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# Fish-Habitat Relationships and the Effectiveness of Habitat Restoration

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# Fish-Habitat Relationships and the Effectiveness of Habitat Restoration

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# Executive Summary

A major underpinning of recovery efforts for Pacific salmon (*Oncorhynchus* spp.) listed under the Endangered Species Act is that there is a strong relationship between freshwater habitat quantity and quality and salmon abundance, survival, and productivity in the freshwater environment. This is a major component of Endangered Species Act recovery plans and biological opinions for salmon and steelhead (*O. mykiss*), including the 2008 Federal Columbia River Power System Biological Opinion (BiOp). With regard to habitat, the 2008 BiOp incorporates an expanded tributary habitat program that requires implementation of habitat improvement actions, including actions to protect and improve mainstem and side channel habitat for fish migration, protect and improve spawning and rearing, and restore floodplain function. Because this is a key underpinning of the 2008 BiOp and other biological opinions, 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 technical memorandum provides a synthesis of scientific literature and our current level of knowledge on these three topics.

Decades of fish-habitat relationship research have 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 made to quantify the effectiveness of various 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 have shown localized (reach scale) increases in fish abundance for placement of instream structures and reconnection of both tributary and floodplain habitats. Also, 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 reach and watershed scales.

Extrapolating these reach-scale effects up to the watershed or population scale requires either watershed-level or population-level evaluation or salmon life cycle modeling. Several intensively monitored watershed studies are currently underway to quantify population-level survival and production responses to multiple restoration actions throughout a watershed. 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 stage-specific 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; multiple models are needed. Models are population specific due to unique characteristics of each watershed and population, so 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. In addition, 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.

# Acknowledgments

This work was supported by funding from NOAA under the Federal Columbia River Power System Biological Opinion. A portion of the literature review on the effectiveness of restoration techniques was funded by the Bonneville Power Administration. Patty Dornbusch, Tom Cooney, and others from the NOAA Fisheries West Coast Region and Northwest Fisheries Science Center provided helpful comments that greatly improved the quality and clarity of this report. We thank Jennifer O'Neal, Tetra Tech Inc., for reports and information on ongoing evaluations of restoration projects funded by the Washington State Salmon Recovery Funding Board and Oregon Watershed Enhancement Board. We thank Clara Salazar, Northwest and Alaska Fisheries Science Centers Library, for locating hard-to-find documents. We also thank Ed Quimby, Northwest Fisheries Science Center, for technical editing and formatting, which improved the organization, accuracy, and usability of this report.

# Introduction

A major underpinning of recovery efforts for Pacific salmon (*Oncorhynchus* spp.) listed under the Endangered Species Act is that there is a strong relationship between freshwater habitat quantity and quality and salmon abundance, survival, and productivity in the freshwater environment. This is a major component of Endangered Species Act recovery plans and biological opinions for salmon and steelhead (*O. mykiss*), including 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 the adverse effects of the hydropower system, as well as research, monitoring, and evaluation actions to support and inform adaptive management.

With regard to habitat, the RPA (FCRPS BiOp 2008) 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.

Given that restoration of tributary habitat in the Columbia River basin is a key underpinning of the FCRPS BiOp (2008), 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 technical memorandum 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 on a suite of habitat types and associated environmental conditions over the course of their life cycle that is necessary for individual survival and, ultimately, population sustainability (Bjornn and Reiser 1991). Habitat requirements for salmonids thus include physical features (i.e., habitat area, wood and instream cover, etc.), and the 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; decades of research have documented considerable information on the habitat quantity and quality requirements for Pacific salmonids by life stage and species (Bjornn and Resier 1991, Groot and Margolis 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 water temperature and turbidity levels that do not delay migration (Bjornn and Reiser 1991). Once on their spawning grounds, Pacific salmonids are affected by multiple variables at various scales—regional (climate, elevation, topography, geology), watershed (stream channel gradient, size, type), stream reach (stream temperature, channel hydraulics), and site (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 (*O. tshawytscha*) at colder, higher elevation sites typically spawn earlier than Chinook salmon at warmer, lower 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. Large-bodied species or larger 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 (*O. kisutch*), and Atlantic salmon (*Salmo salar*) (Montgomery et al. 1999, Moir et al. 2004). Reach-specific and site-specific variables 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 eggs can develop into alevins, move through the gravels, and move up into the stream or lake environment. Fine organic material and sediment must be at low levels (typically <15–20%) so 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 mainstem, 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 that 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, Brakensiek and Hankin 2007, Jeffres et al. 2008, 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, woody debris and 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 on 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, nearshore 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 in the freshwater environment, salmonids in the estuary 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, 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 mainstem 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. 2013b). 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, timber harvest activities 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. In particular, 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. 2003). Even if pools are available, utilization may not occur due to other factors such as stream temperature. Torgersen 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 River occurred downstream of the reaches occupied by adult Chinook salmon. Stream temperatures in the downstream reaches of both forks exceed the tolerance level for spring Chinook salmon, thus rendering numerous downstream pool habitats inaccessible (Torgersen 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 (Torgersen 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 on specific life stages that lead 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 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. 2013a). 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 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 mainstem 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 reestablishment of native riparian vegetation, reduction of unnatural sediment supply from roads and bank erosion due to land use impacts, and reintroduction of wood, nutrients, and mammals such as beaver (*Castor canadensis*) 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 Columbia Basin to improve tributary habitat and recover salmon and steelhead populations. These include but are not limited to fish passage, instream structures, floodplain restoration, riparian improvement, sediment reduction, land acquisition, and instream flow augmentation (see Table 1 for project categories used by action agencies).

These project actions are designed to address specific limiting factors[1] that have been identified for each population 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 FCRPS BiOp. Several long-term studies including intensively monitored watersheds (IMW)[2] are underway within the Columbia 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 and the 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 design and implementation.

## 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 examined 345 papers that reported the results of effectiveness monitoring of various habitat improvement techniques. In this technical memorandum, we supplemented these two reviews with other papers and technical reports that have been published between 2006 and 2013. As a result, we examined an additional 64 papers or reports, a total of 409 published studies. While many of these documents examine restoration efforts outside the Columbia River basin and the Pacific Northwest, the techniques used in other countries are similar to those used in the basin and in many cases focus on salmonids. For some action types, such as remeandering of stream channels, much of the

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[1] In the context of the FCRPS 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 Bonneville Power Administration (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 the Columbia Basin; little published literature on effectiveness of actions implemented in the basin is yet available.

| **Project action category** | **Subcategory** | **No. of studies located** |
|---|---|---|
| Fish passage | | 22 (mostly dam removal) |
| | Barriers | |
| | Entrainment/screens | |
| Instream structures | | 209 |
| | Complexity | |
| | Stabilization | |
| | Large engineered structures | |
| | Spawning gravel addition | |
| | Beaver introductions | |
| Off-channel/floodplain habitat | | 82 |
| | Side channel | |
| | Floodplain | |
| | Wetland restoration | |
| | Confinement | |
| Riparian improvement | | 53 |
| | Fencing | |
| | Planting | |
| | Removal | |
| Sediment reduction | | 27 |
| | Roads | |
| | Agricultural | |
| Acquisition and protection | | 1 |
| | Acquisition | |
| | Protection | |
| Flow augmentation | | 15 (flood restoration) |
| | Water quality | |
| | Barriers | |

existing literature is from European studies (except see Utz et al. 2012); however, the vast majority of published evaluations of habitat improvement techniques is 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 Basin, though many of the results are applicable to Chinook and coho salmon and steelhead in the 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 cite all the papers referenced in the two aforementioned literature reviews, we cite 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 A.

# Fish Passage

## Barrier Removal

Studies evaluating the effectiveness of projects that have removed impassable 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 and Hightower 2006, Stanley et al. 2007, Roni et al. 2008, Zitek et al. 2008, Nakamura and Komiyama 2010, Pess et al. 2012b, 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 and Hightower 2006, Stanley et al. 2007, Kiffney et al. 2009, Nakamura and Komiyama 2010, Pess et al. 2012b, 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 juvenile and adult salmon and steelhead within 5 years (Kiffney et al. 2009, Pess et al. 2011). Martens and Connally (2010) demonstrated movement and recolonization of Chinook salmon, steelhead, and other fishes after improved passage at irrigation diversions in the Methow River basin. Similarly, evaluation of culvert removal projects in Washington state indicated increased fish numbers within 2 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 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, 2008). The rate at which salmon and trout recolonize these habitats, however, is highly dependent on 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, 2012b). 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). It recommended continued compliance monitoring of these projects, as screens need periodic cleaning and maintenance to retain their efficiency. Walters et al. (2012) modeled that the estimated cumulative effect of the unscreened diversions in the Lemhi River could be a loss of 71.1% of outmigrating Chinook salmon smolts due to entrainment. The Lemhi has undergone an extensive screening program and most diversions encountered by Chinook salmon have been screened. The modeling by Walters et al. (2012) suggests that this screening program has potentially reduced Chinook mortality due to entrainment to 1.9%.

## 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, 2008). For example, of the 409 published evaluations of effectiveness that we reviewed and summarized in Appendix A, 209 examined placement of instream structures. Most of these studies have focused on the effects of such actions on salmonid fishes (particularly coho salmon, steelhead/rainbow trout (*O. mykiss*), or other trout species). The vast majority of these have shown a positive response (increased abundance) for juvenile salmonids (Figure 1 and Figure 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

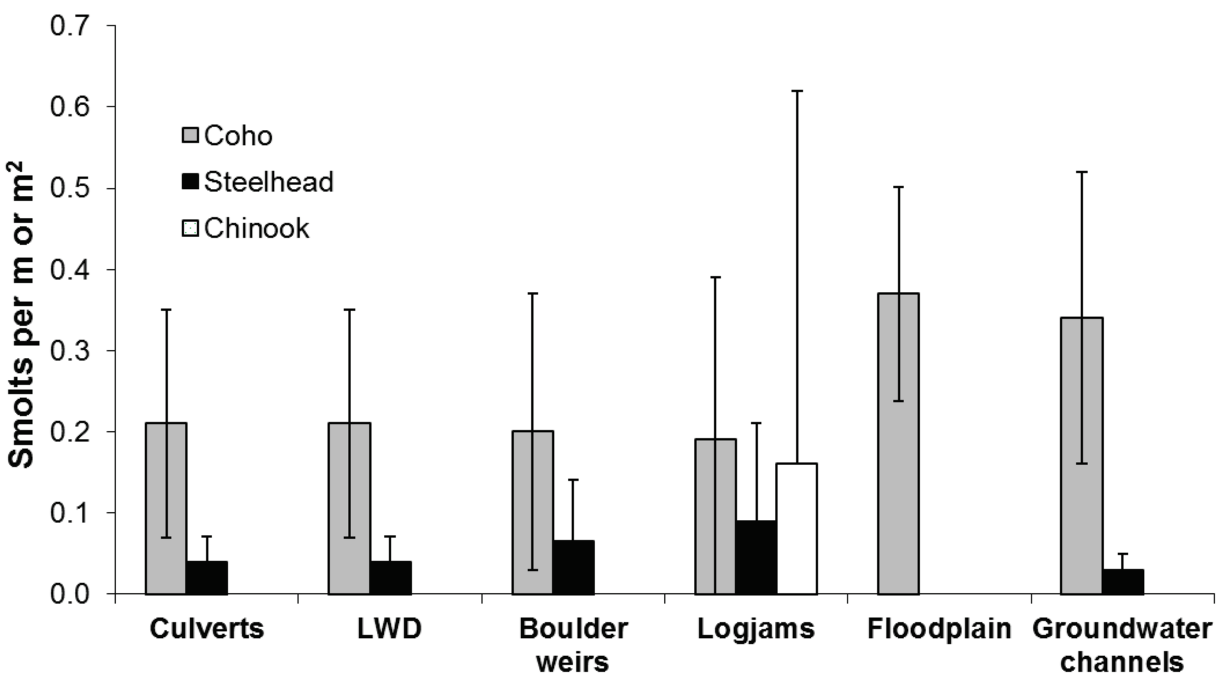


Figure 1. Mean increase in coho salmon, steelhead, and Chinook salmon smolts reported from different types of habitat improvement examined by Roni et al. 2010. Note that data are largely from coastal streams in Western Washington and Oregon not inhabited by Chinook salmon; Chinook data were only available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

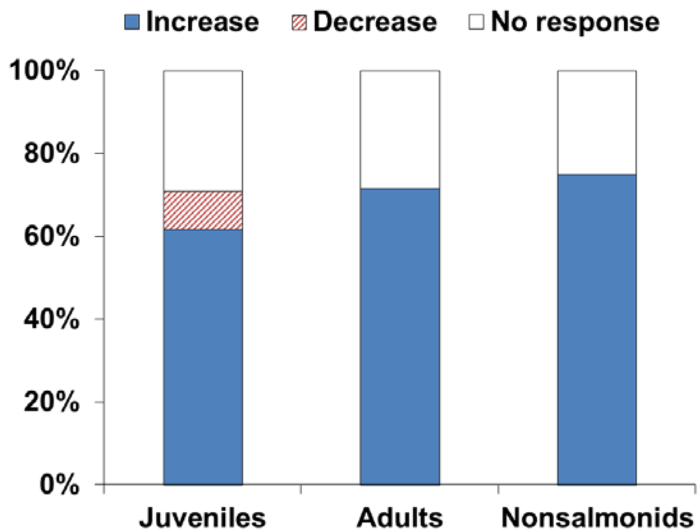


Figure 2. Percent of published studies evaluating instream habitat improvement that have shown an increase, small decrease, or no response of juvenile and adult salmon to placement of instream structures. Overall, 99 studies reported information on juvenile salmonids, 14 on adult salmonids, and 24 on nonsalmonids. 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. (Data from Roni et al. 2008.)

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 be effective for juvenile coho salmon and, to a lesser extent, steelhead, cutthroat trout (*O. clarkii clarkii*), 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 been shown to be useful for creating habitat for juvenile Chinook salmon, coho salmon, steelhead, and other fishes (Abbe et al. 2002, Roni et al. 2002, 2008, Pess et al. 2012a). For example, ongoing monitoring of constructed logjams in the Grays River (a lower Columbia River 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, Roni et al. 2008, Senter and Pasternack 2011), as well as to juvenile Chinook growth (Utz et al. 2012). While a few studies have examined juvenile Chinook salmon and steelhead response to placement of instream structures, most studies have focused on coho salmon and coastal streams. Thus additional information is needed on effectiveness of these action types for Chinook salmon and steelhead in the Columbia Basin.

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 fine sediment often overwhelm them (Roni et al. 2013).

A relatively new type of instream habitat improvement is the addition of structures to enhance beaver populations. 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 salmon in interior Columbia River tributaries (Pollock et al. 2007, 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 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 (DeVries et al. 2012, Pollock et al. 2012). Unpublished evidence from Bridge Creek also indicates improvements in juvenile steelhead abundance and survival following placement of beaver enhancement structures (Pollock unpubl. data).

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 bankfull 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.

## Off-Channel/Floodplain Habitat

Four 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, constructing ponds or side channels, and restoring meanders.

## 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 salmon (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 on the streamflow, depth, morphology, and water source; ponds and wetlands with little flow were used mostly by coho salmon, while surface water–fed side channels were generally more effective for Chinook salmon 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 the United States and Europe demonstrate that these techniques can reestablish 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, and organic matter retention, as well as 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 main stem (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 on 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 River tributary) showed high levels of chum salmon (*O. keta*) egg-to-fry survival (50–85%) and ideal spawning and incubation conditions (Hilton 2010). As with 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.

### Channel Restoration

Restoring the sinuosity or remeandering straightened and confined channels is a common technique to restore constrained or channelized streams (Pess et al. 2005, Vought and 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. 1993). 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 and 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 salmon following remeandering of a California river. In contrast, other studies have reported little fish response to remeandering (Moerke and Lamberti 2003, Cowx and 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 and 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 and 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 a 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: planting and other silviculture treatments, fencing, and 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 numbers 1987-100-01, 1997-056-00, 2003-011-00, and 2007-231-00; project reports available from BPA, P.O. Box 3621, Portland, OR 97208-3621). 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 (LWD). 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, reduced temperatures, and improvement of water quality—all factors that 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, 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 in the Pacific Northwest and elsewhere (see Medina et al. 2005 or Roni et al. 2008 for a review, Tetra Tech 2010), particularly for complete livestock exclusion. Rest-rotation grazing systems are generally less successful than complete livestock exclusion and results depend on 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 River 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). But rather than indicate 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 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 on 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

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, and 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 landslides, fine sediment, and runoff. Apart from studies that looked at fish recolonization after removing impassable road culverts, little monitoring and evaluation has been done to examine the response of fish or other biota to road treatments.

Less information exists on the impacts of various agricultural practices on salmon. While the agricultural impacts 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.

## Acquisition and Protection

Monitoring and evaluation of land acquisition, conservation easements, and other protection measures can be problematic, 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 re-create them after they are 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, see also the Riparian Improvement subsection above). 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 lead to improved bank stability and water quality (e.g., Osborne and Kovacic 1993, Barling and Moore 1994, Dosskey et al. 2005, Mayer et al. 2005, Puckett and Hughes 2005, Vought and Locoursière 2010, Tetra Tech 2013).

## 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, however, is a key habitat improvement strategy in many rivers and streams in the Interior Columbia Basin.

There is an obvious and clear relationship between minimum instream flows and salmonids or 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 (Jordan unpubl. 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 Demonstration 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, riparian zone condition, groundwater 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 409 studies on restoration we examined, 19 reported on changes in survival (Appendix B). 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 (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), Atlantic salmon, coho salmon, Chinook salmon, and steelhead. Of these 19 studies, about 13 suggested that survival improved postrestoration 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 salmon that are equivalent to those 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 salmon 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 were 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. Based on the literature, however, 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. This also emphasizes that we have considerable information for some actions and limiting factors and little for others. For example, restoration actions such as diversion screens, removal of barriers and culverts, and placement of instream structures have considerable evidence that they address limiting factors (Table 2). While other restoration techniques such as increased instream flows may clearly address limiting factors related to flow or temperature, there is less information available on how they affect limiting factors related to other water quality factors. This is not to say that they do not affect these factors, but that either little information is published on the topic or existent studies 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? There is evidence to suggest that actions to improve longitudinal (i.e., among tributary and mainstem habitats) and lateral (i.e., floodplain channels and 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 (Sommer et al. 2001, Roni et al. 2006a, Jeffres et al. 2008), as well as overall population size in the long term (Pess et al. 2012b). 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). However, recent analyses suggest that large amounts of habitat need to be restored or improved to detect a population-level response in salmon or steelhead parr or smolts. For example, Roni et al. (2010) found that, based on average responses to various restoration techniques, 20% or more of a watershed would need to be restored to detect a 25% change in smolt production. Yet they also found that, due to the variation in fish response among projects, 100% of the habitat would need to be restored to be 95% certain of detecting a 25% increase in smolt production.

Table 2. Limiting factors addressed[a] by each restoration action type and subtype, and the strength of evidence in published literature that a particular action subcategory addresses a limiting factor or habitat impairment. The list of action categories and limiting factors was provided by BPA, August 2012. Acquisitions were not included in the table because little information exists on their effects on limiting factors and they often focus on protecting habitat.

| **Action subcategory** | **Limiting factor/habitat impairment** | **Evidence from the literature[b]** |
|---|---|---|
| Barriers–passage | Migration barriers (road crossings) | High |
| Barriers–screens | Entrainment | High |
| Habitat complexity | Habitat diversity/complexity | High |
| | Habitat quality | High |
| | Habitat quantity | High |
| | LWD | High |
| | Pool quality | High |
| | Pool quantity | High |
| | Side channel connectivity | Low |
| Bank stabilization | Habitat quality | Medium |
| Engineered structures | LWD | High |
| Beaver introductions | Fine sediment | Low |
| | LWD | Low |
| | Pool quality | High |
| | Pool quantity | High |
| Confinement/remeandering | Channel alteration and confinement | High |
| | Channel complexity | High |
| | Channel morphology | High |
| | Streambank condition/erosion | Low |
| | Streambank instability | Low |
| Side channel | Floodplain connectivity | Medium |
| Floodplain | Riparian condition and function | Medium |
| | Floodplain connectivity | Medium |
| | Wetland structure and function | Low |
| Riparian fencing | Streambank condition/erosion | High |
| | Riparian condition and function | High |
| Riparian planting | Streambank condition/erosion | High |
| | Riparian condition and function | Medium |
| 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 |

Table 2 continued. Limiting factors addressed[a] by each restoration action type and subtype, and the strength of evidence in published literature that a particular action subcategory addresses a limiting factor or habitat impairment. The list of action categories and limiting factors was provided by BPA, August 2012. Acquisitions were not included in the table because little information exists on their effects on limiting factors and they often focus on protecting habitat.

| **Action subcategory** | **Limiting factor/habitat impairment** | **Evidence from the literature[b]** |
|---|---|---|
| Agricultural (continued) | Water quality (pH) | NA |
| | Water temperature | NA |
| | Fine sediment | High |
| Flow–water quality | Water quality (chemical pollution) | ? |
| | Water quality (dissolved oxygen) | Medium |
| | Water quality (excess nutrients) | ? |
| | Water quality (heavy metal contamination) | ? |
| | Water quality (high turbidity) | ? |
| | Water quality (low nutrients) | ? |
| | Water quality (pH) | ? |
| | Water temperature | Medium |
| | Instream flows/water quantity | High |
| Flow–barriers | Passage or migration barriers (diversions) | Medium |

[a] The term "limiting factor" here refers to a major habitat impairment rather than a factor limiting a specific salmon life stage. By addressing a 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.
[b] High = many studies have confirmed this, Medium = some studies have documented this, Low = little to no information is available, ? = no information reported, and NA = not applicable (limiting factor not typically measured or addressed by this action type.

# 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-scale or watershed-scale processes (riparian restoration, sediment reduction) often require 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.

# Restoration Effectiveness at the Population Level

Population-scale or watershed-scale assessments of the effectiveness of restoration actions are quite rare, although a number of them are underway in the Pacific Northwest, for

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

| Category | Common factors |
|---|---|
| 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 | Wood and boulder 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) |
| | Gravel addition: amount and size of substrate added, frequency of addition, location of additions, instream flows, natural sediment supply, delivery, and transport |
| 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 | 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 |
| 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 |

example, 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 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 postrestoration 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 reopening access to large amounts of habitat (Roni et al. 2008, Pess et al. 2012b). 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 of only four published population-scale studies examining responses of coho salmon or steelhead populations to physical manipulation of habitats (Nickelson et al. 1992, Reeves et al. 1997, Solazzi et al. 2000, Slaney et al. 2003). Nickelson et al. (1992) and Reeves et al. (1997) 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 et al. (2000) 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 unpubl. data).

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 the ability to detect a salmon population response to restoration. Five of these basins appear to have sufficient pretreatment monitoring (Entiat, Potlatch, Asotin, Bridge Creek, and Lower Columbia), 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 after 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 subpopulation scale, and most restoration actions were planned for implementation in 2012 or 2013. 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 occurred in 2012 or 2013. 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 reconnect 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.

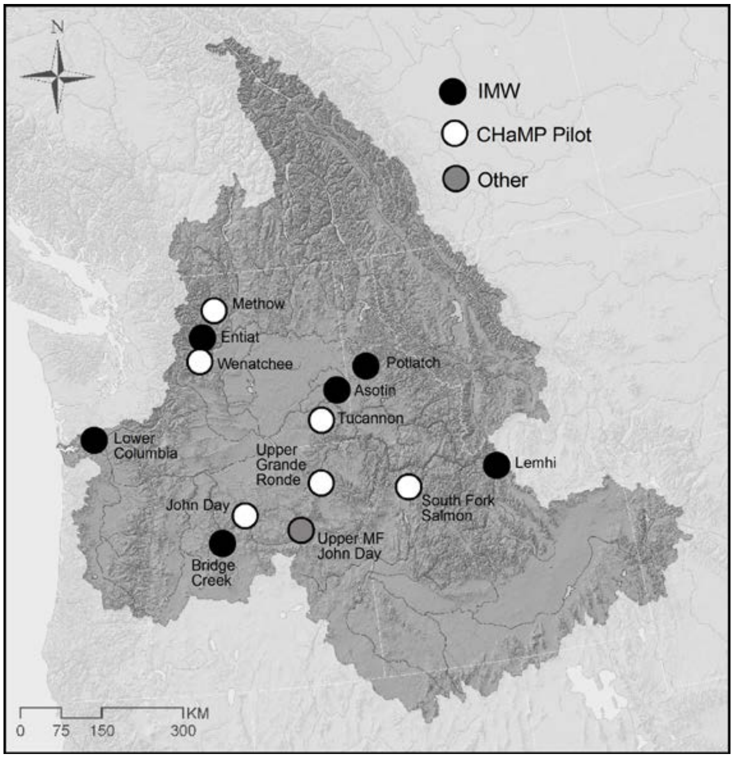


Figure 3. Map of IMWs and CHaMP (Columbia Habitat Monitoring Program) pilot watersheds in the Columbia River basin.

# What Can Models Tell Us about Population Responses?

In the absence of empirical data showing population-level effects of restoration actions on salmon, modeling approaches can be used. For this purpose, modeling approaches require density and survival information specific to habitat types, and such 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 must be able 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, 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. In 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., Moussalli 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, 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 River and Stillaguamish River basins in Washington state, assessments of historical and current habitat capacities illustrated that winter-rearing habitats were likely limiting both historically and recently, 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 salmon and steelhead rearing-capacity improvements that might be achieved by various restoration options in the Trinity River, California (Beechie et al. 2012). 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. The analysis illustrated that potential increases in Chinook salmon 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.

