (grazing exclosure) reaches of 11 NE Oregon streams). Results not easily converted to simple quantities of change, but significantly higher veg. cover, composition and structure and species richness. Improvement in geomorphology including channel width, depth and number of pools also detected. YOY rainbow trout (redband) in ungrazed sections, but no change in parr or adult trout. Redside shiners and speckled dace decreased.
Riparian/Grazing	Kauffman et al., 2004	Examined lives stock exclusion on 3 sites in MF John Day 9-18 yrs. after grazing in dry and wet meadows. Below ground biomass (TBGB) was 50% and 62% greater in exclosures in dry and wet meadows respectively. Mean infiltration rate was 12.9x greater (1191%) and 233% greater in dry and wet meadows, respectively.
Riparian/Grazing	Keller and Burnham 1982	Fencing to exclude livestock in Summit Cr, ID lead to more trout in ungrazed sections- 1.56x more fish on average. Also fish in ungrazed sections were larger.
Riparian/Grazing	Kondolf, G. M., 1993	Examined channel morphology within and downstream of grazing exclosure - no change in channel width downstream of exclosure despite higher veg. height and cover in exclosure.
Riparian/Grazing	Laffaille et al., 2000	Effects of sheep grazing on salt march in France and seabass foraging. Change in veg . following removal of grazing led to more food (inverts) for seabass. Seabass consumed less inverts in grazed areas (abstract only)

Riparian/Grazing	Li et al., 1994	Comparison of shaded and unshaded streams in John Day basin. Shaded streams cooler by up to 5C, greater rainbow trout biomass by ~ 2 fold in those with canopy vs. those without (hard to estimate average increase from graphs)
Riparian/Grazing	Long et al., 2003	Examined recovery of riparian areas following removal of grazing and seeding in White Mtn. Apache Reservation. Found emergent wetland plants 4.7 to 55.5% higher in reaches with perennial flow compared to initial condition. (abstract only)
Riparian/Grazing	Lyons et al., 2000	Effects of rest rotation grazing on bank erosion and fish - intensive rest rotation grazing and grazing buffers had less bank erosion and fine sediment compared to continuous grazing. NO effect was detected on trout abundance, IBI or other physical or biological variables (abstract only)
Riparian/Grazing	Meals and Hopkins 2002	Examined phosphorous reduction in BACI watershed (2 treatments = 1 control) design to grazing and riparian treatments. P concentrations and loads decreased 20% and total P load 20-50%
Riparian/Grazing	Meals, D.W., 2001	Same as Meals and Hopkins but preliminary findings (abstract only). See Meals and Hopkins 2002
Riparian/Grazing	Medina and Steed 2002	Examination of Westfork Grazing allotment (See also Medina et al. 2004/5) and different grazing treatments (with and without cattle and elk). No effects on channel morphology or fish (Apache trout) were detected. Little to no response in vegetation metrics measured. Results complicated by elk trampling and grazing and other environmental factors.

Riparian/Grazing	Medina et al. 2005	Book chapter in Roni 2005 - Three case studies on grazing removal 1) Rio de Las Vacas exclosures - No fish response, streambank stability was 100% in exclosures but 64% in grazed areas, overhanging veg slightly higher in grazed areas, no difference in nutrients - study design confounded results. 2)West Fork Grazing Allotment looked at exclusion of cattle, cattle and elk or both. Standing biomass of veg increased in all three treatments, but most in control, no fish response. 3) Verde River - No differences in WQ. Veg cover composition and density improved at grazed and ungrazed sites. Numbers of exotic species have continued to increase.
Riparian/Grazing	Medina, A. L., 2001	Examined vegetation in channel conditions in Verde River, AZ following grazing removal and large flood. Did not detect effect of grazing though flooding, invasive species and study design limited ability to detect change (note - report does not provide clear info on study design very well and focuses on changes across basin rather than grazing treatments
Riparian/Grazing	Myers and Swanson 1995	Looked at effects of grazing removal on physical habitat in 1 watershed and rest rotation grazing strategies in 2 Nevada watersheds. Streambank soil stability, type and amount of vegetation cover, and qualities of pools improved in all three streams. Bank stability increased 28 to 37% in streams with and without roads and rest rotation grazing. Gravel cobble substrate increase 13% in one stream without roads, but not in others.
Riparian/Grazing	Myers and Swanson 1996	Compared recovery from abusive grazing management on two similar NW Nevada, Streams. Mahogany Cr had livestock grazing excluded, while Summer Camp Cr. Had rest rotation grazing. Bank stability improved during grazing period and fine sediment decreased except below road crossings. Tree cover increased 35% at both streams. W/D ratio did not change much due to inherent stability of both stream systems.

