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Stream and Watershed Restoration

Christopher A. Frissell and Stephen C. Ralph

Overview

- Restoration is the process of returning a river or watershed to a condition that relaxes human constraints on the development of natural patterns of diversity. Restoration does not create a single, stable state but enables the system to express a range of conditions dictated by the biological and physical characteristics of the watershed and its natural disturbance regime.
- Most restoration efforts to date have focused on the alteration of physical habitat characteristics at small spatial scales, most often the placement of logs, rocks, or wire gabions in a channel to create pools or collect gravel. The effect of such efforts on the production and survival of the target fish species is uncertain.
- Relatively few projects have attempted restoration at the reach scale. However, this approach may be well suited for severely degraded stream reaches, although accurate documentation of the effectiveness of the approach is not available.
- Restoration of an entire watershed is very rarely attempted. However, addressing restoration from this broad spatial perspective is often necessary to relax human constraints on system function. A well-designed and evaluated watershed restoration project conducted in Redwood National Park illustrates the potential effectiveness of a camprehensive approach.
- Restoration efforts are constrained by a lack of a clear understanding of how human activities have altered the processes at work within a watershed. In large part, this deficiency is the result of the failure to include monitoring as an integral part of restoration projects. Evaluation and monitoring may pay large dividends in terms of developing a full understanding of which approaches to restoration work and which do not. Monitoring also may enable the identification of small adjustments in a program that greatly increase effectiveness or reduce costs.

Introduction

In the Pacific Northwest, decades of benign neglect, denial, and inertia in aquatic resource management have only recently yielded to the reluctant realization that a once substantial heritage of aquatic resources may become a mere relic of their historical potential to provide economic, cultural, and spiritual sustenance. The challenge to reverse these declines is formidable. The inevitability of Endangered Species Act (ESA) listings that mandate comprehensive salmon recovery plans for depleted stocks provides political imperative to promote restoration of aquatic communities. The growing number of Habitat Conservation Plans (HCPs) agreements negotiated between federal agencies and private landowners to address future aquatic habitat and fish species needs under the ESA provide an opportunity to evaluate watershed-scale recovery processes and timeliness in managed landscapes. Similarly, recent federal court decisions under the Clean Water Act (CWA) could require state water quality agencies and the Environmental Protection Agency to design and implement water resource recovery plans to restore imperiled water courses (presently thousands of water bodies fail to conform to established water quality criteria) that currently are impaired in their capacity to support aquatic resources. Growing social and political interest has the potential to greatly accelerate the adoption of restoration as a solution. This chapter presents a perspective on the present capability of aquatic restoration to address the challenge of protecting and restoring the integrity of Pacific coastal rivers and streams. The chapter discusses how holistic restoration might reverse declining trends.

In the Pacific coastal ecoregion, restoration of freshwater ecosystems is undergoing fundamental changes. In the last decade especially, fish biologists and stream ecologists have benefited greatly from the techniques and knowledge of physical scientists working in the related fields of fluvial geomorphology, sediment transport, channel hydraulics, and hydrology. The assessment techniques common to these disciplines, some of which were developed decades ago, have aided in assessing hillslope and channel processes that control input and routing of sediment and water through a stream system (see discussion in Chapters 2, 3, and 11).

From a long-standing emphasis on the small-scale, site-specific addition of artificial structures to favor individual species, restoration is graduating to an increasing emphasis on regional and watershed-scale reestablishment of the biophysical processes and structures that promote natural ecosystem recovery (Minns et al. 1996). This transition necessitates thinking across larger scales of space and time. It promises a future not of endless bounty, but at least of more effective conservation of biological resources, with the potential of net gains in the productivity and resilience of some ecosystems and species.

Unfortunately, existing institutional, political, and educational constraints tend to hinder wider acceptance and participation in such a conceptual transition (Frissell et al. 1997). If aquatic ecosystem restoration devolves into thinking simplistically about habitat alteration, the result could be economically and biologically costly failure on a scale larger than ever before. Successful negotiation of this transition requires a thoughtful and cautious approach that avoids blind faith in generic prescriptions of dubious benefit, acknowledges inherent uncertainty in biological outcomes, and embraces monitoring and evaluation as integral elements of any restoration project (Minns et al. 1996).

Although much of the current enthusiasm for watershed restoration is based on laudable objectives, success often is limited by a fundamental misunderstanding of the cause and effect relationship of processes operating at a scale that can overwhelm limited, site specific restoration efforts. The massive scale of the task and the need for strategic and focused solutions does not become clear until the magnitude and extent of environmental change that has occurred in the Pacific coastal ecoregion over the past century (Bisson et al. 1992) is fully appreciated. The effects of these changes have recently become all too obvious, as underscored by the depleted status of once abundant Northwest native stocks of salmon and trout (Nehlsen et al. 1991, Frissell 1993). The specific causes of these outcomes, however, are not so easily identified.

Fundamental concepts about and the need for integrated, interdisciplinary approaches to stream and watershed restoration have gained wide acceptance in aquatic ecology only in the last decade or so (Gore 1985, Heede and Rinne 1990). Although the evaluation of stream habitat projects is not a new concept (Ehlers 1956, Hunt 1971, Gard 1972), accurate documentation of the ecological success or failure of contemporary stream and watershed restoration efforts has only recently begun to appear in print (Williams et al. 1997). Many such reports are after-the-fact evaluations of small-scale projects at a limited number of locations (Beschta et al. 1994, Parry and Seaman 1994, BioWest 1995). However, a truly sustained watershed-scale effort to evaluate a fish habitat restoration program took place in Fish Creek in the Clackamas Basin in Oregon (Everest et al. 1987, Reeves et al. 1991, Reeves et al. 1997). These evaluations provide a valuable primer on how to judge success of restoration efforts and emphasize the importance of clearly defining the physical and biological rationales and expected outcomes from restoration treatments.

In the face of past failure to achieve restoration goals, scientists and managers must reconcile the need to balance the political and social imperative to "do something" with the need to be judicious with their actions and accountable for the outcomes. Choosing where and how to invest increasingly scarce public resources to ensure the best chance of a beneficial and sustainable outcome requires wisdom and creativity. The potential effectiveness of restoration actions depends upon how the rates and patterns of processes that control the character or expression of aquatic communities have changed. Different land uses affect these processes in different ways and to differing degrees across the diverse landscape of the Pacific coastal ecoregion. Sorting out the history of the interaction of processes and land use is the first step in the path to successful restoration (Cairns 1989, Beechie et al. 1994, Sear 1994, Frissell and Bayles 1996, Frissell et al. 1996, Stanford et al, 1996).

In some situations, for example removing a road culvert to restore access for fish to miles of historical spawning and rearing habitats, the "fix" is obvious. Similarly, where the river experiences seasonally excessive water withdrawals, restoration of some level of in-stream flow regimes may allow at least partial recovery of the historical aquatic habitat potential. In many other cases, however, the solution is much more elusive. Several investigators provide excellent summaries identifying individual strengths and weaknesses of the host of techniques that are commonly used for alteration and rehabilitation of stream habitats in the Pacific coastal ecoregion (Wesche 1985, Reeves et al. 1991, Parry and Seaman 1994).

This chapter focuses on the ecological and ecosystem management contexts of restoration activities, and emphasizes the need to strategically reconfigure and rescale concepts and approaches to stream ecosystem restoration. Several case studies that provide relatively positive examples of restoration projects at a range of scales are examined. Discussion of the central practical importance of monitoring and evaluation emphasizes the need for professional humility, controlled experimentation. and critical evaluation to improve future ecological stream and watershed restoration efforts.

Defining Restoration-Scope and Scale

Restoration is the act of returning a river or watershed (or assisting its recovery) to a condition in which it can function ecologically in a self-sustaining way, more nearly resembling its former function prior to human-induced disturbance (Cairns 1989, Bisson et al. 1992, Sear 1994). Taking a dynamic, coevolutionary view of streams and watersheds, Ebersole et al. (1997) and Frissell et al. (1996) define restoration as the act of relaxing human constraints on the development of natural patterns of diversity. In this view, a restored ecosystem does not necessarily return to a single ideal and stable state (i.e. pristine) but is free to express a range of natural successional trajectories and states, as constrained by the historical biological and physical capacity of its encompassing environment. The principal effect of human disturbance is to alter or suppress key successional stages, thereby eliminating certain desirable characteristics of diversity that the ecosystem would otherwise include. Most such capacity to develop system diversity is retained in the biota and the suite of processes that shape habitats and can be expressed if specific human constraints are relaxed (Regier et al. 1989, Stanford et al. 1996, Ebersole et al. 1997). This definition implies idealy that restoration measures should not focus on directly recreating natural structures or states, but on identifying and reestablishing the conditions under which natural states create themselves. The focus is on ecosystem processes and patterns at larger scales, within which local habitats and individual organisms are embedded (Frissell et al. 1986, Naiman et al. 1992, Kondolf and Larson 1995). However, population extinctions, introductions or invasions of nonindigenous species, and major changes in geological features and processes can permanently alter the capacity of the watershed system to recover former states, precluding full restoration. Moreover, extensive human occupation of ecosystems frequently leads to permanent loss of ecosystem developmental capacity and diversity, and in a growing number of cases, these losses have to be accepted as permanent constraints on restoration (Sear 1994, Frissell et al. 1997, Stanford et al. 1996).