## 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 do not model habitat capacity at

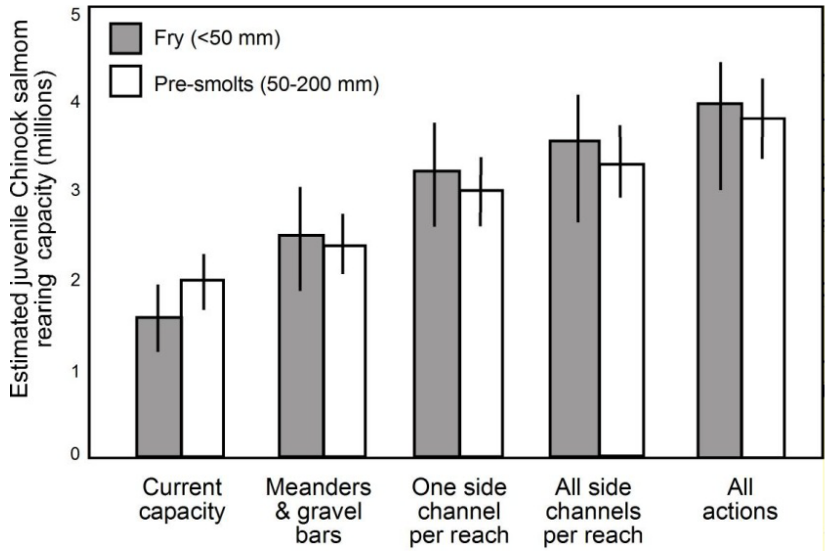


Figure 4. Estimated increases in juvenile Chinook salmon habitat carrying capacity, assuming an increase in habitat area and habitat quality by rehabilitation action in all reaches of 64 km of the Trinity River, from Lewiston Dam to the confluence of the North Fork Trinity River. (Modified from Beechie et al. 2012.)

each life stage or survival between life stages, and therefore are 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 estimated at the scale of reaches or subbasins 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 the life cycle model (e.g., Bartz et al. 2006), 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 River basin indicated that fine sediment levels in spawning gravels are a function of forest road density, whereas prespawning temperatures are a 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 prespawning 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 in 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 effects 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, relating habitat or restoration actions to habitat response, and relating habitat response to fish response (Scheuerell et al. 2006). Once all of these relationships have been assembled, the model can be constructed and used to evaluate alternative restoration scenarios. For example, Scheuerell et al. (2006) compared restoring spawning habitat, rearing habitat, or both in the estuary, main stem, lowland tributaries, or headwaters, and found that restoring rearing habitats in the estuary and main stem 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 and Zabel 2006, Crozier et al. 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 of restoration effectiveness, showing that while land use trends and climate change may 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).

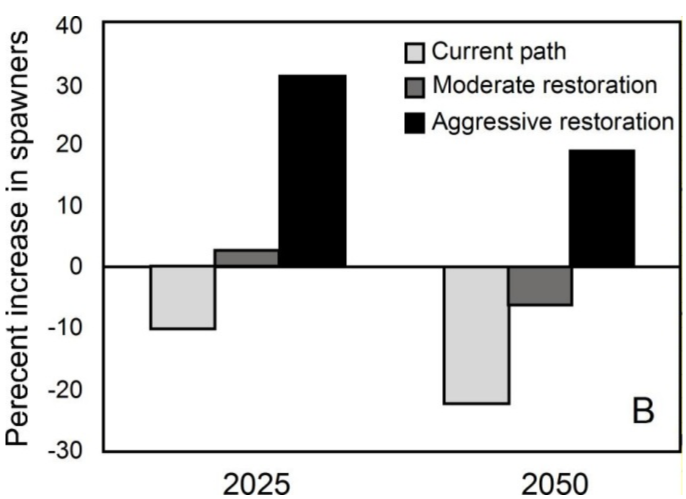


Figure 5. Estimated change in Chinook salmon population size with varying restoration scenarios and climate change. "Current path" represents limited restoration plus continued land use change into the future. The climate change scenario is the moderate A1B emissions scenario. (Adapted from Battin et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

# Summary and Conclusions

Decades of fish-habitat relationship research have 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 focused on 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 have shown localized (reach scale) increases in fish abundance for placement of instream structures and reconnection of both tributary and floodplain habitat. Also, 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 reach and watershed scales.

Scaling these reach-scale effects up to the watershed or population scale requires either watershed or population evaluation or salmonid life cycle modeling. Several IMW studies are 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; multiple models are needed. Models are population specific due to unique characteristics of each watershed and population, so 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. In addition, 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 A: Lists of All the Literature Examined with Summaries of Key Findings

Key findings are listed for 409 published studies we located that report effectiveness of different restoration techniques. The seven categories under headings below are fish passage/barrier removal (22 references), instream structures (209 references), off-channel/floodplain habitat (82 references), riparian/grazing (53 references), sediment/roads (27 references), acquisition and protection (1 reference), and flow (15 references). In each of the following seven lists for these categories, the left column provides the document reference and the right column summarizes the key quantitative findings. In cases where no numeric or quantitative information was reported for fish or habitat, we indicate this as “no numbers” reported. Within each category, the publications are listed alphabetically by author.



## Fish Passage/Barrier Removal References (Subtotal is 22 of 409)

| Reference | Key Quantitative Findings |
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| Born, S. M., K. D. Genskow, et al. 1998. Socioeconomic and institutional dimensions of dam removals: The Wisconsin experience. Environ. Manag. 22(3):359–370. | Financial and social survey, no physical data, just “opinion survey” on impacts and benefits. |
| Bushaw-Newton, K. L., D. D. Hart, et al. 2002. An integrative approach towards understanding ecological responses to dam removal: The Manatawny Creek study. J. Am. Water Resour. Assoc. 38(6):1581–1599. | Channel changes in former impoundment = 0.5 m decrease in elevation above dam, water quality = no change, invertebrates = dominant assemblage changed from lentic to lotic but no other changes, channel changes downstream of dam = 0.5 m aggradation, fish assemblage = none downstream of dam, fish assemblage in former reservoir = change before and after. |
| Doyle, M. W., E. H. Stanley, et al. 2003. Channel adjustments following two dam removals in Wisconsin. Water Resour. Bull. 39(1):1011–1026. | 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. |

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| FAO/DVWK. 2002. Fish passes: Design, dimensions and monitoring. FAO, Rome. | Provides only general information on success of different fish passes, no specific numbers. |
| Glen, D. I. 2002. Recovery of salmon and trout following habitat enhancement works: Review of case studies 1995–2002. *In* Proceedings of the 13th International Salmonid Habitat Enhancement Workshop, Hotel Westport, Mayo, Ireland, 16–19 September 2002, p. 93–112. Central Fisheries Board, Dublin, Ireland. | 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 in 2000 to a mean of $.35/m^2$ in 2001 and $.20/m^2$ in 2002. |
| Grzybkowska, M., J. Hejduk, et al. 1990. Seasonal dynamics and production of Chironomidae in a large lowland river upstream and downstream from a new reservoir in central Poland. Archiv Fur Hydrobiologie 119(4):439–455. | Actually this is not dam removal, but a recently constructed dam—no difference in density or production of macroinvertebrates, but percent collectors higher above dam than below (25.1% vs. 1% below). |
| Hart, D. D., T. E. Johnson, et al. 2002. Dam removal: Challenges and opportunities for ecological research and river restoration. Bioscience 8:669–682. | 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 water quality (typically initial decrease), and change in fish and macroinvertebrate community. |
| Hill, M. J., E. A. Long, et al. 1994. Effects of dam removal on Dead Lake, Chipola River, Florida. Proc. Annu. Conf. Southeastern Assoc. Fish Wildl. Agencies 48:512–523. | Increase in largemouth bass, water quality, and species diversity. |
| Kanehl, P. D., J. Lyons, et al. 1997. Changes in the habitat and fish community of the Milwaukee River, Wisconsin, following removal of the Woolen Mills Dam. N. Am. J. Fish. Manag. 17(2):387–400. | Increased smallmouth bass abundance and biomass, "good" fish Index of Biological Integrity (IBI), and decrease in carp upstream of dam. Initial decrease in smallmouth bass and lower quality fish IBI downstream of dam, but rebounded to preproject levels by 5 years after dam removal. |

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| Kiffney, P. M., G. R. Pess, et al. 2009. Changes in fish communities following recolonization of the Cedar River, WA, USA by Pacific salmon after 103 years of local extirpation. River Res. Appl. 25(4):438–452. Online at http://dx.doi.org [DOI name 10.1002/rra.1174, accessed 12 December 2013]. | Coho salmon, Chinook salmon, cutthroat trout, rainbow trout. 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. |
| Lenhart, C. F. 2003. A preliminary review of NOAA's community-based dam removal and fish passage projects. Coastal Manag. 31(1):79–98. | Looked at 18 NOAA community-based restoration program dam removals. Only reported general results—increased passage for river herring (*Alosa* spp.) and salmonids (*Oncorhynchus* spp.). |
| Martens, K. D., and P. J. Connolly. 2010. Effectiveness of a redesigned water diversion using rock vortex weirs to enhance longitudinal connectivity for small salmonids. N. Am. J. Fish. Manag. 30(6):1544–1552. | Juvenile Chinook salmon, juvenile coho salmon, juvenile steelhead, rainbow trout, 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. Eighty-one percent of those events were rainbow or steelhead. Small rainbow or steelhead ranging 86–238 mm were able to pass. |
| Nelson, J. E., and P. Pajak. 1990. Fish habitat restoration following dam removal on a warm-water river. American Fisheries Society, North Central Division, Rivers and Streams Technical Committee Symposium proceedings: The restoration of midwestern stream habitat, Minneapolis, MN. American Fisheries Society, Bethesda, MD. | Habitat Suitability Index values for smallmouth bass increased following dam removal and channel restoration. On average, the index increased by 0.29 or a 39.5% increase. |

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| Pearson, A. J., N. P. Snyder, et al. 2011. Rates and processes of channel response to dam removal with a sand-filled impoundment. Water Resour. Res. 47(08). Online at http://dx.doi.org [DOI name 10.1029/2010 WR009733, accessed 12 December 2013]. | 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. |
| Price, D. M., T. Quinn, et al. 2010. Fish passage effectiveness of recently constructed road crossing culverts in the Puget Sound region of Washington state. N. Am. J. Fish. Manag. 30:1110–1125. | Evaluated fish passage at 77 permitted culverts. Of those studied, 30% 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. |
| Sethi, S. A., A. R. Selle, et al. 2004. Response of Unionid mussels to dam removal in Koshkonong Creek, Wisconsin (USA). Hydrobiologia 525:1–3. | Density of mussels downstream of dam decreased by 1.2 mussels/$m^2$ and silt and sand increased from 17.9% to 46.3% of total area sampled. |
| Shafroth, P. B., J. M. Friedman, et al. 2002. Potential responses of riparian vegetation to dam removal. Bioscience 52(8):703–712. | This is a review article discussing potential changes in riparian vegetation following dam removal. No specifics provided. |
| Smith, L. W., E. Dittmer, et al. 2000. Breaching of a small irrigation dam in Oregon: A case history. N. Am. J. Fish. Manag. 20(1):205–219. | Mostly a review of sociological aspects including stakeholder input and expectations. They report increased fish passage, but provide no data. |
| Stanley, E. H., M. J. Catalano, et al. 2007. Effects of dam removal on brook trout in a Wisconsin stream. River Res. Appl. 23(7):792–798. | Brook trout. No numbers. No new species colonized the creek in the 2 years after dam removal. Catch per unit effort (CPUE) was lower and young-of-the-year 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 reference reach, indicating a localized effect of the removal. Total length of adults and young-of-the-year and the adult body condition did not vary between years or among reaches. |

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| Stanley, E. H., M. A. Luebke, et al. 2002. Short-term changes in channel form and macroinvertebrate communities following low-head dam removal. J. North Am. Benthol. Soc. 21(1):172–187. | Physical—decrease in cross-sectional area above dam (59 $m^2$ to 11 $m^2$), macroinvertebrate assemblage changed to lotic taxa, but following removal no difference in taxa between upstream and downstream reaches. |
| Tetra Tech. 2010. Reach-scale effectiveness monitoring program. 2009 annual progress report. Tetra Tech EC Inc., Bothell, WA. Online at http://www.rco.wa.gov/documents/monitoring/2009_annual_progress_rpt.pdf [accessed 01 November 2013]. | Using various indicators established by NOAA, monitored eight diversion screening projects 1 and 2 years after installation and found 80% of measured indicators were in compliance with NOAA targets. Note that they also reported on preliminary results of floodplain, fencing, and instream habitat improvement projects. |
| Walters, A. W., D. M. Holzer, et al. 2012. Quantifying cumulative entrainment effects for Chinook salmon in a heavily irrigated watershed. Trans. Am. Fish. Soc. 141(5):1180–1190. | Chinook salmon. Under median-streamflow conditions with unscreened diversions, the estimated cumulative effect of the diversions was a loss of 71.1% of outmigrating 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. |

# Instream Structure References (Subtotal is 209 of 409)

| Reference | Key Quantitative Findings |
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| Aitken, W. W. 1935. Iowa stream improvement work. Trans. Am. Fish. Soc. 65:322–323. | 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 temperature 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 actual installation of stream improvement devices. |
| Albertson, L. K., B. J. Cardinale, et al. 2011. Impacts of channel reconstruction on invertebrate assemblages in a restored river. Restor. Ecol. 19(5):627–638. | 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. Average 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. |
| Aldridge, K. T., J. D. Brookes, et al. 2009. Rehabilitation of stream ecosystem functions through the reintroduction of coarse particulate organic matter. Restor. Ecol. 17(1):97–106. | Reintroduction of coarse particulate organic matter in the form of leaf litter. Before addition, there was no difference in community respiration, but 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. |
| Anderson, J. W. 1981. Anadromous fish projects 1981 USDI-BLM Coos Bay District. *In* T. J. Hassler (ed.), Proceedings: Propagation, Enhancement, and Rehabilitation of Anadromous Salmonid Populations and Habitat in the Pacific Northwest Symposium, p. 109–114. Humboldt State Univ., Arcata, CA. | No numbers. Constructed gabions function well and have been used extensively by anadromous fish for spawning. Chinook salmon, coho salmon, winter steelhead, cutthroat trout, and Pacific lamprey use the structures that 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. |

Angermeier, P. L., and J. R. Karr. 1984. Relationship between woody debris and fish habitat in a small warm-water stream. Trans. Am. Fish. Soc. 113:716–726.

Wood addition. Fish and benthic invertebrates were usually more abundant on the side with debris. Artificial debris was colonized by many invertebrates. They were 3.9 times more abundant on the debris side in July and 5.7 times more abundant on the 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 to increased food availability or protection from strong currents.

Armantrout, N. B. 1991. Restructuring streams for anadromous salmonids. *In* J. Colt and R. J. White (eds.), Fisheries bioengineering, Symposium 10, p. 136–149. American Fisheries Society, Bethesda, MD.

Added large woody debris, 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 salmon, steelhead, and cutthroat trout used undercut banks, root masses, and woody debris in pools behind structures for winter habitat.

Avery, E. L. 1996. Evaluations of sediment traps and artificial gravel riffles constructed to improve reproduction of trout in three Wisconsin streams. N. Am. J. Fish. Manag. 16:282–293.

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.

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| Avery, E. L. 2004. A compendium of 58 trout stream habitat development evaluations in Wisconsin—1985–2000. Wisconsin Dept. Natural Resources, Bureau of Integrated Science Services, Waupaca, WI. | Large woody debris, boulders, beaver, and brush removal. The success of each project was judged on the basis of the percent change within a treatment zone for four categories (or population variables): 1) total number of trout, 2) number of trout ≥6″, 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 = postdevelopment 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 postdevelopment changes for populations of 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″ (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 lb trout per mile to 163 lb trout per mile). |
| Baldigo, B. P., A. S. G. Ernst, et al. 2008. Restoring geomorphic stability and biodiversity in streams of the Catskill Mountains, New York, USA. *In* J. Nielsen, J. J. Dodson, et al. (eds.), Reconciling fisheries with conservation, Symposium 49(2), p. 1777–1790. American Fisheries Society, Bethesda, MD. | 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 $g/m^2$ after restoration, mean biomass differentials differed slightly among the streams, and the response of biomass to restoration differed across the three streams. |

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| Baldigo, B. P., A. S. G. Ernst, et al. 2010. Variable responses of fish assemblages, habitat, and stability to natural-channel-design restoration in Catskill Mountain streams. Trans. Am. Fish. Soc. 139(2):449–467. | 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. |
| Baldigo, B. P., D. R. Warren, et al. 2008. Response of fish populations to natural channel design restoration in streams of the Catskill Mountains, New York. N. Am. J. Fish. Manag. 28(3):954–969. | 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/$m^2$ (a 253% increase) after restoration. Net increase in biomass was significant and averaged 3.65 g/$m^2$ (a 239% increase) after restoration. Brown trout density increased 206% and biomass 253%. |
| Banchetti, R., N. Ceccopieri, et al. 2004. Valutazione della qualità delle acque del fiume Frigido (Totcana) mediante l'indice I.B.E. (Indice Biotico Esteso). [Assessment of the quality of waters of the Frigido river (Tuscany) by means of the index I.B.E. (Extended Biotic Index)]. Atti della Società Toscana di Scienze Naturali, Memorie Serie B 111:55–64. | In Italian. Examined effects of sediment reduction through 1) reduced discharge of sediment from marble works, and 2) physical cleaning of several kilometers of stream to remove fine sediment (marble) from substrate (removed tens of thousands of metric tons, exact number not provided). Measured IBE, a macroinvertebrate-based metric developed for Italian streams, following new regulations and restoration measures. IBE improved from Class III and IV to Class I or II in middle reaches of River Frigido by year 2000. However, lower urbanized/channelized reaches in city of Massa still remain Class IV (polluted or altered) and V (severely polluted or altered), in part due to water extraction and other industrial and civic discharge believed to be impacting water quality in these lower reaches (lower ≈2–3 km are Class V). |
| Barrineau, C. E., W. A. Hubert, et al. 2005. Winter ice processes and pool habitat associated with two types of constructed instream structures. N. Am. J. Fish. Manag. 25(3):1022–1033. | 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 pools. 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 pools 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. |

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| Bates, D. J., G. G. McBain, et al. 1997. Restoration of a channelized salmonid stream, Oullette Creek, British Columbia. *In* J. D. Hall, P. A. Bisson, et al. (eds.), Symposium on sea-run cutthroat trout: Biology, management, and future conservation. American Fisheries Society, Oregon chapter, Corvallis. | Abstract of a poster. Rock weirs built to duplicate natural riffles and pools. 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 salmon and cutthroat trout. |
| Beschta, R. L., W. S. Platts, et al. 1994. Artificial stream restoration—money well spent or expensive failure? *In* Proceedings, environmental restoration, UCOWR 1994 Annual Meeting, Big Sky, MT., August 2–5, 1994, p. 76–104. Universities Council on Water Resources, Southern Illinois Univ. Carbondale. | Wood and rock. Several case studies. Despite large restoration effort, no species of salmon had a significant increase trend. Number of coho salmon produced in the creek was the lowest since smolt trapping began. No Chinook salmon 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 still have not migrated beyond the falls. Channel realignment, bank modification, and planting of riparian vegetation produced no benefits, as Chinook salmon and steelhead 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 trout populations did not reflect difference in habitat conditions between the two reaches. Heavy channel and bank alterations show no young-of-the-year trout response to additions of large amounts of gravel. Juvenile and adult age groups did not respond to channel alterations that supposedly provided deepwater habitat and object cover. |

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| Binns, N. A. 1994. Long-term responses of trout and macrohabitats to habitat management in a Wyoming headwater stream. N. Am. J. Fish. Manag. 14:87–98. | Large woody debris and boulders. Stream developed a narrower channel with deep pools that helped brook trout survive low flows. After 7 years, brook trout 6″ 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 (41 lb/acre) after an extended drought, but this level was 90% better than before habitat development. |
| Binns, N. A. 1999. A compendium of trout stream habitat improvement projects done by the Wyoming Game and Fish Department, 1953–1998. Wyoming Game and Fish Dept., Fish Division, Cheyenne. | Compendium of 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). Eighty-one percent 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″ 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 (RPD) criteria, but log plunges (RPD 1.85 ft) were better than either timber plunges (RPD 1.6 ft) or rock plunges (RPD 1.35 ft). |
| Binns, N. A. 2004. Effectiveness of habitat manipulation for wild salmonids in Wyoming streams. N. Am. J. Fish. Manag. 24:911–921. | Boulders, large woody debris. 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 pretreatment levels. Mean catchable trout numbers (77%) and biomass (62%) also increased significantly. Cover for trout and residual pool depth significantly increased following projects, whereas eroding banks significantly decreased. Both timber and log check dams consistently produced good pools, but rock check dams did not. |

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| Biron, P. M., C. Robson, et al. 2004. Deflector designs for fish habitat restoration. Environ. Manag. 33(1):25–35. | 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 overtopping 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. |
| Black, R. W., and T. A. Crowl. 1995. Effects of instream woody debris and complexity on the aquatic community in a high mountain, desert stream community. *In* D. A. Hendrickson (ed.), Annual symposium of the Desert Fishes Council, Furnace Creek, California, p. 61. | Abstract only. Conference proceedings. Large woody debris. 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. Macroinvertebrate densities did not respond as significantly to changes in habitat complexity as trout densities. The invertebrates appeared to be limited by primary productivity rather than habitat complexity. Habitat complexity was subsequently decreased by a high spring runoff that lowered significance of responses. |
| Blakely, T. J., J. S. Harding, et al. 2006. Barriers to the recovery of aquatic insect communities in urban streams. Freshw. Biol. 51:1634–1645. | 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. |
| Bond, N. R., and P. S. Lake. 2005. Ecological restoration and large-scale ecological disturbance: The effects of drought on the response by fish to a habitat restoration experiment. Restor. Ecol. 13(1):39–48. | Added wood due to sediment. Observed short-term increases in the abundance of mountain galaxias at the four-structure sites, while both the four-structure and the one-structure treatments appeared to buffer against drought-induced declines in two other species. Drought eventually caused the loss of all fish. Beneficial wood is contingent on permanency of flow. |

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| Bond, N. R., S. Sabater, et al. 2006. Colonisation of introduced timber by algae and invertebrates, and its potential role in aquatic ecosystem restoration. Hydrobiologia 556:303–316. | Added large woody debris. 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. Invertebrates colonized the wood extremely rapidly, peaking in abundance and richness in 8 weeks. Invertebrate abundances closely tracked changes in abundance of algae. By 20 weeks, there were sharp decreases in invertebrate and algal abundances and invertebrate species richness. The added timber quickly created habitat with high levels of primary production in an otherwise heterotrophic stream system. |
| Boreman, J. 1974. Effects of stream improvement on juvenile rainbow trout in Cayuga Inlet, New York. Trans. Am. Fish. Soc. 103:637–641. | Log structures. There was no difference in biomass, average weight, or number of rainbow trout between structured and control sections. No differences existed among biomass, average weight, or numbers of sculpin or minnows in bank crib and control sections. However, sculpin in pool digger sections were smaller in biomass, average 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 percent of the total biomass in the crib sections than pool digger sections (66% vs. 48%). |
| Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Wildl. Manag. 18(2):229–239. | Rainbow trout, eastern brook trout, and brown trout. The increase in total pounds of fish following application of brush cover amounted to 258.1%. The three sections that were unaltered increased an average of 22.5%. There was an average increase in legally catchable fish of 0.62 lb 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 lb per inventory per 100 square feet of brush cover removed. It was noted that aquatic vegetation was of value as cover when rooted to the stream bottom and also while free-floating. |

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| Brittain, J. E., J. A. Eie, et al. 1993. Improvement of fish habitat in a Norwegian River channelization scheme. Regul. Rivers: Res. Manag. 8(1-2):189–194. | Addition of rocks and stones to a channelized river increased brown trout densities, especially in areas in contact with the riverbanks. The new areas of rock addition provided cover for fish as well as greater variations in depth and flow conditions. Although there was no significant difference between the unmodified riverbanks with the artificial areas under the bridges, densities were more than twice as high along the modified river banks than under and around the bridges. Increased density of the young trout at the stony areas is probably the result of redistribution of fish in the river. |
| Brock, W. A. 1986. Enhancement of rearing habitat for juvenile steelhead trout (*Salmo giardneri*) by boulder placement in a tributary to the Klamath River. Thesis. Humboldt State Univ., Arcata, CA. | 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%/$m^2$ and 143%/$m^3$. Biomass in the control reach decreased 41%/$m^2$ and 22%/$m^3$. |
| Brooks, A. P., P. C. Gehrke, et al. 2004. Experimental reintroduction of woody debris on the Williams River, NSW: Geomorphic and ecological responses. River Res. Appl. 20(5):513–536. | Created engineered logjams. 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 $m^3$ of sediment storage per 1,000 $m^2$ of channel area (while the control reach experienced a net loss of 15 $m^3$/1,000 $m^2$ 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 reference reach. Eight 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 2,340 fish. |
| Brooks, S. S., M. A. Palmer, et al. 2002. Assessing stream ecosystem rehabilitation: Limitations of community structure data. Restor. Ecol. 10(1):156–168. | Created “high” and “low” heterogeneity treatments in riffles by altering the variability of streambed particle sizes. The initial disturbance and riffle construction significantly reduced invertebrate abundance by 67% in both high and low heterogeneity riffles, but invertebrate abundance and species richness did not differ between treatments. Results support the idea that changes in community structure may be poor indicators of environmental change in highly variable environments inhabited by mobile, fugitive taxa. |

Burgess, S. A., and J. R. Bider. 1980. Effects of stream habitat improvements on invertebrates, trout populations, and mink activity. J. Wildl. Manag. 44(4):871–880.

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.

Carlson, L. D., and M. S. Quinn. 2005. Evaluating the effectiveness of instream habitat structures for overwintering stream salmonids: A test of underwater video. N. Am. J. Fish. Manag. 25(1):130–137.

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.

Cederholm, C. J., R. E. Bilby, et al. 1997. Response of juvenile coho salmon and steelhead to placement of large woody debris in a coastal Washington stream. N. Am. J. Fish. Manag. 17:947–963.

Large woody debris (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 reference site. Increased piece length and abundance resulted in an 11.5-fold increase in total wood volume in the engineered site and a threefold 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 salmon during spring and fall showed no response to enhancement, but juvenile coho responded in the winter. Prior to enhancement, the reference site supported nearly 10 times the number of presmolt coho salmon as the two treatment sites. After enhancement, coho abundance increased twentyfold in the engineered site and sixfold 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 average of 117 smolts/year emigrated from the engineered site and 55 smolts/year from the logger’s choice site. After enhancement, average annual yield increased to 370 smolts/year from the 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.

Champoux, O., P. M. Biron, et al. 2003. The long-term effectiveness of fish habitat restoration practices: Lawrence Creek, Wisconsin. Ann. Assoc. Am. Geogr. 93(1):42–54.

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 $m^2$ to 625 $m^2$ between 1963 and 1966, but has decreased to 488 $m^2$ 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 and the channel is unstable due to high bed-shear stress values, which entrain bed and bank erosion. In 1963, the mean depth was 0.12 m. After improvements, the mean depth increased to 0.21 m 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.

Chapman, D. W. 1996. Efficacy of structural manipulations of instream habitat in the Columbia River basin. Northwest Sci. 5(4):279–293.