Riparian/Grazing	Myers, L. H., 1989	Examined 34 grazing allotments in SW Montana- 74% were unsuccessful in accommodating a positive riparian veg. response within 10 to 20 yr. period owing mostly to stocking rates and days of grazing. No specifics provided other than measurements of plant heights on one plot. Grazed plants were 13 to 86% of ungrazed height depending upon date measured.
Riparian/Grazing	Nagle and Clifton 2003	Examined channel cross sections inside and outside 48yr old exclosure to examine changes cross sections inside and outside exclosure following reduction in grazing outside exclosure(1986 to 1998). Grazed channels showed improvement, but not all significant. Enclosure had narrow W (2.29 vs. 1.45), deeper D (.23 vs. .32 and narrow W/D ratio (14.17 vs. 4.6) than grazed channels.
Riparian/Grazing	Nerbonne and Vondracek 2001	Examined effects of upland BMP implementation (alternative tillage methods) and riparian buffers (grazed, grass buffer, wooded buffer etc.) throughout Whitewater River, MN. Physical habitat differed across buffers but not upland treatments. Grass buffers had sign. lower fines (1997 means = 60 38.7 and59.8 in wood, grass and grazed), embeddedness (1997 means 69.5, 54.9 and 72.6) and exposed stream banks (1997 means 44.6, 4.1 and 27.7) and higher overhanging veg. (.32, .81, and .27) compared to grazed or wood buffers . Benthic invert metrics (RBP - rapid bioassessment protocolsa and Fish IBI did not differ)
Riparian/Grazing	Northington and Hershey 2006	Examined effects of riparian planting and wastewater treatment on aquatic insects and fish in urban streams. Restored sites had significantly higher fish richness ((12 vs. ~7 for forested and 5 for unrestored) and a trend towards greater abundance than unrestored sites (3.5 vs. 2.25 vs. 2/m for forested, unrestored and restored respectively. Small but insignificant differences existed in abundance and IBI of aquatic insects.

Riparian/Grazing	O'Grady et al., 2002	Changes in aquatic flora, inverts and fish following implementation of bank stabilization and fencing in Glengosh River, Ireland. Aquatic moss coverage increased from nearly 0 to 50%. Macro inverts went from 5 to 11 taxa present (pre vs. post in treatment sites), fish stocks saw increases in brown trout and Atlantic salmon parr post treatment. annual increases in entire length restored range from 1620 to 5670 salmon and 3,888 and 9800 trout.
Riparian/Grazing	Opperman and Merenlender 2000	Effects of deer herbivory on riparian plantings in Mendocino Country, CA. Mean density of saplings in deer exclosures was 49/m2 vs. 0.02 in controls (plots with deer). 35% of saplings were less than 1m tall in exclosures while in controls 97% were less than 1m.
Riparian/Grazing	Opperman and Merenlender 2004	Examined recovery of channel morphology and fish habitat 10-20 after livestock excluded fences. Channels within exclosures were narrower(~3m narrower), cooler (mean august 18.2 vs. 22.7, had greater LWD(~325 pieces/ha vs. 75) and higher tree density (.74 plants/m2 vs. .08). Note estimated ~ numbers from graphs other numbers were reported in text.
Riparian/Grazing	Parkyn et al., 2003	Examined effects of fencing and planting on 9 NZ buffer zones 2 to 24yrs after fencing. Treatments had better water quality and channel stability, but nutrient and fecal contaminant levels were variable. Macronverts did not show significant changes toward clean water taxa and macroinvert taxa richness was on average 3.42 higher in controls than treatments. Study suggests planted reaches may need to be longer
Riparian/Grazing	Penczak, T., 1995	Effects of removal and recovery of vegetation on fish in Warta River, Poland. Species diversity decreased from 17 before to 11 following veg. removal. Standing stock increased from 31.9 to 36.5, 66.2 and 40.9 in 3 years following removal and during alder and osier recovery.

