An Approach to Restoring Salmonid Habitat-forming Processes in Pacific Northwest Watersheds

By Tim Beechie and Susan Bolton

ABSTRACT

We present an approach to diagnosing salmonid habitat degradation and restoring habitat-forming processes that is focused on causes of habitat degradation rather than on effects of degradation. The approach is based on the understanding that salmonid stocks are adapted to local freshwater conditions and that their environments are naturally temporally dynamic. In this context, we define a goal of restoring the natural rates and magnitudes of habitat-forming processes, and we allow for locally defined restoration priorities. The goal requires that historical reconstruction focus on diagnosing disruptions to processes rather than conditions. Historical reconstruction defines the suite of restoration tasks, which then may be prioritized based on local biological objectives. We illustrate the use of this approach for two habitat-forming processes: sediment supply and stream shading. We also briefly contrast this approach to several others that may be used as components of a restoration strategy.

Interest in restoring depleted or depressed salmon runs in the Pacific Northwest has grown rapidly in the past decade, primarily because of declining harvest levels, loss of numerous stocks, and petitions to declare several stocks threatened or endangered under the Endangered Species Act (Nehlsen et al. 1991; Lichatowich et al. 1995). Most of the losses or declines were at least partly associated with habitat loss or degradation (Bisson et al. 1992; Gregory and Bisson 1997). Scientists also accept that some of the blame for the salmon "crisis" goes to traditional fishery and habitat management, which focused on managing individual species and habitat characteristics rather than on whole ecosystems (Frissell et al. 1997).

Habitat modifications (e.g., placing log structures, constructing spawning riffles, protecting stream banks) frequently have been unsuccessful at restoring habitats because they have been constructed without consideration of the ecological and landscape contexts of habitat degradation. Neglecting physical and ecological processes that cause degradation can lead to physical failure of projects or increased maintenance costs (Frissell and Nawa 1992; Kauffman et al. 1997). Additionally, using approaches that lack a biological context (i.e., understanding of the species or communities historically present) can result in projects that do not address factors limiting production or that help one species but harm others (Reeves et al. 1991).

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Many authors have suggested recently that restoring and managing watersheds or ecosystems are preferable to managing individual species (e.g., Doppelt et al. 1993; Lichatowich et al. 1995; Reeves et al. 1995). They contend that a more holistic management approach may help avoid the failures common to single-species management. However, others say we must still account for local fishery management objectives such as escapement and harvest goals when establishing restoration plans (Lichatowich et al. 1995). In more extreme cases we may even be required to account for species listed under the Endangered Species Act (Collins et al. 1994).

In this paper we present a restoration approach focused on restoring and managing watershed processes rather than individual habitat characteristics. Our approach concentrates on diagnosing and treating causes of habitat degradation rather than effects of habitat degradation. We also suggest that restoration priorities can be influenced by local biological objectives. We first summarize the approach and explain the physical and biological basis for restoring watershed processes based on historical reconstruction of habitat-forming processes. We then describe the steps for historical reconstruction, identifying restoration tasks and prioritizing tasks. Finally, we give examples of the approach as applied to sediment supply and stream temperature, and contrast the use of this approach with several others.

The need to focus on habitat-forming processes

Despite our understanding that changes in habitat typically cause changes in biota and that habitat degradation is at least partially responsible for declines in salmon abundance (Bisson et al. 1992), there is little in the way of a theoretical basis for describing rates and pathways of recovery for biota or the environment that supports them (Cairns 1990). Consequently, predicting the biological outcome of actions designed to restore habitat is difficult because we cannot yet predict the physical outcome of those actions. From a natural resource management perspective, a better understanding of the processes by which habitats are altered and by which they recover is important to (1) increasing understanding of the likely geomorphological outcome of watershed or stream restoration work and (2) more effectively targeting areas where restoration can provide significant biological benefits.

Empirical data show that stocks of the same salmonid species are adapted to local differences in habitat characteristics such as temperature regime or flow regime (Healey and Prince 1995; Wood 1995), suggesting that managing for a single standard may be inappropriate for many stocks within a region. Habitat standards generally do not recognize that salmonids are adapted to their local environments, which influences local salmonid habitat preferences and to some extent determines the genetic and behavioral diversity of salmonids in the region. Moreover, habitat standards rarely account for the fact that many locations in a channel network are naturally incapable of producing preferred or optimum habitat conditions. If restoration actions are designed to restore processes that form salmonid habitats, habitat conditions will naturally tend to express the array of habitat conditions to which local stocks are adapted.