The National Research Council (NRC 1992) and others (Regier et al. 1989, Sear 1994, Kondolf and Larson 1995, Kondolf et al. 1996, Stanford et al. 1996) stress the importance of taking a systems approach to river restoration, that is, understanding and working in harmony with the dynamic physical forces (processes) associated with flowing water to restore natural or normative patterns of hydrological and ecosystem processes (i.e.. fluvial restoration). In a general sense, the unintended consequence of watershed-scale land use and resource extraction in the Pacific coastal ecoregion is typically expressed in changes to the fundamental driving forces of watershed processes: changes to the flow regime, to the input and routing of sediment and large woody debris, and in the functional capacity of riparian areas. Without reestablishment of the dynamic equilibrium of natural biological and physical processes, recovery of the biotic community to its full productive potential may never occur. This is especially true in rivers where sediment aggradation, channel widening and consequent decrease in depth have created aquatic environments that provide poor habitat to meet the life history requirements of native fish, aquatic insects and amphibians. Once this complex ecosystem is disrupted, the time frame necessary for natural recovery of meander length, amplitude, radius of curvature, bankfull width and width-to-depth ratio, and other physical. features is highly uncertain. Although trends toward channel recovery from aggraded states are documented (Lisle 1981 and 1982), reestablishment of mature floodplain and riparian forests is necessary for full recovery of most Pacific coastal streams, and may take centuries (Bisson et al. 1992, FEMAT 1993). The requisite experience to reliably estimate the time required for recovery of dynamic equilibrium to watershed processes is simply lacking.

Scientists and managers must take care not to mistake an apparent trend toward a recovering condition as evidence that natural recovery has been achieved or even fully initiated (Espinosa et al. 1997). Until recovery trends are manifested in some self-sustaining, relatively naturally functioning condition, restoration or recovery has not truly occurred. For example, Platts et al. (1989) found that the channel bed conditions in the South Fork Salmon River in Idaho partially recovered during the 20 years following a massive influx of sediment, but then stabilized at an incompletely recovered state. Platts et al. suggest that in its present state of arrested recovery, the river remains highly sensitive to even very small anthropogenic increases in erosion and sediment delivery. In this condition, extensive areas of the river no longer provide substrate conditions suitable to support spawning habitat required by chinook salmon (*Oncorhynchus tshawytscha*). Time, careful protection, and perhaps additional erosion control measures are necessary to create the conditions that could allow South Fork Salmon River ecosystem to eventually recover enough to provide the full complement of historical chinook salmon habitats.

Opportunities to assist in the recovery of watershed-scale processes and ecosystem dynamics may be seriously limited without a clear understanding of the basin wide and historical context of a proposed project (or array of projects) (Reeves et al. 1991, Frissell and Nawa 1992, Wissmar et al. 1994, Minns et al. 1996). The need for integrated, watershed-scale restoration programs is increasingly recognized (FEMAT 1993, Williams et al. 1997) and some resources are becoming available for such efforts. However, large-scale restoration projects are being implemented at a pace that continues to vastly outdistance the ability to accurately evaluate their results and effectively apply such knowledge to future projects. New projects fail to receive the potential benefit of knowledge gained from adequate analysis of past mistakes and successes because resources committed to monitoring and evaluation are limited.

The following section describes a number of restoration activities that demonstrate varying approaches to solve common problems affecting water resource and habitat integrity. Examples include those applied at the habitat unit scale (i.e., microhabitat); the reach scale (linked habitat units encompassing as few as several pool-riffle sequences to several kilometers of stream and floodplain systems); to an example applied at the whole watershed scale. This latter example illustrates a model comprehensive approach to address multiple factors operating over large areas and over many decades.

Interventions at the Microhabitat Scale

Until the mid 1990s, agency-sponsored stream "improvement" and "enhancement" programs in the Pacific coastal ecoregion almost exclusively emphasized restoration at the microhabitat or pool and riffle scale (see Chapter 5 for discussion of classification levels). Placement of log weirs (Figure 24.1), wire gabions, and other in-stream structures to create individual pool riffle habitat units were favored over such other techniques as riparian tree planting and off-channel pond development. Although in-stream habitat structures are clearly well suited for artificially altering the structure of pools and riffles in certain kinds of stream reaches (Wesche 1985, House and Boehne 1986, Reeves et al. 1991), their effectiveness in increasing the production and survival of fish has always been and remains uncertain (Carufel 1964, Platts and Nelson 1985, Hamilton 1989, Reeves et al. 1991, Reeves et al. 1997). Moreover, in some situations, such projects have unintended adverse effects on native fish and wildlife species (Rinne and Turner 1991, Fuller and Lind 1992), and it is probable that many other negative side effects occur but have not been noticed or documented because evaluations have focused on a narrow set of habitat parameters or target fish species.

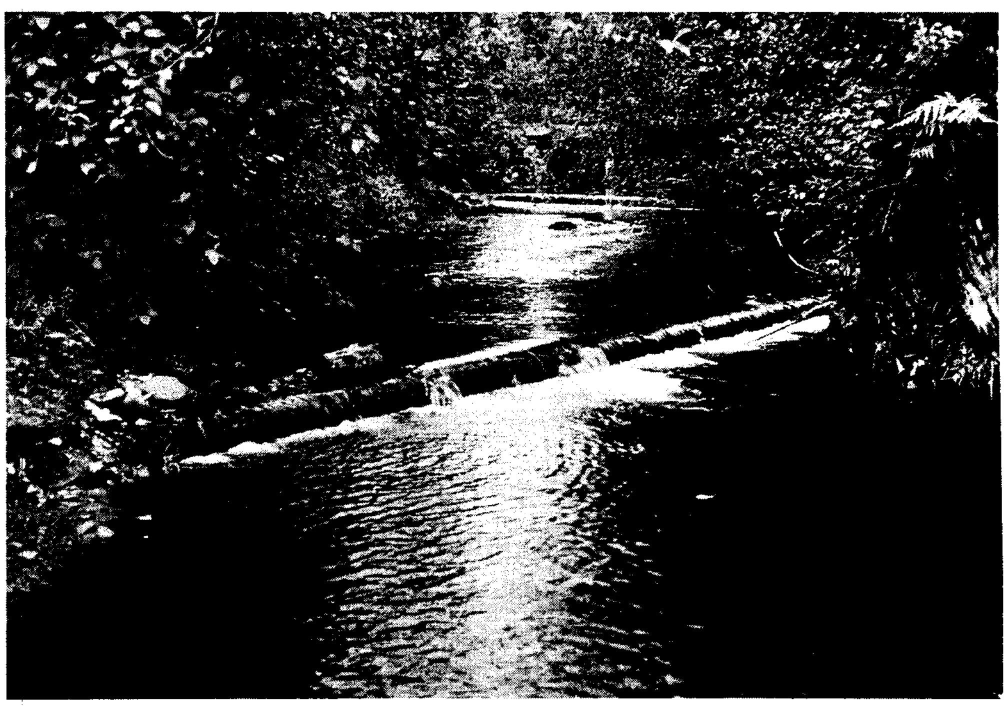


FIGURE 24.1. Typical log weir structure placed in a channel by the U.S. Forest Service in an attempt to enhance production of a small run of native summer steelhead (*Oncorhynchus mykiss*) in Trout Creek, a tributary of the Wind River in the Cascades Range of south-western Washington (Photo: R. Nawa, Oregon State University).

One intervention commonly employed at the microhabitat scale is treatment or replacement of streambed gravel to provide improved spawning habitat for salmonid fishes (Reeves et al. 1991). Such projects often fail, because the problem (poor quality or absent spawning gravel) is caused by a persistent source (e.g., chronically accelerated input of fine sediments, changes in flow regime and channel form that preclude storage of appropriate-sized particles on the bed). For example, in a massive and costly project in the Merced River in California, reconstructed gravel riffles were destroyed during a peak stream flow with a return period of just 1.5 years (Kondolf et al. 1996). The project designers failed to consider the full scope of effects on sediment and flow regimes caused by dam regulation and other human modifications, including long-term alteration of channel configuration and hydraulics of the reach where the project took place (Kondolf et al. 1996).