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 streambank treatment, while at higher densities (1.5 times 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 invertebrate abundance, which subsequently resulted in an increase of salmonid biomass. Barrier removal: activities after removal did not show any increase in salmonid biomass in the upper stations. Biomass remained low and the length frequency distributions of fish 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 four redds in 1995 and 23 in 1996 and had the highest success of gravel retention, greater than 90% as compared to approximately 50% in other sites. Major restoration/rewatering: average 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 average 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 average 2.6 times the biomass of large brook trout than those without lunkers. The average 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 in 1996 was 263.94 kg, a 14.7-fold increase from prerestoration levels. The site had a habitat gain of 215 units (30% increase) and increase in potential production of 246 kg from 1990 to 1996.

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| Clarke, K., and D. Scruton. 2002. Evaluating efforts to increase salmonid productive capacity through habitat enhancement in the low diversity/production systems of Newfoundland, Canada. *In* Proceedings of the 13th International Salmonid Habitat Enhancement Workshop, Hotel Westport, Mayo, Ireland, 16–19 September 2002, p. 160–182. Central Fisheries Board, Dublin, Ireland. | Summarized several habitat improvement projects evaluated in Newfoundland. (Noel Paul's Brook and 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 were successful in meeting objectives, but results varied by project (see publication for details). |
| Coe, H, J., P. M. Kiffney, et al. 2006. A comparison of methods to evaluate the response of periphyton and invertebrates to wood placement in large Pacific coastal rivers. Northwest Sci. 80(4):298–307. | See Coe et al. 2009 below. |
| Coe, H., P. M. Kiffney, et al. 2009. Periphyton and invertebrate response to wood placement in large Pacific coastal rivers. River Res. Appl. 25(8):1025–1035. | No fish. Periphyton and invertebrates. Among years and rivers, periphyton biomass and invertebrate densities were significantly higher on engineered logjams than on cobbles within the same reach. Adding wood to reaches with little or no naturally occurring wood increased overall habitat surface area and the potential of increased productivity relative to reaches with low levels of wood. Among years, mean ash-free dry mass, chlorophyll *a* concentration, and autotrophic index were as much as 1.5, six, and four times higher, respectively, on wood than on cobble in the Elwha River. In the Stillaguamish River, mean ash-free dry mass, chlorophyll *a* concentration, and autotrophic index were three, eight, and five times higher, respectively, on wood. |

Crispell, J. K., and T. A. Endreny. 2009. Hyporheic exchange flow around constructed in-channel structures and implications for restoration design. Hydrol. Process. 23(8):1158–1168.

No fish, no good numbers. Study of constructed in-channel structure controls on hyporheic exchange flow 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 streamflows result in changes in hyporheic exchange flow spatial patterns and magnitude at each structure.

Crispin, V., R. House, et al. 1993. Changes in instream habitat, large woody debris, and salmon habitat after the restructuring of a coastal Oregon stream. N. Am. J. Fish. Manag. 43:96–102.

Large woody debris. Restructuring caused substantial changes favoring suitable habitat for coho salmon; 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 fivefold in the treated reach at summer low flow. In the treated reach, newly recruited large woody debris 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 fivefold and suitable winter habitat increased sixfold; in the untreated reach suitable summer habitat decreased by half and no winter habitat was available.

D'Aoust, S. G., and R. G. Millar. 2000. Stability of ballasted woody debris habitat structures. J. Hydraul. Eng. 126(11):810–817.

Stability of placed large woody debris (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.

Dauwalter, D. C., R. G. Hyler, et al. 2004. Responses of fish populations to the installation of rock vanes in Spring Creek, Oklahoma. *In* J. R. Copeland, F. Fiss, et al. (eds.), Warm-water Streams Symposium II, p. 49–52. Southern Division American Fisheries Society, Oklahoma City, OK.

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 bass 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 abundance in the control site decreased. Smallmouth bass abundance did not appear to change at the project site.

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| DeVries, P., K. L. Fetherston, et al. 2012. Emulating riverine landscape controls of beaver in stream restoration. Fisheries 37(6):246–255. | 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. |
| Dewberry, C., P. Burns, et al. 1998. After the flood. The effects of the storms of 1996 on a creek restoration project in Oregon. Restor. Manag. Notes 16(2):174–182. | Flood effects on salmonid production varied among species and depended on the life history stage of the species. Steelhead and cutthroat trout more than 1 year old appeared to be the least affected by the floods and their smolt numbers were higher after the flood than before. Chinook salmon outmigrants dropped from 247,000 in 1995 to 50,000 in 1996. |
| Ebrahimnezhad, M., and D. M. Harper. 1997. The biological effectiveness of artificial riffles in river rehabilitation. Aquat. Conserv.: Mar. Freshw. Ecosyst. 7(3):187–197. | Artificial riffles. Mean diversity of invertebrates 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, and a 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) and Chironomidae were slightly more abundant in run sites (64.7%) than the artificial riffle sites (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 in the artificial ones (2.4%, 3.1%, 2.9%). |
| Ehlers, R. 1956. An evaluation of stream improvement project devices constructed 18 years ago. Calif. Fish Game 42:203–217. | Large woody debris 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. |

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| Ernst, A. G., B. P. Baldigo, et al. 2010. Effects of natural-channel-design restoration on habitat quality in Catskill Mountain streams, New York. Trans. Am. Fish. Soc. 139(2):468–482. | 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 ratio generally increased, whereas mean channel width, percent streambank coverage by trees, and shade decreased. Habitat suitability indices for salmonids increased at four of six reaches after restoration. |
| Filoso, S., and M. A. Palmer. 2011. Assessing stream restoration effectiveness at reducing nitrogen export to downstream waters. Ecol. Appl. 21(6):1989–2006. | No fish. Evaluation of whether stream restoration to improve water quality is effective at reducing the export of nitrogen (N) in streamflow 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 flow, 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. |
| Floyd, T. A., C. MacInnis, et al. 2009. Effects of artificial woody structures on Atlantic salmon habitat and populations in a Nova Scotia stream. River Res. Appl. 25(3):272–282. | Atlantic salmon. Large woody debris 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. |
| Frimpong, E. A., J. G. Lee, et al. 2006. Cost-effectiveness of vegetative filter strips and instream half-logs for ecological restoration. J. Am. Water Resour. Assoc. 42(5):1349–1361. | Logs/large woody debris. Cost-effectiveness ratios for vegetative filter strips decreased from $387 to $277 per 100 m for a 1% increase in Index of Biological Integrity 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 two-thirds to half as cost-effective as vegetative filter strips. |

Frissell, C. A., and R. K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. N. Am. J. Fish. Manag. 12:182–187.

Large woody debris 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 15 m 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.

Fuller, D. D., and A. J. Lind. 1992. Implications of fish habitat improvement structures for other stream vertebrates. *In* Proceedings of the Symposium on Biodiversity of Northwestern California, October 28–30, 1991, Santa Rosa, CA, p. 96–104. Wildland Resources Center, Division of Agriculture and Natural Resources, Univ. California, Berkeley.

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 30 m reach for breeding during the 3 years prior to deflector placement, but not during the 3 years after. The diet of the western aquatic garter snake appeared to differ after placement.

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| Gard, R. 1961. Creation of trout habitat by constructing small dams. J. Wildl. Manag. 52(4):384–390. | Dams of rock and wood. Greatly reduced current resulted in ponds with an average deposition of 3.3″ of silt, organic material, and gravel after 1 year and 4.8″ after 3 years. Holes were created by the digging action of the water passing over the dams. An average water depth of 4.5″ increased to 17.2″ after damming, but fell to 5.8″ by 1960. During the three summers following dam installation, the numbers of introduced brook trout were counted. Forty-nine trout were collected the second summer, yielding a 1-year survival rate of 38%. Seventy-three percent of the fish surviving to the second summer were collected the third summer and 39% of those surviving to the third summer lived to the fourth. The introduced trout spawned successfully. Average weights of bottom organisms per unit area at the pond sites in 1958 and 1959 were five and eight times heavier than the average weight per unit area at the same site before ponding. Average number of grams per square foot of summer standing crops of bottom organisms was 0.67 before dams, 5.12 after 1 year, and 3.48 after 2 years. |
| Gard, R. 1972. Persistence of headwater check dams in a trout stream. J. Wildl. Manag. 36:1363–1367. | Headwater check dams. After 12 years, about half of the dams were in good to excellent condition. Log dams held up better than rock dams for the first 3 years, but rock dams were generally in better condition after 12 years. Average depth of the ponds decreased from 16″ to 10″, but holes 9–13″ deep were created below the dams. The standing crop of trout of catchable sizes (≥100 mm) was estimated to be 93 trout weighing 9.6 lb (= 394 trout per acre weighing 41 lb). Cost of dams and trout introduction was $154, or $12.80 per year over the 12 years. |
| Gargan, P., M. O'Grady, et al. 2002. The effectiveness of habitat enhancement on salmon and trout stocks in streams in the Corrib Catchment. *In* Proceedings of the 13th International Salmonid Habitat Enhancement Workshop, Hotel Westport, Mayo, Ireland, 16–19 September 2002, p. 220–223. Central Fisheries Board, Dublin, Ireland. | 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 for brown trout in the five sites in Lough Carra-Lough Mask catchment streams (0.32 vs. 0.07 fish/m) (salmon are not present in these watersheds). |

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| Gerhard, M., and M. Reich. 2000. Restoration of streams with large wood: Effects of accumulated and built-in wood on channel morphology, habitat diversity, and aquatic fauna. Int. Rev. Hydrobiol. 85(1):123–137. | Large woody debris. The addition of wood improved the channel morphology within 4 years. The variation in channel width and depth was considerably larger than in a regulated section. The extension of the riparian zone, especially of the semiaquatic gravel and sand bars, was strongly correlated with the amount of large wood that accumulated in a single section. The number of microhabitats and their patchiness on the stream bottom was higher in restored sections, as well as the density of invertebrates and the number of 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. |
| Giannico, G. R., and S. G. Hinch. 2003. The effect of wood and temperature on juvenile coho salmon winter movement, growth, density, and survival in side channels. River Res. Appl. 19(3):219–231. | Wood addition increased juvenile coho salmon winter carrying capacity and spring smolt output only in the “colder” surface-fed side channel. In contrast, in the groundwater-fed side channel, with relatively higher water temperatures, 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 January 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. |
| Gidley, C. A., D. L. Scarnecchia, et al. 2012. Fish community structure associated with stabilized and unstabilized shoreline habitats, Coeur d’Alene River, Idaho, USA. River Res. Appl. 28(5):554–566. | Bank stabilization. Seventeen 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 fish relative abundance, diversity, and species composition under the existing low fraction (2.5%) of bank stabilization. |

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| Gore, J. A., D. J. Crawford, et al. 1998. An analysis of artificial riffles and enhancement of benthic community diversity by physical habitat simulation (PHABSIM) and direct observation. Regul. Rivers: Res. Manag. 14(1):69–77. | 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. |
| Gore, J. A., and S. W. Hamilton. 1996. Comparison of flow-related habitat evaluations downstream of low-head weirs on small and large fluvial ecosystems. Regul. Rivers: Res. Manag. 12(4–5):459–469. | Wood weirs. Simulation using PHABSIM (physical habitat simulation) demonstrated that benthic invertebrate 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. |
| Gortz, P. 1998. Effects of stream restoration on the macroinvertebrate community in the River Esrom, Denmark. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):115–130. | Restoration using gravel, 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 reference section. The fauna showed higher similarity to the fauna found on the stony bottom sections due to immigration of taxa preferring stony substrate. Saprobic index and Danish fauna index generally improved from II to/toward 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 reference section. Five times as many trout spawning redds occurred in the restored sections as in the nonrestored. However, electrofishing revealed few young-of-the-year trout and did not reflect spawning success. |
| Gowan, C., and K. D. Fausch. 1996a. Long-term demographic responses of trout populations to habitat manipulations in six Colorado streams. Ecol. Appl. 6:931–946. | Log weirs. Mean depth, pool volume, total cover, and the proportion of the fine substrate particles in the streambed 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. |

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| Gowan, C., and K. D. Fausch. 1996b. Mobile brook trout in two high-elevation Colorado streams: re-evaluating the concept of restricted movement. Can. J. Fish. Aquat. Sci. 53:1370–1381. | 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 50 m (up to 3,380 m), 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. |
| Haapala, A., T. Muotka, et al. 2003. Distribution of benthic macroinvertebrates and leaf litter in relation to streambed retentivity: Implications for headwater stream restoration. Boreal Environ. Res. 8(1):19–30. | Boulders and leaf retention. Streambed complexity increased, stream channel widened, water velocity lowered, and moss cover decreased. 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. |
| Hale, J. G. 1969. An evaluation of trout stream habitat improvement in a north shore tributary of Lake Superior. Minn. Fish. Investig. 5:37–50. | Artificial deflectors and shelters. Average depth of cross-sectional 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. Fifty-seven log shelters increased surface cover by 3.8% of total surface area. Abundance of young-of-the-year brook trout increased 894% and older trout 223%. Total standing crop of brook trout increased 356% while in the reference area the increase was only 65%. Anglers increased by 219 vs. 46 in the reference area. After alteration there was a 362% increase in average annual harvest vs. 51% in reference area. Catch rate of native brook trout rose from 0.58 before to 0.89 after, while reference sector dropped from 0.82 to 0.75 fish per man hour. Average 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. |

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| Hamilton, J. B. 1989. Response of juvenile steelhead to instream deflectors in a high gradient stream. *In* R. E. Gresswell, B. A. Barton, et al. (eds.), Practical approaches to riparian resource management, p. 149–158. U.S. Bureau of Land Management, Billings, MT. | 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%) reaches. |
| Harper, D., M. Ebrahimnezhad, et al. 1998. Artificial riffles in river rehabilitation: Setting the goals and measuring the successes. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8:5–16. | Artificial riffles. Twenty of 26 riffles retained their original physical character while six 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 that resulted in richness of functional habitats not found elsewhere. Invertebrate 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. |
| Harper, D. J., and J. T. Quigley. 2005. No net loss of fish habitat: A review and analysis of habitat compensation in Canada. Environ. Manag. 36(3):343–355. | Development activities that resulted in the greatest percent 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. |

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| Harrison, S. S. C., J. L. Pretty, et al. 2004. The effect of instream rehabilitation structures on macroinvertebrates in lowland rivers. J. Appl. Ecol. 41(6):1140–1154. | Artificial riffles and flow deflectors. Artificial riffle benthos had a faster current, a coarser substratum, and was shallower than reference area. Depth and substratum particle size differed little between flow deflector and reference area, although velocity downstream of the deflector tip was great and velocity in the lee of the deflector lower than reference area. At a habitat scale, the benthos of artificial riffles, but not flow deflectors, had higher abundance, taxon richness, and diversity than reference area. The impact of artificial riffles was most marked for benthic rheophilic taxa. Invertebrate 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. |
| Hartzler, J. R. 1983. The effects of half-log covers on angler harvest and standing crop of brown trout in McMichaels Creek, Pennsylvania. N. Am. J. Fish. Manag. 3:228–238. | Installed half-log covers. Anglers caught 10% more trout in treated sections and brown trout harvest declined 11% in untreated sections. Number and weight of larger trout collected by electrofishing rose by 12% and 14% respectively, but those increases were not statistically significant. Response of “catchable size” brown trout to cover enhancement was poor. |
| Hester, E. T., M. W. Doyle, et al. 2009. The influence of instream structures on summer water temperatures via induced hyporheic exchange. Limnol. Oceanogr. 54(1):355–367. | 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°C. Streambed hydraulic conductivity appears to be the overriding factor determining the magnitude of weir-induced hyporheic influence on surface and subsurface water temperatures. |

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| Hilderbrand, R. H., A. D. Lemly, et al. 1997. Effects of large woody debris placement on stream channels and benthic macroinvertebrates. Can. J. Fish. Aquat. Sci. 54(4):931–939. | Large woody debris (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 two pools while the other seven were created by single LWD pieces. Debris-formed pools increased from six to 14 (61%) 1 year after additions. Total invertebrate 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. |
| Hilderbrand, R. H., A. D. Lemly, et al. 1998. Design considerations for large woody debris placement in stream enhancement projects. N. Am. J. Fish. Manag. 18(1):161–167. | Log length exerted a critical influence in stabilizing large woody debris (LWD) pieces. Logs longer than the average bankfull 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 streamflow; aggradation occurred above and below pieces oriented as dams angled to the current. Microscale channel responses to LWD additions varied. |
| House, R. 1984. Evaluation of improvement techniques for salmonid spawning. *In* T. J. Hassler (ed.), Proceedings: Pacific Northwest Stream Habitat Management Workshop, p. 5–13. Humboldt State Univ., Arcata, CA. | Chinook salmon, pink salmon, chum salmon, coho salmon, and steelhead. Gabions increased the usable spawning area, trapping an average of 15.9 $m^2$ in one creek and 8.3 $m^2$ 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. |

House, R. 1996. An evaluation of stream restoration structures in a coastal Oregon stream 1981–1993. N. Am. J. Fish. Manag. 16:272–281.

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. After structures were installed, peak returns of adult coho increased sixfold from the 1980–1984 average and the percentage of wild spawners increased from 36% before to 84% after construction. Coho juveniles increased from an average of 3,754 fish during 1981–1983 to an average of 9,458 fish during 1984–1989. Between 1981 and 1992, more than 50% of the coho salmon and steelhead spawned on newly deposited, higher quality gravels associated with 15 gabion structures that fully spanned the bankfull 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.

House, R. A., and P. L. Boehne. 1985. Evaluation of instream enhancement structures for salmonid spawning and rearing in a coastal Oregon stream. N. Am. J. Fish. Manag. 5:283–295.

Stream enhancement structures installed were successful and functional after two winters with usual freshets. The structures dramatically increased the diversity of the streambed, 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. Water volume increased 84.8 $m^3$ and surface area increased 187 $m^2$ after installation. Maximum depth increased by 22 cm in 1982 and 35 cm in 1983 on treated sites, whereas control sites showed no increase in 1982 and an increase of only 9 cm in 1983. The pool/riffle ration changed from 1:3 before treatment to 4:1 after treatment. Pool habitat in treated sites increased by 53% while pool habitat in control areas increased by 22%. Coho salmon and steelhead spawning increased substantially, as well as the numbers of rearing coho, steelhead fry, and steelhead and cutthroat trout parr. Coho fry densities in 1982 were 422% and 541% greater, respectively, in sites with two gabions than in those with one gabion.

House, R. A., and P. L. Boehne. 1986. Effects of instream structures on salmonid habitat and populations in Tobe Creek, Oregon. N. Am. J. Fish. Manag. 6:38–46.

Large woody debris caused the development of secondary channels, meanders, pools, and undercut banks in an unlogged, mature-conifer, 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 salmon 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% and usable spawning gravel area increased 25-fold. The section above the culvert was supporting 12 times as many coho as below the culvert. Trout were about three times more abundant above the culvert than below. There was a positive correlation between coho numbers and the presence of large woody debris. Structure is most likely a more important factor than shade in a stream's capacity for producing salmonids.

House, R., V. Crispin, et al. 1989. Evaluation of stream rehabilitation projects—Salem District (1981–1988). U.S. Dept. Interior, Bureau of Land Management, Portland, OR.

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 square feet for each 3 feet of treated stream. The potential increase in populations was an estimated 92,140 juvenile coho salmon, 14,170 trout fry, 6,780 yearling steelhead, and 2,560 sea-run and resident yearling cutthroat trout. Generally the greatest increase occurred in channels more than 39 feet wide 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 thirteenfold increase in adult coho, with an average 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 tributaries and upper mainstem rivers, manage riparian zones to produce optimum numbers of mature conifers, continue rehabilitation work in key reaches of coastal streams, and continue long-term evaluations to determine accurate project benefits.

Hunt, R. L. 1969. Effects of habitat alteration on production, standing crops, and yield of brook trout in Lawrence Creek, Wisconsin. *In* T. G. Northcote (ed.), Symposium on Salmon and Trout in Streams, H. R. Macmillan lectures in fisheries, p. 281–312. Univ. British Columbia, Vancouver, BC.

Bank covers and current deflectors reduced surface area by 50%, increased average 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%. Average number of legal-sized trout (8″ plus) increased by 156%, annual production increased by 17%, and mean standing crop of trout increased by 40%. Age 1+ trout accounted for 78% of average standing crop before alteration, but 87% after. Yield increased by 196% and food consumption increased by 28%.

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| Hunt, R. L. 1976. A long-term evaluation of trout habitat development and its relation to improving management-related research. Trans. Am. Fish. Soc. 105:361–364. | Large woody debris. Mean annual biomass of trout, mean annual number of trout over 15 cm, and annual production increased significantly during the 3 years following development, but even more so during the second 3 years. Maximum number and biomass and number of legal trout did not occur until 5 years after completion of the development. Peak number of brook trout more than 20 cm was reached the sixth year postdevelopment. |
| Hunt, R. L. 1988. A compendium of 45 trout stream habitat development evaluations in Wisconsin during 1953–1985. Wisconsin Dept. Natural Resources, Madison. | Forty-five case studies. Success was judged on the basis of percentage changes within treatment zones for each of six possible variables standardized to "per mile:" total number of trout, number of 6″ or larger (legal size), number of 10″ or larger (quality size), total biomass, angler hours, and angler harvest. Level 1 success = postdevelopment variable increases of 25% or more, Level 2 = increases of 50% or more. Approximately 60% of the quantified changes in the six 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. Approximately 72% of the 185 measurements of change among the four standardized population variables in these zones were positive, 26% were negative, and 2% showed no average change. Average empirical postdevelopment changes for the population's wild trout in 41 treatment zones included a 21% increase in number of 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 lb/mile). |
| Huusko, A., and T. Yrjänä. 1995. Evaluating habitat restoration of rivers channelized for log transport: A case study of the River Kutinjoki, northern Finland. Bulletin Français de la Pêche et de la Pisciculture 337–339:407–413. | 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. The restoration increased the river width from 22% to 53%. |

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| Huusko, A., and T. Yrjänä. 1997. Effects of instream enhancement structures on brown trout, Salmo trutta L., habitat availability in a channelized boreal river: a PHABSIM approach. Fish. Manag. Ecol. 4:453–466. | 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 riverbed 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 postrehabilitation areas. Improved habitat conditions were able to sustain a larger trout population. |
| Hvidsten, N. A., and B. O. Johnsen. 1992. River bed construction: Impact and habitat restoration for juvenile Atlantic salmon, Salmo salar L., and brown trout, Salmo trutta L. Aquacult. Fish. Manag. 23:489–498. | 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 were seven fish per 100 $m^2$ prior to draining. After restoration, densities of juvenile salmon varied from 25 to 125 fish per 100 $m^2$. |
| Jähnig, S. C., K. Brabec, et al. 2010. A comparative analysis of restoration measures and their effects on hydromorphology and benthic invertebrates in 26 central and southern European rivers. J. Appl. Ecol. 47:671–680. | Hydromorphology and invertebrates. Mean Shannon-Wiener indices for both mesohabitats (1–1 nonrestored, 1–7 restored) and microhabitats (1–0 nonrestored, 1–3 restored), while Shannon-Wiener indices for invertebrate communities were not significantly different (2–4 nonrestored, 2–3 restored). |

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| Jester, D. B., and H. J. McKirdy. 1966. Evaluation of trout stream improvement in New Mexico. Proc. Annu. Conf. Western Assoc. State Game Fish Comm. 46:316–333. | Logs and boulders. A mean increase of 3.5 feet in width provided 36 additional acres of water. Increase of approximately 3″ in mean depth and volume has almost doubled from 639 to 1,226 acre feet. Minor changes in water temperature occurred. Silt caused significant decreases in depth of pools on the upstream side of structures in six of 32 streams observed. Increases of invertebrates were found at 14 stations, no change at two, and decreases at two. Thirty-six additional acres of water have provided habitat for stocking increase of 6,840 lb or 34,200 rainbow trout annually. Overwinter survival was enhanced by presence of structures. Of 122 tagged fish, 97 were recaptured at the release sites, 19 moved past one structure, 5 moved past two structures, and 1 moved past three structures. Total spread from this movement was approximately 300 feet. Mean catch rate in all 11 streams and sections has increased from .79 to .89 trout per man-hour. Water temperature increased at six of 16 stations and remained stable or decreased at 10 stations in eight streams. Mean temperature in all eight streams decreased 2°F. No change in chemical composition. |
| Johnson, S. L., J. D. Rodgers, et al. 2005. Effects of an increase in large wood on abundance and survival of juvenile salmonids (*Oncorhynchus* spp.) in an Oregon coastal stream. Can. J. Fish. Aquat. Sci. 62(2):412–424. | Large woody debris. 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 and steelhead smolt populations increased in the reference stream, although steelhead freshwater survival did not. Coho salmon populations remained unchanged in the reference stream. The number of key pieces of wood increased from 7.1 pieces $km^{-1}$ in the pretreatment count to 38.8 pieces $km^{-1}$ in the post-treatment count. The increase was observed in all four reaches in the main stem, where the number of key pieces increased 2.5 times in Reach 1, 5.7 times in Reach 2, 7.4 times in Reach 3, and 10.4 times in Reach 4. Results illustrate the potential shortcomings of the before-after control-impact design under field conditions and the potential for misinterpreting results. |

Jones, N. E., and W. M. Tonn. 2004. Enhancing productive capacity in the Canadian Arctic: Assessing the effectiveness of instream habitat structures in habitat compensation. Trans. Am. Fish. Soc. 133:1356–1365.

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.

Kasahara, T., and A. R. Hill. 2006a. Effects of riffle-step restoration on hyporheic zone chemistry in N-rich lowland streams. Can. J. Fish. Aquat. Sci. 63(1):120–133.

The effect of constructed riffles and a step on hyporheic exchange flow and chemistry in restored reaches of several nitrate-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 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 dissolved oxygen 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.

Kasahara, T., and A. R. Hill. 2006b. Hyporheic exchange flows induced by constructed riffles and steps in lowland streams in southern Ontario, Canada. Hydrol. Process. 20:4287–4305.

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 greater than 10% stream water zone in a small and a large constructed riffle extended to greater than 0•2 m and greater than 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.

Keim, R. F., A. E. Skaugset, et al. 2000. Dynamics of coarse woody debris placed in three Oregon streams. For. Sci. 46(1):13–22.

Coarse woody debris (CWD). 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 three streams for at least 1 year and accumulations associated with key pieces were larger after 3 years 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.