Traditional approaches to salmonid habitat restoration or enhancement focus on repairing or augmenting specific habitat conditions rather than on restoring landscape processes that form and sustain salmonid habitat. By focusing on conditions, these approaches typically lead to engineering solutions aimed at creating or modifying habitats so they do not move in space or change through time (e.g., protecting stream banks or installing woody debris structures). However, many natural habitats such as off-channel ponds or debris-formed pools that appear relatively stable at one point in time have been created by dynamic processes, and processes such as channel migration or large, woody debris (LWD) recruitment continually re-create these habitats (Peterson and Reid 1984; Benda 1994; Abbe and Montgomery 1996). Therefore, attempts to build "stable" habitats may interrupt long-term processes that maintain a diversity of habitats.

An approach to diagnosing and restoring disrupted habitat-forming processes

A process-oriented restoration goal

In light of the preceding points, Beechie et al. (1996) proposed a goal of restoring and maintaining landscape processes that formed and sustained the habitats to which salmonid stocks are adapted. This landscape context is important for two main reasons:

(1) Spatial and temporal variations in landscape processes create a dynamic mosaic of habitat conditions in a river network (Naiman et al. 1992; Benda 1994; Reeves et al. 1995).

(2) Salmonid stocks are adapted to local environmental conditions (Miller and Brannon 1982; Healey 1991).

Together, these statements imply that salmonid stocks are adapted to spatially and temporally variable habitats, and may further imply that such variability is important to their long-term survival (Reeves et al. 1995).

The intent of this goal is to help avoid errors such as those made in the past when we tried to create habitat conditions that were "good for salmon." For example, widespread LWD removal during the 1970s and early 1980s was intended to facilitate upstream migration of adult salmon, but the practice also affected juvenile rearing habitats by reducing pool abundance and cover

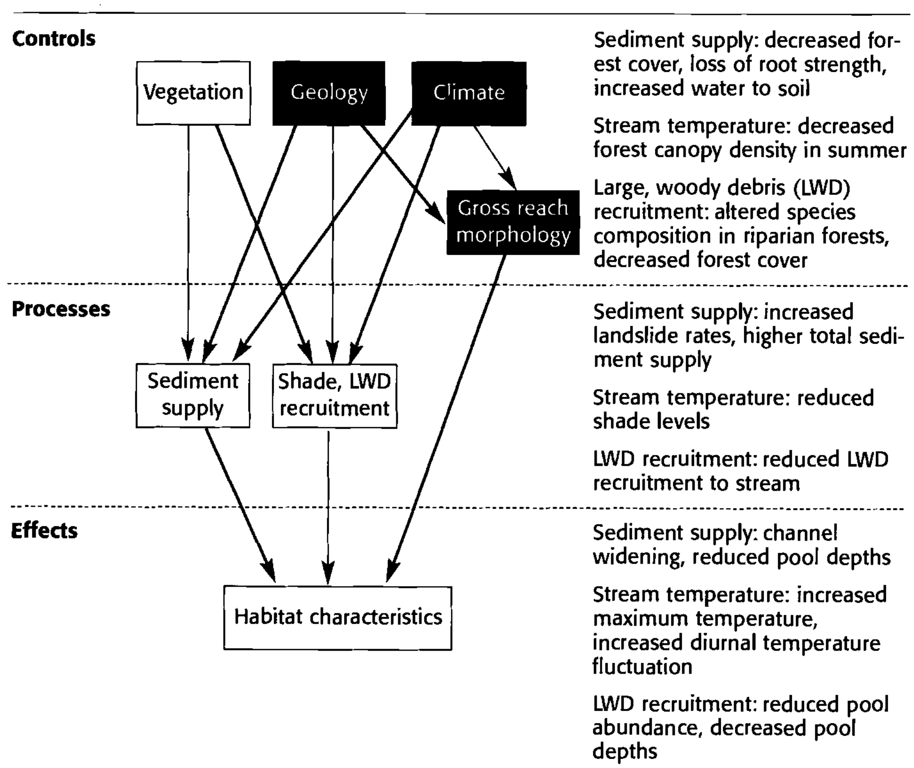

Figure 1 shows linkages among controls on watershed processes, the processes themselves, and habitat characteristics, with narrative descriptions for three habitat-forming processes (adapted from Beechie 1998). Black boxes indicate controls that are not affected by land use. Gross reach morphology refers to average channel slope, approximate size of the channel, and floodplain width.