Riparian/Grazing	Platts and Nelson 1985	Compared effects of rest-rotation grazing vs. regular grazing management in 11 Idaho streams. Rest-rotation resulted in 8 to 12% greater usage of riparian areas than adjacent range or pasture. Rest-rotation grazing also lead to decline in streambank stability. This study indicates that improperly controlled rest-rotation grazing can lead to more intensive grazing than expected and degradation of riparian zones and stream channels.
Riparian/Grazing	Platts, W. S., 1981	Summarized findings from three studies on grazing. First was reported in Platts and Nelson 1995. and dealt with rest rotation grazing, which was found to degrade habitat because grazing was more intensive than before. Other studies in Nevada (Tabor Cr) and Utah (Big Creek) examined grazing removal (Exclosures) and found improvements in stream width, depth, percent fines, embeddedness, cover, and bank stability. Large tables with statistics provided, but hard to synthesize due to multiple years and treatments.
Riparian/Grazing	Rinne, J. N., 1999	Review article - also discusses case studies examined in Medina et al. 2005. Most studies did not do statistical analysis and were confounded by management actions or natural disturbance (floods, elk, beaver etc.) See that article for details
Riparian/Grazing	Robertson and Rowling 2000	Examined veg structure and composition in paired sites with and without livestock in size sites in the Murrumbidgee R. Eucalyptus tree species were up to 1000 times more abundant in areas without livestock, and biomass of ground cover 10 times more abundant. Species richness did not differ, but plant species composition did differ. CPOM and terrestrial fine wood outside of channel were consistently more abundant in areas without stock. Instream fine and coarse wood were higher in areas without livestock in mainstem, but not tributary site. Generally sites that livestock had been excluded for more than 50 years had biggest differences.
Riparian/Grazing	Roelle and Gladwin 1999	Abstract only. Eradicating saltcedar by reflooding the lower elevations of the annual drawdown zones each fall. After 3 years, at least one of three native woody species survived on 41.1% of the plots while saltcedar was present on only 6.1%.

Riparian/Grazing	Schilling and Thompson 2000	A paired watershed study was used to determine the effects of converting row crop to native prairie in Iowa. Land use changes implemented on 19.4 % of basin. First 3 years of monitoring show encouraging signs, but no definitive WQ improvements (Nitrate, pesticides, etc.) have been detected. (Abstract only)
Riparian/Grazing	Sovell, et al., 2000	Examined fish, WQ, macroinverts and physical habitat to different treatments - continuous grazed, rest-rotation, grass buffers and wood buffers. Fecal coliform and turbidity were higher at continuously grazed than rest-rotation sites. Percent fines higher in wood than grass buffer sites. Benthic macroinverts were not consistently different across grazed or bugger types. Fish abundance was related to buffer type rather than grazing practice (abstract only)
Riparian/Grazing	Sprenger et al., 2002	Saltcedar eradication using root plows, herbicides and floodings. Mechanically cleared areas had fewer resprouts (26 per ha) than chemically treated areas (2,500 per ha). Saltcedar and cottonwood seedling density and cottonwood survival were greater in the mechanically treat areas than in the chemically treated areas. Cottonwood seedling density and survival did not differ between 5 cm/day and 10 cm/day stage drawdowns.
Riparian/Grazing	Stuber et al., 1985	Examined trout and trout habitat along a fenced and unfenced Colorado stream. Fish habitat within fenced areas was narrower, deeper, less altered and had more streamside veg. than unfenced sections. Trout standing stock was 2x higher in fenced areas. There was more non-game fish in unfenced areas (Abstract only)
Riparian/Grazing	Suren and McMurtrie 2005	Examined response of macroinverts to restructuring and riparian planting of five urban streams in Christchurch, NZ before and 5 years after. Only small changes were noted with only subtle shifts in overall abundance, species evenness, diversity and ordination.