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| Kelly, F. L., and J. J. Bracken. 1998. Fisheries enhancement of the Rye Water, a lowland river in Ireland. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):131–143. | 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. 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 seven sites postworks. Results indicate that the channel became deeper at six of nine sites due to increase in the number of pools. Velocity and discharge values were lower at all cross sections, while maximum depth increased at all sites. |
| Kennedy, G. J. A., and P. M. Johnston. 1986. A review of salmon (*Salmo salar L.*) research on the River Bush. *In* W. W. Crozier and P. M. Johnson (eds.), Proceedings of the 17th Annual Study Course, p. 49–69. Univ. Ulster, Institute of Fisheries Management, Coleraine, UK. | Atlantic salmon. Areas that were drained 20–30 years prior by straightening the river channel and removing the substrate had very low densities of salmonids compared to undrained areas. After re-stoning, there was a highly significant correlation of total fish densities to the proportion of the substrate comprised of stones greater than 10 cm diameter at each site. There was no significant correlation of total fish density to water depth within the narrow range of site depths investigated. Following restocking of salmon fry, the mean survival was more than four times greater in the control sites (mean density 33.8 per 100 $m^{-2}$) than in the drained sites (mean density 7.5 per 100 $m^{-2}$). |

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| Klassen, H. D. 1991. Operational stream rehabilitation trial at Clint Creek, Sewell Inlet. Land Management Rep. No. 68. Ministry of Forests, Victoria, BC. | Large woody debris. No significant changes in stream width. Number of pools in the thalweg increased from four before rehabilitation to 18 after and to 13 pools 7 months later. Several sediment lobes dispersed with rehabilitation, 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 rehabilitation. There was a reduction of the majority of overhanging vegetation. Critical overwinter rearing habitat tripled and habitat diversity more than doubled. Fifty percent of the logs were underscoured, reducing average pool depths but also adding diversity. Sediment storage areas averaging approximately 14 $m^2$ per log developed over the winter. Streambank erosion from rehabilitation averaged 1 m per log. |
| Klassen, H. D., and T. G. Northcote. 1988. Use of gabion weirs to improve spawning habitat for pink salmon in a small logged watershed. N. Am. J. Fish. Manag. 8(1):36–44. | 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/hr 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 reference sites. |
| Knaepkens, G., L. Bruyndoncx, et al. 2004. Spawning habitat enhancement in the European bullhead (*Cottus gobio*), an endangered freshwater fish in degraded lowland rivers. Biodivers. Conserv. 13(13):2443–2452. | Tiles as artificial spawning substrate. Tiles were successfully used by European bullhead for spawning . Of the 100 recovered tiles, 69 had one egg cluster, 25 tiles had two clusters, three tiles had three clusters, two tiles had four clusters, and one tile had five egg clusters, indicating a 30% use of recovered tiles as spawning substrate. 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. |
| Koljonen, S., A. Huusko, et al. 2012. Body mass and growth of overwintering brown trout in relation to stream habitat complexity. River Res. Appl. 28(1):62–70. | Brown trout. Channelized vs. seminatural 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. |

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| Kondolf, G. M., J. C. Vick, et al. 1996. Salmon spawning habitat rehabilitation on the Merced River, California: An evaluation of project planning and performance. Trans. Am. Fish. Soc. 125:899–912. | Riffle reconstruction with gravel. In the 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 to 1994 were 16, 8, 41, 46, and 56, respectively. |
| Korsu, K. 2004. Response of benthic invertebrates to disturbance from stream restoration: The importance of bryophytes. Hydrobiologia 523(1–3):37–45. | Boulders. Response of invertebrates to disturbance. Restoration procedure destroyed nearly half of the bryophytes present in the study reach and invertebrate densities decreased sharply immediately after restoration (total number reduced by 50% on day 1 and 83% on day 4). Within 2 weeks, invertebrates had recolonized the disturbed reach and, within 1 month, peak numbers were attained. Invertebrates showed a clear association with bryophytes, especially after restoration. |
| Laasonen, P., T. Muotka, et al. 1998. Recovery of macroinvertebrate communities from stream habitat restoration. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):101–113. | 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 3 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 invertebrates 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. |

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| Lacey, R. W. J., and R. G. Millar. 2004. Reach scale hydraulic assessment of instream salmonid habitat restoration. J. Am. Water Resour. Assoc. 40(6):1631–1644. | Large woody debris and rock groyne. 2-D flow model velocity and depth predictions compare favorable to measured field values with mean SEs 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%. The most beneficial aspect of instream structures is to increase preferred habitat areas during high flow events for steelhead and coho salmon fry and juveniles. Structures create low velocity zones on their downstream sides where fish can hold and rest. |
| Laitung, B., J. L. Pretty, et al. 2002. Response of aquatic hyphomycete communities to enhanced stream retention in areas impacted by commercial forestry. Freshw. Biol. 47(2):313–323. | Large woody debris. The average concentration of fungal spores in reference sections was nearly 10 times greater in French streams than in English. The number of hyphomycete species was also higher in French streams. The difference was 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. Large woody debris can increase detritus retention and enhance hyphomycete diversity and productivity. |
| Larson, M. G., D. B. Booth, et al. 2001. Effectiveness of large woody debris in stream rehabilitation projects in urban basins. Ecol. Eng. 18:211–226. | Large woody debris (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 on low-gradient streams. |

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| Latta, W. C. 1972. The effects of stream improvement upon the anglers catch and standing crop of trout in the Pigeon River, Otsego County, Michigan. Michigan Dept. Natural Resources, Ann Arbor. | Large woody debris. 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 more than 3 feet deep and decline in the amount of cover, but little or no change in bottom soil types. |
| Lawrence, J. E., V. H. Resh, et al. 2013. Large wood loading from natural and engineered processes at the watershed scale. River Res. Appl. 29(8): 1030–1041. | 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. |
| Lehane, B. M., P. S. Giller, et al. 2002. Experimental provision of large woody debris in streams as a trout management technique. Aquat. Conserv.: Mar. Freshw. Ecosyst. 12(3):289–311. | Large woody debris. 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 large woody debris. Pool habitat increased from 16% of total surface area to 35%; riffles decreased from 31% to 25%. Preinstallation (March 1998) fish survey had 664 trout in two reaches; postsurveys captured 1,170 (Sept. 1998), then 670 (1999), and finally 523 (2000). Recapture rates suggest that loss rates over time appear to be lower in debris segments. |

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| Lemly, A. D., and R. H. Hilderbrand. 2000. Influence of large woody debris on stream insect communities and benthic detritus. Hydrobiologia 421(1):179–185. | Large woody debris (LWD). After LWD additions, total area occupied by pools more than doubled (from 222 $m^2$ to 546 $m^2$) concurrent with a 42% decrease in riffle area (from 768 $m^2$ to 443 $m^2$). Pools contained significantly more benthic detritus than riffles but showed no post-treatment response of LWD relative to the reference 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. |
| Lepori, F., D. Palm, et al. 2005a. Does restoration of structural heterogeneity in streams enhance fish and macroinvertebrate diversity? Ecol. Appl. 15(6):2060–2071. | 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 invertebrates were comparable between restored and channelized sites. Despite substantial differences in heterogeneity across different spatial scales, most components of fish and invertebrate diversity were similar between restored and channelized sites. |
| Lepori, F., D. Palm, et al. 2005b. Effects of stream restoration on ecosystem functioning: Detritus retentiveness and decomposition. J. Appl. Ecol. 42(2):228–238. | 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 reference 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 temperature and shredder abundance. CPOM mass loss was similar between restored and reference sites, however, breakdown was slightly faster at most channelized sites. |

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| Lester, R. E., and W. Wright. 2009. Reintroducing wood to streams in agricultural landscapes: Changes in velocity profile, stage, and erosion rates. River Res. Appl. 25(4):376–392. | 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. |
| Linlokken, A. 1997. Effects of instream habitat enhancement on fish population of a small Norwegian stream. Nord. J. Freshw. Res. 73:50–59. | Weirs. The mean density of brown trout in the experimental section was 18.3 per 100 m prior to enhancement, and increased by 200% after weir construction. The increase was due to increased number of specimens greater than 10 cm, whereas number of fish less than 10 cm decreased. |
| Lonzarich, D. G., and T. P. Quinn. 1995. Experimental evidence for the effect of depth and structure on the distribution, growth, and survival of stream fishes. Can. J. Zool. 73:2223–2230. | Large woody debris. 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 trout and steelhead were almost never collected in shallow pools—100% of cutthroat and 83% of steelhead were found in two deepwater treatments. Habitat selection by age-0 trout was strongly associated with structure, as fish were three times more abundant in structured (75%) than in unstructured treatments (25%). Age-1+ cutthroat trout and coastrange sculpin were positively associated with deep-water habitat, age-0 trout were associated with structure, and age-1+ steelhead and coho salmon 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 salmon 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-nonstructures treatment (29% and 33%, respectively). Water depth appeared to be more important than structure in determining the distribution of large age-1+ cutthroat trout and steelhead, while structure alone (age-0 trout) or both structure and depth (coho salmon) were important for the small salmonids. |

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| Louhi, P., H. Mykra, et al. 2011. Twenty years of stream restoration in Finland: Little response by benthic macroinvertebrate communities. Ecol. Appl. 21(6):1950–1961. | Following treatment, invertebrate densities decreased in all treatments, but less so in the controls. Taxonomic richness also decreased. In the long-term comparative study, invertebrate species richness shows 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. |
| Lyons, J., and C. C. Courtney. 1990. A review of fisheries habitat improvement projects in warm water streams, with recommendations for Wisconsin. Tech. Bull. No. 169. Wisconsin Dept. Natural Resources, Madison. | Case studies. Little specific information. Five recommendations for habitat improvements. Large woody debris and boulders. Some studies showed increases in fish, some with no change, and a few with decreases. |
| MacInnis, C., T. A. Floyd, et al. 2008. Large woody debris structures and their influence on Atlantic salmon spawning in a stream in Nova Scotia, Canada. N. Am. J. Fish. Manag. 28(3):781–791. | Atlantic salmon. Redd counts increased for the first 4 years after restoration from 43 in 1992 to 592 in 1996. After that, redd 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. |
| McCubbing, D. J. F., and B. R. Ward. 1997. The Keogh and Waukwaas rivers paired watershed study for B.C.'s Watershed Restoration Program: Juvenile salmonid enumeration and growth 1997. Ministry of Environment, Lands, and Parks and Ministry of Forests, Vancouver, BC. | Large woody debris, boulders, nutrients. Complex lateral debris jams had highest coho salmon fry densities (mean = 80 fry per 100 $m^2$), while boulder clusters had greatest steelhead parr abundance (mean = 6 parr per 100 $m^2$) or average 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 (5–10 cm) and weight (>30%) of coho fry and steelhead fry in fertilized areas compared to untreated areas. |

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| McCubbing, D. J. F., and B. R. Ward. 2000. Stream rehabilitation in British Columbia's Watershed Restoration Program: Juvenile salmonid response in the Keogh and Waukwaas rivers 1998. Ministry of Environment, Lands, and Parks and Ministry of Forests, Vancouver, BC. | Large woody debris (LWD), nutrients, boulders. Significant increases were found in steelhead parr and fry abundance and coho salmon fry abundance overall at the watershed level and in reaches treated with structures, compared to untreated controls 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 average increase of 20 parr per 100 m within reaches of the Keogh, a mean increase of 110%. In contrast, three of four 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 salmon fry densities were lower in both watersheds compared to 1997 data, except in the uppermost 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. |
| Merz, J. E., and L. K. O. Chan. 2005. Effects of gravel augmentation on macroinvertebrate assemblages in a regulated California river. River Res. Appl. 21(1):61–74. | 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 in unenhanced sites. |

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| Merz, J. E., and J. D. Setka. 2004. Evaluation of a spawning habitat enhancement site for Chinook salmon in a regulated California River. N. Am. J. Fish. Manag. 24(2):397–407. | 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 salmon began spawning at the previously unused site within 2 months after gravel placement and continued to use the site during the three spawning seasons encompassed by the study. Average bed elevation increased by .12 m and average velocities increased by .24 m/s. |
| Merz, J. E., J. D. Setka, et al. 2004. Predicting benefits of spawning-habitat rehabilitation to salmonid (*Oncorhynchus* spp.) fry production in a regulated California river. Can. J. Fish. Aquat. Sci. 61(8):1433–1446. | 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. |
| Miller, S. W., P. Budy, et al. 2010. Quantifying macroinvertebrate responses to instream habitat restoration: Applications of meta-analysis to river restoration. Restor. Ecol. 18(1):8–19. | No fish. Meta-analysis of 24 separate studies. Increasing habitat heterogeneity had significant, positive effects on macroinvertebrate richness, although density increases were negligible. Large woody debris produced the largest and most consistent responses, whereas responses to boulder additions and channel reconfigurations were positive yet highly variable. On average, richness estimates in restored reaches were 14.2% greater than in unrestored control reaches and density estimates were 28% greater. On average, richness and density increases were greater for large woody debris than boulder additions, 83% and 75%, respectively. |
| Miller, J. R., and R. C. Kochel. 2010. Assessment of channel dynamics, instream structures, and postproject channel adjustments in North Carolina and its implications to effective stream restoration. Environ. Earth Sci. 59(8):1681–1692. | 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. |

Mitchell, J., R. S. McKinley, et al. 1998. Evaluation of Atlantic salmon parr responses to habitat improvement structures in an experimental channel in Newfoundland, Canada. Regul. Rivers: Res. Manag. 14(1):25–39.

Boulders. Results showed that the midchannel 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 streambank treatment, and salmon parr in the midchannel 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. No significant differences were found in the densities of benthic invertebrates in each replicate or treatment. The drift in the channel was significantly different than the drift in the reference site.

Moore, K. M. S., and S. V. Gregory. 1988. Response of young-of-the-year cutthroat trout to manipulation of habitat structure in a small stream. Trans. Am. Fish. Soc. 117(2):162–170.

Large woody debris. Cutthroat trout. Young-of-the-year 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 average number of age-0 fish. Straightening stream sections reduced the area of lateral habitat 86% and resulted in an 83% reduction in average number of age-0 cutthroat trout.

Moreau, J. K. 1984. Anadromous salmonid habitat enhancement by boulder placement in Hurdygurdy Creek, California. *In* T. J. Hassler (ed.), Proceedings: Pacific Northwest Stream Habitat Management Workshop, p. 97–116. Humboldt State Univ., Arcata, CA.

Steelhead and Chinook salmon. Population estimates for steelhead parr increased by 100% 2 years after boulder placement in one stream section, while estimates in two control sections declined by 56% and 61%. Large areas of spawning gravel were created, increases in both steelhead parr habitat and gravel spawning areas were attained, and costs ranged from \$41 to \$77 per $m^3$.

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| Morley, S. A., J. D. Toft, et al. 2012. Ecological effects of shoreline armoring on intertidal habitats of a Puget Sound urban estuary. Estuar. Coasts 35(3):774–784. | Fourteen fish species. Mean substrate temperatures were significantly warmer at armored sites, but water temperature was similar to unarmored habitats. Epibenthic invertebrate densities were more than 10 times greater on unarmored shorelines and taxa richness double that of armored locations. Taxa richness of neuston invertebrates was also higher at unarmored sites, but abundance was similar. There was no difference in Chinook salmon diet, but a higher proportion of benthic prey for chum salmon was observed from unarmored sites. |
| Mueller, G., and C. R. Liston. 1994. Use of low-profile artificial cover to enhance fisheries found in concrete lined irrigation canals, Arizona-California. Bull. Mar. Sci. 55(2–3):1347. | Abstract only. Low-profile artificial reefs. Fish and invertebrate data indicated reefs significantly benefitted aquatic organisms. Fish species diversity increased by 120% and abundance was 20 times greater than at control sites. No species named. |
| Muotka, T., and P. Laasonen. 2002. Ecosystem recovery in restored headwater streams: The role of enhanced leaf retention. J. Appl. Ecol. 39(1):145–156. | Boulders. Leaf retention. Substrate heterogeneity increased by moss cover decreased dramatically. Retention efficiency in restored streams was higher than in channelized, but lower than in natural streams. Algae-feeding scrapers were the only macroinvertebrate whose density increased significantly: three times higher in restored than in channelized streams. |
| Muotka, T., R. Paavola, et al. 2002. Long-term recovery of stream habitat structure and benthic invertebrate communities from instream restoration. Biol. Conserv. 105(2):243–253. | Boulders/gravel. Invertebrate communities in unmodified streams changed little, whereas those in restored streams had undergone considerable changes. |
| Nagayama, S., F. Nakamura, et al. 2012. Effects of configuration of instream wood on autumn and winter habitat use by fish in a large remeandering reach. Hydrobiologia 680(1):159–170. | Twelve fish species including rainbow trout, chum salmon, masu salmon, and white-spotted charr. No good numbers. Fish diversity was higher at the simple wood structure (SWS) and the logjam (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 diverse flow conditions during autumn. During the winter, the LJ sites had slower currents and finer bed materials. |

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| Naslund, I. 1989. Effects of habitat improvement on the brown trout, *Salmo trutta L.*, population of a northern Swedish stream. Aquacult. Fish. Manag. 20:463–474. | Boulders and logs. Boulder dams increased brown trout densities by up to three times and standing crop by up to five times. Log deflectors gave similar effects on standing crop while boulder groupings and boulder deflectors seemed to be inefficient. |
| Negishi, J. N., and J. S. Richardson. 2003. Responses of organic matter and macroinvertebrates to placements of boulder clusters in a small stream of southwestern British Columbia, Canada. Can. J. Fish. Aquat. Sci. 60:247–258. | 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 invertebrate abundance (280%). Effect of boulder clusters on taxonomic richness was negligible. |
| Newbury, R., and M. Gaboury. 1988. The use of natural stream characteristics for stream rehabilitation works below the Manitoba escarpment. Can. Water Resour. J. 14(4):35–51. | Riffles and boulders. Based on egg density measurements, more walleye spawned on the paired riffles (3.6 eggs/sq. mile) than on the single riffles (1.1 eggs/sq. mile). The number of newly hatched walleye larvae caught below paired riffles was significantly greater than the number caught below any single riffles. |
| Newbury, R., and M. Gaboury. 1993. Exploration and rehabilitation of hydraulic habitats in streams using principles of fluvial behaviour. Freshw. Biol. 29(2):195–210. | Riffles and boulders. Walleye, brook trout, and rainbow trout. Inconclusive results. |
| Nickelson, T. E., M. F. Solazzi, et al. 1992. Effectiveness of selected stream improvement techniques to create suitable summer and winter rearing habitat for juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49(4):790–794. | Log, gabion, and rock. When placed across the full stream width, structures provided good summer habitat but poor winter habitat for juvenile coho salmon. No numbers. |

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| Nicol, S. J., J. A. Lieschke, et al. 2004. Observations on the distribution and abundance of carp and native fish, and their responses to a habitat restoration trial in the Murray River, Australia. New Zealand J. Mar. Freshw. Res. 38(3):541–551. | Large woody debris (LWD). Carp and native fish. Little support that competition for LWD habitat has population level effects; there was a statistically significant relationship between native fish, LWD, and location within a meander and curvature of the meander. Carp response to LWD placement was inconclusive. |
| O'Grady, M. 1995. The enhancement of salmonid rivers in the Republic of Ireland. J. Chartered Institution Waters Environ. Manag. 9:164–172. | Boulders and brush removal. All numbers were estimates. Enhancement costs were estimated as £0.34–2.13 per fish caught on a rod and line. Shrub-pruning salmon production was estimated at ≥£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. |
| O'Grady, M. F., J. J. King, et al. 1991. The effectiveness of two physical instream works programmes in enhancing salmonid stocks in a drained Irish lowland river system. *In* D. Mills (ed.), Strategies for the rehabilitation of salmon rivers—Proceeding of a joint conference held at The Linnean Society, p. 154–178. The Atlantic Salmon Trust, The Institute of Fisheries Management, and The Linnean Society of London, London, UK. | Rubble and brush removal. Velocity increased (7.5 cm/s in control to 46.2 cm/s in treatment). Depth decreased from 176.7 cm in control location to 34 cm in treatment with rubble mats. |
| Overton, K., W. A. Brock, et al. 1981. Restoration and enhancement program of anadromous fish habitat and populations on Six Rivers National Forest. *In* T. J. Hassler (ed.), Proceedings: Propagation, Enhancement, and Rehabilitation of Anadromous Salmonid Populations and Habitat in the Pacific Northwest Symposium, p. 158–168. Humboldt State Univ., Arcata, CA. | Boulders. Steelhead and Chinook salmon. Project resulted in a twofold and a fourfold 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 in the treated section. Treatment reach increased 19% in surface area and streamflow volume increased 75% where boulders were placed in clusters. The increase in pool stilling area averaged 1.10 $m^3$ 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%. |

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| Palm, D., E. Brannas, et al. 2007. The influence of spawning habitat restoration on juvenile brown trout (*Salmo trutta*) density. Can. J. Fish. Aquat. Sci. 64:509–515. | Boulders. Brown trout. After restoration, density of age 0+ trout increased significantly in the boulder-plus-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, whereas 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-plus-gravel section compared to the boulder-only section, 10.3% (±2.6) vs. 1.7% (±1.1). |
| Paulsen, C. M., and T. R. Fisher. 2005. Do habitat actions affect juvenile survival? An information-theoretic approach applied to endangered Snake River Chinook salmon. Trans. Am. Fish. Soc. 134(1):68–85. | 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. |
| Pess, G. R., M. C. Liermann, et al. 2012. Juvenile salmon response to the placement of engineered logjams in the Elwha River, Washington State, USA. River Res. Appl. 28(7):872–881. Online at http://dx.doi.org [DOI name 10.1002/rra.1481, accessed 12 December 2013]. | Chinook salmon, coho salmon, and trout. Juvenile salmonid density was higher in engineered logjam (ELJ) units for all control-treatment pairs except one in 2002 and 2003. Positive mean differences in juvenile densities between ELJ and non-ELJ units were observed in 2 of 4 years for all juvenile salmon, trout greater than 100 mm, and juvenile Chinook salmon. Positive mean differences occurred in 1 of 4 years for juvenile coho salmon and trout less than 100 mm. |

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| Peters, R. J., B. R. Missildine, et al. 1998. Seasonal fish densities near river banks stabilized with various stabilization methods. U.S. Fish and Wildlife Service, Lacey, WA. | Summary of studies. No specific numbers. Examined seasonal fish densities at streambanks stabilized using riprap, riprap with large woody debris (LWD) incorporated into the project, rock deflectors, rock deflectors with LWD (combination projects), and LWD. LWD-stabilized sites were the only project types that consistently had greater fish densities than their control areas during spring, summer, and winter surveys. Riprap sites consistently had lower fish densities than their control sites during all surveys. Fish densities were generally lower at deflector sites than their controls during the spring and summer, but greater during the winter. Although large differences (between stabilized sites and controls) existed in some cases, the differences were rarely statistically significant due to high variation and small sample size. Instream LWD cover and overhead riparian cover were the habitat variables that most consistently influenced fish densities at stabilized and control sites surveyed. Fish densities were generally positively correlated with increasing surface area of LWD and increased overhead riparian cover within 30 cm of the water surface. |
| Pierce, R., C. Podner, et al. 2013. Response of wild trout to stream restoration over two decades in the Blackfoot River basin, Montana. Trans. Am. Fish. Soc. 142(1):68–81. | 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 after 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 years) average response trends were positive, trends varied spatially and native trout responded more strongly in the upper portion of the basin. |
| Poulin, V. A., and Associates Ltd. 1991. Stream rehabilitation using LWD placements and off-channel pool development. Ministry of Forests, Victoria, BC. | Large woody debris, gabion. Coho salmon, rainbow trout, and Dolly Varden trout. Juvenile salmonid response to large organic debris structures was positive, with substantially increased densities after construction in two creeks (from 1% to 210% and from 13% to 194% of control densities). Juvenile densities in blast pool sections of one tributary increased substantially after construction (from 61% to 485%). |

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| Pretty, J. L., and M. Dobson. 2001. A possible strategy for enhancing the stream biota in areas of intensive commercial forestry. Int. Assoc. Theor. Appl. Limnol. 27(2):1075–1078. | Large woody debris. No numbers. Increases in detritus levels were slight, standing stocks remained very low, and the invertebrate fauna was unaffected. |
| Pretty, J. L., S. S. C. Harrison, et al. 2003. River rehabilitation and fish populations: Assessing the benefit of instream structures. J. Appl. Ecol. 40(2):251–265. | 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 (*Cottus gobio*) and stone loach. |
| Price, D. J., and W. J. Birge. 2005. Effectiveness of stream restoration following highway reconstruction projects on two freshwater streams in Kentucky. Ecol. Eng. 25(1):73–84. | Riprap, vegetation. Nonsalmonids (bass, sunfish, darters). No good numbers. A decrease in total habitat assessment scores was observed at the remediated sector in each stream. However, the Index of Biological Integrity fish assemblage scores were similar for upstream and remediated sectors, indicating that habitat impact resulted in limited effects on assemblages. |
| Pulg, U., B. T. Barlaup, et al. 2013. Restoration of spawning habitats of brown trout (*Salmo trutta*) in a regulated chalk stream. River Res. Appl. 29(2):172–182. | 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 young-of-the-year brown trout increased clearly after restoration. Sediment on the test sites collimated 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 after restoration. |
| Purcell, A. H., C. Friedrich, et al. 2002. An assessment of a small urban stream restoration project in northern California. Restor. Ecol. 10(4):685–694. | No numbers. Both biological and habitat quality improved in the restored compared with the unrestored section, but the restored area was of lower quality than a stream restored 12 years before. |
| Quinn, J. W., and T. J. Kwak. 2000. Use of rehabilitated habitat by brown trout and rainbow trout in an Ozark tailwater river. N. Am. J. Fish. Manag. 20(3):737–751. | Large woody debris and rocks. Brown, rainbow, brook, and cutthroat trout. Rainbow and brown trout accounted for most of the total trout density (87%) and biomass (97%) in the reference reach and modified reach (76% density, 90% biomass). Mean total trout density was 463 fish/ha (103 kg/ha) in the reference reach and 1,854 fish/ha (252 kg/ha) in the modified reach. |

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| Raborn, S.A., and H. L. Schramm Jr. 2003. Fish assemblage response to recent mitigation of a channelized warm-water stream. River Res. Appl. 19:289–301. | Large woody debris/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. Eighty-five species. |
| Reeves, G. H., D. B. Hohler, et al. 1997. Fish habitat restoration in the Pacific Northwest: Fish Creek of Oregon. *In* J. E. Williams, C. A. Wood, et al. (eds.), Watershed restoration: Principles and practices, p. 335–359. American Fisheries Society, Bethesda, MD. | Large woody debris. Juvenile coho salmon 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 young-of-the-year 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 age-1 steelhead were on average 12.5% and 4.1% larger, respectively, in the period after restoration. |
| Reich, M., J. L. Kershner, et al. 2003. Restoring streams with large wood: A synthesis. American Fisheries Society, Bethesda, MD. | Large woody debris. Synthesis of case studies. Gives project details but not results. |
| Riley, S. C., and K. D. Fausch. 1995. Trout population response to habitat enhancement in six northern Colorado streams. Can. J. Fish. Aquat. Sci. 52:34–53. | Large woody debris. 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 $m^3$ to 115–150 $m^3$. Cover increased significantly. Abundance and biomass of adult trout (age-2 or older) and often juveniles (age-1) increased significantly. |
| Rinne, J. N. 1982. Movement, home range, and growth of a rare southwestern trout in improved and unimproved habitats. N. Am. J. Fish. Manag. 2(2):150–157. | One hundred twenty-nine recaptured Gila trout moved less than 0.1 km and grew less in streams containing larger fish populations and in streams containing log improvement structures. Those that moved traveled greater distances downstream; less than 2% moved upstream over structures and such movement was limited by structures ≥0.5 m high. |