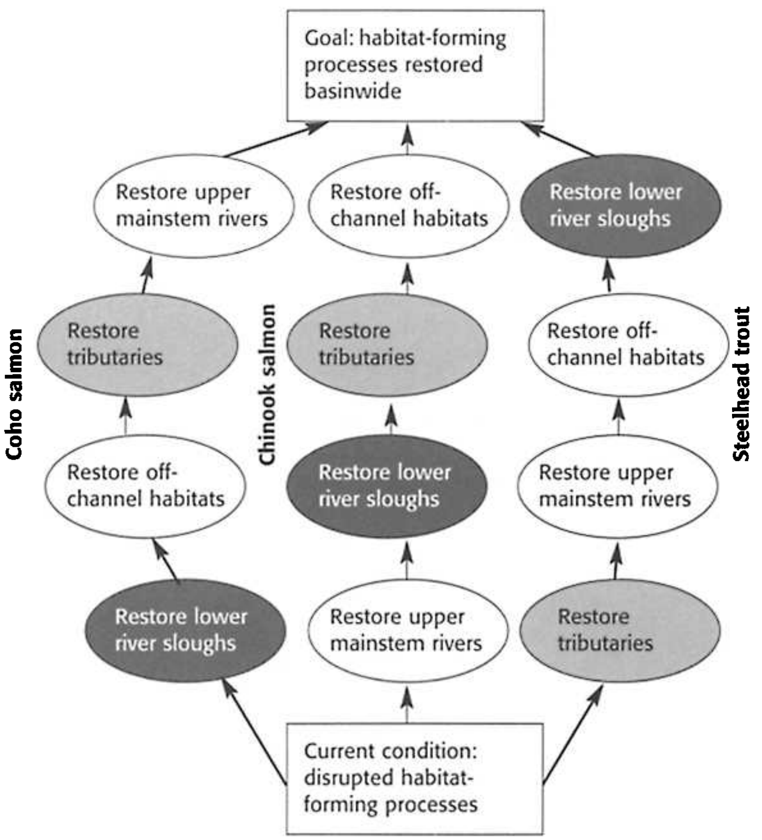

Figure 2 shows how restoration actions may be sequenced differently depending on local management objectives. This schematic illustrates spatial prioritization of restoration actions, each of which is required to restore all of the habitat-forming processes in a large watershed. Where coho salmon is a priority (pathway on left), restoration efforts may first focus on reconnecting lower river sloughs that once provided significant overwintering habitat in the study area (Beechie et al. 1994). Where steelhead trout are a priority (pathway on right), restoration may focus on tributaries first (Collins et al. 1994). Restoration designed to favor chinook salmon might follow a third sequence of actions (center pathway).

complexity. Such mistakes are less likely to occur if the restoration goal is to reestablish processes to which salmonids were adapted. In addition, the process-oriented goal should help identify actions that restore habitat for all salmonids (Peterson et al. 1992). This is particularly advantageous in cases where we want to restore a diversity of aquatic species rather than a specific salmonid stock. The goal also allows management agencies to move away from a limited range of habitat manipulations relevant primarily to one species, thereby avoiding attempts to give all stream reaches the same characteristics despite variability in geomorphological potential from reach to reach.

This approach departs from traditional restoration and enhancement methods that attempt to create specific habitat attributes static in space and time (e.g., engineered LWD structures to create pools, rip-rapped banks to resist erosion). Instead, it focuses on the natural potential of a stream channel and on land use effects on channel characteristics via altered habitat-forming processes (Harvey and Watson 1986; Newbury and Gaboury 1988; Beechie et al. 1994). Figure 1 illustrates the hierarchical relationship among land use, watershed processes, and habitat characteristics. Traditional methods that focus on modifications to habitat characteristics (the level of "effects" in Figure 1) are unlikely to effectively restore habitat conditions in the long term because they do not correct disruptions to processes. Our restoration goal focuses on correcting causes of changes to habitat-forming processes (the level of "controls" in Figure 1). Such actions are more likely to result in sustainable and cost-effective restoration of habitat characteristics because they address the root cause of degradation.