Localized interventions are most effective where the principal cause of ecosystem damage is a local alteration, such as the historical forestry practice of removing trees and downed woody debris from a stream channel and riparian area. A relatively well-documented and partially successful project involving habitat modification at the pool and riffle occurred in the North Fork of Porter Creek in western Washington (Cederholm et al. 1997). This low-gradient (2%) stream with a mean bankfull channel width of about 10 m supports both resident and anadromous salmonids. Like many similar forested streams in the Pacific coastal ecoregion, this one has reduced levels of in-stream woody debris as a consequence of past forestry practices. Restoration efforts focused on creating pool habitat and cover through the reintroduction of large woody debris. A 1,500 m section of the creek was divided into three study sections, a control (no treatment), an "engineered" treatment with intensive and carefully designed placement of structures and anchoring of debris, and a "logger's choice" treatment where woody debris was placed (as was practical in the field), with limited preplacement design and little or no anchoring.

After completion, the levels of large woody debris increased 10 times in the engineered section and 2.7 times in the logger's choice reach of North Fork Porter Creek (Cederholm et al. 1997). The surface area of pools increased significantly in both treated reaches, while it declined somewhat in the control reach. Subsequent increases in juvenile coho salmon (*O. kisutch*) wintering in both treated habitat reaches (judged against preproject levels from 1989-1994 survey data) were observed. Coho smolt production (measured as counts of outmigrating individuals) also increased significantly after large woody debris additions, but declined in the control section. Lack of juvenile steelhead (0. *mykiss*) production or utilization in the treated sites, suggests that habitats associated with the input of woody debris were more useful to coho than steelhead.

Costs of treatment were US$164 per lineal stream meter for the engineered reach and US$13 for the logger's choice reach. However, a cost efficiency analysis projected over the anticipated project life, estimated costs adjusted per coho smolt produced in the two treatments to be about equal (US$13–US$15 per smolt), largely because woody debris placed in the engineered treatment was considered more persistent (expected to last ca 25yr) than that in the logger's choice treatment (expected to last ca 5yrs). Even a casual inspection and extrapolation of these costs suggest that projects of this type are quite expensive, and the aggregate cost over a significant fraction of many thousands of kilometers of such streams across the Pacific coastal ecoregion is prohibitive. Moreover, the benefits of such projects at best are likely to accrue only to a subset of the species of interest.

Several projects that create, enlarge, or excavate low-flow connections of floodplain ponds with main channels along major alluvial river segments have increased the survival and production of juvenile salmonids, especially coho salmon, in the Pacific coastal ecoregion (Cederholm et al. 1988). These projects typically constitute field interventions defined at the scale of a single pool, riffle, or off-channel habitat. Although they are conceived and designed at the microhabitat or habitat scale, the biological and physical effects (both beneficial and adverse) of such in-stream projects can potentially propagate to influence a larger area of the reach within which they are nested. Peterson (1982) investigated the role of off-channel ponds in the overwintering survival of coho juveniles in tributaries of the Clearwater River, Washington. To increase the availability of winter habitat, explosives were used to create pools in Paradise Creek, an existing 10-km long floodplain springbrook (i.e., wall-based channel) of the Clearwater River (Cederholm et al. 1988). The short stream reach chosen for blasting the pools was a mud bottom section that meandered through a sedge marsh wetland complex. A 1.5-m high dam was built at the downstream outlet to control water levels in the ponds. Monitoring of fish movement and survival occurred for two years prior to and two years after pond construction using a two-way fish trap constructed to allow capture of fish moving into and out of the ponds. Winter survival was estimated from recapture of a subsample of freeze-branded juveniles. The average overwinter survival (i.e., from one year's winter to the next spring) of marked juvenile coho that had immigrated into Paradise Creek increased from 11% of juveniles surviving before, to 56% after pond construction. Based on an extensive smolt trapping study in the main river (Cederholm et al. 1988), the investigators estimated that restoration efforts accounted for a 2.8% (1,968 smolts) increase in the total annual smolt yield from the Clearwater basin for the two years evaluated. The total project cost was less than US$10,000.

Although the development of floodplain ponds holds promise for improved survival of coho salmon and perhaps other fishes, some important considerations may limit this technique. Based on verbal accounts from the managers of projects in Washington, Oregon, and British Columbia, to remain effective such projects often require a high level of diligent monitoring and maintenance, especially of connecting channels and control structures. Moreover, seasonally dense aggregations of juvenile fish in small ponds typically attract concentrations of avian, terrestrial, and piscine predators. Finally, floodplain ponds may afford important breeding and rearing habitats for native frogs and salamanders, especially where fish access is limited (C. Frissell and B. Cavallo, Flathead Lake Biological Station, The University of Montana, Polson, Montana, unpublished data). Amphibian eggs and larvae are highly vulnerable to fish predation and to physical disturbance, such as gravel excavation or alteration of water levels associated with project construction and management. Thus, alterations of floodplain habitats intended to benefit fish may adversely affect amphibians and other native aquatic animals and plants, many of which are themselves regionally declining and threatened.

High failure rates and escalating costs of maintenance have been reported for many in-stream structure projects and other site-specific interventions in the western United States (Ehlers 1956, Carufel 1964, Platts and Nelson 1985, Rinne and Turner 1991, Frissell and Nawa 1992, Beschta et al. 1994, Kondolf et al. 1996) and elsewhere (Sear 1994). Such projects are consistently unsuccessful in watersheds where high erosion and sedimentation rates, high peak flows, or other watershed alterations or stresses are pervasive (Hamilton 1989, Frissell and Nawa 1992). Where the physical integrity of these structures fail, they can cause significant collateral damage to downstream habitat and non-target biota (Frissell and Nawa 1992). The cumulative ecological costs of such failures and the maintenance burdens incurred are rarely recognized by those completing the projects.

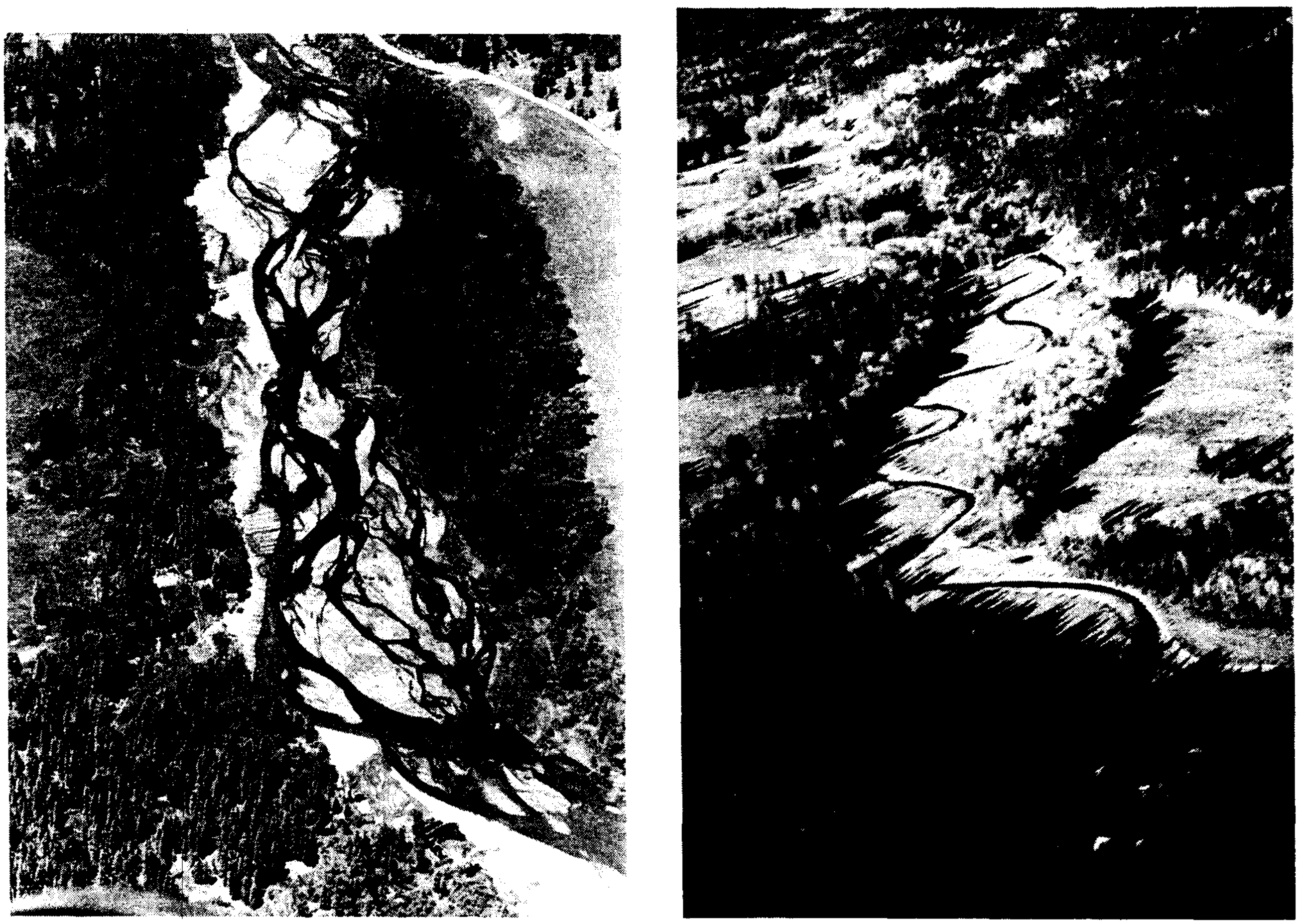
In general, treating large-scale land-use related problems-such as deforestation, accelerated erosion, and altered hydrologic and sediment regimes-with small-scale interventions (such as importation of gravel for spawning or construction of in-stream structural devices) is ineffective and costly (Frissell and Nawa 1992, Doppelt et al. 1993, Beschta et al. 1994, Kondolf et al. 1996, Poole et al. 1997). To be effective, restoration interventions must be scaled appropriately to the cause and consequences of ecosystem damage (Sear 1994, Kondolf and Larson 1995, Kondolf et al. 1996). Moreover, the causes of the problem must be controlled before the damage itself can be effectively repaired (Platts and Rinne 1985, Frissell and Nawa 1992, Sear 1994, Stanford et al. 1996, Reeves et al. 1997).