Riparian/Grazing	Suren et al., 2005	Examined response of habitat to restructuring and riparian planting of five urban streams in Christchurch, NZ before and 5 years after restoration. Treated sites had generally higher veg. cover and increasing overhanging riparian veg, Stream enhancement increased variability in velocity and substrate changed as concrete and timber line channels were converted to stream channel.
Riparian/Grazing	Sweeney et al., 2002	Examined success of riparian forest planting techniques (bare root vs. containerized), herbivory (tree shelters), and weed control (herbicide, mowing, tree mats) for oak, birch and maple at two riparian sites near Chester River, MD. Results of four growing seasons showed no sig. dif. In survival or growth between bare-root and containerized seedlings. Overall survival and growth was different for sheltered and unsheltered seedlings 49% and 77.6cvm vs. 12.1% and 3.6 cm) across species and weed control treatments. The highest 4 year survival was associated with seedlings protected by shelters and herbicide (88.8%/125.7cm) and shelters and weed matts (57.5%/73.5cm). Thus only a combination of shelters and weed protection provided had survivorship high enough to be considered successful (>50%).
Riparian/Grazing	Taylor and McDaniel 1998	Saltcedar eradication using herbicide, burning and mechanical control - and planting of cottonwood and black willows. Saltcedar resprouts were still common after burning, herbicides and bull-dozing. Replanting resulted in cottonwood survival of over 80% 4 years after planting. Deep tillage to 3m and drip irrigation for 165 days resulted in 100% of cottonwood and black willow survival when plantings were made on a dredge spoil site.
Riparian/Grazing	Wohl and Carline 1996	Examined riparian grazing impacts on three streams (2 grazed, 1 ungrazed) . Annual sediment loads were lower in ungrazed stream (113t vs. 255 and 273 t. Substrate permeability, densities of inverts were higher in ungrazed stream. Densities of brown trout were 5 to 23 times higher in ungrazed than two grazed streams

Riparian/Grazing	Wootton 2012	Coho, steelhead, cutthroat. Reducing riparian canopy cover caused trapped leaf letter to decline by two-thirds, UW radiation to increase 12-fold, and photosynthetically active radiation to increase 42-fold. Water temp, benthic substrate, and variation in water depth did not differ statistically with treatment. Nutrients, dissolved organic carbon and silicates did not vary significantly with riparian treatment. Algal production increase 13-fold, grazer-free algal accrual increased 55-fold, algal standing biomass increased by 60%, and algal standing chlorophyll a increased 2.4-fold. Aquatic insect abundance increased 7-fold with all major taxonomic groups showing elevated populations. Densities of juvenile salmonids increased on average 77% in manipulated reaches.
Roads	Bergeron, K. D., 2003	effect of different combinations of soil treatments on veg cover and biomass. Results showed that biosolids, compost and fertilizer increased native plant biomass and veg cover. Presence of non-natives had no impact on native plant biomass. In a second study, saturated hydraulic conductivity rates were examining biosolids, application of fertilizer and straw. No sig difference was found among treatments. (Abstract only)
Roads	Bloom, A. L., 1998	Examined sediment delivery and erosion on treated and untreated roads. Treated roads yielded significantly less erosion and sediment delivery to streams. (Abstract only)
Roads	Brown, T. M., 2002	Effects of stream crossing obliteration. Downstream turbidity was significantly higher except at mitigated sites which were not different upstream or downstream of treatment (abstract only)
Roads	Burroughs, Jr. and King 1989	Literature review summarizing major findings of other studies and providing recommendations to managers
Roads	Carter and Rasmussen 2005	Green roofs for urban stream restoration - for 32 storm events tested, green roof stormwater retention ranged from 39 to 100%
Roads	Cloyd and Musser 1997	Stabilization reduced road related impacts 67% of failures occurred on untreated roads.