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| Rodgers, J. D., S. L. Johnson, et al. 1993. The seasonal use of natural and constructed habitat by juvenile coho salmon (*Oncorhynchus kisutch*) and preliminary results from two habitat improvement projects on smolt production in Oregon coastal streams. *In* L. Berg and P. W. Delaney (eds.), Proceedings of the coho workshop, Nanaimo, BC, May 26–28, 1992, p. 334–351. DFO Canada, Vancouver, BC. | Large woody debris/alcoves. Juvenile coho salmon. Average overwinter survival increased from 11% in one creek to 51% the first year, and 40% the second year after treatment. In another creek it increased from 14% to 63% in the first year. Fork length increased more in treatment reaches than in control streams. |
| Roni, P. 2003. Responses of benthic fishes and giant salamanders to placement of large woody debris in small Pacific Northwest streams. N. Am. J. Fish. Manag. 23:1087–1097. | Large woody debris. Densities and mean lengths of giant salamanders, reticulate sculpins, torrent sculpins, and lampreys did not differ significantly between treatment and control reaches. Lamprey densities and length of age-1 and older reticulate sculpins among streams were positively correlated with large woody debris within the wetted channel. Lamprey lengths were also positively correlated with differences in percent of pool area. |
| Roni, P., T. Bennett, et al. 2006. Rehabilitation of bedrock stream channels: The effects of boulder weir placement on aquatic habitat and biota. River Res. Appl. 22(9):967–980. | Boulders. Pool area, number of boulders, total large woody debris (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 salmon and trout were higher in treatment reaches, while dace were more abundant in control reaches. |

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| Roni, P., and T. P. Quinn. 2001a. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Can. J. Fish. Aquat. Sci. 58(2):282–292. | Large woody debris (LWD). Juvenile coho salmon densities were 1.8 times and 3.2 times higher in treated reaches compared with reference reaches during summer and winter, respectively. Densities of age-1+ cutthroat trout and steelhead did not differ between treatment and reference reaches during summer, but were 1.7 times higher in treatment reaches during winter. Total pieces of LWD per 100 m was significantly higher in treatment than in reference reaches during summer (20–80 vs. 8–63) and winter (16–78 vs. 4–64) and averaged 1.83 times 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 reference reaches during summer and winter and averaged 2.83 times and 2.96 times greater in treatment than in reference reaches. Pool area in treatment reaches averaged 1.52 times that in reference 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 reference reaches in summer and 1.48 times more in winter. Total number of habitat units was 1.11 times and 1.22 times higher in treatment than in reference reaches during summer and winter, respectively. |
| Roni, P., and T. P. Quinn. 2001b. Effects of wood placement on movements of trout and juvenile coho salmon in natural and artificial stream channels. Trans. Am. Fish. Soc. 130:675–685. | Large woody debris. Juvenile coho salmon, steelhead, and cutthroat trout. Zero to 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 did not. |

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| Roni, P., D. Van Slyke, et al. 2008. Adult coho salmon and steelhead use of boulder weirs in southwest Oregon streams. N. Am. J. Fish. Manag. 28(3):970–978. | Boulders. Coho salmon and steelhead. Number of coho spawners and peak redd counts were significantly higher in treatment reaches than in control reaches (average 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 tributary reaches were higher than those in mainstem reaches either with or without boulder weirs. Spawner density and redd density were positively correlated with percent gravel. Of observed redds, 43% were located within 10 m of a boulder weir. More than 80% of those redds were within 3 m upstream of a boulder weir. |
| Roper, B., D. Konnoff, et al. 1998. Durability of Pacific Northwest instream structures following floods. N. Am. J. Fish. Manag. 18:686–693. | 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 two times as likely (25%) 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 combination of logs and boulders (57%). Structures were less durable in the 20% of the subbasins having the highest landslide frequencies. |
| Rosenfeld, J., D. Hogan, et al. 2011. Contrasting landscape influences on sediment supply and stream restoration priorities in northern Fennoscandia (Sweden and Finland) and coastal British Columbia. Environ. Manag. 47(1):28–39. | 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. |
| Rosi-Marshall, E. J., A. H. Moerke, et al. 2006. Ecological responses to trout habitat rehabilitation in a northern Michigan stream. Environ. Manag. 38:99–107. | Large woody debris and k-dams increased the relative abundance of harvestable trout (>25 cm), but not overall trout abundances. Both techniques increased maximum channel depth and organic matter retention, but only k-dams increased overall habitat quality. Macroinvertebrate density, diversity, and functional feed group composition were not significantly affected by the treatments. The percent of harvestable trout was three times higher in the skyboom reach than in the control reach. |

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| Rubin, J. F., C. Glimsäter, et al. 2004. Characteristics and rehabilitation of the spawning habitats of the sea trout, *Salmo trutta*, in Gotland (Sweden). Fish. Manag. Ecol. 11:15–22. | 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. |
| Saunders, J. W., and M. W. Smith. 1962. Physical alteration of stream habitat to improve brook trout production. Trans. Am. Fish. Soc. 91:185–188. | Boulders, large woody debris. 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. |
| Schmetterling, D. A., and R. W. Pierce. 1999. Success of instream habitat structures after a 50-year flood in Gold Creek, Montana. Restor. Ecol. 7(4):369–375. | Large woody debris and rock. Of the original 66 structures, 55 (85%) were intact following the flood. The mean maximum 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. |
| Sear, D. A., and M. D. Newson. 2004. The hydraulic impact and performance of a lowland rehabilitation scheme based on pool-riffle installation: The River Waveney, Scole, Suffolk, UK. River Res. Appl. 20(7):847–863. | 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. |
| Senter, A. E., and G. B. Pasternack. 2011. Large wood aids spawning Chinook salmon (*Oncorhynchus tshawytscha*) in marginal habitat on a regulated river in California. River Res. Appl. 27(5):550–565. | Chinook salmon. Spawners built 85% of redds within one average channel width (31 m) of large wood. Spawners utilized large wood within a 10 m 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. |

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| Shetter, D. S., O. H. Clark, et al. 1949. The effects of deflectors in a section of a Michigan trout stream. Trans. Am. Fish. Soc. 76:248–278. | Log deflectors. Brook trout. Deflectors raised the number of good pools from 9 to 29, increased average pool depth by 6″, and exposed additional gravel without significantly changing the average 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 number of smaller trout present after deflector addition with a slight decrease in average size. Postimprovement showed an increase of 120% in the total catch and of 46% in pounds caught per hour with a 64% increase in angling pressure. |
| Shields Jr., F. D., and C. V. Alonso. 2012. Assessment of flow forces on large wood in rivers. Water Resour. Res. 48(4):W04516. | 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. |
| Shields Jr., F. D., C. M. Cooper, et al. 1993. Initial habitat response to incised channel rehabilitation. Aquat. Conserv.: Mar. Freshw. Ecosyst. 3(2):93–103. | Plantings and boulders. Number 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 7,255% larger than their prerestoration counterparts, respectively. Twelve species were captured postrestoration that were absent prior to restoration. Wood cover increased from 38% to 66%. Mean depth and mean scour hole depth corrected for stage variation increased 44% and 82%, respectively. Mean scour hole width increased 130%. |
| Shields Jr., F. D., S. S. Knight, et al. 1995a. Incised stream physical habitat restoration with stone weirs. Regul. Rivers: Res. Manag. 10:181–198. | Boulders. Restoration increased pool habitat availability, overall physical heterogeneity, riparian vegetation, 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. |

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| Shields Jr., F. D., S. S. Knight, et al. 1995b. Rehabilitation of watersheds with incising channels. Water Resour. Bull. 31(6):971–982. | 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 vegetation 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. |
| Shields Jr., F. D., S. S. Knight, et al. 1998a. Addition of spurs to stone toe protection for warm water fish habitat rehabilitation. J. Am. Water Resour. Assoc. 34(6):1427–1436. | Rock (stone spurs). Spur addition resulted in modest increases in base flow 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. Mean water width and pool habitat availability increased by 16% and 10%, respectively, in the treated reach following spur addition, but mean depth and velocity showed little change. In the immediate vicinity of the spurs, mean depth increased from 30 cm before toe addition to 49 cm 2 years later, and maximum depth increased from about 72 cm to 100 cm. Spurs increased the length of stable, stony shoreline in the treated reach by 24%. Surviving willow posts increased the fraction of sandbar margin supporting vegetation from 0 to 80%. |
| Shields Jr., F. D., S. S. Knight, et al. 1998b. Rehabilitation of aquatic habitats in warm water streams damaged by channel incision in Mississippi. Hydrobiologia 382:63–86. | Large woody debris 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 rehabilitation. |

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| Shields Jr., F. D., S. S. Knight, et al. 2003. Response of fishes and aquatic habitats to sand-bed stream restoration using large woody debris. Hydrobiologia 494:251–257. | Large woody debris 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 second year after rehabilitation. Scour adjacent to the woody debris structures and beaver dams resulted in deeper (nearly two times) and slightly wider aquatic habitats and base flow relative to preconstruction conditions. Mean water width in the treated reached increased from 3 m to 5 m in 2 years. Addition of pool habitat following debris addition increased the fraction of numbers and biomass comprised by centrarchids in the treated reach from 3% to 10% and from 13% to 23%, respectively. |
| Shields Jr., F. D., S. S. Knight, et al. 2006. Large wood addition for aquatic habitat rehabilitation in an incised, sand-bed stream, Little Topashaw Creek, Mississippi. River Res. Appl. 22:803–817. | Large woody debris 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 rehabilitation, but only biomass and size were statistically significant. Thirty-two species. |
| Shields Jr., F. D., N. Morin, et al. 2004. Large woody debris structures for sand-bed channels. J. Hydraul. Eng. 130(3):208–217. | Large woody debris. 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%. Invertebrates showed a positive response to large woody debris both within treatment and downstream. |
| Shuler, S. W., R. B. Nehring, et al. 1994. Diel habitat selection by brown trout in the Rio Grande River, Colorado, after placement of boulder structures. N. Am. J. Fish. Manag. 14:99–111. | Boulders. On average, 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. Eighty-nine percent of juveniles were not associated with structures during the day and 91% of those at night occupied positions near natural cover. |

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| Slaney, P. A., B. O. Rublee, et al. 1994. Debris structure placements and whole-river fertilization for salmonids in a large regulated stream in British Columbia. Bull. Mar. Sci. 55:1160–1180. | Large woody debris and fertilization. Juvenile Chinook salmon highly colonized stream-side debris structures. Fry density was similar to that in natural woody cover. Adult rainbow trout also more extensively colonized debris structures than nonstructure sites. |
| Smokorowski, K. E., and T. C. Pratt. 2007. Effect of a change in physical structure and cover on fish and fish habitat in freshwater ecosystems—a review and meta-analysis. Environ. Rev. 15:15–41. | Meta-analysis of many studies. On the whole, decreases in structural habitat complexity are detrimental to fish diversity and can change species composition. Increases in structural complexity showed increases, decreases, or no measurable changes in species 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. |
| Solazzi, M. F., T. E. Nickelson, et al. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Can. J. Fish. Aquat. Sci. 57:906–914. | Large woody debris. Average winter rearing habitat increased 13 times over that in the previous year, while the reference area stayed the same. Fast water habitat in the treatment stream decreased by about 6,000 $m^2$ but remained relatively constant in the reference stream. Mean summer population of juvenile coho salmon increased by 50%, while there was a 25% decrease in the reference stream. Mean number of coho smolts increased by more than 200%, while the reference stream stayed the same. Mean number of coho migrants doubled, but decreased 75% in the reference stream. Overwinter survival of coho salmon increased from a mean of .13 to .38 (reference was .17 to .20). In another stream, mean overwinter survival increased 250% from .11 to .39, but fell in the reference stream from .19 to .10. Mean number of steelhead migrants increased by more than 800%. Cutthroat trout migrants in the treatment stream increased by 275% and decreased 75% in the reference stream. |
| Spanhoff, B., W. Riss, et al. 2006. Effects of an experimental enrichment of instream habitat heterogeneity on the streambed morphology and chironomid community of a straightened section in a sandy lowland stream. Environ. Manag. 37(2):247–257. | Large woody debris effects on invertebrates. 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 second sampling period. |

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| Stewart, G. B., H. R. Bayliss, et al. 2009. Effectiveness of engineered instream structure mitigation measures to increase salmonid abundance: A systematic review. Ecol. Appl. 19(4):931–941. | Review of 17 studies. Meta-analysis shows that evidence regarding the effectiveness of instream devices is 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. |
| Sudduth, E. B., and J. L. Meyer. 2006. Effects of bioengineered streambank stabilization on bank habitat and macroinvertebrates in urban streams. Environ. Manag. 38(2):218–226. | Amount of wood and root bank habitat was much higher at the reference site and three of four bioengineered sites than at the unrestored site or the fourth 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 invertebrate taxon richness, total biomass, and shredder biomass. |
| Sundermann, A., S. Stoll, et al. 2011. River restoration success depends on the species pool of the immediate surroundings. Ecol. Appl. 21(6):1962–1971. | 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 invertebrate assemblages improved by the restoration. Beyond the 5 km rings, the recolonization effect was no longer detected. |
| Tarzwell, C. M. 1937. Experimental evidence on the value of trout stream improvement in Michigan. Trans. Am. Fish. Soc. 66:177–187. | Large woody debris structures. Each deflector produced on average 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 average was 2,027 sq. ft. in one river and 1,418 in another. More legal trout were taken and the average 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 3–5 times greater after improvements than before. In the riffle areas produced by the barriers, 4.53 times as much food was found as before improvements. |

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| Tarzwell, C. M. 1938. An evaluation of the methods and results of stream improvement in the Southwest. Trans. Third North Am. Wildl. Conf. 1938:339–364. | Large woody debris structures. Rainbow trout, brook trout, brown trout, and Yellowstone native trout. 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 control reach by 8.6 lb in 1 year, and by 16.6 lb 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 1 lb of trout to 4.97 lb of bottom organisms and the treatment creek had 1 lb of trout to 5.48 lb of bottom organisms. |
| Thom, B. A. 1997. The effects of woody debris additions on the physical habitat of salmonids: A case study on the northern Oregon coast. Master's thesis. Univ. Washington, Seattle. | Examined physical effects of large woody debris placement in nine streams with paired treatment and reference reaches using a before-after control-impact design. Positive treatment effects were observed for various large woody debris and habitat metrics (number of pieces, jams, habitat units, number of pools, slack water pools). Treatment reaches increased from 11.7 to 17.2 pieces of wood and from 21.1 to 25.1 $m^3$ of wood per 100 m. Key pieces increased on average 0.8 pieces per 100 m and decreased in control reaches 0.50 pieces per 100 m. Proportion of slack water pools (alcoves, backwaters, dammed pools, etc.) in treatment reaches after treatment increased fourfold in summer and sevenfold in winter. |
| Thompson, D. M. 2002. Long-term effect of instream habitat-improvement structures on channel morphology along the Blackledge and Salmon rivers, Connecticut, USA. Environ. Manag. 29(2):250–265. | Large woody debris. Cover structures have produced a 30% reduction in streamside vegetation with over 75% less overhead cover than unaltered reaches. |
| Thompson, D. M. 2006. Did the pre-1980 use of instream structures improve streams? A reanalysis of historical data. Ecol. Appl. 16(2):784–796. | Review of 79 publications. Little evidence of the successful use of instream structures to improve fish populations exists prior to 1980. |

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| Tikkanen, P., P. Laasonen, et al. 1994. Short-term recovery of benthos following disturbance from stream habitat rehabilitation. Hydrobiologia 270(2):121–130. | Boulders. The immediate effect of rehabilitation 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 invertebrate community. The detection of effects was obscured by rapid life cycle phenomena taking place at the same time. |
| Van Zyll De Jong, M. C., I. G. Cowx, et al. 1997. An evaluation of instream habitat restoration techniques on salmonid populations in a Newfoundland stream. Regul. Rivers: Res. Manag. 13:603–614. | Boulders/logs. Boulder clusters were the most effective structure, increasing densities of 0+, 1+ and 3+ juvenile Atlantic salmon. V dams were effective in increasing the density of both 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. |
| Vehanen, T., A. Huusko, et al. 2003. Habitat preference by grayling (*Thymallus thymallus*) in an artificially modified, hydropeaking riverbed: A contribution to understand the effectiveness of habitat enhancement measures. J. Appl. Ichthyol. 19(1):15–20. | Boulders. Grayling largely stayed in the restored area and avoided the unchanged channel. The range of daily movement was from stationary to 2,700 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. |
| Vehanen, T., A. Huusko, et al. 2010. Effects of habitat rehabilitation on brown trout (*Salmo trutta*) in boreal forest streams. Freshw. Biol. 55(10):2200–2214. | Brown trout. Treatments were large woody debris with boulders, boulders alone, and unmodified. Restoration increased streambed complexity but did not have a detectable effect on brown trout stocks for large woody debris 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 fish, but not for the younger age-classes. |

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| Viola, A. E., M. L. Schuck, et al. 1991. An evaluation of instream habitat alterations in southeast Washington, 1983–1989. Fisheries Management Division Series: FM 91-11. Washington Dept. Wildlife, Olympia. | Large woody debris. There was a significant increase in the density and biomass of older aged wild rainbow trout/steelhead. Altered streams had wild rainbow/steelhead biomass increase from 37.7 g/100 $m^2$ to 1508.3 g/100 $m^2$ 5 years postconstruction. Biomass in the control reaches was 52.2 g/100 $m^2$ preconstruction and 605.2 g/100 $m^2$ postconstruction. The instream habitat structures concentrated hatchery fish and provided increased harvest within habitat-altered river sections, created aesthetically pleasing areas for anglers, and increased spawning use by steelhead and Chinook salmon. |
| Violin, C. R., P. Cada, et al. 2011. Effects of urbanization and urban stream restoration on the physical and biological structure of stream ecosystems. Ecol. Appl. 21(6):1932–1949. | No fish. Compared physical and biological structure of four urban degraded, four urban restored, and four 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 invertebrate 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. Invertebrate 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. |
| Wallace, J. B., J. R. Webster, et al. 1995. Influence of log additions on physical and biotic characteristics of a mountain stream. Can. J. Fish. Aquat. Sci. 52:2120–2137. | Large woody debris. 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. |

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| Ward, B. R., and P. A. Slaney. 1981. Further evaluations of structures for the improvement of salmonid rearing habitat in coastal streams of British Columbia. *In* T. J. Hassler (ed.), Proceedings: Propagation, Enhancement, and Rehabilitation of Anadromous Salmonid Populations and Habitat in the Pacific Northwest Symposium, p. 99–108. Humboldt State Univ., Arcata, CA. | Large woody debris and boulders. The mean number of steelhead parr and coho salmon fry in boulder groupings increased to 0.10 $m^2$ and 0.27 $m^2$, respectively. Groupings ranked highest in salmonid standing crop. Gabions failed to increase steelhead parr abundance, but significantly increased juvenile coho salmon. 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. |
| Warner, K., and I. R. Porter. 1960. Experimental improvement of a bulldozed trout stream in northern Maine. Trans. Am. Fish. Soc. 89(1):59–63. | Boulder structures. Sixty-three 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″ deep. Young-of-the-year trout were moderately abundant where few had been seen previously. |
| Weber, C., and A. Peter. 2011. Success or failure? Do indicator selection and reference setting influence river rehabilitation outcome? N. Am. J. Fish. Manag. 31(3):535–547. | 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 (five 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 (one 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, three studies showed inconsistent results. |

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| West, J. P. 1984. Enhancement of salmon and steelhead spawning and rearing conditions in the Scott and Salmon rivers, California. *In* T. J. Hassler (ed.), Proceedings: Pacific Northwest Stream Habitat Management Workshop, p. 117–127. Humboldt State Univ., Arcata, CA. | Chinook salmon, steelhead. Fine sediment was reduced about 18%. Use of treated areas rose from no use to approximately 29 redds/season. After boulder placement, steelhead juvenile rearing increased tenfold. Salmon and steelhead spawner use increased threefold. Use of control area was relatively static. |
| Wheaton, J. M., G. B. Pasternack, et al. 2004. Use of habitat heterogeneity in salmonid spawning habitat rehabilitation. In D. Garcia de Jalon Lastra and P. Vizcano Martinez (eds.), Fifth International Symposium on Ecohydraulics, Aquatic Habitats: Analysis & Restoration, p. 791–796. Madrid, Spain. | Chinook salmon. 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. |
| White, S. L., C. Gowan, et al. 2011. Response of trout populations in five Colorado streams two decades after habitat manipulation. Can. J. Fish. Aquat. Sci. 68(12):2057–2063. | Log weirs. Brook trout. Pool volume remained more than three times 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 an average of 54% more adult trout in 2009. |
| Whiteway, S. L., P. M. Biron, et al. 2010. Do instream restoration structures enhance salmonid abundance? A meta-analysis. Can. J. Fish. Aquat. Sci. 67(5):831–841. | Analysis of 211 projects using instream structures. Seven species. Showed significant increase in pool area (mean effect size = .65), average depth (mean effect = .29), large woody debris (mean effect size = .73), and percent 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 or 167%) and biomass (mean effect size of .48 or 162%). Large differences were observed between species, with rainbow trout showing the largest increases in density and biomass. Projects with multiple structures increased pool area more than those with only one type of structure. |

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| Wilkins, L. P. 1960. Construction and evaluation of stream alteration structures. Project F-6-R. Tennessee Game and Fish Commission, Nashville. | Logs and boulders. Wild rainbow trout populations declined in the 2 years after construction, but this was associated with an increase in anglers. A significant increase in young-of-the-year trout occurred, while the standing crop of age-group-1 trout has gradually increased despite greater fishing intensity. |
| Yrjana, T. 1998. Efforts for instream fish habitat restoration within the River Iijoki Finland—goals, methods, and test results. *In* L. C. De Waal, A. R. G. Large, et al. (eds.), Rehabilitation of rivers: Principles and implementation, p. 239–250. Wiley & Sons Ltd., Chelsea, UK. | 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. |
| Zika, U., and A. Peter. 2002. The introduction of woody debris into a channelized stream: Effect on trout populations and habitat. River Res. Appl. 18(4):355–366. | Large woody debris. Brown trout and rainbow trout. No good numbers. Abundance and biomass of brown and rainbow increased. Maximum 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 the treatment section. Trout sought woody debris for cover. |

## Off-Channel/Floodplain Habitat References (Subtotal is 82 of 409)

| **Reference** | **Key Quantitative Findings** |
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| Akita, M., Y. Makiguchi, et al. 2006. Upstream migration of chum salmon through a restored segment of the Shibetsu River. Ecol. Freshw. Fish 15:125–130. | Remeander. Radiotagged chum salmon held in deep, slow current near bottom near the banks in the canalized river. In the restored area, chum swam in more shallow areas against stronger currents. |
| Albert, S., and T. Trimble. 2000. Beavers are partners in riparian restoration on the Zuni Indian reservation. Ecol. Restor. 18(2):87–92. | Beaver reintroduction. With new dams, water flow slowed, streambed raised, hydrology improved, salt cedar infestation reduced, and willows increased. Problems were farmland flooding and destruction of many large trees. |

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| Apple, L. L. 1985. Riparian habitat restoration and beavers. *In* R. R. Johnson, C. D. Ziebell, et al. (eds.), Riparian ecosystems and their management: Reconciling conflicting uses, p. 489–490. Gen. Tech. Rep. RM-120. U.S. Forest Service, Rocky Mountain Forest and Range Experimental Station, Fort Collins, CO. | No concrete numbers. Beavers built three major dam complexes that developed subirrigated meadow areas. Mud bars formed behind the dams, water tables were elevated, and full riparian recovery was underway. |
| Baattrup-Pedersen, A., T. Riis, et al. 2000. Restoration of a Danish headwater stream: Short-term changes in plant species abundance and composition. Aquat. Conserv.: Mar. Freshw. Ecosyst. 10(1):13–23. | Effects of stream restoration (remeandering) on plant communities. Number of species decreased 25% in the stream and 9% on the banks, increased 15% in the stream valley. On the bank, dominance changed from nonriparian species to more diverse communities. Little change to plant communities in the valley. |
| Biggs, J., A. Corfield, et al. 1998. Restoration of the rivers Brede, Cole and Skerne: A joint Danish and British EU-LIFE demonstration project, V: Short-term impacts on the conservation value of aquatic macroinvertebrate and macrophyte assemblages. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):241–255. | No fish. Invertebrates and aquatic vegetation Wetland macrophyte species richness quickly reached prerestoration levels relative to control sections. Emergent plant species richness remained the same or increased after restoration. One year after restoration, the mean emergent plant species richness increased from 27 to 38 species/500 m 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 prerestoration to 7.0 species within a month of restoration and 8.0 species 1 year postrestoration. The abundance of invertebrates generally recovered less rapidly than species richness. Downstream of the restored area showed a relative decline in invertebrate species richness 1–2 months after restoration. |
| Blackwell, C. N., C. R. Picard, et al. 1999. Smolt productivity of off-channel habitat in the Chilliwack River watershed. Rep. 14. Watershed Restoration Program, Ministry of Environment, Lands, and Parks and Ministry of Forests, Vancouver, BC. | Four restored and three natural off-channel habitats monitored during smolt migration. No difference in coho salmon 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 m$^2$). Coho smolt abundance varied from less than 2/100 m$^2$ to greater than 50/100 m$^2$. |