The goal also pushes scientists and managers to achieve greater understanding of processes that create and maintain stream habitats, which should help avoid restoration efforts that attempt to constrain processes that create productive salmonid habitats. For example, attempts to restrict bank erosion disrupt the process of channel migration, which creates oxbow lakes or terrace tributary channels (Peterson and Reid 1984). These off-channel habitats provide important overwintering areas that persist for decades (Peterson and Reid 1984; Scarlett and Cederholm 1984). Where channel migration is successfully controlled, new off-channel habitats will not form, and existing habitats will eventually develop into forests that are not salmonid habitat. Our goal should help avoid restoration projects that disrupt habitat-forming processes and should encourage those that require less maintenance.

Locally defined restoration priorities

Restoration priorities may be based on a narrower range of biological objectives, but only to the extent that prioritization remains subordinate to the goal of restoring natural processes (Collins et al. 1994; Lichatowich et al. 1995; Beechie et al. 1996). Consideration of local management goals is especially important when they are economically or legally important to various landowners and commercial interests. For example, the performance of a wild stock that influences regionwide harvest rates or the potential listing of a species under the Endangered Species Act can affect local economies and warrants consideration when restoration plans are developed.

Prioritization does not alter the types of restoration identified under the goal of restoring natural processes. Rather, it alters the sequence in which restoration actions are carried out (Figure 2). For example, Beechie et al. (1994) found most coho salmon (*Oncorhynchus kisutch*) habitat losses in the Skagit River basin were due to elimination of side-channel sloughs, and much smaller losses were caused by impassable culverts that isolated tributary habitats. For both situations the first restoration step is to reconnect habitats so migrating fishes have access to historically productive areas. If managers selected coho salmon as the priority species for restoration in this basin, restoration could first focus on lower-river, off-channel habitats that would recoup the greatest amount of coho production. However, steelhead trout (*O. mykiss*) do not make significant use of slough habitats (Cederholm and Scarlett 1984), and selection of steelhead trout as the priority species would shift the initial focus toward restoring tributary habitats. In neither case would a restoration action supersede the goal of restoring natural processes, and completion of the highest priority tasks would not mean that remaining areas or processes can be ignored. However, each sequence would favor recovery of the priority species while also benefitting other species.

Implementation

This strategy focuses analyses on causes of habitat degradation rather than on habitats or biota. Although in-stream diagnostics can provide valuable insight into causes of degradation, they cannot by themselves identify where watershed processes are disrupted and what actions may be required to restore them. The approach described here requires analysis of habitat-forming processes at the scale of watersheds in order to identify which processes are disrupted as well as locations and timing of land use effects on those processes. Restoration actions can then be identified directly from the results of the analysis. Thus, this approach complements in-stream diagnostics that assess either habitat characteristics or biotic responses to habitat change.

The strategy takes a two-tiered approach, first identifying restoration actions through diagnosis of altered habitat-forming processes and then prioritizing restoration actions. It aims to accomplish several objectives. First, it is intended to restore habitat for all salmonid species while simultaneously allowing local managers to sequence restoration activities in a way that favors recovery of a selected species. Second, the strategy should help managers avoid failures associated with attempting to engineer habitats that are static in space and time. And finally, the approach allows managers to evaluate the cost-effectiveness of different restoration options. Under this strategy, managers identify all restoration actions by assessing changes in habitat-forming processes with respect to natural rates and magnitudes, and prioritization only alters the sequence of restoration activities. As long as all restoration actions are consistent with the over-riding goal of restoring watershed processes, aquatic habitats will be restored for many species but in a sequence that favors the local management objective.

Restoration actions that substitute constructed habitats for recovery of habitat-forming processes are inconsistent with our goal. However, in some cases such actions may be useful if the local biological objective requires it (e.g., for a stock at risk of extinction). These actions are less desirable in restoration because they address symptoms rather than causes (Frissell and Nawa 1992) and are typically expensive relative to the benefit provided. Managers who use constructed habitats in restoration should consider costs, expected benefits, and risk of failure. For example, it may be inappropriate to pay for high-benefit projects with low probabilities of success rather than first preserving a remnant stock with projects that have lower potential benefit but higher probability of success. In any case, careful consideration of the historical context should help with the design of constructed habitats that approximate the conditions to which local salmonid stocks are adapted.

In practice, application of the strategy includes five steps:

(1) Estimate natural rates of habitat-forming processes;
(2) Assess changes in rates of habitat-forming processes due to land use;
(3) Identify actions required to restore habitat-forming processes;
(4) Evaluate probable improvement in local biological indicator (for each task); and
(5) Prioritize actions based on costs and potential improvement in biological indicator.