Larger-Scale River Restoration

Cumulative ecological alterations of streams and rivers occur most often at the larger spatial scales of stream reaches, valley segments, or entire drainage basins. Because these large-scale changes can seriously limit the recovery potential of anadromous fishes like salmon, restoration efforts have been scaled up to address these problems. The following examples are but a few of these initial efforts-but the lessons learned from them will help such efforts in the future.

An example of a restoration effort to directly treat a highly altered stream–riparian–floodplain system at the scale of several contiguous kilometers took place on the Blanco River in southwestern Colorado (Rosgen 1988. NRC 1992). In the course of the three-year river and floodplain reconstruction project, a stable 20-m wide channel (with a large pool to riffle ratio) was excavated to replace nearly 4.34 km of braided river channel, which had widened to nearly 121m and contained few pools to support resident trout (Figure 24.2a,b).

Before restoration efforts, the affected reach had been channelized by the U.S. Army Corps



(a) (b)

FIGURE 24.2. (a) Aerial views of the Blanco River showing the highly braided, unstable channel form resulting from channel changes after channel straightening and flood dike construction but before restoration efforts. This channel form reflects the D4 type in Rosgen's classification scheme. (b) Aerial views of more stable single thread channel form (C4) following substantial reconstruction of historical channel meander pattern, width-to-depth cross-section, channel slope, and reconnection with historical floodplain system (from Rosgen 1996).

of Engineers (COE) to protect adjacent grazing lands from erosion following a flood in 1970. After the flood, portions of the river were straightened, widened and entrenched within a levee network so that what had been a stepped, low-flow channel, terrace, and floodplain, was converted to a wide, flat-bottomed, trapezoid-shaped channel in cross-section. The resulting loss of the historical meander pattern (as seen in plan view) decreased the length of the stream and increased local channel slope, leading initially to degrading of bed elevation through down and headward erosion until local channel slope reached equilibrium. Enlarging the width-to-depth ratio by channelization reduced the sediment transport capacity of the channel, which resulted in deposition of bed material (gravel and cobble) in the reach after flooding. With build up of gravel deposits in its center, the channel subsequently took on a highly unstable, braided character while active lateral migration and bank erosion once again threatened agricultural use of the adjacent lands. Subsequent floods and increased shear stress (a function of bed slope and channel shape) along channel margins led to erosion of the constructed levees, increased additional sediment input, and bed aggradation. The river's value for resident fish production declined further because the now shallow, wide river was exposed to severe freezing in winter and elevated summer temperatures, and had lost much of its former structural habitat complexity.

The primary goal of the Blanco River restoration project was to stabilize the channel in a configuration that resembled its natural state of dynamic equilibrium, so that it could handle floods and provide in-stream habitat for fish, even under low flow conditions. Rosgen's approach was to rebuild the channel geometry to interact naturally with its floodplain and historical river valley. This involved narrowing the channel and reestablishing the historical floodplain to accommodate overbank flows, thus reducing shear stress along the channel margins. In selecting design criteria, project managers first located similar streams in the vicinity that were undisturbed and found that their dimensions and channel patterns were consistent with a particular channel type in the Rosgen stream classification scheme (Rosgen 1994, Chapter 5, this volume). The channel characteristics of these nearby, more intact streams served as the design criteria or template for the reconstruction of the 4.34-km reach of the Blanco River. To determine the river's previous character, physical dimensions were calibrated locally by evaluating a time series of aerial photos of the braided reach, and using a stable downstream reach as the model for reconstruction. Sources and volumes of sediment input, both upstream and from bank erosion, were evaluated to ensure that the restored channel would have the appropriate transport capacity. This evaluation helped project managers target the causes of the river's instability and deliberately tailor solutions to match the processes that controlled them. The final design was based on existing flow and channel relationships inferred from Rosgen's predictive model for comparable channels (NRC 1992).

Treatments on the Blanco River project included carefully surveying the site and shaping the desired channel pattern with bulldozers and scrapers. Natural materials (e.g., layers of logs and root wads held in place by boulders) were set in place to protect the newly excavated outside meander bends from erosion. Rock weirs were placed selectively within the channel to focus the flow and scour local pool habitat. A key element of this project was revegetation of riparian zones with mature plant materials salvaged from adjacent sites on the floodplain to simulate vegetation processes that occur naturally after a large flood. These plantings greatly accelerated the stabilization of banks with root masses and vegetation cover.

As a result of this project, a more natural looking, stable river channel developed, deep pools returned, bank erosion decreased, and in-stream habitats and fish production reportedly increased (Figure 24.2a,b) (NRC 1992). Costs for the Blanco River restoration work were about US$30 per lineal foot of stream; the total cost for the project (born by the landowner) was about US$400,000. From this investment, the landowner recovered nearly 68.8 hectares of agricultural land in the floodplain, at a cost about equal to the market rate for similar lands in the valley.

Although the available information suggests the Blanco River project was successful relative to the preexisting physical and biological conditions, documentation of the success of the project is not available in the scientific literature. This lack of documentation is an unfortunate but common shortcoming that prevents the claims of success for many restoration projects from being critically evaluated (Hamilton 1989, Reeves et al. 1991, Frissell and Nawa 1992), and hinders broader recognition of truly successful projects that could be used as models for other projects.

Off-Channel Habitat Restoration at the Reach Scale

Rivers that were systematically dredged during gold placer mining activities are numerous in western North America, and because of the severity of channel and floodplain alteration and habitat loss (Wissmar et al. 1994) these rivers are often targeted for habitat restoration efforts (Richards et al. 1992). Dredging in river reaches during placer mining changes the magnitude of the channel, and the general character of the river valley imposes both constraints and important (but limited) opportunities for designing restoration features. An advantage of projects in dredged or otherwise highly altered rivers is that the risk of adverse impacts from failed treatments or unanticipated effects generally is relatively low (because existing habitat values and biodiversity are usually quite low). Nevertheless, care should be taken to avoid further negative impacts.

In the case of the Yankee Fork of the Salmon River, Idaho, a reach targeted for restoration was, prior to dredging, important historical spawning and rearing for now severely depleted native chinook salmon (Richards et al. 1992). As part of the extensive efforts of the Northwest Power Planning Council and others to recover this threatened population of salmon, a series of off-channel juvenile rearing habitats were excavated within the dredge and settling ponds isolated from but adjacent to the existing channel. This project focused on controlling flow and establishing stable surface-water linkages from the ponds to the river.