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| Boedeltje, G., A. J. P. Smolders, et al. 2001. Constructed shallow zones along navigation canals: Vegetation establishment and change in relation to habitat characteristics. Aquat. Conserv.: Mar. Freshw. Ecosyst. 11:453–471. | 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. |
| Bryant, M. D. 1988. Gravel pit ponds as habitat enhancement for juvenile coho salmon. PNW-GTR-212. U.S. Forest Service, Pacific Northwest Research Station, Portland, OR. | No numbers. Gravel pits flooded and connected to rivers. The ponds were found to support coho salmon throughout the winter. Number of coho fluctuated, but was high (2,000 coho) throughout study. Coho in the less productive ponds appeared to be less robust than those in the other two ponds. |
| Carl, J. 2001. Habitat surveys as a tool to assess the benefits of stream rehabilitation 3: Fish. Int. Assoc. Theor. Appl. Limnol. Proc. (27):1515–1519. | Abundance results indicate restoration measures (remeandering and discontinuance of stream maintenance) can improve the overall stream environment and increase total abundance of trout, but it is not clear what habitat types are beneficial to improving abundance. |
| Caruso, B. S. 2006. Effectiveness of braided, gravel bed river restoration in the Upper Waitaki Basin, New Zealand. River Res. Appl. 22(8):905–922. | Evaluates the effectiveness of a river recovery project. No numbers. Lists recommended elements and restoration components with no specifics. |
| Cederholm, C. J., and N. P. Peterson. 1989. A summary comparison of two types of winter habitat enhancement for juvenile coho salmon (*Oncorhynchus kisutch*) in the Clearwater River, Washington. *In* B. G. Shepherd (ed.), Proceedings of the 1988 Northeast Pacific Chinook and Coho Salmon Workshop, p. 227–239. Ministry of Environment, Penticton, BC. | Constructed pond: winter coho salmon 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 (postconstruction 20 mm length and 5.6 g weight—no preconstruction data). |
| Cederholm, C. J., W. J. Scarlett, et al. 1988. Low-cost enhancement technique for winter habitat of juvenile coho salmon. N. Am. J. Fish. Manag. 8:438–441. | Constructed habitat. Overwinter survival and growth of coho salmon increased significantly after construction (survival .11 to .56, mean change in length from 13 to 41 mm, mean change in weight from 3 to 13 g). |

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| Childers, D. L., D. M. Iwaniec, et al. 1999. How freshwater Everglades wetlands mediate the quality of recently enhanced water inflows to the Florida Bay estuary. Gulf Res. Rep. 11:70–71. | Abstract only (Gulf Estuarine Research Society meeting). No fish. Nutrient concentrations more than doubled immediately after levee removal, from about 0.2 to 0.4 µM [micromolar?] total phosphorus and from about 45 to 140 µM total nitrogen. However, the sawgrass marsh quickly took up this nutrient load. Flume sampling showed ammonium and dissolved organic carbon uptake, and total organic carbon release. The periphyton zone imported total nitrogen, while nitrate-nitrite flux was dominated by marsh dynamics. |
| Childers, D. L., N. J. Oehm, et al. 1998. How freshwater Everglades wetlands mediate changes in water flow and nutrient loadings to the Florida Bay estuary. Gulf Res. Rep. 10:72. | Abstract only (Gulf Estuarine Research Society meeting). See Childers et al. 1999 above. |
| Chovanec, A., F. Schiemer, et al. 2002. Rehabilitation of a heavily modified river section of the Danube in Vienna (Austria): Biological assessment of landscape linkages on different scales. Int. Rev. Hydrobiol. 87:2–3. | 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. |
| Clarke, S. J., and G. Wharton. 2000. An investigation of marginal habitat and macrophyte community enhancement on the River Torne, UK. Regul. Rivers: Res. Manag. 16:225–244. | Evaluated marginal habitat and macrophyte community 5 years after bank reprofiling and planting program. Enhanced reaches were floristically distinct and had higher values of wetland species diversity, percent of wetland species, bank width, soil moisture, and lower bank angles. |
| Clayton, S. R. 2002. Quantitative evaluation of physical and biological responses to stream restoration. Doctoral dissertation. Univ. Idaho, Moscow. | Remeander. Following restoration, reach-median maximum depths at base flow increased 56% to 0.43 m and velocities decreased 24% to 0.28 m/s. At bankfull discharge, reach-median maximum depths increased 30% to 1.5 m and velocities decreased 17% to 0.85 m/s. Pool frequency increased by 50%, resulting in an even pool:riffle ratio. |

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| Cooperman, S., G. Hinch, et al. 2006. Rapid assessment of the effectiveness of engineered off-channel habitats in the southern interior of British Columbia for coho salmon production. Rep. 2768. DFO Canada, Vancouver, BC. | Coho salmon. Ten studies, not a lot of numbers. Eight of 10 off-channel projects appear to be functioning as designed, although five of those have conditions that could compromise their utility to young coho (beaver dams 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. |
| Cott, P. A. 2004. Northern pike (*Esox lucius*) habitat enhancement in the Northwest Territories. DFO Canada, Yellowknife, Northwest Territories. Can. Tech. Rep. Fish. Aquat. Sci. 2528. | 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 revegetated itself. Ultimate habitat gain was calculated to be more than 11:1. |
| Cowx, I. G., and M. Van Zyll de Jong 2004. Rehabilitation of freshwater fisheries: Tales of the unexpected? Fish. Manag. Ecol. 11(3–4):243–249. | Case study 1: Boulder treatments caused significant +0 and +1 salmon density increase, V-dam treatment significantly increased +0 salmon in second post-treatment year, half-log cover increased +0 salmon density for both post-treatment 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 reasonably good brown trout populations reaching 46 per 100 m$^{-2}$, 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. |
| Decker, A. S., and M. J. Lightly 2004. The contribution of constructed side channels to coho salmon smolt production in the Oyster River, Nanaimo, BC, Canada. Can. Tech. Rep. Fish. Aquat. Sci. 40. | Constructed three side channels. Mean density of outmigrating coho salmon smolts was 2.3 times greater in the side channels than in the main stem (4,857 vs. 2,117 smolts km$^{-1}$). Smolt 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. |
| Florsheim, J. L., and J. F. Mount. 2002. Restoration of floodplain topography by sand-splay complex formation in response to intentional levee breaches, Lower Cosumnes River, California. Geomorphology 44(1–2): 67–94. | Levees breached and subsequent study of sand-splay complexes. Rapid vertical accretion and scour occurred. Maximum deposition measured on the splay surface was 0.36 m/year and maximum scour in channels was 0.27 m/year. |

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| Friberg, N., B. Kronvang, et al. 1998. Long-term, habitat-specific response of a macroinvertebrate community to river restoration. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):87–99. | Remeandering. Created a physically stable environment in less than 3 years with an improved density and diversity of macroinvertebrates. |
| Grift, R. E. 2001. How fish benefit from floodplain restoration along the lower River Rhine. Wageningen Univ., Institute of Animal Sciences, Wageningen, The Netherlands. | 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 young-of-the-year fish community. Secondary channels provide suitable nursery habitat for rheophilic cyprinids. |
| Grift, R. E., A. D. Buijse, et al. 2001. Restoration of the river-floodplain interaction: Benefits for the community in the River Rhine. Arch. Hydrobiol. Large Rivers 12(2–4):173–185. | 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. |
| Grift, R. E., A. D. Buijse, et al. 2003. Suitable habitats for 0-group fish in rehabilitated floodplains along the lower River Rhine. River Res. Appl. 19(4):353–374. | 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 vegetation was important habitat for the larvae of all species. Floodplain water bodies should have complex shorelines and a high variability of flow velocities. |
| Habersack, H., and H. P. Nachtnebel. 1995. Short-term effects of local river restoration on morphology, flow field, substrate, and biota. Regul. Rivers: Res. Manag. 10:291–301. | Constructed side channel. Study showed higher growth of algae, higher numbers of species of macroinvertebrates, and greater densities of fish species. |
| Hammersmark, C. T., M. C. Rains, et al. 2008. Quantifying the hydrological effects of stream restoration in a montane meadow, northern California, USA. River Res. Appl. 24(6):735–753. | 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 base flow. “Pond and plug” type stream restoration has the capacity to reestablish hydrological processes necessary to sustain riparian systems. |

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| Hansen, H. O. 1998. Stream restoration: Rehabilitation of a headwater stream and its riparian areas—Layman Report. Final Layman report from the EU-LIFE project. Ministry of Environment and Energy, National Environmental Research Institute, Silkeborg, Denmark. | Remeander, raised stream water level, added coarse substrate for spawning. At 2 years post-treatment, only terrestrial plants had recovered. Fish and invertebrates had not reached expected levels, however, the number of brown trout caught post-treatment approached expected levels. No numbers. |
| Hein, T., C. Baranyi, et al. 1999. Hydrology as a major factor determining plankton development in two floodplain segments and the River Danube, Austria. Arch. Hydrobiol. Large Rivers 11:439–452. | 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. |
| Henning, J. A., R. E. Gresswell, et al. 2006. Juvenile salmonid use of freshwater emergent wetlands in the floodplain and its implications for conservation management. N. Am. J. Fish. Manag. 26:367–376. | Reconnection. Added water control structures to emergent wetlands to provide an outlet for fish emigration. Resulted in higher abundance of age-1 coho salmon 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. |
| Hoffmann, C. C., M. L. Pedersen, et al. 1998. Restoration of the rivers Brede, Cole and Skerne: A joint Danish and British EU-LIFE demonstration project, IV–Implications for nitrate and iron transformation. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):223–240. | Remeander. Ninety-two kg $NO_3$-N $ha^{-1}$ $year^{-1}$ of nitrate was removed during passage through the river valley. Iron leaked from the floodplain to the river at 400 kg $ha^{-1}$ $year^{-1}$. There was higher removal of nitrate along the restored reach during a 3-month period of flooding right after restoration. |
| Holubova, K., and M. J. Lisicky. 2001. River and environmental processes in the wetland restoration of the Morava river. *In* R. A. Falconer and W. R. Blain, River basin management, p. 179–180. WIT, Southampton, UK. | 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 five. Invertebrates showed a shift from stagnicolous to semireophilous species composition. A large gravel-sand bank formed, creating a new habitat used in the first year by terrestrial annual plants. |

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| Iversen, T. M., B. Kronvang, et al. 1993. Re-establishment of Danish streams: Restoration and maintenance measures. Aquat. Conserv.: Mar. Freshw. Ecosyst. 3(2):73–92. | Remeander. Invertebrates 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. |
| Jähnig, S. C., S. Brunzel, et al. 2009. Effects of re-braiding measures on hydromorphology, floodplain vegetation, ground beetles, and benthic invertebrates in mountain rivers. J. Appl. Ecol. 46:406–416. | Rebraiding. Number 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 nonrestored 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 nonrestored sections. 169 benthic invertebrate taxa were recorded. Values of metrics were always slightly higher in restored sections. |
| Jeffres, C. A., J. J. Opperman, et al. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environ. Biol. Fishes 83(4):449–458. | Juvenile Chinook salmon. 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. |
| Jungwirth, M., S. Muhar, et al. 1995. The effects of re-created instream and ecotone structures on the fish fauna of an epipotamal river. Hydrobiologia 303:195–206. | Remeander. Number of fish species increased from 10 in straightened sections to 19 in restructured sites. |

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| Jungwirth, M., S. Muhar, et al. 2002. Reestablishing and assessing ecological integrity in riverine landscapes. Freshw. Biol. 47(4):867–887. | 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. |
| Jutagate, T., C. Krudpan, et al. 2005. Changes in the fish catches during a trial opening of sluice gates on a run-of-the-river reservoir in Thailand. Fish. Manag. Ecol. 12(1):57–62. | Flooding—sluice gates open on dam. Catch per unit effort ranged from 0.38 to 1.70 and 0.61 to 2.71 kg fisherman$^{-1}$ night$^{-1}$ downstream and upstream of the dam, respectively. Month percent index of relative importance of the fish species caught varied between months. |
| Klein, L. R., S. R. Clayton, et al. 2007. Long-term monitoring and evaluation of the Lower Red River Meadow Restoration Project, Idaho, USA. Restor. Ecol. 15(2):223–239. | Channel length increased 60%, resulting in a 60% increase in sinuosity. Median bankfull velocity was significantly slower immediately following restoration, but not 3 years later. Model simulation showed an average increase in postrestoration 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 from 49 to 43%. Total number of habitat units increased by 52% from 48 to 73, then increased to 102 in 2003. Proportion of fines decreased significantly. Temperatures exhibited significant increasing temporal trends. Salmonid densities fluctuated and ranged from 7.1 fish/100 m$^2$ in 2003 to 27.8 fish/100 m$^2$ in 2001. No significant increasing trend in salmonid density or percent composition was detected in the restored reach. Annual Chinook salmon redd density fluctuated, no significant increase. Bird numbers increased significantly from 52 in 1996 to 91 in 2003. |
| Kronvang, B., L. M. Svendsen, et al. 1998. Restoration of the rivers Brede, Cole, and Skerne: A joint Danish and British EU-LIFE demonstration project, III−Channel morphology, hydrodynamics, and transport of sediment and nutrients. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):209–222. | 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. |

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| Langler, G. J., and C. Smith. 2001. Effects of habitat enhancement on 0-group fishes in a lowland river. Regul. Rivers: Res. Manag. 17(6):677–686. | Construction of off-channel habitats. Abundance (t = 3.94. df = 61, $P < 0.001$) and diversity (t = 6.48, df = 50, $P \leq 0.001$) of 0-group fishes (nonsalmonid) was significantly higher in treatment areas. |
| Lister, D. B., and W. E. Bengeyfield. 1998. An assessment of compensatory fish habitat at five sites in the Thompson River system. Rep. 2444. DFO, Habitat and Enhancement Branch, Vancouver, BC. | Constructed ponds. No clear numbers. At four of five 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. |
| Martin, A. E., M. S. Wipfli, et al. 2010. Aquatic community responses to salmon carcass analog and wood bundle additions in restored floodplain habitats in an Alaskan stream. Trans. Am. Fish. Soc. 139(6):1828–1845. | Juvenile coho salmon. 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 invertebrate 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. |
| Marttin, F., and G. J. De Graaf. 2002. The effect of a sluice gate and its mode of operation on mortality of drifting fish larvae in Bangladesh. Fish. Manag. Ecol. 9(2):123–125. | Mortality rate (percent of total larvae recaptured) of carp hatchlings (±SE) for undershot and overshot operations of the sluice gates. Overshot = 11.8 (±3.6), undershot = 44.0 (±5.6). |
| McKinstry, M. C., and S. H. Anderson. 1999. Attitudes of private- and public-land managers in Wyoming, USA, toward beaver. Environ. Manag. 23(1):95–101. | 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. Beaver 2–3.5 years old had higher average success than older or younger beaver. |

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| McKinstry, M. C., P. Caffrey, et al. 2001. The importance of beaver to wetland habitats and waterfowl in Wyoming. J. Am. Water Resour. Assoc. 37(6):1571–1578. | Beaver reintroduction. Survey of land managers found that beaver had been removed from 23% of streams managers knew of. There are more than 3,500 km of streams where beaver could improve habitat. Riparian width in streams with beaver ponds averaged 33.9 m compared to 10.5 m without. There are more ducks in areas with beaver ponds. Waterfowl are quick to respond to creation of beaver-created wetlands. |
| Moerke, A. H. 2004. Landscape influences on stream ecosystems: Implications for restoration and management. Diss. Abstr. Int. B Sci. Eng. 65(1):46. | Dissertation 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. |
| Moerke, A. H., K. J. Gerard, et al. 2004. Restoration of an Indiana, USA, stream: Bridging the gap between applied and basic lotic ecology. J. North Am. Benthol. Soc. 23:647–660. | Remeander. One year post-treatment, periphyton, invertebrates, and fish recovered or exceeded levels in the control reach, but 5 years post-treatment, invertebrate diversity and fish abundance in restored reaches were similar to or below levels in the control reach. |
| Moerke, A. H., and G. A. Lamberti. 2003. Responses in fish community structure to restoration of two Indiana streams. N. Am. J. Fish. Manag. 23(3):748–759. | Remeander. Increase in size distribution and number of redds for trout. Fish community changed from rheophilic species to highly tolerant, slow-water species. Fish population and community metrics for one creek suggested nearly complete fish colonization by 9 months after restoration, although metrics seldom exceeded the levels of unrestored, channelized reaches. Trout populations responded rapidly to the restoration by spawning only in the restored reaches. |
| Moerke, A. H., and G. A. Lamberti. 2004. Restoring stream ecosystems: Lessons from a midwestern state. Restor. Ecol. 12(3):327–334. | On-site assessments revealed that restored reaches had significantly lower stream widths and greater depths than upstream unrestored reaches, but riparian canopy cover often was lower in restored than in unrestored reaches. |

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| Morley, S. A., P. S. Garcia, et al. 2005. Juvenile salmonid (*Oncorhynchus* spp.) use of constructed and natural side channels in Pacific Northwest rivers. Can. J. Fish. Aquat. Sci. 62(12):2811–2821. | Juvenile salmonid use of constructed vs. natural side channels. Total salmonid density (fish × $m^{-2}$) 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 salmon 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. |
| Muhar, S., M. Jungwirth, et al. 2008. Restoring riverine landscapes at the Drau River: Successes and deficits in the context of ecological integrity. *In* H. Habersack, H. Piegay, et al., Gravel-bed rivers VI: From process understanding to river restoration, p. 779–803. Elsevier B.V., Amsterdam, Netherlands. | 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 trout and rainbow trout showed higher values in the channelized sections. |
| Muhar, S., G. Unfer, et al. 2004. Assessing river restoration programmes: Habitat conditions, fish fauna, and vegetation as indicators for the possibilities and constraints of river restoration. *In* D. Garcia de Jalon and P. V. Martinez (eds.), Proceedings of the Fifth International Conference on Ecohydraulics–Aquatic habitats: Analysis and restoration, p. 300–305. International Association of Hydraulic Engineers, Madrid, Spain. | Levee removal and constructed side channel. Aquatic area increased by 67%, initiating five additional aquatic habitat types, riparian and floodplain vegetation restoration was successful in terms of characteristic plant species and associations, and new shallow water areas in restored areas were utilized by juvenile graylings of 70–140 mm more than twice as often as in unrestored stretches. |

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| Nagayama, S., Y. Kawaguchi, et al. 2008. Methods for and fish responses to channel remeandering and large wood structure placement in the Shibetsu River Restoration Project in northern Japan. Landsc. Ecol. Eng. 4(1):69–74. | Remeander and large woody debris. 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 salmon) 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. |
| Nakano, D., and F. Nakamura. 2006. Responses of macroinvertebrate communities to river restoration in a channelized segment of the Shibetsu River, northern Japan. River Res. Appl. 22(6):681–689. | 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 streambank created by the reconstructed meander and groyne reaches had higher total density and taxon richness of invertebrates than those in channelized reaches. |
| Nakano, D., and F. Nakamura. 2008. The significance of meandering channel morphology on the diversity and abundance of macroinvertebrates in a lowland river in Japan. Aquat. Conserv.: Mar. Freshw. Ecosyst. 18(5):780–798. | 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 invertebrate density and richness. |
| Neilsen, M. 2002. Lowland stream restoration in Denmark: Background and examples. J. Chartered Institution of Water and Environ. Manag. 16(3):189–193. | Remeander, improve hydraulic interaction between river and meadows, restore wetlands. Water storage increased, natural habitat improved for plants and animals including salmon, and water quality increased. No numbers. |
| Payne, A. I., and V. Cowan. 1998. Review of stock enhancement in the floodplains of Bangladesh. *In* T. Petr, Inland fishery enhancements, p. 153–158. FAO Fisheries Tech. Rep. 374. FAO, Rome. | Carp and catfish. Yields increased from 1,863 kg/ha to 11,384 kg/ha, which partly resulted from improved access to fishing and number of fishing days increased from 396 to 810 over a year. The percentage of the catch due to major carp and large catfish increased from 2% to 24%, indicating that immigration and recruitment had increased substantially. |

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| Pedersen, M. L., J. M. Andersen, et al. 2007. Restoration of Skjern River and its valley: Project description and general ecological changes in the project area. Ecol. Eng. 30:131–144. | Remeander. River valley changed from agricultural fields into meadows with a rapid succession in plant species. The new river was rapidly colonized with plants and invertebrates 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. |
| Pedersen, T. C. M., A. Baattrup-Pedersen, et al. 2006. Effects of stream restoration and management on plant communities in lowland streams. Freshw. Biol. 51(1):161–179. | 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. |
| Raastad, J. E., A. Lillehammer, et al. 1993. Effect of habitat improvement on Atlantic salmon in the regulated River Suldalslagen. Regul. Rivers: Res. Manag. 8(1–2):95–102. | 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 115 g wheat/$m^2$ resulted in a threefold increase in benthic fauna compared to control area. Largest increase was in Chironomidae in August-September. |
| Rahman, M., D. A. Capistrano, et al. 1999. Experience of community managed wetland habitat restoration. *In* H. A. J. Middendorp, P. M. Thompson, et al. (eds.), Sustainable inland fisheries management in Bangladesh, p. 111–121. ICLARM, Makati City, Philippines. | Canal rehabilitation to reestablish fish migration and fish conservation and create fish sanctuaries. Catch in beel and floodplain increased from 2,481 kg to 12,222 kg and from 1,451 kg to 5,181 kg in pagars. Major carp catch increased from 29 kg to 1,221 kg in pagars and species recorded increased from 46 to 59. |

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| Richards, C., P. J. Cernera, et al. 1992. Development of off-channel habitats for use by juvenile Chinook salmon. N. Am. J. Fish. Manag. 12:721–727. | Excavated channels to reconnect ponds to river. Highest juvenile Chinook salmon density ($5.2/m^2$) was in the new channel habitat with cover, low water velocity, and moderate depths. |
| Richardson, C. J., P. Reiss, et al. 2005. The restoration potential of the Mesopotamian marshes of Iraq. Science 307(5713):1307–1311. | No numbers. Reflooded marsh area shows rapid reestablishment, high productivity, and reproduction of native flora and fauna. Survey 1 year after reflooding indicates that water flowing into the marshes from the Euphrates and especially the Tigris is of higher quality than originally hypothesized, and as a result, early successional stages of marsh restoration are occurring. There is partial reestablishment of many of the dominant plant species, but biomass and species numbers are low compared with historical records at one site. Chlorophyll *a* concentrations reveal mesotrophic conditions at all sites. |
| Rohde, S., M. Schutz, et al. 2005. River widening: An approach to restoring riparian habitats and plant species. River Res. Appl. 21(10):1075–1094. | No numbers. River widening in general was 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. |
| Roni, P., S. A. Morley, et al. 2006a. Coho salmon smolt production from constructed and natural floodplain habitats. Trans. Am. Fish. Soc. 135:1398–1408. | 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. |

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| Rosenfeld, J. 2005. Annual report to Habitat Conservation Trust Fund, Vancouver, B.C. Appendix 3: Effectiveness assessment of off-channel habitat structures. B.C. Ministry of Water, Land, and Air Protection, Aquatic Ecosystem Science Section, Vancouver. | Stream off-channel habitats produce higher numbers and biomass of juvenile parr during summer and fall than pond off channels (mostly coho salmon data). Parr abundance in channels was approximately four times higher than in other habitat types and total biomass was also higher in channels (8.01 g/$m^2$ in channels compared to 2.37 g/$m^2$ in ponds) Average parr size tended to be higher in ponds than in channels (5.98 g vs. 3.14 g) and small ponds appear to be more productive per $m^2$ than large ponds. Smolt production per unit area in the spring is not statistically different between ponds and stream off channels. Biomass of drifting invertebrates in inlet enclosures was 10 times higher than drifting biomass in enclosure outlets. |
| Rosenfeld, J. S., E. Raeburn, et al. 2008. Effects of side channel structure on productivity of floodplain habitats for juvenile coho salmon. N. Am. J. Fish. Manag. 28(4):1108–1119. | Juvenile coho salmon. Review of studies. Average density and biomass of coho parr were significantly higher in stream-type side channels (3.4 parr/$m^2$ and 8.01 g/$m^2$, respectively) than in pond-type side channels (0.8 parr/$m^2$ and 2.37 g/$m^2$). Although total parr biomass was three 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 mainstem 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. |
| Schmutz, S., C. Giefing, et al. 1998. The efficiency of a nature-like bypass channel for pike-perch (*Stizostedion lucioperca*) in the Marchfeldkanalsystem. Hydrobiologia 371: 1–3. | Reconnection via bypass channel. Although more than 57,000 fish of 35 species passed the bypass channel, pike-perch were underrepresented. Bypass not successful for all species—it represents a bottleneck for the immigration of pike-perch. |

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| Schmutz, S., A. Matheisz, et al. 1994. Erstbesiedelung des Marchfeldkanals aus fischökologischer sicht. [Colonization of a newly constructed canal, Marchfeldkanal, by fish]. Wissenschaft, Österreichs Fischerei [Austrian Fisheries] 47:158–178. | In German; key quantitative findings listed here are based on the English summary on page 178. 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 young-of-the-year fish. |
| Sear, D. A., A. Briggs, et al. 1998. A preliminary analysis of the morphological adjustment within and downstream of a lowland river subject to river restoration. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):167–183. | 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. |
| Sheng, M. D., M. Foy, et al. 1990. Coho salmon enhancement in British Columbia using improved groundwater-fed side channels. Rep. 2071. DFO Canada, Vancouver. | Constructed/excavated to create groundwater-fed channels. Recruited annually 50–250 coho salmon spawners in the first 3 years. Channels appear to be fully seeded each year. Channels can produce up to three coho smolts/$m^2$. Riprap armoring can increase smolt productivity more than tenfold (crevices provide sanctuary for presmolts). Cover availability is closely related to coho smolt abundance in groundwater-fed channels. |
| Simons, J., C. Bakker, et al. 2001. Man-made secondary channels along the River Rhine (the Netherlands): Results of postproject monitoring. Regul. Rivers: Res. Manag. 17(4–5):473–491. | 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. Rheophilic taxa made up 4% of the total number of taxa. This percentage increased to 14–21% after the creation of the secondary channel. |
| Sommer, T., B. Harrell, et al. 2001a. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26(8):6–16. | References many results from Sommer et al. 2001b. No good numbers. Floodplain is a valuable spawning and rearing habitat for splittail and young Chinook salmon. 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. |

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| Sommer, T. R., M. L. Nobriga, et al. 2001b. Floodplain rearing of juvenile Chinook salmon: Evidence of enhanced growth and survival. Can. J. Fish. Aquat. Sci. 58(2): 325–333. | 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 mm (±2) in floodplain and 85.7 mm (±1.4) in river; in 1999, 89.0 (±2.6) in floodplain and 82.1 (±1.7) in river. Apparent growth rate (mm × $\text{day}^{-1}$) in 1998 was .80 (±.06) in floodplain vs. 0.52 (±.02) in river; in 1999, 0.55 (±.06) in floodplain and .43 (±03) in river. |
| Stroh, M., A. Kratochwil, et al. 2005. Rehabilitation of alluvial landscapes along the River Hase (Ems River basin, Germany). Large Rivers 15(1–4):243–260. | 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 noninoculated 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 noninoculated plots. |
| Sudduth, E. B., B. A. Hassett, et al. 2011. Testing the field of dreams hypothesis: Functional responses to urbanization and restoration in stream ecosystems. Ecol. Appl. 21(6):1972–1988. | No fish. Stream metabolism did not differ between stream types in either season and 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, variation in stream temperature and canopy cover explained 80% of the variation across streams in nitrate uptake. |
| Thompson, P. M., and M. M. Hossain. 1998. Social and distributional issues in open water fisheries management in Bangladesh. *In* T. Petr, Inland fishery enhancements, p. 351–370. Fisheries Tech. Rep. 374. FAO, Rome. | Carp and "small fish." After restoration, catch from the beel and floodplain increased by about six times (part of this increase was due to greater flood extent in the second year), while in the floodplain the catch from fish aggregating devices (ditches or pagars) increased 3.6 times. |