The following sections state the objectives of each step and briefly describe examples of methods and data that may be used. A summary of the steps and examples of methods also are listed in Table 1.

(1) Estimate historical rates of habitat-forming processes.

Application of this approach first requires an understanding of the behavior of habitat-forming processes under natural conditions. The level of resolution required in the analysis can vary depending on the level of sophistication or detail that managers expect in their restoration plans. Greater resolution in these analyses should allow managers more flexibility to find solutions that restore habitat-forming processes while maintaining other land management objectives. This step uses many existing methods for characterizing fire regimes (Booth 1991), sediment supply rates (Reid et al. 1981; Roberts and Church 1986; Paulson 1997), dynamics of riparian forests (Agee 1988; Featherston et al. 1995), stream temperature regimes (Collins et al. 1994), or rates of other watershed processes. Such methods typically rely on measurements of features such as landslides, forest patches, or stream widths at one or more points in time from aerial photographs. These photos are then used to estimate rates of various natural processes such as sediment supply (Paulson 1997), fire return (Booth 1991), or channel migration (Collins et al. 1994). Additionally, regional or local rates of natural processes are sometimes already known but are not used to advantage because analyses tend to focus on conditions rather than processes. For the North Cascades of Washington State, some examples of useful data are unpublished fire history maps or other regional fire data (U.S. Forest Service 1996), sediment budgets or landslide inventories (Parks 1992; Paulson 1997), and published U.S. Geological Survey hydrologic data (Williams et al. 1985).

(2) Estimate current rates of habitat-forming processes.

The second step is to assess how land uses have altered habitat-forming processes. This step identifies mechanisms by which land uses have altered habitat-forming processes,

Table 1 summarizes analysis steps and examples of methods or data may be used in each step.

Step	Examples of methods or data
(1) Historical reconstruction: identify natural processes, and	• Sediment budget (magnitude of sediment supply by process and land use)
(2) Historical reconstruction: land use effects on processes	• Analyses of stand types from aerial photos and maps (e.g., patchy or uniform, maturity, species composition, fire regime, land-use alterations) • Temperature models (changes in shade values and stream temperatures through time) • Hydrographs (flood magnitudes, runoff processes) • Analyses of channel and habitat characteristics (changes in channel widths, changes in pool depths or abundance, temporal and spatial agreement between channel responses and floods or sediment inputs)
(3) Identify restoration tasks	*Passive restoration*: • Mapping of mass wasting hazard areas (allow natural recovery of mass wasting rates by avoiding or modifying land uses in hazard areas) • Mapping of recovering riparian areas (allow natural recovery of riparian functions by avoiding or modifying land use) *Active restoration*: • Inventory blockages to fish passage (restore connectivity of habitats) • Inventory road failure hazards to repair (prevent future road-related failures), • Map riparian areas to thin or replant (enhance recovery of riparian functions)
(4) Evaluate probable effectiveness of restoration tasks with respect to locally chosen biological priorities	• Estimate changes in fish production based on changes in habitat conditions (habitat-based fish production models) • Qualitative estimate of effects of changing temperature regimes (estimate effects of change in temperature on biological indicator species) • Qualitative estimates of fine sediment effects on macro-invertebrate production or survival to emergence
(5) Prioritize restoration tasks	• Rank relative effectiveness of different restoration options (i.e., based on greatest change in biological indicator per dollar cost) • Rank options based on shortest recovery time

and indicates which of the altered processes are most likely responsible for observed changes in habitat conditions. Methods are typically the same as those used in Step 1 in order to facilitate comparisons between historical and current rates of habitat-forming processes (Table 1). Comparisons between historic and current rates indicate which habitat-forming processes have been significantly altered from their natural rates, and the largest differences usually indicate which processes have been most disrupted. In general, the level of resolution here should correspond to that of Step 1. However, in some cases greater resolution may be desirable if restoration actions are to be management-intensive. For example, active management of riparian forests requires greater understanding of stand dynamics and silvicultural methods than does historical reconstruction of riparian functions.

(3) Identify restoration tasks.