It was not practical to observe the reaction of native chinook juveniles to these newly created habitats because the number of returning adult chinook salmon was and continues to be so low. Thus, managers evaluated the Yankee Fork project by releasing 60,000 juvenile chinook salmon of hatchery origin into two series of ponds, and tracking their movements over time. Observed densities of juvenile hatchery chinook in the constructed habitats were higher than expected. However, Richards et al. (1992) caution that such a novel and perhaps somewhat unnatural rearing environment (and the artificial method of fish introduction) could confound natural behavior and habitat selection in ways that have unexpected consequences for evaluation studies, and for survival or growth of wild fish in the altered stream system. Conclusive evaluation of the biological success of such a project requires a much longer period and should include tracking salmon through a complete generation to the returning adults. The second generation of adult returns should reflect any improvement in the productive capacity of the system; however, improvement may not be evident until 6 to 10 years (or more) after completion of the habitat treatments.

Similar projects involving excavation or reconnection of off-channel ponds along rivers in the Pacific Northwest appear to have sustained high densities of juvenile fishes for two or more salmon generations. For example, in Fish Creek, Oregon, reconnected off-channel ponds have clearly benefited coho salmon far more than numerous, more costly in-channel treatments (Everest et al. 1987, Reeves et al. 1991). However, other comparable projects in the same region are unsuccessful in sustaining natural production, for reasons that are unclear. Again, published evaluations spanning the time scale of two or more salmon generations are generally lacking. In Washington, the relatively indiscriminate and often poorly documented release of fish from state, federal, and tribal hatcheries severely confounds the relationship between locally observed fish production and local habitat conditions. Although reconnected off-channel ponds have been successful and cost efficient. keeping these ponds functional requires constant vigilance and maintenance (Dave Heller, USDA Forest Service, Pacific Northwest Region, Portland, Oregon, personal communication). This suggests such treatments may be less satisfactory in remote areas lacking ready access for monitoring and maintenance.

Watershed-Scale Restoration—An Example

A truly watershed-scale restoration project took place in Redwood Creek Basin, Redwood National Park, California. For more than a decade, experimental treatments have focused on upslope erosion sources which are the principal and continuing cause of problems in the stream channels (i.e., persistent bed aggradation and channel instability) (Weaver et al. 1987). This well-conceived and remarkably well-documented program is a preeminent model for future, large-scale watershed restoration programs (Weaver and Hagans 1995, Ziemer 1997).

The restoration program in Redwood Creek Basin did not begin as an effort focused on fish, but rather the broader goal was generally to restore natural watershed and stream channel processes. This goal sought protection of, multiple natural resources inside the park boundaries, not the least of which was riparian old-growth redwood trees threatened by aggradation and lateral erosion of Redwood Creek itself. The program began with a barrage of qualitative and quantitative assessments conducted by physical and biological scientists (Kelsey et al. 1981), and field restoration efforts started almost simultaneously. Acknowledging the experimental nature of such projects, teams of physical and biological scientists designed and executed an extensive monitoring and evaluation effort to examine the effectiveness of each restoration method in the context of watershed-scale and site-specific processes. Most projects were geared toward reducing potential sediment sources to streams (Figure 24.3), but ancillary projects for special purposes also were conducted (e.g., modifying and removing logging debris jams that block fish passage). The watershed restoration program included detailed mapping and inventory to identify problem sites, development and interdisciplinary review of prescriptions for site treatments, implementation of field treatments, and monitoring and evaluation to adjust methods and evaluate their effectiveness in reducing overall erosion rates (Weaver et al. 1987). Some field treatments such as road ripping, changing orientation of road surface drainage, construction of cross-road drains and ditches, excavation of road fill at stream crossings, removal of unstable fill along roads and landings, and placement of rock armor in newly excavated channels involved using heavy equipment (Figure 24.4). Other treatments relied on hand labor, including constructing check dams; hand placing rock armor, flumes, water ladders, contour trenches, wooded terraces, and gravel catchers; and planting bank protection features such as living willow wattles and stem cuttings, mulching and seeding, and transplanting several species of container grown plants (Weaver et al. 1987). Different experimental areas received different combinations of treatments. Table 24.1 summarizes some of the many treatments used in Redwood Creek Basin and includes costs and assessed benefits (in terms of reduction of sediment inputs to streams).

In response to the monitoring and evaluation program, over time the program emphasized the use of heavy equipment, particularly at stream crossings and on unstable slopes where the potential for delivery of substantial volumes of sediment to streams could be averted (Weaver et al. 1987). Hand labor treatments, although locally effective in reversing surface and gully erosion processes, proved less effective in reducing sediment delivery problems in the basin overall. In most circumstances if sufficient care was taken during equipment operations, park staff found they could rely largely on natural revegetation. Several valuable manuals providing evaluation and guidance for watershed restoration methods have emerged from the Redwood National Park program (Weaver et al. 1987, Spreiter 1992) and from subsequent efforts of

FIGURE 24.3. Rills and gullies beginning to form on the surface of a newly constructed logging road on private timber lands above the Pistol River in southwestern Oregon. Left unattended, such poorly constructed or badly maintained roads are potential major sediment sources to streams, and likely initiation sites of stream diversions, debris flows, and landslides that can have serious and long-lasting adverse effects on stream habitat. Selective obliteration or structural rehabilitation of the thousands of kilometers of such roads residing on forest, range, and crop lands is a major restoration challenge and opportunity across the Pacific coastal ecoregion. The greatest gains from such work are preventative: the most effective treatments must be applied before a large storm triggers a major episode of erosion and sediment delivery from the road to stream channels (Photo credit: Christopher A Frissell, Oregon State University).

specialists from this program applying their earned expertise to other areas of northern California and elsewhere (Weaver and Hagans 1994).

Nonetheless, the Redwood Creek Basin example also illustrates the tragedy of cumulative effects of watershed disturbance. Although millions of public dollars were invested in restoration of the lower two-thirds of the basin, the downstream impacts from logging on unprotected, private timberlands in the headwaters of the basin threaten the benefits of erosion control efforts within the borders of Redwood National Park (Kelsey et al. 1981, Hagans et al. 1986, Hagans and Weaver 1987).

Monitoring and Evaluating Restoration Projects

Although evaluation of the outcome of restoration actions is essential for improving and documenting their effectiveness, long-term evaluation (in effect, monitoring) of restoration actions usually is left out of the overall planning and implementation cost equation. In most cases, the enthusiastic rush to address perceived problems leaves little time for planning and implementing follow-up actions to learn what did and did not work, and measures of success are often based on inappropriate

FIGURE 24.4. Excavation of a stream crossing during a road obliteration project in Redwood National Park. Road fill is removed to expose the original stream channel and side slope contour, thus restoring natural drainage patterns. and excavated material is transported by dump truck to a waste site away from streams and potentially unstable hillslopes (Photo credit: Christopher A Frissell, Oregon State University).

criteria (Minns et al. 1996). For example, historically, evaluation of the "success" of some in-stream habitat structures on federal forest lands in the Pacific coastal ecoregion was based on whether the structures survived the first year's winter storm events, rather than whether they provided any measurable ecological benefits to fish. Unfortunately, many expensive projects did not even pass the first test (Frissell and Nawa 1992). Further, past allocations of annual restoration funding to U.S. Forest Service ranger districts have been based more on the number of projects built the previous year (i.e., whether previous short-term targets were met), rather than on the demonstrated effectiveness of restoration efforts. When local specialists have managed to find resources to evaluate projects, the results have often been ambiguous because of design or data limitations (House 1996).

Committing to a long-term program of monitoring is the most practical and effective way to assess a restoration program and document the recovery of ecosystems. Although most restoration projects are hampered by a lack of baseline and reference data, the use of such data in a well-designed, systematic monitoring program provides the best opportunity to document overall success or failure of a program (NRC 1992). Existing conditions can be characterized through collection of pretreatment, baseline data, which provides a partial basis for comparison of the treatment effects following the application of restoration activities. Reference data is especially important because it provides a measure of site potential, or a sense of what level of recovery is reasonable and desirable given the larger context of the stream or basin. Reference data may come from a reach of the river targeted for restoration or from a reach in a different river with similar characteristics of channel morphology and basin hydrology. Assessing the unrestored condition of a river allows investigators to gauge the effects of restoration efforts, and to better understand natural rates of recovery (Cairns 1989). Bryant (1995) describes a well-reasoned approach to long term monitoring for tracking the outcome

TABLE 24.1. Selected watershed restoration techniques and measures of their cost and benefits (in 1987 US dollars) in Redwood National Park.