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| Van Liefferinge, C., D. De Smedt, et al. 2003. Ecological evaluation for river meandering restoration. A case study on five Flemish rivers. *In* C. A. Brebbia (ed.), River basin management II, p. 377–387. WIT Press, Southampton, Boston. | Twelve Belgian species. Prerestoration evaluation of fish assemblage and the macroinvertebrate communities mainly on the population level. Used species composition, diversity, and Index of Biological Integrity for fish and the Belgian Biotic Index for invertebrates. In one case, the preevaluation 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 four other sites would result in a higher ecological value. |
| Weber, C., E. Schager, et al. 2009. Habitat diversity and fish assemblage structure in local river widenings: A case study on a Swiss river. River Res. Appl. 25(6):687–701. | Twenty species. No good numbers. River widenings vs. canalized reaches. Habitat diversity (depth, flow, velocity, cover availability) was considerable greater in the two longer widenings (>900 m length) than in the canalized reaches and in the shortest widening (300 m), 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 number of species or total fish abundance. Highest winter abundance was observed in deep, well-structured backwaters of rehabilitated reaches. Assemblage structure and composition were similar in both reaches. |
| Zurowski, W., and B. Kasperczyk. 1988. Effects of reintroduction of European beaver in the lowlands of the Vistula Basin. Acta Theriologica 33(12–25):325–338. | Reintroduced 168 beavers. In first year they set up 64 sites. Loss of beaver was 15% in first year after reintroduction. Forty-four 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. |

# Riparian/Grazing References (Subtotal is 53 of 409)

| Reference | Key Quantitative Findings |
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| Briggs, M. K. 1996. Riparian ecosystem recovery in arid lands: Strategies and references. University of Arizona Press, Tucson. | Provides only general information on results of various case studies, no specific numbers. |
| Carline, R. F., and M. C. Walsh. 2007. Responses to riparian restoration in the Spring Creek watershed, central Pennsylvania. Restor. Ecol. 15(4):731–742. | 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 two treatment streams. Suspended sediments during base flow and storm flow decreased 47–87%. Invertebrate densities increased in both treated streams. |
| Chen, H., J. X. Zhou, et al. 2005. The impact of vegetation restoration on erosion-induced sediment yield in the middle Yellow River and management prospect. Science in China Series D-Earth Sciences 48(6):724–741. | Vegetation restoration on erosion-induced sediment yield. Annual precipitation of 530 mm is the critical annual precipitation for forest and grass in the middle Yellow River. The rate of watershed forest coverage in key counties should at least exceed 30%. |
| Clary, W. P. 1999. Stream channel and vegetation responses to late spring cattle grazing. J. Range Manag. 52(3):218–217. | Ten-year grazing study comparing high, medium, and no grazing on Stanley Creek, Idaho. Stream channel narrowed (ratios of after/before .54, .52, and .29 for high, medium, and no grazing, respectively), embeddedness decreased, stability increased. Height of willows increased .35, .28, and .4 m for high, medium, and no grazing treatments; willow cover increased by 29, 37, and 56% in three treatments; and little change was detected in herbaceous cover. |
| Clary, W. P., N. L. Shaw, et al. 1996. Response of a depleted sagebrush steppe riparian system to grazing control and woody plantings. Research Rep. INT-RP-492. U.S. Forest Service, Intermountain Research Station, Ogden, UT. | Detailed study of riparian response to grazing control 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. Width/depth ratio increased in all treatments except those not subjected to grazing. |

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| Connin, S. 1991. Characteristics of successful riparian restoration projects in the Pacific Northwest. Environmental Protection Agency, Seattle. | Review of 13 fencing and other similar riparian projects. Results varied by study, but overall studies reported increased spawning gravels, bank stability, and decrease in channel width and erosion. Twenty-five 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. |
| Cooperman, A. S., S. G. Hinch, et al. 2007. Streambank restoration effectiveness: Lessons learned from a comparative study. Fisheries 32(6):278–291. | Grading, plantings, rock deflectors, and fencing. Invertebrate abundance did not differ between treatment and control sites, but was affected by channel gradient and river segment. Sites did not 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. |
| Dobkin, D. S., A. C. Rich, et al. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwestern Great Basin. Conserv. Biol. 12(1):209–221. | Examined recovery of livestock grazing on plots on a 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). |
| Emmingham, W. H., S. S. Chan, et al. 2000. Silviculture practices for riparian forests in the Oregon coast range. Oregon State Univ., Forest Research Laboratory, Corvallis. | Reviewed several conifer conversion projects along the Oregon coast, provided only qualitative results. Relatively poor growth and survival due to shade, predation (beaver and deer), and competition. Provides recommendations for improving project success (control of predation, shade, competition). |
| Gladwin, D. N., and J. E. Roelle. 1998. Survival of plains cottonwood (*Populus deltoides* subsp. Monilifera) and saltcedar (*Tamarix ramosissima*) seedlings in response to flooding. Wetlands 18(4):669–674. | Response of saltcedar and cottonwood to fall and spring flooding. Fall flooding survival of saltcedar was 0.8% vs. 21% for cottonwood. Spring flooding survival was 94% vs. 99% for cottonwood. Fall flooding recommended to control saltcedar. |
| Holmes, T. P., J. C. Bergstrom, et al. 2004. Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. Ecol. Econ. 49(1):19–30. | Economic evaluation of riparian restoration based on cost and survey of “values” or “benefits.” Benefit/cost ratio for riparian restoration ranged from 4.03 (for 2 miles of restoration) to 15.65 (for 6 miles of restoration), demonstrating that riparian restoration was cost-effective. |

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| Hook, P. B. 2003. Sediment retention in rangeland riparian buffers. J. Environ. Qual. 32(3):1130–1137. | Sediment retention on rangeland riparian buffers. Sediment retention ranged from 63% to 99%, depending on vegetation type and buffer width. In 6 m wide buffers, 94% to 99% retention, regardless of vegetation type or hillslope. |
| Humphrey, J. W., and G. S. Patterson. 2000. Effects of late summer cattle grazing on the diversity of riparian pasture vegetation in an upland conifer forest. J. Appl. Ecol. 37(6):986–996. | Scottish study looking at effects of grazing on plant species diversity. Grazing led to greater species richness, but decrease in vegetation height. |
| Kauffman, J. B., P. Bayley, et al. 2002. Research/evaluate restoration of NE Oregon streams: Effects of livestock exclosures (corridor fencing) on riparian vegetation, stream geomorphic features, and fish populations. BPA Rep. DOE/BP-00006210-1. Oregon State Univ., Corvallis. | Examined control (grazed) and treatment (grazing exclosure) reaches of 11 northeast Oregon streams). Results not easily converted to simple quantities of change, but significantly higher vegetation cover, composition, and structure and species richness. Improvement in geomorphology including channel width, depth, and number of pools also detected. Young-of-the-year rainbow trout (redband) in ungrazed sections, but no change in parr or adult trout. Redside shiners and speckled dace decreased. |
| Kauffman, J. B., A. S. Thorpe, et al. 2004. Livestock exclusion and belowground ecosystem responses in riparian meadows of eastern Oregon. Ecol. Appl. 14(6):1671–1679. | Examined livestock exclusion on three sites in middle fork John Day River 9–18 years after grazing in dry and wet meadows. Total belowground biomass was 50% and 62% greater in exclosures in dry and wet meadows, respectively. Mean infiltration rate was 12.9 times greater (1,191%) and 233% greater in dry and wet meadows, respectively. |
| Keller, C. R., and K. P. Burnham. 1982. Riparian fencing, grazing, and trout habitat preference on Summit Creek, Idaho. N. Am. J. Fish. Manag. 2:53–59. | Fencing to exclude livestock in Summit Creek, Idaho, led to more trout in ungrazed sections—1.56 times more fish on average. Also fish in ungrazed sections were larger. |
| Kondolf, G. M. 1993. Lag in stream channel adjustment to livestock exclosure, White Mountains, California. Restor. Ecol. 1(4):226–230. | Examined channel morphology within and downstream of grazing exclosure—no change in channel width downstream of exclosure despite higher vegetation height and cover in exclosure. |

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| Laffaille, P., J. C. Lefeuvre, et al. 2000. Impact of sheep grazing on juvenile sea bass, *Dicentrarchus labrax L.*, in tidal salt marshes. Biol. Conserv. 96(3):271–277. | Effects of sheep grazing on salt march in France and seabass foraging. Change in vegetation following removal of grazing led to more food (invertebrates) for seabass. They consumed less invertebrates in grazed areas. |
| Li, H. W., G. A. Lamberti, et al. 1994. Cumulative effects of riparian disturbances along high desert trout streams of the John Day Basin, Oregon. Trans. Am. Fish. Soc. 123(4):627–640. | Comparison of shaded and unshaded streams in the John Day Basin. Shaded streams cooler by up to 5°C, greater rainbow trout biomass by approximately twofold in those with canopy vs. those without (hard to estimate average increase from graphs). |
| Long, J. W., A. Tecle, et al. 2003. Marsh development at restoration sites on the White Mountain Apache Reservation, Arizona. J. Am. Water Resour. Assoc. 39(6):1345–1359. | Examined recovery of riparian areas following removal of grazing and seeding in White Mountain Apache Reservation. Found emergent wetland plants 4.7% to 55.5% higher in reaches with perennial flow compared to initial condition. Mean cover of aquatic plants declined from 7.4% to 0.2%. As fine sediments and emergent vegetation accumulated within the channel, mean cover of coarse materials declined from 38.5% to 0.3%. Mean cover of woody plants increased from 0.8% to 2.7%. |
| Lyons, J., S. W. Trimble, et al. 2000. Grass versus trees: Managing riparian areas to benefit streams of central North America. J. Am. Water Resour. Assoc. 36(4):919–930. | 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, Index of Biological Integrity, or other physical or biological variables. |
| Marshall, D. W., A. H. Fayram, et al. 2008. Positive effects of agricultural land use changes on cold-water fish communities in southwest Wisconsin streams. N. Am. J. Fish. Manag. 28(3):944–953. | Brown trout. Effects of planting cool- or warm-season grass cover on highly erodible croplands along stream corridors. Preplanting fish communities had a relatively high diversity of eurythermal species and low cold-water Index of Biological Integrity (IBI) scores. They found significant increases in cold-water 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 cold-water 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. |

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| Meals, D. W. 2001. Water quality response to riparian restoration in an agricultural watershed in Vermont, USA. Water Sci. Technol. 43(5):175–182. | Same as Meals and Hopkins 2002, but preliminary findings. See Meals and Hopkins 2002 below. |
| Meals, D. W., and R. B. Hopkins. 2002. Phosphorus reductions following riparian restoration in two agricultural watersheds in Vermont, USA. Water Sci. Technol. 45(9):51–60. | Examined phosphorous (P) reduction in before-after control-impact watershed (2 treatments = 1 control) design to grazing and riparian treatments. P concentrations and loads decreased 20% and total P load 20–50%. |
| Medina, A. L. 2001. A preliminary analysis of riparian habitat conditions of the upper Verde River. *In* C. DeCarlo, C. Schlinger, et al. (eds.), Verde Watershed Symposium: State of the Watershed in 2001, p. 16–24. Northern Arizona Univ., Flagstaff. | Examined vegetation and channel conditions in the Verde River, Arizona, following grazing removal and large flood. Did not find 1) that the riparian habitats were dysfunctional, 2) that recent livestock grazing had a negative effect on woody plant densities, or 3) that channel conditions were impaired due to excessive sedimentation. The study design limited the ability to detect change. Note that the report does not provide clear information on study design very well and focuses on changes across basin rather than grazing treatments. |
| Medina, A. L., J. N. Rinne, et al. 2005. Riparian restoration through grazing management: Considerations for monitoring project effectiveness. *In* P. Roni (ed.), Monitoring stream and watershed restoration, p. 97–126. American Fisheries Society Bethesda, MD. | Book chapter. Three case studies on grazing removal. First, Rio de Las Vacas exclosures, no fish response, streambank stability was 100% in exclosures, but 64% in grazed areas, overhanging vegetation slightly higher in grazed areas, no difference in nutrients, study design confounded results. Second, West Fork grazing allotment looked at exclusion of cattle, cattle and elk, or both. Standing biomass of vegetation increased in all three treatments, but most in control, no fish response. Third, Verde River, no differences in water quality. Vegetation cover composition and density improved at grazed and ungrazed sites. Numbers of exotic species have continued to increase. |
| Medina, A. L., and J. E. Steed. 2002. West Fork allotment riparian monitoring study 1993–1999. U.S. Forest Service, Rocky Mountain Research Station, Flagstaff, AZ. | Examination of West Fork grazing allotment (see also Medina et al. 2005) 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. |

Myers, L. H. 1989. Grazing and riparian management in southwestern Montana. *In* R. E. Gresswell, B. A. Barton, et al. (eds.), Practical approaches to riparian resource management: An education workshop, p. 117–120. U.S. Bureau of Land Management, Billings, MT.

Examined 34 grazing allotments in southwest Montana—74% were unsuccessful in accommodating a positive riparian vegetation response within a 10 to 20 year 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 13–86% of ungrazed height, depending on date measured.

Myers, T. J., and S. Swanson. 1995. Impact of deferred rotation grazing on stream characteristics in central Nevada: A case study. N. Am. J. Fish. Manag. 15(2):428–439.

Looked at effects of grazing removal on physical habitat in one watershed and rest rotation grazing strategies in two Nevada watersheds. Streambank soil stability, type and amount of vegetation cover, and qualities of pools improved in all three streams. Bank stability increased 28–37% in streams with and without roads and rest rotation grazing. Gravel cobble substrate increased 13% in one stream without roads, but not in others.

Myers, T. J., and S. Swanson. 1996. Long-term aquatic habitat restoration: Mahogany Creek, Nevada, as a case study. Water Resour. Bull. 32(2):241–252.

Compared recovery from abusive grazing management on two similar northwest Nevada streams. Mahogany Creek had livestock grazing excluded, while its tributary Summer Camp Creek 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. Width/depth ratio did not change much due to inherent stability of both stream systems.

Nagle, G. N., and C. F. Clifton. 2003. Channel changes over 12 years on grazed and ungrazed reaches of Wickiup Creek in eastern Oregon. Phys. Geogr. 24(1):77–95.

Examined channel cross sections inside and outside a 48-year-old exclosure to compare changes following reduction in grazing outside the exclosure (1986 to 1998). Grazed channels showed improvement, but not all significant. Enclosure had narrower width (2.29 vs. 1.45), deeper depth (.23 vs. .32), and narrower width/depth ratio (14.17 vs. 4.6) than grazed channels.

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| Nerbonne, B. A., and B. Vondracek. 2001. Effects of local land use on physical habitat, benthic macroinvertebrates, and fish in the Whitewater River, Minnesota, USA. Environ. Manag. 28(1):87–99. | Examined effects of upland best management practices implementation (alternative tillage methods) and riparian buffers (grazed, grass buffer, wooded buffer, etc.) throughout the Whitewater River. Physical habitat differed across buffers, but not upland treatments. Grass buffers had significantly lower fines (1997 means = 60, 38.7, and 59.8 in wood, grass, and grazed), embeddedness (1997 means = 69.5, 54.9, and 72.6), and exposed streambanks (1997 means = 44.6, 4.1, and 27.7) and higher overhanging vegetation (.32, .81, and .27) compared to grazed or wood buffers. Benthic invertebrate metrics (rapid bioassessment protocols and fish indices of biological integrity) did not differ. |
| Northington, R. M., and A. E. Hershey. 2006. Effects of stream restoration and wastewater treatment plant effluent on fish communities in urban streams. Freshw. Biol. 51:1959–1973. | 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. ≈7/100 m for forested and 5 for unrestored) and a trend toward 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 Index of Biological Integrity of aquatic insects. |
| O'Grady, M., P. Gargan, et al. 2002. Observations in relation to changes in some physical and biological features of the Glenglosh River following bank stabilisation. *In* Proceedings of the 13th International Salmonid Habitat Enhancement Workshop, Hotel Westport, Mayo, Ireland, 16–19 September 2002, p. 61–77. Central Fisheries Board, Dublin, Ireland. | Changes in aquatic flora, invertebrates, and fish following implementation of bank stabilization and fencing in Glenglosh River, Ireland. Aquatic moss coverage increased from nearly 0 to 50%. Macroinvertebrates went from 5 to 11 taxa present (before vs. after in treatment sites), fish stocks saw increases in brown trout and Atlantic salmon parr after treatment. Annual increases in entire length restored range from 1,620 to 5,670 salmon and 3,888 to 9,800 trout. |
| Opperman, J. J., and A. M. Merenlender. 2000. Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. Restor. Ecol. 8(1):41–47. | Effects of deer herbivory on riparian plantings in Mendocino Country, California. Mean density of saplings in deer exclosures was 49/$m^2$ vs. 0.05 in controls (plots with deer). Thirty-five percent of saplings were less than 1 m tall in exclosures, while in controls 97% were less than 1 m. |

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| Opperman, J. J., and A. M. Merenlender. 2004. The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. N. Am. J. Fish. Manag. 24(3):822–834. | Examined recovery of channel morphology and fish habitat 10–20 years after livestock exclusion fences. Channels within exclosures were narrower (≈3 m narrower), were cooler (mean August 18.2°C vs. 22.7°C), had greater large woody debris (≈275 pieces/ha vs. 75), and had higher tree density (.74 plants/$m^2$ vs. .08). Note that the approximate numbers were from graphs and the other numbers were reported in text. |
| Parkyn, S. M., R. J. Davies-Colley, et al. 2003. Planted riparian buffer zones in New Zealand: Do they live up to expectations? Restor. Ecol. 11(4):436–447. | Examined effects of fencing and planting on nine buffer zones 2–24 years after fencing. Treatments had better water quality and channel stability, but nutrient and fecal contaminant levels were variable. Macroinvertebrates did not show significant changes toward clean water taxa and macroinvertebrate taxa richness was on average 3.42 higher in controls than treatments. Study suggests planted reaches may need to be longer. |
| Penczak, T. 1995. Effects of removal and regeneration of bankside vegetation on fish population dynamics in the Warta River, Poland. Hydrobiologia 303(1–3):207–210. | Effects of removal and recovery of vegetation on fish in the Warta River. Species diversity decreased from 17 before to 11 following vegetation 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. |
| Platts, W. S. 1981. Impairment, protection, and rehabilitation of Pacific salmonid habitats on sheep and cattle ranges. *In* T. J. Hassler (ed.), Proceedings: Propagation, Enhancement, and Rehabilitation of Anadromous Salmonid Populations and Habitat in the Pacific Northwest Symposium, p. 82–92. Humboldt State Univ., Arcata, CA. | Summarized findings from three studies on grazing. The 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 Creek) 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 are provided, but hard to synthesize due to multiple years and treatments. |
| Platts, W. S., and R. L. Nelson. 1985. Impacts of rest-rotation grazing on streambanks in forested watersheds in Idaho. N. Am. J. Fish. Manag. 5:547–556. | Compared effects of rest rotation grazing vs. regular grazing management in 11 streams. Rest rotation resulted in 8–12% greater usage of riparian areas than adjacent range or pasture. Rest rotation grazing also led 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. |

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| Rinne, J. N. 1999. Fish and grazing relationships: The facts and some pleas. Fisheries 24(8):12–21. | 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 Medina et al. 2005 for details. |
| Robertson, A. I., and R. W. Rowling. 2000. Effects of livestock on riparian zone vegetation in an Australian dryland river. Regul. Rivers: Res. Manag. 16(5):527–541. | Examined vegetation structure and composition in paired sites with and without livestock in six sites in the Murrumbidgee River. Eucalyptus tree species were up to 1,000 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. Coarse particulate organic matter and terrestrial fine wood outside of channel were consistently more abundant in areas without livestock. Instream fine and coarse wood were higher in areas without livestock in the main stem, but not the tributary site. Generally sites where livestock had been excluded for more than 50 years had the biggest differences. |
| Roelle, J. E., and D. N. Gladwin. 1999. Establishment of woody riparian species from natural seedfall at a former gravel pit. Restor. Ecol. 7(2):183–192. | 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%. |
| Schilling, K. E., and C. A. Thompson. 2000. Walnut Creek watershed monitoring project, Iowa: Monitoring water quality response to prairie restoration. J. Am. Water Resour. Assoc. 36(5):1101–1114. | A paired watershed study was used to determine the effects of converting row crop to native prairie in Iowa. Land use changes were implemented on 19.4 % of the basin. The first 3 years of monitoring show encouraging signs, but no definitive water quality improvements (nitrate, pesticides, etc.) have been detected. |
| Sovell, L. A., B. Vondracek, et al. 2000. Impacts of rotational grazing and riparian buffers on physicochemical and biological characteristics of southeastern Minnesota, USA, streams. Environ. Manag. 26(6): 629–641. | Examined fish, water quality, macroinvertebrates, 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 was higher in wood than grass buffer sites. Benthic macroinvertebrates were not consistently different across grazed or buffer types. Fish abundance was related to buffer type rather than grazing practice. |

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| Sprenger, M. D., L. M. Smith, et al. 2002. Restoration of riparian habitat using experimental flooding. Wetlands 22(1):49–57. | 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 treated 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. |
| Stuber, R. J. 1985. Trout habitat, abundance, and fishing opportunities in fenced vs. unfenced riparian habitat along Sheep Creek, Colorado. *In* R. R. Johnson, C. D. Ziebell, et al. (tech. coords.), Riparian ecosystems and their management: Reconciling conflicting uses, p. 310–314. First North American Riparian Conference, 1985 April 16–18, Tucson, AZ. Gen. Tech. Rep. RM-GTR-120. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. | 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 vegetation than unfenced sections. Trout standing stock was two times higher in fenced areas. There was more nongame fish in unfenced areas. |
| Suren, A. M., and S. McMurtrie. 2005. Assessing the effectiveness of enhancement activities in urban streams: II. Responses of invertebrate communities. River Res. Appl. 21(4):439–453. | Examined response of macroinvertebrates to restructuring and riparian planting of five urban streams in Christchurch, New Zealand, before and 5 years after. Only small changes were noted with only subtle shifts in overall abundance, species evenness, diversity, and ordination. |
| Suren, A. M., T. Riis, et al. 2005. Assessing the effectiveness of enhancement activities in urban streams: I. Habitat responses. River Res. Appl. 21(4):381–401. | Examined response of habitat to restructuring and riparian planting of five urban streams in Christchurch, New Zealand, before and 5 years after restoration. Treated sites had generally higher vegetation cover and increasing overhanging riparian vegetation. Stream enhancement increased variability in velocity and substrate changed as concrete and timber line channels were converted to stream channel. |

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| Sweeney, B. W., S. J. Czapka, et al. 2002. Riparian forest restoration: Increasing success by reducing plant competition and herbivory. Restor. Ecol. 10(2):392–400. | 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, Maryland. Results of four growing seasons showed no significant difference in survival or growth between bare-root and containerized seedlings. Overall survival and growth was different for sheltered and unsheltered seedlings (49% and 77.6 cm 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%/125.7 cm) and shelters and weed matts (57.5%/73.5 cm). Thus only a combination of shelters and weed protection provided had survivorship high enough to be considered successful (>50%). |
| Taylor, J. P., and K. C. McDaniel. 1998. Restoration of saltcedar (*Tamarix* sp.)–infested floodplains on the Bosque del Apache National Wildlife Refuge. Integrated systems for noxious weed management on rangelands. Weed Technol. 12:345–352. | Saltcedar eradication using herbicide, burning, and mechanical control—and planting of cottonwood and black willows. Saltcedar resprouts were still common after burning, herbicides, and bulldozing. Replanting resulted in cottonwood survival of more than 80% 4 years after planting. Deep tillage to 3 m and drip irrigation for 165 days resulted in 100% of cottonwood and black willow survival when plantings were made on a dredge spoil site. |
| Wohl, N. E., and R. F. Carline. 1996. Relations among riparian grazing, sediment loads, macroinvertebrates, and fishes in three central Pennsylvania streams. Can. J. Fish. Aquat. Sci. 53:260–266. | Examined riparian grazing impacts on three streams (two grazed, one ungrazed). Annual sediment loads were lower in ungrazed stream (113 metric tons vs. 255 and 273 metric tons). Substrate permeability and densities of invertebrates were higher in ungrazed stream. Densities of brown trout were 5–23 times higher in ungrazed than two grazed streams. |

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| Wootton, J. T. 2012. River food web response to large-scale riparian zone manipulations. Plos One 7(12). | Coho salmon, steelhead, and cutthroat trout. Reducing riparian canopy cover caused trapped leaf litter to decline by two-thirds, UV radiation to increase twelvefold, and photosynthetically active radiation to increase 42-fold. Water temperature, 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 increased thirteenfold, 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 sevenfold, with all major taxonomic groups showing elevated populations. Densities of juvenile salmonids increased on average 77% in manipulated reaches. |

## Sediment/Road References (Subtotal is 27 of 409)



| Reference | Key Quantitative Findings |
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| Bergeron, K. D. 2003. The effects of an organic soil amendment on native plant establishment and physical soil properties on an obliterated forest road. Master's thesis. Univ. Washington, College of Forest Resources, Seattle. | Effect of different combinations of soil treatments on vegetation cover and biomass. Results showed that biosolids, compost, and fertilizer increased native plant biomass and vegetation cover. Presence of nonnatives had no impact on native plant biomass. In a second study, saturated hydraulic conductivity rates were examining biosolids, application of fertilizer, and straw. No significant difference was found among treatments. The highest vegetative cover was found in the 10 cm biosolids compost application (90%), compared to the control (57%) and fertilizer treatments (59%). The difference between the three biosolids compost amendments and the control and fertilizer remained statistically significant. The greatest gain in biomass was observed in biosolids compost treatments, with a mean biomass of 53 g in the 2.5 cm application, 65 g in the 5 cm application, and 80 g in the 10 cm application. The biomass was 33 g for the control and 37 g for fertilizer. The no seed/hay treatment had the highest mean total plant biomass (69 g), compared to the seed treatment (47 g), seed and hay treatment (48 g), and hay treatments (49 g). |