This step identifies the types of actions (both passive and active) necessary to restore natural habitat-forming processes. The restoration plan should describe the physical and biological objectives of each aspect of restoration as well as the land areas affected (e.g., how to identify a mass wasting hazard in the field). It also should describe restoration options (e.g., a range of harvest, thinning, and planting options for restoring riparian vegetation patterns) (Collins et al. 1994). In the absence of significant land use constraints, restoration plans may attempt to fully restore most habitat-forming processes. However, urban and agricultural land uses often constrain the degree to which habitat-forming processes can be restored. In these cases restoration plans may target only selected watershed processes to avoid dramatic changes in land use. Where only selected processes will be restored, analysts should identify actions that restore as many processes as possible while accommodating local land use priorities. Such solutions are expected to move toward the restoration goal but with an understanding that the goal will not be fully achieved and that partial restoration of processes may involve higher long-term costs.

(4) Estimate effectiveness of restoration tasks with respect to local biological objectives.

Step Four is to evaluate the relative effectiveness of different restoration options in terms of the response of a biological indicator, which is here taken to be a salmonid species of interest. This step evaluates which of the disrupted habitat-forming processes have had the greatest effect on the biological indicator, and estimates the degree to which specific types of restoration actions can restore the freshwater habitats of a species of interest. In some cases effectiveness can be estimated using habitat-based production models, but in many cases it will be evaluated qualitatively based on changes in other factors that affect survival rates (Collins et al. 1994). Specific methods required for this step depend on the types of processes found to be most severely altered and on the types of restoration actions considered at a location (Table 1).

(5) Prioritize restoration tasks.

Lastly, the restoration actions described in Step Three may be prioritized based on the predicted effect on local biological objectives and estimates of cost. Restoration actions may be prioritized in various ways, although the original intent of the strategy was to use a simple cost-effectiveness approach (Beechie et al. 1996). In that approach, projects were ranked in order of decreasing benefit per dollar cost of restoration, where benefits were expressed as the magnitude of the expected increase in a biological indicator. However, other prioritization methods also may be used depending on local preferences. Other factors that may influence priorities are identification of refugia, landowner willingness to participate, and availability of funds for specific project types.

Examples

Sediment supply

The sediment budget is one tool for estimating both historic sediment supply (Step 1) and the change in rate of sediment supply due to land use (Step 2). Paulson (1997) used sediment budgets to estimate natural rates of various sediment supply processes in several sub-watersheds of the Skagit River basin in Washington State. She described how average annual sediment supply differs between the pre-European settlement fire regime and the past five to six decades of timber harvest practices in the Skagit River basin. For the natural regime, Paulson (1997) found that mass wasting was the dominant sediment supply process in most basins and that much of the spatial variability in mass wasting rates was a function of geology and land form. Mass wasting in the Skagit River basin varied by a factor of three as a function of underlying geology, and more than 75% of all mass wasting originated from two easily identified land forms covering less than 25% of the watershed area.

Forest management activities increased average annual sediment supply by 10%–140% depending on geology and intensity of land use (Step 2). In subbasins dominated by valley-filling glacial deposits on the order of 10^1–10^2 m thick, recent sediment supply (i.e., the past 50 years) was dominated by mass wasting associated with clear-cut logging. Road locations in those basins were typically on terrace surfaces where mass wasting rates were extremely low, and timber harvest in deeply incised stream valleys had the greatest effect on mass wasting rates. In subbasins having steep slopes underlain by high-grade metamorphic rocks, recent sediment supply was dominated by road-related mass wasting, especially where roads were located such that failures directly entered streams.

Two types of restoration actions were identified from this analysis: active restoration of road-related mass wasting and passive restoration of mass wasting from deeply incised stream valleys (Step 3). Locations of all hazard areas were mapped during the analysis so restoration actions would be identified with little additional field work. Road-related mass wasting was predominantly caused by failure of sidecast material on slopes >30° or by failure of stream-crossing fills. Active restoration should include (1) removal of sidecast material where it may affect streams, and (2) reconstruction of stream crossings so culvert failures do not initiate mass wasting. Clear-cut-related mass wasting originates primarily from deeply incised stream valleys. Passive restoration on this land form should include avoidance of logging in the most unstable areas and reduced timber removal where the hazard is less (e.g., Collins et al. 1994). The relative importance of active or passive restoration techniques varies by watershed and is a function of the primary cause of mass wasting. For example, where most mass wasting originates from unstable land forms without roads, active restoration of road systems is of lesser importance.