Roads	Cotts et al., 1991	Examined different road surface treatments for abandoned roads - top soil significantly increased plant cover (abstract only)
Roads	Elseroad et al., 2003	Examined experimental treatments including combination seeding with native species, topsoil addition, mulching. Total cover and plant density sig higher on all seeded plots. Combinations of treatment not significantly different. Stats not provided, but graphs suggest seeded treatments had ~150 plants/m2 two months following treatment, while unseeded had ~ 5, 14 months later differences were ~75/m2 vs. 10 plants/m2.
Roads	Foltz and Elliot 1997	Abstract only. Sediment eroded from the low-quality aggregate surfaced roads an avg. of 45% less with moderately reduced tire pressure than from highway tire pressure sections. An avg. of 80% was measured from the section used by trucks with low tire pressure. Lowering tire pressures in logging rucks on unpaved roads can reduce the sediment loss from many unpaved road surfaces.
Roads	Foltz, R.B. 1998	Traffic and no-traffic on aggregate surfaced road - sediment production from marginal was 4 to 17 higher than on good quality aggregate. Sections with logging truck traffic produced 2 to 25 times as much sediment. (abstract only)
Roads	Glen, D., 2002	Removal of culverts Wauchope Burn and other Scottish streams. Salmon fry found upstream of former culvert immediately after removal and numbers went from 0 before removal (2000) to a mean of .35/m2 in 2001 and .20/m2 in 2002.
Roads	Harr and Nichols 1993	Examined cost and landslide of decommissioning roads (stabilizing fill, removing stream crossings, recontouring slopes). In contrast to unused roads, decommissioned roads showed now damage following 50yr event and a severe rain on snow event that damaged main haul roads in Northwest Washington. From 1967 to 1983 17 road related landslides occurred, after decommissioning (1987&88) and two large events 1989/1990 no failures on decommissioned roads.

Roads	Hickenbottom, J. A., 2000	Compared existing and contoured roads (removed) in two geology and slope classes (> & < 45%). In all cases it was found that recontoured roads produced sediment and runoff similar or higher than road segments. However, after 1 year, the volume of runoff and erosion greatly decreased to near natural slope conditions. (abstract only)
Roads	Kitagawa and Okawara 1998	Improved method for constructing roads with a sub-base mat that intercepts flow and disperses on downvalley slope. Long-term observations show this method functions well after many years and has several advantages over traditional construction methods (short paper - no stats provided)
Roads	Klein, R. D., 1987	Examined stream channel adjustments following road removal in Redwood NP. Tech report with multiple regressions but no specific stats. Adjustments in stream channels depended upon amount of organic matter (LWD) and other roughness elements left at former crossings that prevented scour and erosion.
Roads	Kochenderfer and Helvey 1987	Compared forest roads with and without 3 inches of gravel. Soil losses from roads without gravel were 47tons/acre vs. 6 tons/acre for graveled roads
Roads	Kohler et al., 2004	Examined effect of constructed wetlands on golf course runoff. Wetland successfully reduce lowered concentration of 13 of 17 parameters (all but K, AL, Mg and Si) during storm events. During non-storm event wetland reduced N-NO3/NO2 by 95% and removal was 100% for other measures during non-storm events.
Roads	Kolka and Smidt 2001	Looked at sediment delivery on retired forest roads including recontoured, subsoiled and control plots on roads. Sediment production was lower from subsoiled and recontoured than control, with recontouring producing ~14g/m2 of sediment vs. 31g/m2 for subsoiled, vs. 34 for control and 0 for undisturbed hillslope