Restoration method	Unit	Unit cost	Estimated unit benefit	Unit cost per benefit
Excavation of road stream crossings using heavy equipment, with end hauling of excavated fill	L-l-5 Road in Bond Creek unit and M-7-5-l Road in Bridge Creek unit (11 crossings)	$1,213–11,597 per crossing	195–1,500 m^3 potential sediment removed per crossing	$3.90-9.45 per m^3 of potential sediment removed (does not include prevented gully erosion)
Excavation of skid trail stream crossings. with limited end hauling	Skid trails in Bond Creek unit (10 crossings)	$80–$1,345 per crossing	5-155 m^3 potential sediment removed per crossing	$4.45-19.00 per m^3 of potential sediment removed (does not include prevented gully erosion)
Outsloping and cross-draining major haul roads	L-l-5 Road in Bond Creek unit and M-7-5-l Road in Bridge Creek unit (11 crossings)	$7,600–$71,000 per road mile	Uncertain: if untreated, only a limited portion of mobilized sediment would enter streams	Uncertain (but small compared to stream crossing removal)
Partial removal of in-stream logging debris, excavation and endhauling of aggraded alluvium and adjacent unstable hillslope	Bridge Creek	$10,250 (including riprapping of exposed streambanks)	1,300 m^3 of sediment and potential sediment removed	$7.88 per m^3 of potential sediment removed
Outsloping and ripping landing fill material	Bridge Creek and Copper Creek units (total 12 landings treated)	$1.960-8.200 per landing (high end reflects larger landings and longer end haul to dispose of fill)	Uncertain; if untreated, only a limited portion of mobilized sediment would enter streams	Uncertain; probably greater than road surface outsloping, less than stream crossing treatments
Hand construction of checkdams in stream channels and gullies	Bond Creek, Bridge Creek. and Copper Creek units	$19.52–47.60 per structure or treated site; not quantified by channel length	Benefits limited by malfunction and short life span of many structures, pre-project erosion	Uncertain; probably small since most erosion occurred prior to treatment
Hand labor: mulching and revegetation using grass seed, stem cuttings, wattles, and transplants	Bond Creek. Bridge Creek, and Copper Creek units	3-28% of total project costs; not quantified by area	Uncertain but small: natural revegetation was rapid except where hindered by grass seed or mulch	Uncertain, possibly negative when natural revegetation is hindered

of restoration efforts. This strategy of pulsed monitoring combines extensive long-term surveys repeated over long intervals (10–15 years) interspersed with intensive short-term (3-5 years) studies that focus on specific questions. Ideally, pretreatment baseline studies and parallel studies at reference sites are included. Bryant's approach addresses broad watershed-scale conditions while examining treatment effects and outcomes at the most ecologically significant stream reaches.

Of course, fundamental principles of the design and implementation of evaluation and monitoring programs must be understood whether they are applied on a basin-wide or limited project scale. Ecologists or technicians involved with the design and placement of such habitat structures may lack engineering and other technical support to define the problem behind the need for the project and to design and implement solutions that take into account the watershed context of such restoration activities (Reeves et al. 1991, Frissell and Nawa 1992, Beschta et al. 1994, Sear 1994, Kondolf et al. 1996). MacDonald et al. (1991) describe many fundamental principles of monitoring water quality and in-stream conditions in situations where timber harvesting is the dominant land use. Like any environmental study, effective restoration efforts must identify the purpose, questions, hypotheses, models, sampling designs, statistical analyses, tests of hypotheses, and the interpretation and presentation of results (Green 1984, Kershner 1997).

Designing restoration projects requires explicit definition of the setting and problem to be corrected, which determines the nature of the objectives and the hypotheses that form the core of the evaluation and monitoring approach. Until and unless this critical but often neglected step is taken, subsequent monitoring is not likely to provide the desired information (Minns et al. 1996). MacDonald et al. (1991) and Platts et al. (1987) address some aspects of selecting monitoring methods and designing sampling plans, but this subject continues to warrant further research and development (Kondolf 1995, Poole et al. 1997). No standard checklist, blueprint, or catalogue exists for monitoring and evaluation that can be applied to all river and stream restoration programs and projects. (A more thorough discussion of monitoring and assessment is presented in Chapter 18.)

A number of methods are commonly applied to quantify physical channel conditions before and following restoration activities (Platts et al. 1983 and 1987, Olson-Rutz and Marlow 1992, Meador et al. 1993, Nawa and Frissell 1993, Harrelson et al. 1994). However, many habitat parameters routinely applied in stream surveys have not been fully evaluated as to their usefulness or sensitivity in detecting meaningful changes (Peterson et al. 1992, Poole et al. 1997). Other techniques that focus on biotic assemblages have been successfully applied to such questions (Roth et al. 1996), but only recently to Pacific coastal rivers, and widespread implementation awaits testing and further regional development (Karr et al. 1986, Miller et al. 1988, Pflakin et al. 1989, Imhoff et al. 1996).

Monitoring is about detecting if, when, and how change occurs, and what change itself means in ecological terms. Change reflects natural processes that are an essential part of natural history and evolution. Maintaining natural ecological values of river systems becomes increasingly difficult when the rate of change induced by human activities accelerates, the overall magnitude and persistence of the effects increases, and the spatial distribution of human activities affects growing portions of the landscape (Doppelt et al. 1993, Frissell and Bayles 1996, Minns et al. 1996). Effective assessment and subsequent. monitoring provide the major link between science and management by directly determining whether objectives are met (e.g. whether habitat complexity is maintained, whether loss of riparian vegetation and bank erosion remain within expected natural patterns) (Naiman et al. 1992, Stanford and Poole 1996). Such assessment is especially critical when there is uncertainty about whether management objectives (including investing public dollars in restoration measures) will actually address the underlying causes of the apparent conditions targeted for correction. Such uncertainty is the rule for the complex task of restoring streams that suffer from multiple impacts across entire watersheds.

A Nested Experimental Design for Monitoring

Ideally, restoration projects should be approached on an experimental basis. The effects of a restoration action should be measured against the performance of a comparable, untreated system that can serve as a reasonable basis to judge performance. Studies that attempt to relate habitat conditions to specific species responses, such as the abundance of returning adult migratory salmonids, are plagued by factors beyond the control of experimental design (Lichatowich and Cramer 1979), including ocean or riverine survival, fisheries harvest as a mortality factor, and related conditions acting independent of early life history of juvenile salmon. Yet, documenting desired biological responses is viewed as the bottom line for a restoration program. Although spatial and temporal factors prohibit strict experimental controls in field studies, the ability to demonstrate a biological response to a restoration project in the face of natural variation depends strongly on careful selection and monitoring of untreated control or reference systems (Minns et al. 1996).

The most effective monitoring designs should include designated functional controls nested at a series of spatial scales (Frissell et al. 1986, Minns et al. 1996, Poole et al. 1997), from habitat units at the scale of pools and riffles (nested within a reach in which other units have been treated) through reaches and valley segments, up to and including whole watersheds if possible. Many of the possible consequences of scale discussed earlier can be explicitly evaluated with such a hierarchical approach (Poizat and Pont 1997). A nested design allows quantitative assessment of possible regional (off-site) or indirect ecological effects of site-specific habitat alterations.

For example, it is often hypothesized but rarely substantiated that reach- or stream-scale juvenile fish recruitment increases following localized improvements in survival or growth, or that the concentration of adult fish increases where habitat complexity expanded with placement of artificial structures (Gowan and Fausch 1996). On the other hand, it is equally plausible that many projects may simply attract and concentrate fish that would otherwise be dispersed over a larger area, with no net effect (or possible adverse effect) on overall production. A spatially nested design allows these various hypotheses about biological responses to be tested (Figure 24.5). If restoration treatments have local effects only, fish abundance should increase in treated habitat units, with no response (positive or negative) in untreated habitat units. If both local and regional benefits accrue, fish abundance should increase in both treated habitats and at least some nearby untreated control habitats in restored streams. If concentration without compensation occurs, abundance should increase in treated habitats with a corresponding decrease in untreated habitats. Untreated streams should show no consistent or comparable trend either at individual habitat unit or reach scales.

Effective evaluation using such a hierarchically nested design must be conducted over a series of posttreatment years. The power of the analysis is potentially increased with prolonged pretreatment monitoring to assess interannual correlation among habitat units within streams and among treatment and control streams. Interpretation of biological mechanisms underlying the results is critical to understanding the significance and generality of such an experiment. Such understanding can be improved markedly by marking individuals to assess the movements and growth of animals among habitats in both the treated and control streams (Gowan and Fausch 1996).

Application of a similar spatially nested and hierarchical design to a physical monitoring program also addresses questions about possible spatial diffusion of physical effects (Frissell et al. 1986, Sear 1994), such as whether installation of in-stream structures changes the thermal regime of an entire reach, or whether local control of bank erosion results in desired changes in the sediment dynamics or structure of downstream habitats (and the distance from the treatment site that any benefits measurably accrue). Such a hierarchical approach to evaluation of stream restoration projects has been applied rarely anywhere (Imhoff et al. 1996), and perhaps never in the Pacific coastal ecoregion.