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| Bloom, A. L. 1998. An assessment of road removal and erosion control treatment effectiveness: A comparison of 1997 storm erosion response between treated and untreated roads in Redwood Creek basin, northwestern California. Master's thesis. Humboldt State Univ., Arcata, CA. | Examined sediment delivery and erosion on treated and untreated roads. Treated roads yielded significantly less erosion and sediment delivery to streams. On upper and middle hillslope roads, the untreated roads contributed 27 times more sediment per mile to streams than treated roads, and 59 times more sediment per mile to streams than minimally treated roads. The lower hillslope untreated roads contributed 1.5 times more sediment per mile of road to streams than treated roads, and 1.1 times more sediment per mile of road to streams than minimally treated roads. On the upper and middle hillslopes, more than four times as many road failures were initiated on treated roads than minimally treated or untreated roads. On the lower hillslopes, minimally treated roads initiated two times as many road failures as the treated roads and more than five times as many as the untreated roads. |
| Brown, T. M. 2002. Short-term total suspended-solid concentrations resulting from stream crossing obliteration in the Clearwater National Forest, Idaho. Master's thesis. Univ. Washington, Seattle. | Effects of stream crossing obliteration. Downstream turbidity was significantly higher except at mitigated sites, which were not different upstream or downstream of treatment. Total suspended-solid concentrations upstream ranged from 1.0 to 5.7 mg/L; downstream concentrations were highly variable, ranging from 2.9 to approximately 68,500 mg/L. Upstream suspended sediment yields ranged from 0.1 to 0.8 kg, while downstream yields ranged from 0.8 to 95.4 kg. The use of two sediment traps reduced peak concentrations an order of magnitude from 68,500 mg/L to 3,000 mg/L, and suspended sediment yields 10 to 30 times. |
| Burroughs Jr., E. R., and J. G. King. 1989. Reduction of soil erosion on forest roads. U.S. Forest Service, Intermountain Research Station, Ogden, UT. | Literature review summarizing major findings of other studies and providing recommendations to managers. |
| Carter, T. L., and T. C. Rasmussen. 2005. Use of green roofs for ultra-urban stream restoration in the Georgia Piedmont (USA). *In* K. J. Hatcher (ed.), Proceedings of the 2005 Georgia Water Resources Conference. Univ. Georgia, Athens. | Green roofs for urban stream restoration—for 32 storm events tested, green roof stormwater retention ranged from 39% to 100%. |

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| Cloyd, C., and K. Musser. 1997. Effectiveness of road stabilization. *In* H. Plumley (ed.), Assessment of the effects of the 1996 flood on the Siuslaw National Forest, p. 19–23. U.S. Dept. Agriculture, Siuslaw National Forest, Corvallis, OR. | Stabilization reduced road-related impacts—67% of failures occurred on untreated roads. |
| Cotts, N. R., E. F. Redente, et al. 1991. Restoration methods for abandoned roads at lower elevations in Grand Teton National Park, Wyoming. Arid Soil Res. Rehabil. 5(4):235–249. | Examined different road surface treatments for abandoned roads—top soil significantly increased plant cover. Indigenous plant materials that were collected on site produced greater plant cover (23%) than the native materials (19%) purchased from a commercial supplier. Nonseeded, topsoiled treatments produced significant plant community development (18% cover), resulting from natural invasion from local intact communities. Nontopsoiled, scarified treatments seeded to indigenous materials provided appreciable plant cover (12%) following 2 years of growth. |
| Elseroad, A. C., P. Z. Fule, et al. 2003. Forest road revegetation: Effects of seeding and soil amendments. Ecol. Restor. 21(3):180–185. | Examined experimental treatments including combination seeding with native species, topsoil addition, and mulching. Total cover and plant density was significantly higher on all seeded plots. Combinations of treatment were not significantly different. Statistics not provided, but graphs suggest seeded treatments had approximately 150 plants/$m^2$ 2 months after treatment, while unseeded had approximately five. Differences 14 months later were approximately 75/$m^2$ vs. 10 plants/$m^2$. |
| Foltz, R. B. 1998. Traffic and no-traffic on an aggregate surfaced road: Sediment production differences. *In* Proceedings of the seminar on environmentally sound forest roads and wood transport, Sinaia, Romania, 17–22 June, 1996, p. 195–204. FAO, Rome. | Traffic and no-traffic on aggregate surfaced road—sediment production from marginal was 4–17 times higher than on good quality aggregate. Sections with logging truck traffic produced 2–25 times as much sediment. |

Foltz, R. B., and W. J. Elliot. 1997. Effect of lowered tire pressures on road erosion. Transportation Research Board Paper No. 970638. Transp. Res. Rec.: J. Transp. Res. Board 1589:19–25.

Sediment eroded from the low-quality aggregate surfaced roads an average of 45% less with moderately reduced tire pressure than from highway tire pressure sections. An average of 80% was measured from the section used by trucks with low tire pressure. Lowering tire pressures in logging trucks on unpaved roads can reduce the sediment loss from many unpaved road surfaces.

Harr, R. D., and R. A. Nichols. 1993. Stabilizing forest roads to help restore fish habitats: A northwest Washington example. Fisheries 18(4):18–23.

Examined cost of decommissioning roads (stabilizing fills, removing stream crossings, recontouring slopes, and reestablishing drainage patterns to reduce landslide hazards). In contrast to unused roads, decommissioned roads showed no damage following a 50-year 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 (1987–1988) and two large events (1989–1990), no failures on decommissioned roads.

Hickenbottom, J. 2000. A comparative analysis of surface erosion and water runoff from existing and recontoured forest roads: O'Brien Creek watershed, Lolo National Forest, Montana. Master's thesis. Univ. Montana, Missoula.

Abstract only. Compared existing and contoured roads (removed) in two geology and slope classes (>45% and <45%). In all cases, it was found that recontoured roads produced sediment and runoff similar to or higher than road segments. However, after 1 year, the volume of runoff and erosion greatly decreased to near natural slope conditions.

Kitagawa, K., and S. Okawara. 1998. Development of a forest road with a newly designed sub-base structure. *In* Proceedings of the seminar on environmentally sound forest roads and wood transport, Sinaia, Romania, 17–22 June, 1996, p. 226–231. FAO, Rome.

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 statistics provided.

Klein, R. D. 1987. Stream channel adjustments following logging road removal in Redwood National Park. Watershed Rehabilitation Tech. Rep. No. 23. National Park Service, Redwood National Park, Arcata, CA.

Examined stream channel adjustments following road removal in the park. Technical report with multiple regressions but no specific statistics. Adjustments in stream channels depended on the amount of organic matter (large woody debris) and other roughness elements left at former crossings that prevented scour and erosion.

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| Kochenderfer, J. N., and J. D. Helvey. 1987. Using gravel to reduce soil losses from minimum-standard forest roads. J. Soil Water Conserv. 42:46–50. | Compared forest roads with and without 3″ of gravel. Soil losses from roads without gravel were 47 tons/acre vs. 6 tons/acre for graveled roads. |
| Kohler, E. A., V. L. Poole, et al. 2004. Nutrient, metal, and pesticide removal during storm and nonstorm events by a constructed wetland on an urban golf course. Ecol. Eng. 23:285–298. | Examined effect of constructed wetlands on golf course runoff. Wetland successfully reduced concentration of 13 of 17 parameters (all but K, Al, Mg, and Si) during storm events. During nonstorm events, wetland reduced $N\text{-}NO^3/NO^2$ by 95% and removal was 100% for other measures. |
| Kolka, R., and M. Smidt. 2001. Revisiting forest road retirement. Water Resour. Impact 3(3):15–18. | 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 approximately 14 $g/m^2$ of sediment vs. 31 $g/m^2$ for subsoiled vs. 34 $g/m^2$ for control and 0 for undisturbed hillslope. |
| Luce, C. H. 1997. Effectiveness of road ripping in restoring infiltrating capacity of forest roads. Restor. Ecol. 5(3):265–270. | Examined effectiveness of road ripping on infiltration capacity. Results showed that road 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 of 0–4 mm/hr whereas ripped roads had 20–40 mm/hr. |
| Madej, M. A. 2001. Erosion and sediment delivery following removal of forest roads. Earth Surf. Process. and Landf. 26(2):175–190. | Erosion and 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 $m^3$/km of road treated. In contrast, untreated roads produced 1,500 to 4,700 $m^3$ of sediment per kilometer. |
| Madej, M. A., B. Barr, et al. 2001. Effectiveness of road restoration in reducing sediment loads. U.S. Geological Survey, Redwood Field Station, Arcata, CA. | Essentially the same as Madej 2001. See those key findings above. |

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| Maynard, A. A., and D. E. Hill. 1992. Vegetative stabilization of logging roads and skid trails. N. Am. J. Appl. For. 9(4):153–157. | Stabilization of logging roads—evaluated the effects of fertilizer and mulch treatments on plant density. Results were hard to quantify, as findings and recommendations vary by whether the site was sunny, shady, or wet. Addition of fertilizer and lime enhanced plant density and survival at all sites. |
| McCaffery, M., T. A. Switalski, et al. 2007. Effects of road decommissioning on stream habitat characteristics in the South Fork Flathead River, Montana. Trans. Am. Fish. Soc. 136(3):553–561. | No good numbers. Significant positive correlations were found between the percent 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 roads 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 100 m or maximum pool depth among three treatment groups. |
| McNabb, D. H. 1994. Tillage of compacted haul roads and landings in the boreal forests of Alberta, Canada. For. Ecol. Manag. 66(1–3): 179–194. | Tillage of compacted haul roads and landings. Tillage significantly reduced mean bulk soil density. Minimizing the area in degraded soil, fracturing compacted soil (regardless of the method) to increase frost action, and spreading displaced soil is the most promising combination of treatments for protecting and rehabilitating degraded soils in the boreal forest. |
| Scully, R. J., E. J. Leitzinger, et al. 1990. Idaho habitat evaluation for off-site mitigation record. 1988 Annual Report to Bonneville Power Administration. U.S. Dept. Energy, BPA, Portland, OR. | Section of a large report. Steelhead and Chinook salmon. 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 greater than 1.5%. B channels average 28% boulders, compared to 4% in C channels. Mean annual steelhead parr densities ranged 2–3 times greater in B channels than C channels (6.1/100 m$^2$ vs. 2.5/100 m$^2$). Mean Chinook parr density was lowest (14.1/100 m$^2$) in C channel streams where percent sand was less than 10%, and highest in the 10–20% sand interval with density declining for each 10% increase in percent sand above 20%. |
| Switalski, T. A., J. A. Bissonette, et al. 2004. Benefits and impacts of road removal. Front. Ecol. Environ. 2(1):21–28. | 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 seven studies indicate that mean erosion rates on treated roads range from 27 to 97 m$^3$/km compared to 115 to 235m$^3$/km. |

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| Wildlands CPR. 2012. Road reclamation: Measuring success. The Road RIPorter, Autumn Equinox 2012:3–10. | 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%. |
| Wright, D. L., and R. E. Blaser. 1990. Establishment of vegetation on graded road cuts as influenced by topsoiling and tillage. West. J. Appl. For. 5(4):419–422. | 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/cm$^3$ 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. |



## Acquisition and Protection Reference (Subtotal is 1 of 409)

| Reference | Key Quantitative Findings |
|---|---|
| Tetra Tech. 2013. Reach-scale effectiveness monitoring program. 2012 annual progress report. Tetra Tech EC Inc., Bothell, WA. Online at http://www.rco.wa.gov/documents/monitoring/2012Report.pdf [accessed 01 November 2013]. | Evaluated the ecological condition of 10 habitat protection projects implemented across Washington state over an 8-year period. Looked at 21 indicators of upland and riparian vegetation, instream habitat, and fish and macroinvertebrate metrics. Projects have shown significant improvements in several of the upland vegetation indicators, including nonnative herbaceous absolute cover, nonnative herbaceous relative cover, and coniferous basal area, but no significant change for other indicators. Most notably, significant results were not found for any of the fish or riparian indicators in Year 8. The Index of Biotic Integrity scores for most projects were in the good range for macroinvertebrates and fish, though scores have been decreasing with time (i.e., the average score decreased from 90 to 89 to 74 in years 0, 3, and 8, respectively). Note that they also reported on ongoing monitoring of instream and floodplain enhancement projects. |

# Flow References (Subtotal is 15 of 409)

| Reference | Key Quantitative Findings |
|---|---|
| Bednarek, A. T., and D. D. Hart. 2005. Modifying dam operations to restore rivers: Ecological responses to Tennessee River dam mitigation. Ecol. Appl. 15:997–1008. | Dissolved oxygen increased from 4.7 to 7.1 mg/L (34%), temperature decreased from 16.1 to 13.3, velocity increased 1.5 times (59%), discharge increased 528%, invertebrate family richness increased 36%, percent 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. |
| Dominick, D. S., and M. P. O'Neill. 1998. Effects of flow augmentation on stream channel morphology and riparian vegetation: Upper Arkansas River basin, Colorado. Wetlands 18(4):591–607. | Comparison of natural streams to streams where they augmented flow: increase in bankfull width and width/depth ratio in augmented streams; median particle size in augmented streams ranged from 38 to 56 mm, while it was 15 to 26 mm in natural basins; and 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. |
| Dyer, F. J., and M. C. Thoms. 2006. Managing river flows for hydraulic diversity: An example of an upland regulated gravel-bed river. River Res. Appl. 22:257–267. | Examined a variety of flows releases in an 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 that results probably are not applicable to other streams. |
| Galat, D. L., L. H. Fredrickson, et al. 1998. Flooding to restore connectivity of regulated, large-river wetlands. Bioscience 48(9):721–733. | Examines use of reconnected floodplain habitats following a 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. |
| Hill, M. T., and W. S. Platts. 1998. Ecosystem restoration: A case study in the Owens River gorge, California. Fisheries 23(11):18–27. | Restoration of flows and flood pulsed to dewatered reach. Increased pulse and base flows led to establishment and rapid growth of riparian vegetation and good quality microhabitat (pools, runs, depth, and wetted width). Brown trout numbers increased 40% and catch rates increased from 0/hour to 5.8–7.1 fish/hour. |

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| Johansson, M. E., and C. Nilsson. 2002. Responses of riparian plants to flooding in free-flowing and regulated boreal rivers: An experimental study. J. Appl. Ecol. 39(6):971–986. | Compared riparian vegetation 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*. |
| Jurajda, P., M. Ondrackova, et al. 2004. Managed flooding as a tool for supporting natural fish reproduction in man-made lentic water bodies. Fish. Manag. Ecol. 11(3–4): 237–242. | Managed flooding of former borrow pits to examine effect on species diversity. Species richness was higher in flooded than nonflooded borrow pits (14.7 vs. 11). Adult fish abundance (catch per unit effort) was three to 14 times higher in flooded vs. nonflooded pits and juvenile abundance was nearly two times higher in flooded vs. nonflooded. |
| Rood, S. B., C. R. Gourley, et al. 2003. Flows for floodplain forests: A successful riparian restoration. Bioscience 53(7):647–656. | Restoration of flows to Truckee River led to recovery of cottonwood and sandbar willow, also led to return of 10 of 19 bird species that had been extirpated. Increased spring and summer flows produced a tenfold increase in the adult cui-ui sucker (*Chasmistes cujus*) population. |
| Rood, S. B., and J. M. Mahoney. 2000. Revised instream flow regulation enables cottonwood recruitment along the St. Mary River, Alberta, Canada. Rivers 7(2):109–125. | Recruitment of cottonwood in a regulated river following natural and restored floods. High cottonwood recruitment following 1995 flood (seedling density 200/m$^2$), but uncertain whether full recovery will occur as imposed base and flood flows may not reach those seen in natural floods (1995). |
| Sabaton, C., Y. Souchon, et al. 2008. Long-term brown trout population responses to flow manipulation. River Res. Appl. 24(5):476–505. | Brown trout. Flow manipulation. On average, the potential habitat in bypass sections increased by 39% (a factor of 1.4 between the two flow levels). Average weighted usable area was 68% of the maximum before enhancement and rose to 87% postenhancement. For all bypass section sites, there was a 22.8% mean increase in the numbers of adults in the postenhancement period, as opposed to preincrease. |
| Scruton, D. A., T. C. Anderson, et al. 1998. Pamehac Brook: A case study of the restoration of a Newfoundland, Canada, river impacted by flow diversion for pulp transportation. Aquat. Conserv.: Mar. Freshw. Ecosyst. 8(1):145–157. | Restoration of flows to dewatered stream. Before and 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 eighteenfold. Biomass increased from 68.4 g/unit to 281 g/unit or total production from 18 kg to 330 kg. |

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| Speierl, T., K. H. Hoffmann, et al. 2002. Fischfauna und habitatdiversität: Die auswirkungen von renaturierungsmabnahmen an Main und Rodach. [Fish communities and habitat diversity: The effect of river restoration measures on the Main and Rodach.] Natur und Landschaft Stuttgart 77(4):161–171. | In German; key quantitative findings listed here are based on the English abstract only. Restored reaches vs. regulated reaches. More species and individuals were caught in restored vs. regulated for larvae, juvenile, and adult fishes. No details. |
| Stevens, L. E., T. J. Ayers, et al. 2001. Planned flooding and Colorado River riparian trade-offs downstream from Glen Canyon Dam, Arizona. Ecol. Appl. 11(3):701–710. | Test flood in Colorado River: restored sandbars, 10.7% of endangered snail habitat and 7% of population was lost, buried riparian vegetation under greater than 1 m of sand. |
| Theiling, C. H., J. K. Tucker, et al. 1999. Flooding and fish diversity in a reclaimed river-wetland. J. Freshw. Ecol. 14(4):469–475. | Studied response of reclaimed river wetland to flooding: eight species found prior to flooding vs. 26 species afterward. Thirty-three species were found the following June, but only 16 in subsequent collections in August, suggesting temporary or seasonal increases in diversity due to flooding. |
| Weisberg, S. B., and W. H. Burton. 1993. Enhancement of fish feeding and growth after an increase in minimum flow below the Conowingo Dam. N. Am. J. Fish. Manag. 13:103–109. | Diversity of consumed prey increased 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 after treatment. |

# Appendix B: Subset of the Literature Examined that Reported on Survival

Table B-1. Key findings from a subset of papers on restoration effectiveness in Appendix A that reported survival or changes in survival due to restoration. Off-channel/floodplain treatment projects are listed first (the first five references, in alphabetical order by author), followed by instream habitat treatment projects (the next 14 references, in alphabetical order by author).

| Reference | Treatment and location | Key survival results |
|---|---|---|
| Cederholm, C. J., and N. P. Peterson. 1989. A summary comparison of two types of winter habitat enhancement for juvenile coho salmon (*Oncorhynchus kisutch*) in the Clearwater River, Washington. *In* B. G. Shepherd (ed.), Proceedings of the 1988 Northeast Pacific Chinook and Coho Salmon Workshop, p. 227–239. Ministry of Environment, Penticton, BC. | Constructed floodplain habitat in Washington | Significant increase in winter coho salmon overwinter survival (rate = .57). |
| Cederholm, C. J., W. J. Scarlett, et al. 1988. Low-cost enhancement technique for winter habitat of juvenile coho salmon. N. Am. J. Fish. Manag. 8:438–441. | Constructed floodplain habitat in Washington | Overwinter survival and growth of coho salmon increased significantly after construction (survival .11 to .56, mean change in length from 13 to 41 mm, mean change in weight from 3 to 13 g). |
| Henning, J. A., R. E. Gresswell, et al. 2006. Juvenile salmonid use of freshwater emergent wetlands in the floodplain and its implications for conservation management. N. Am. J. Fish. Manag. 26:367–376. | Reconnected wetland in Washington | Yearling coho salmon 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, J. E., A. Lillehammer, et al. 1993. Effect of habitat improvement on Atlantic salmon in the regulated River Suldalslagen. Regul. Rivers: Res. Manag. 8(1–2):95–102. | Constructed side channel in Norway | Survival of age-1+ Atlantic salmon was 30%. |
| Sommer, T. R., M. L. Nobriga, et al. 2001b. Floodplain rearing of juvenile Chinook salmon: Evidence of enhanced growth and survival. Can. J. Fish. Aquat. Sci. 58(2):325–333. | Levee removal in California | Survival indices for coded-wire-tagged Chinook salmon were somewhat higher for those released in the floodplain than for those released in the river, but the differences were not statistically significant. |

Table B-1 continued. Key findings from a subset of papers on restoration effectiveness in Appendix A that reported survival or changes in survival due to restoration. Off-channel/floodplain treatment projects are listed first (the first five references, in alphabetical order by author), followed by instream habitat treatment projects (the next 14 references, in alphabetical order by author).

| Reference | Treatment and location | Key survival results |
|---|---|---|
| Gard, R. 1961. Creation of trout habitat by constructing small dams. J. Wildl. Manag. 52(4):384–390. | Large woody debris (LWD) and boulder structures in California | During the three summers following dam installation, the numbers of introduced brook trout were counted. Forty-nine trout were collected the second summer, yielding a 1-year survival rate of 38%. Seventy-three percent of the fish surviving to the second summer were collected the third summer and 39% of those surviving to the third summer lived to the fourth. |
| Giannico, G. R., and S. G. Hinch. 2003. The effect of wood and temperature on juvenile coho salmon winter movement, growth, density, and survival in side channels. River Res. Appl. 19(3):219–231. | LWD additions in BC, Canada | 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, C., and K. D. Fausch. 1996a. Long-term demographic responses of trout populations to habitat manipulations in six Colorado streams. Ecol. Appl. 6:931–946. | LWD additions in Colorado | Recaptures of tagged trout and batch-marked trout revealed that immigration was primarily responsible for increased adult abundance and biomass, whereas no biologically significant differences occurred for recruitment, survival, or growth. |
| Jester, D. B., and H. J. McKirdy. 1966. Evaluation of trout stream improvement in New Mexico. Proc. Annu. Conf. Western Assoc. State Game Fish Comm. 46:316–333. | LWD and boulder structures in New Mexico | Trout overwinter survival was enhanced by the presence of structures. |
| Johnson, S. L., J. D. Rodgers, et al. 2005. Effects of an increase in large wood on abundance and survival of juvenile salmonids (*Oncorhynchus* spp.) in an Oregon coastal stream. Can. J. Fish. Aquat. Sci. 62(2):412–424. | LWD additions in Oregon | Steelhead smolt abundance, steelhead freshwater survival, and coho salmon freshwater survival increased in one creek after the input of wood, but similar results were found in the reference stream. |
| Klassen, H. D., and T. G. Northcote. 1988. Use of gabion weirs to improve spawning habitat for pink salmon in a small logged watershed. N. Am. J. Fish. Manag. 8(1):36–44. | Rock structures (gabions) in BC, Canada | Pink salmon egg survival at one site in its first year did not differ significantly from two nearby reference sites. |

Table B-1 continued. Key findings from a subset of papers on restoration effectiveness in Appendix A that reported survival or changes in survival due to restoration. Off-channel/floodplain treatment projects are listed first (the first five references, in alphabetical order by author), followed by instream habitat treatment projects (the next 14 references, in alphabetical order by author).

| Reference | Treatment and location | Key survival results |
|---|---|---|
| Lonzarich, D. G., and T. P. Quinn. 1995. Experimental evidence for the effect of depth and structure on the distribution, growth, and survival of stream fishes. Can. J. Zool. 73:2223–2230. | LWD additions in Washington | Coho salmon survival was greatest in the deep, structured treatment (89%), nearly twice that in the shallow, nonstructured treatment (47%). Both age-0 and age-1+ steelhead showed higher survival in the deep, structured treatment (71% and 89%) than in the shallow, nonstructured treatment (29% and 33%, respectively). |
| Merz, J. E., J. D. Setka, et al. 2004. Predicting benefits of spawning-habitat rehabilitation to salmonid (*Oncorhynchus* spp.) fry production in a regulated California river. Can. J. Fish. Aquat. Sci. 61(8):1433–1446. | Gravel additions in California | 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, K., W. A. Brock, et al. 1981. Restoration and enhancement program of anadromous fish habitat and populations on Six Rivers National Forest. *In* T. J. Hassler (ed.), Proceedings: Propagation, Enhancement, and Rehabilitation of Anadromous Salmonid Populations and Habitat in the Pacific Northwest Symposium, p. 158–168. Humboldt State Univ., Arcata, CA. | Boulder stuctures in California | Steelhead egg-to-fry survival ranged from 71% to 98%. Not clear how this compared to unrestored areas. |
| Paulsen, C. M., and T. R. Fisher. 2005. Do habitat actions affect juvenile survival? An information-theoretic approach applied to endangered Snake River Chinook salmon. Trans. Am. Fish. Soc. 134(1):68–85. | Various in Idaho | There was a positive, significant correlation between the number of habitat actions in a basin and Chinook salmon parr-to-smolt survival. |
| Pulg, U., B. T. Barlaup, et al. 2013. Restoration of spawning habitats of brown trout (*Salmo trutta*) in a regulated chalk stream. River Res. Appl. 29(2):172–182. | Gravel cleaning in Germany | In the first 2 years, highly suitable conditions were maintained, with a potential brown trout egg survival of more than 50%. Afterward, the sites offered moderate conditions, indicating an egg survival of less than 50%. |

Table B-1 continued. Key findings from a subset of papers on restoration effectiveness in Appendix A that reported survival or changes in survival due to restoration. Off-channel/floodplain treatment projects are listed first (the first five references, in alphabetical order by author), followed by instream habitat treatment projects (the next 14 references, in alphabetical order by author).

| Reference | Treatment and location | Key survival results |
|---|---|---|
| Riley, S. C., and K. D. Fausch. 1995. Trout population response to habitat enhancement in six northern Colorado streams. Can. J. Fish. Aquat. Sci. 52: 34–53. | LWD structures in Colorado | 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, J. D., S. L. Johnson, et al. 1993. The seasonal use of natural and constructed habitat by juvenile coho salmon (*Oncorhynchus kisutch*) and preliminary results from two habitat improvement projects on smolt production in Oregon coastal streams. *In* L. Berg and P. W. Delaney (eds.), Proceedings of the coho workshop, Nanaimo, BC, May 26–28, 1992, p. 334–351. DFO Canada, Vancouver, BC. | LWD additions in Oregon | Average coho salmon overwinter survival increased from 11% in one creek to 51% the first year, and 40% the second year after treatment. In another creek, it increased from 14% to 63% in the first year. |
| Solazzi, M. F., T. E. Nickelson, et al. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Can. J. Fish. Aquat. Sci. 57:906–914. | LWD additions in Oregon | Overwinter survival of coho salmon increased from a mean of .13 to .38 (reference was .17 to .20). In another stream, mean overwinter survival increased 250% from .11 to .39, but fell in the reference stream from .19 to .10. |

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