Roads	Luce, C. H., 1997	Examined effectiveness of road ripping on infiltration capacity. Results showed that road that ripping increases hydraulic conductivities enough to reduce risk of runoff but does not restore natural hydraulic conductivity of a forest slope. Unripped roads had hydraulic conductivity from 0-4mm/hr whereas ripped roads had 20-40 mm/hr
Roads	Madej et al., 2001	Essentially same as Madej 2001. Erosion an sediment following road removal. Post-treatment erosion on roads was related to method of treatment, hillslope position, and date of treatment. Sediment delivery from treated roads on upper, middle, and lower hillslopes was 10, 35 and 550 m3/km of road treated. In contrast untreated roads produced 1500 to 4700 m3 of sediment per kilometer.
Roads	Madej, M. A., 2001	Erosion an sediment following road removal. Post-treatment erosion on roads was related to method of treatment, hillslope position, and date of treatment. Sediment delivery from treated roads on upper, middle, and lower hillslopes was 10, 35 and 550 m3/km of road treated. In contrast untreated roads produced 1500 to 4700 m3 of sediment per kilometer.
Roads	Maynard and Hill 1992	Stabilization of logging roads - evaluated the effects of fertilizer and mulch treatments on plant density. Results hard to quantify as findings and recommendations vary by whether site was sunny, shady or wet. Addition of fertilizer and lime enhanced plant density and survival at all sites.
Roads	McCaffery, Switalski et al.	No good numbers. Significant positive correlations were found between the % of fine sediment in substrate and various measures of road impact; watersheds with roads in use had higher percentages of fine sediment than those without toads and those with decommissioned roads; watersheds with high levels of vegetative regrowth on decommissioned roadbeds had a lower percentage of fines in stream sediment; there were no statistically significant differences in the number of pools per 100m or max pool depth among three treatment groups.

Roads	McNabb, D. H., 1994	Tillage of compacted haul roads and landings. Tillage significantly reduced mean bulk soil density. Abstract only - no details or stats provided
Roads	Price et al. 2010	Evaluated fish passage at 77 permitted culverts. 30% studied, were, in fact, barriers. Those permitted as no-slope or as an unknown design type were barriers in 45% of the cases. Most failures were due to noncompliance with permit provisions, particularly culvert slope and a lack of critical evaluation of proposed plans in the context of site conditions. No species listed.
Roads	Scully et al., 1990	Section of a large report. KH printed results section. Steelhead and Chinook. Based on Rosgen's (1985) channel classifications: B channels have less pool and run habitat and much more pocket water than C channels but both have similar mean widths and depths. B channels have a gradient less than 1.5% while C channels have gradients >1.5%. B channels avg. 28% boulders , compared to 4% in C channels. Mean annual steelhead parr densities ranged from 2-3 times greater in B channels than C channels (6.1/100 m2 vs. 2.5/100m2). Mean Chinook parr density was lowest (14.1/100 m2) in C Channel streams where % sand was <10%, and highest in the 10-20% sand interval with density declining for each 10% increase in % sand above 20%.
Roads	Switalski et al., 2004	Literature review - - long-term monitoring and initial research show that road removal reduces chronic erosion and the risk of landslides. Sediment loss on treated and untreated roads from 7 studies indicate that mean erosion rates on treated roads range from 27 to 97 m3 /km compared to 115 to 235m3/km.
Roads	Wildlands CPR 2012	No fish. Using GRAIP (The Geomorphic Roads Analysis and Inventory Package). Decommissioned roads and stormproofing roads. For decommissioned roads, road-stream hydrologic connectivity was -58%, fine sediment delivery was -64%, drainpoint problem rate was -86% and unit sediment was -64%. For stormproofed roads, road-stream hydrologic connectivity was -9%, fine sediment delivery was -119%, drainpoint problem rate was -48% and unit sediment was -1.4%.

Roads	Wright and Blaser 1990	Effects of grading and tillage on road cuts - bulk density of smooth or roughened topsoil or subsoil ranged from 1.38 to 1.42 compared to 1.76 g/cm3 on compacted smooth subsoil. Total porosity was increased from 22 to 42% by roughening. The altered physical properties from roughening increased plant growth by increasing soil moisture content 23% and decreased soil temperature.

Appendix 2

Key findings from subset of papers on restoration effectiveness in Appendix 1 that reported survival or changes in survival due to restoration. Floodplain projects are listed first followed by instream habitat projects. References are in alphabetical order by first author.