Cost Accounting for Watershed Restoration

In an effort to integrate socioeconomic information into regional planning for watershed restoration and salmon recovery, Fluharty et al. (1996) developed the Habitat Restoration Cost Estimation Model (HRCEM) for the National Marine Fisheries Service (NMFS). As part of their Pacific Northwest regional strategy to address threatened and endangered stocks of Pacific salmon, NMFS is interested in the costs

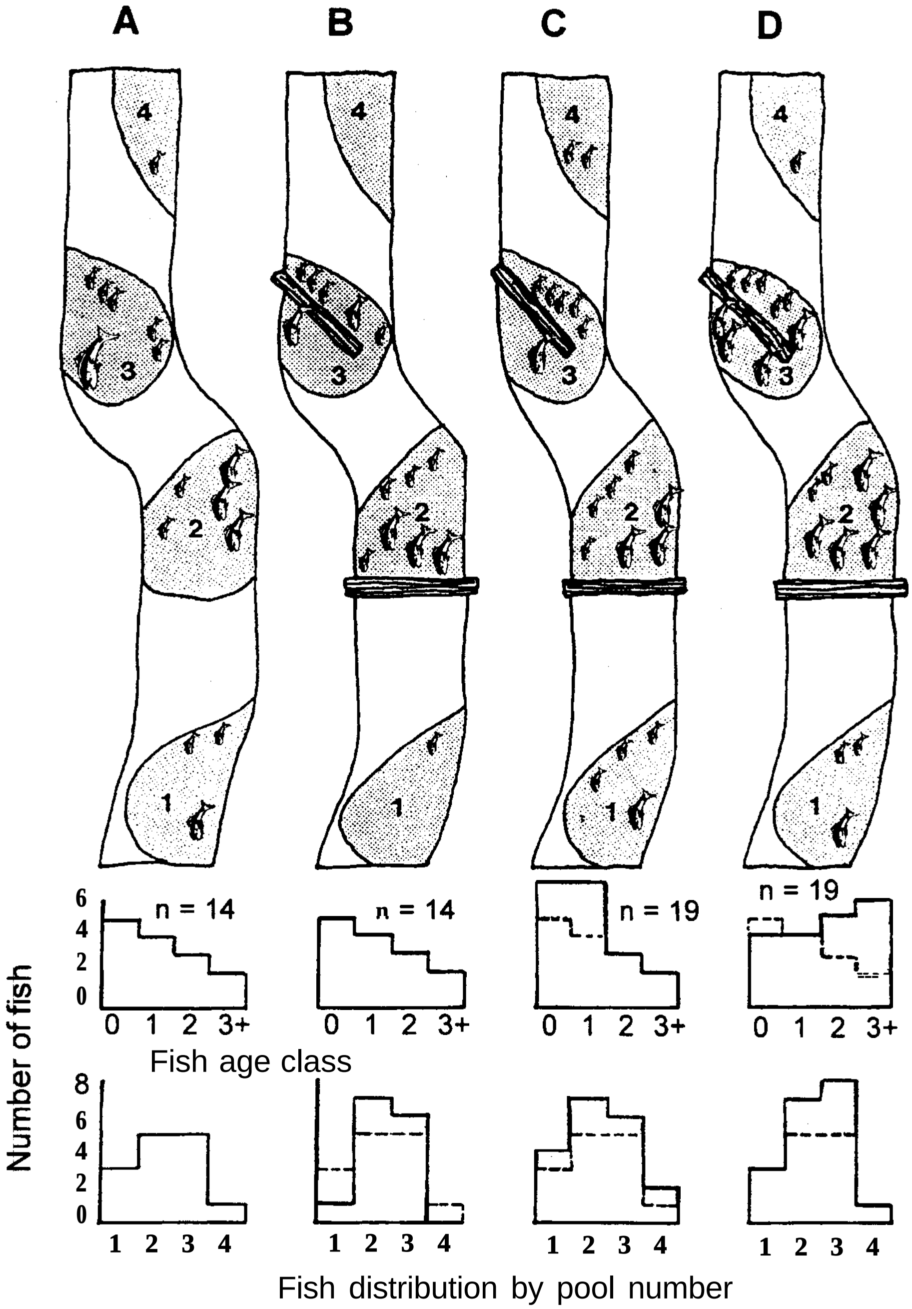


FIGURE 24.5. Greatly simplified depiction showing four hypothetical scenarios of fish response to alteration of stream habitats at the scales of reach and pool habitats (i.e., habitat unit scale). Four pools are numbered in downstream sequence. The pretreatment baseline or control is shown in panel A; treatment (panels B-D) is installation of a log weir in pool 2 and lateral deflector in pool 3. Inset graphs depict hypothetical population age structure and spatial distribution under each response scenario (relative to the baseline, dashed bars) two years after treatment. Under scenario B, apparent increases in fishes in treated pools are offset by decreases in untreated pools (which would not be detected if untreated pools were not monitored). In scenario C, populations are supplemented by increased survival and juvenile recruitment within the reach. In scenario D, populations are supplemented by increased retention of older immigrants originating outside the reach. Even though a local positive response is observed in the treated habitat units in all cases, only scenario C represents clear evidence of net increased production attributable to the treatment at a reach or larger scale. Scenario D might imply a net positive response, assuming retention of immigrants in the treated reach opens space for fishes in other reaches that would otherwise have been lost to the population through competitive displacement (Gowan and Fausch 1996) or cannibalism. Moreover, even under a scenario like C it is possible that increased juvenile recruitment will be nullified by survival bottlenecks at later life stages (Reeves et al. 1991); to ascertain whether gains in juvenile survival for this species (assumed to mature at age two or three) translate into increased adult populations requires monitoring through three or more years posttreatment.

and distribution of efforts for watershed restoration. HRCEM combines several information sources (including hydrologic data from the U.S. Geological Survey, Rivers Information Systems for California, Idaho, Oregon and Washington, and USDA National Resources Inventory and Major Land Resource Area databases) into an integrated data system based on river reach and watershed acre units at the 1:250,000 scale. The resulting information is used to develop estimates of the nature and extent of administratively adopted land management practices meant to deter erosion, water quality. and other impacts of agriculture and other land uses (i.e., Best Management Practices) or to determine what rehabilitation activities would promote aquatic habitat recovery or protection. Together with estimates of costs for various methods of river alteration and habitat rehabilitation, the HRCEM method results in a regionally aggregated estimate of project installation, operation, and maintenance costs annualized over a 20-year period. The model can be used to evaluate scenarios using different levels of management effort and methods. Among the aggregated "restoration" measures included in HRCEM are streambank and shoreline protection (rip-rap and revetments), fish stream improvement measures (in-stream structures), livestock fencing along riparian areas (Figure 24.6), and revegetation and tree planting in critical areas. Costs for each measure (on a per stream miles basis) are then applied to estimates of anadromous habi-

FIGURE 24.6. Three-year-old fenced cattle exclosure constructed along Elk Creek, a tributary of Joseph Creek in northeastern Oregon. A joint venture of Bonneville Power Administration, Oregon Department of Fish and Wildlife, and the private landowner from whom the exclosed plot was leased, this approach attempts to address causes, rather than symptoms of stream ecosystem deterioration. However, note that during a flood of approximately 5–10 year return period, the stream waters are well outside the fenced area (at left). The small sedge wetland in the middle foreground, also outside the exclosure, occupies an old channel swale, and is probably connected to the present channel through groundwater flow paths. In such biologically important alluvial valleys, channel migration and the presence of broad floodplains and fluvial wetland complexes challenge the conventional notion of protection through exclusion of activities within narrow streamside buffers. Long-term restoration of such streams depends on recovery of the ecological integrity (woody vegetation, soil structure, and natural channel and groundwater dynamics) of the entire valley floor (Photo credit: Christopher A Frissell, Oregon State University).

tat (e.g., miles of spawning habitat) within any particular basin.

Fluharty et al. (1996) suggest the HRCEM can further the use of economic data in comprehensive watershed management planning to help establish priorities for rehabilitation efforts and to identify the hidden costs of failing to provide adequate protection of aquatic resources now, in lieu of dubious restoration in the future. They caution, however, that assumptions in the model regarding the costs for various management practices need to be validated because the estimated costs varied widely between watersheds throughout California, Idaho, Oregon, and Washington.