The potential benefit of restored sediment supplies can be estimated by combining in-channel diagnostics with sediment budget information (Step 4). For example, Collins et al. (1994) linked changes in mass wasting to changes in steelhead trout parr production using a habitat-based steelhead production model. They found that increased sediment supply in the 1980s had filled pools and reduced mainstem rearing habitat capacity by an estimated 35%. Among potential restoration actions identified for sediment supply processes, Collins et al. (1994) concluded that an effort to stop a single large slide was not warranted based on the facts that sediment supply was already declining, and potential remedies were very expensive (Step 5). However, reconstruction of 56 road sites and reduced timber harvest in 5 mass wasting hazard areas (17% of the watershed area) were considered high priorities for restoration.

Stream temperature

Collins et al. (1994) assessed pre-logging riparian forests using the historical aerial photo record as part of the historical reconstruction of summer temperature regime in the 173-km^2 Deer Creek basin in northwest Washington (Step 1). Prior to logging, mature conifer forests covered virtually the entire floodplain along a 13-km stretch of low-gradient river, indicating that virtually no river migration occurred for at least the preceding several decades. Reaches confined by valley walls also were bordered by mature conifer forests. Based on typical heights of mature conifer forests and pre-logging channel widths in sample reaches throughout the basin, Collins et al. (1994) used two empirical temperature models (from Sullivan et al. 1990) to estimate historic maximum temperature and diurnal temperature range. They showed that temperatures at some basin locations were historically high due primarily to naturally wide channels where even mature forests provided little shade. Furthermore, their estimates suggested that seven out of eight study reaches historically exceeded the "optimum" salmonid rearing temperature range of 10°C–14°C (e.g., Bjornn and Reiser 1991). At least one reach may have exceeded the state water quality standard for maximum temperature (18°C), even with a mature conifer riparian forest.

To gauge changes in stream temperature due to land use, Collins et al. (1994) estimated pre-logging (1943) and post-logging (1991) summer stream temperatures and identified which watershed processes were most likely responsible for the changes (Step 2). Between 1942 and 1991, estimated maximum stream temperature increased by more than 4°C in 63% of the study reaches as a result of reduced shading, and by less than 3°C in the remaining reaches. Comparisons of timing of floods, sediment inputs from mass wasting events, and riparian logging suggested that riparian logging and flooding were most likely responsible for reduced shade. However, the assessment of impacts of timber harvest on flooding suggested that land use was a minor factor. Thus, Collins et al. (1994) concluded that restoration should focus on restoring large conifer riparian forests to maintain a narrower channel and increase shade levels.

Proposed riparian restoration actions varied by land form and stand type, with several management options for most situations (Step 3). Twelve combinations of land form and stand type were identified for potential restoration, and 21 generalized management prescriptions were developed. The most intensive management prescriptions targeted devegetated floodplains (intensive planting where probability of success is high) and deciduous stands (thinning and interplanting shade-tolerant conifer). Thinning of conifer stands was considered appropriate for young stands where increased growth rates could significantly improve the recovery of stable LWD, but not for older stands where shade and LWD recruitment were adequate.

Collins et al. (1994) concluded that riparian restoration actions in reaches with little temperature change between 1942 and 1991 would afford little increase in salmonid survival. On the other hand, restoring reaches with temperature increases of more than 4°C would provide a relatively large increase in salmonid survival (Step 4). Therefore, they suggested that restoration efforts target areas with maximum temperature increases greater than 4°C (Step 5), approximately 15 km of stream. They also estimated costs of different restoration options and the length of time to reach a target stand type as a way of comparing the relative cost-effectiveness of restoration options.

Prioritization incorporating the refugia concept

Prioritization of restoration actions may consider factors besides simple cost-effectiveness estimates such as the strategic importance of refuge areas. Collins et al. (1994) suggested that recovery of a depressed summer-run steelhead stock would be most efficient if portions of a large watershed were secured as refugia before proceeding with restoration across the entire basin. In that case, refugia were identified as subbasins where (1) habitats for all freshwater life history stages of steelhead trout were present, (2) recovery was independent of processes in the rest of the basin, and (3) restoration was likely to be relatively efficient and rapid. Restoration in refuge areas had the short-term objective of stabilizing the steelhead trout population and the long-term objective of providing colonists to the rest of the basin. Upon securing the refugia, the plan then called for restoring key habitat areas, which were areas that contained a large proportion of the rearing capacity for steelhead trout and coho salmon. These areas had the short-term objective of stabilizing coho salmon and resident trout populations by restoring off-channel rearing areas and small tributaries. The long-term objective was to restore the productive capacity of mainstem and off-channel rearing habitats.