Reference (State/Country)	Restoration Treatment	Key Survival Results
Cederholm and Peterson 1989 (WA)	constructed floodplain habitat	Significant increase in winter coho overwinter survival (rate = .57)
Cederholm et al., 1988 (WA)	constructed floodplain habitat	Overwinter survival and growth of coho increased significantly post construction (survival .11 to .56; mean change in length from 13 to 41g; mean

		change in weight from 3 to 13 g)
Henning et al. 2006 (WA)	reconnected wetland	Yearling coho had comparable specific growth rate and minimum estimates of survival (1.43%/d by weight and 30%; 1.37%/d and 57%) to other side-channel rearing studies.
Raastad et al. 1993 (Norway)	constructed side channel	Survival of age 1+ Atlantic salmon was 30%.
Sommer et al. 2001 (CA)	levee removal	Survival indices for coded-wire-tagged Chinook were somewhat higher for those released in the floodplain than for those released in the river, but the differences were not statistically significant.
Gard, R., 1961 (CA)	LWD and boulder structures	During the 3 summers following dam installation, the numbers of introduced brook trout were counted. 49 trout were collected the 2nd summer giving a 1-year survival rate of 38%. 73% of the fish surviving to the 2nd summer were collected the 3rd summer and 39% of those surviving to the 3rd summer lived to the 4th.

Giannico and Hinch 2003 (BC)	LWD additions	Although the values of the relative index of survival for juvenile coho salmon varied widely between both side-channels and from year to year, they were consistently higher in the wood-treated side.
Gowan and Fausch 1996a (CO)	LWD additions	Recaptures of trout that were tagged and others that were batch marked revealed that immigration was primarily responsible for increased adult abundance and biomass, whereas no biologically significant differences occurred for recruitment, survival, or growth.
Jester and McKirdy 1966 (NM)	LWD and boulder structures	Trout overwinter survival was enhanced by presence of structures.
Johnson et al., 2005 (OR)	LWD additions	Steelhead smolt abundance, steelhead freshwater survival, and coho salmon freshwater survival increased in one creek after the input of wood, but similar results found in control.
Klassen and Northcote 1988 (BC)	rock structures (gabions)	Pink salmon egg survival at one site in its first year did not differ significantly from two nearby ref. sites.

Lonzarich and Quinn 1995 (WA)	LWD addition	Coho survival was greatest in the deep and structured treatment (89%) nearly twice that in the shallow, no structure treatment (47%). Both age-0 and age 1+ steelhead showed higher survival in the deep-structure treatment (71 and 89%) than in the shallow-non-structures treatment (29 and 33% respectively).
Merz et al., 2004 (CA)	gravel additions	Chinook salmon embryos planted in enhanced gravels had higher rates of survival to the swim-up stage than embryos planted in unenhanced spawning gravels
Overton et al., 1981	boulder structures	Steelhead egg- to-fry survival ranged from 71% to 98%. Not clear how compared to unrestored areas.
Paulsen and Fisher 2005 (ID)	various	There was a positive, significant correlation between number of habitat actions in a basin and Chinook parr-to-smolt survival.
Pulg et al. 2011 (Germany)	gravel cleaning	In the first 2 years, highly suitable conditions were maintained, with a potential Brown trout egg survival of more than 50%. Afterwards, the sites offered moderate conditions, indicating an egg survival of less than 50%.

Riley and Fausch 1995 (CO)	LWD structures	Recaptures of tagged trout in two streams showed that the logs did not result in increased growth or survival of resident trout, although recaptures of fin-clipped trout in other streams suggested that apparent survival may have increased temporarily in treatment sections
Rodgers et al., 1993 (OR)	LWD additions	Average coho overwinter survival increased from 11% in one creek to 51% the first year, and 40% the 2nd year after treatment. In another creek it increased from 14% to 63% in the 1st year.
Solazzi et al., 2000 (OR)	LWD addition	Overwinter survival of coho increased from a mean of .13 to .38 (ref. was .17 to .20) In another stream, mean overwinter survival increased 250% from .11 to .39 but fell in the ref stream from .19 to .10.