This ambitious approach has additional limitations that require further attention or improvement. Presently, the model does not incorporate estimates of actual fish production benefits or restoration success that might accrue from the various restoration activities. Although this is understandable given the difficulty of predicting the success of such projects, unless the likely effectiveness of restoration projects is somehow evaluated in ecological terms, economic assessments of any kind may remain of limited value. Many of the kinds of projects incorporated in the Fluharty model and similar efforts to date (including many in-stream fish habitat structures and tree planting in riparian areas) are questionable in terms of their actual net benefits, in large part because details of project implementation were not readily available at the scale that would allow such assessment. Traditional stream bank stabilization projects using large rock or concrete structures for example, should be assumed to have negative net value for native fishes, their habitats, and aquatic ecosystem integrity in the long term. As directed by the NMFS, the HRCEM looked at scenarios with hundreds of miles of such treatments in coastal river basins, ostensibly for the purpose of salmon recovery. Possibly such scenarios reflect the present well-intentioned ambitions of certain management agencies and commercial interests, but they may be misguided ecologically if they are not critically evaluated in terms of the ecological context in which they will occur.

Fluharty et al. (1996) recognize that the most effective economic assessments of restoration projects focus not simply on the costs of applying a smorgasbord of remedial actions, but on a fuller accounting of the costs and benefits of redirecting human activities on the landscape in configurations that facilitate natural recovery of aquatic ecosystems (Chapter 23). Such evaluations may eventually show that substantial recovery is possible in many ecosystems with little regional net economic cost and only modest capital investment (Doppelt et al. 1993, Stanford et al. 1996).

Numerous watershed-scale restoration programs are now underway in the Pacific coastal ecoregion, (e.g., Big Quilcene River, Washington; Grande Ronde River, Oregon; Upper Clark Fork River, western Montana), as a result of identification by FEMAT (1993) and related regional assessments, but few if any of these programs show evidence of an institutional commitment to long-term, integrated monitoring and evaluation of outcomes that is equal to the environmental and technological challenges posed. In developing effective restoration programs, citizens' involvement councils and funds spent on retrospective watershed analyses or quantified engineering specifications cannot substitute for a carefully designed and controlled, adequately staffed, extensive monitoring and evaluation program.

Watershed Restoration and Adaptive Ecosystem Management

Determining the success of watershed or river restoration depends on the nature and the temporal and spatial extent of the degradation. For example, it is a relatively simple matter to evaluate the effectiveness of reducing pollution if the damage is caused by the discrete point discharge of factory or sewage effluents into a stream. The problem (low dissolved oxygen, elevated temperatures, elevated nutrient levels) can be easily defined and the cause-effect relationship easily established with existing knowledge. The response of the biological community following effluent reduction is relatively simple to predict, assuming the effects are primarily local in scale.

Predicting the outcome of restoration efforts at the scale of a whole watershed, stream network, or large river segment, however, is highly problematic due in large part to the diffuse, persistent, and time-dependent nature of cumulative effects operating within a basin (Montgomery 1995, Kershner 1997), and the problem that as a science, ecology still largely lacks (and may always lack) a robust predictive capability for specific sites and cases (Bella and Overton 1972, Cairns 1989, Ludwig et al. 1993). These limitations present an imperative for ecologists to link their descriptive skills with the better developed predictive capabilities of physical scientists to better understand and predict the outcome of physical processes acting on biological systems in a given context (Sear 1994, Stanford et al. 1996, Stanford and Poole 1996). One promising avenue in this respect is ***adaptive management,*** a management system designed to provide the information necessary for defensible, timely tests of the assumptions upon which interim decisions are based, so that informed "mid-course correction" of management programs can take place (Walters and Hilborn 1978, Walters and Holling 1990). Adaptive management is not a new idea, but government agencies recently have promoted it as a chief premise of ecosystem management (FEMAT 1993, Dombeck 1996, Thomas 1996). As difficult as implementing a sound adaptive management plan for a large ecosystem seems to be (Halbert 1993, Walters et al. 1993), adaptive management is essentially nothing more than avoiding past mistakes on a large scale, and learning from both successes and failures.

Unfortunately, adaptive management and environmental monitoring are often prescribed by managers as a "general tonic" that allows environment-damaging activities to proceed, as long as they are somehow monitored. Further, reliable predictive capability about linkages between specific watersheds, aquatic habitats, and biota remains limited. Large variation in the rate and pattern of natural processes and disturbance events often triggers changes in aquatic ecosystems that are neither predictable nor easily interpreted at particular locales on time scales of years to decades. Therefore, conservative assumptions are necessary to avoid unanticipated, irreversible consequences of management actions (Bella and Overton 1972, Ludwig et al. 1993, Montgomery 1995, Frissell and Bayles 1996). This fundamental precautionary principle includes deliberately avoiding the assumption that habitat restoration methods alone will suffice to induce full physical and biotic recovery of streams, a politically appealing presumption that is often employed as a conventional rationale for proceeding with human alteration of the landscape (Doppelt et al. 1993).

A corollary axiom of adaptive ecosystem management could be that distributing human activities and risks over the landscape would ensure that strategically selected, significantly large areas remain relatively free of the multiple threats posed by human activities. What this means is that the first step in an ecologically effective restoration program is a deliberate assessment of all management actions to ensure that regulatory systems are rigorous enough to minimize the future need for restoration. In other words, avoid making the same mistakes everywhere. For example, landscape alteration increases the need to establish and maintain relatively natural "safe havens" (Li et al. 1995) or large-scale refugia (Sedell et al. 1990, Frissell and Bayles 1996, Frissell 1997) to conserve representative aquatic habitats and biota at key points across the landscape (Ebersole et al. 1997). This axiom applies equally well to restoration, in which the recovery of specific habitats may be increasingly critical for maintaining key species or biotic resources on the landscape, as it does to the activities that alter landscapes and generate the need for restoration in the first place. Such a strategic, scientific assessment of priorities and reallocation of management impacts and restoration efforts is one stated goal of state and federal procedures for watershed analysis (FEMAT 1993, Montgomery et al. 1995, Chapter 19), but few if any existing examples of watershed analysis to date come close to meeting this goal (Keeton 1995, Weaver and Hagans 1995, Frissell and Bayles 1996, Collins and Pess 1997a, b).

Elements of Successful Restoration and Monitoring

In terms of improving interdisciplinary working knowledge of successful restoration techniques, benefits of evaluation and monitoring may be vastly more important than the particular biological benefits directly accrued from any single project. Monitoring is also invaluable for identifying small adjustments that can greatly increase the ecological efficacy and reduce the costs of a project or program, as exemplified in the monitoring program of Redwood National Park's large watershed restoration program. Resources devoted to monitoring and evaluation early in the program revealed that many early methods were relatively ineffective in the face of large-scale alteration of watershed processes. The results allowed managers to target resources to other methods that were more clearly cost-effective for addressing the overriding ecological objectives, including sediment reduction and restoration of slope and drainage network stability (Weaver et al. 1987).

To be successful, a substantial portion of the cost of even the most routine restoration projects must be dedicated to monitoring and evaluation (including pre- and postproject studies) (Minns et al. 1996). In fact, projects of a highly experimental nature may merit allocation of a predominant share of total project costs for monitoring and evaluation. The requirement for specific monitoring plans cannot be excluded from funds for planning. New institutional mechanisms are needed to establish site-dedicated, carryover funding to ensure long-term, postproject monitoring. Moreover, agencies must cooperatively develop institutional arrangements and fiscal support for independent evaluation and quality assurance of data and program monitoring. A regional, independent scientific panel or commission to direct the design and implementation of stream and watershed monitoring criteria and programs may be appropriate. It would, however, require a significant discretionary budget for a separate, competitive research grants program to develop innovative monitoring methods. The scientific oversight panel should be engaged in evaluating the efficacy and timeliness of management program responses to monitoring results (Stanford and Poole 1996). The oversight process must include provision that allows agencies and citizens access to monitoring data. Effective adaptive and cooperative ecosystem management requires closely integrating monitoring impacts of ongoing development activities and restoration programs (Minns et al. 1996).

The most fundamental challenge facing successful restoration of aquatic systems is to establish a clear understanding of the cause and effect relationships between the physical processes at work within a watershed, how the expression of these processes (rate, magnitude, and distribution) has been altered by human activities, and what short- and long-term restoration strategies best address such factors. Such strategies must consider the inherent constraints dictated by the characteristics of the watershed, the legacy of natural disturbances, and the distribution, magnitude, and persistence of management-induced changes. The examples in this chapter illustrate both the promise and problems of restoration efforts at the microhabitat, reach, and watershed scales. From the simple to the highly engineered approach, the inherent and collateral costs of recovery techniques and the spatial extent of the problem suggests traditional approaches need to be fundamentally rethought.

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