Discussion and conclusions

Managers may take many different approaches to identifying types of habitat degradation and prioritizing salmonid habitat restoration and management activities. Some approaches focus on effects of degradation as the primary diagnostics (e.g., Karr 1993; Lichatowich et al. 1995), whereas others focus on the change in disturbance patterns between the current land use regime and the historic fire regime (e.g., Reeves et al. 1995). In-stream diagnostics focus on changes in habitat characteristics and may indicate which types of habitat-forming processes have been altered. Approaches that directly address land use patterns target the management of human effects on habitat-forming processes without attempting to understand specific processes or habitat characteristics they create. Neither approach identifies the magnitude of changes to habitat-forming processes or locates specific sites where land uses have altered processes. The process-based restoration strategy presented here focuses on understanding changes to habitat-forming processes and identifies locations where specific restoration actions are needed to restore such processes. Thus, it fills an information gap between in-stream diagnostics of habitat degradation and large-scale assessments of disturbance patterns on a landscape.

Two examples of in-stream diagnostic approaches are patient-template analysis (Lichatowich et al. 1995) and the index of biotic integrity (IBI, Karr 1991). Both focus on diagnosing how habitat conditions have changed since European settlement, whereas restoring habitat-forming processes focuses on the causes of altered conditions. If you accept the premise that restoring processes (as opposed to characteristics) is critical to successfully restoring long-term habitat conditions, then some analysis of habitat-forming processes is necessary even when either of the other two diagnostics is used. In other words, to correct the root causes of degradation, we must identify which processes have been disrupted, which land uses have caused the disruption, and where those land uses have caused the disruption. Historical reconstruction of habitat-forming processes provides a benchmark rate for each process, and comparisons of current process rates to historic rates describe the magnitude of changes to those processes. Historical reconstruction also identifies locations of land uses that disrupt habitat-forming processes, which correspond to locations of potential restoration actions.

Many diagnostics of habitat condition do not account for natural spatial or temporal variation in habitat characteristics, although you can describe variability by using a distribution of reach-level habitat conditions (e.g., Lichatowich et al. 1995; Bisson et al. 1997). However, knowing the distribution of current conditions does not provide guidance on how to manage land uses in a way that restores the natural distribution of habitat conditions. The process-based approach to restoration avoids this problem by focusing on how land uses affect habitat-forming processes. The historical analysis identifies how and where land uses have altered habitat-forming processes, which then guides how to manage land use effects on natural processes. The goal of restoring natural habitat-forming processes shifts managers away from attempts to control processes and allows the natural variation of processes to vary habitat characteristics. In addition, restoring habitat-forming processes should recover and sustain conditions for the long term because such processes will maintain habitat conditions without continual management intervention.

These comparisons are not intended to suggest that a focus on habitat-forming processes can always substitute for the other two approaches. No single approach to restoration is "best" in all respects, and each approach has advantages in specific situations. The IBI has advantages in that a wide array of degraded conditions can be detected with a single sampling method, and it directly measures aspects of biological resources about which managers may be concerned. Patient-template analysis also has a greater focus on biological resources than does the process-based approach, although it is much narrower in scope than IBI. The process-based approach is largely focused on landscape-level processes for identifying degraded conditions and only incorporates a biological element in prioritizing restoration actions.

A combined approach that employs historical reconstruction of habitat-forming processes, biological diagnostics such as IBI, and assessment of habitat characteristics and life history patterns of salmonids would increase our understanding of linkages between actions on the landscape and consequences to stream habitats and biota. However, applying a combined approach over large areas would be prohibitively expensive. Therefore, each approach may be used where it provides the greatest advantage. For example, there are many potential causes of habitat degradation in agricultural and urban areas. In those areas IBI could help focus the assessment of habitat-forming processes on the significant causes of degradation in a given watershed, and the historical assessment of habitat-forming processes could be streamlined by reducing attention to less-significant processes. A combination of the two approaches would reduce the cost of assessments and would improve the understanding of causes of habitat loss over the use of IBI alone. By contrast, there are fewer potential causes of degradation in forest lands than in agricultural or urban areas. Where fewer potential causes of degradation exist, historical reconstruction of habitat-forming processes may be the more direct approach because relatively few assessments can describe how processes and conditions have changed. Furthermore, the assessments can lead directly to spatially and temporally explicit conclusions about the causes of degradation and can identify appropriate actions for restoration. Thus, focusing on habitat-forming processes can be a more cost-effective approach to identifying restoration actions in forest lands or other areas with few potential causes of degradation.

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