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[Article]

Setting River Restoration Priorities: a Review of Approaches and a General Protocol for Identifying and Prioritizing Actions

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Abstract.—Implicit in the question, "How should I prioritize restoration actions?" is often the unstated question, "What should I restore?" Distinguishing between these questions helps clarify the restoration planning process, which has four distinct steps: (1) identify the restoration goal, (2) select a project prioritization approach that is consistent with the goal, (3) use watershed assessments to identify restoration actions, and (4) prioritize the list of actions. A well-crafted restoration goal identifies the biological objective of restoration, addresses underlying causes of habitat change, and recognizes that social, economic, and land use objectives may constrain restoration options. Once restoration goals are identified, one of six general approaches can be selected for prioritizing restoration actions: project type, refugia, decision support systems, single-species analysis, multispecies analysis, and cost effectiveness. Prioritizing by project type, refugia, or a decision support system requires the least quantitative information, and each approach is relatively easy to use. Single-species, multispecies, and cost effectiveness approaches require more information and effort but often most directly address legal requirements. Watershed assessments provide most of the information used to identify and prioritize actions and should be explicitly and carefully designed to support the goals and prioritization scheme. Watershed assessments identify causes of habitat degradation, habitat losses with the greatest effect on biota and ecosystems, and local land and water uses that may limit restoration opportunities. Results of assessments are translated into suites of restoration options, and analysis of land use and economic constraints helps to evaluate the feasibility of various options. Finally, actions are prioritized based on assessment results and the selected prioritization scheme. In general, we recommend the use of simple decision support systems for cases in which watershed assessments provide incomplete information; the cost effectiveness approach is recommended for cases in which watershed assessments identify (1) restoration actions needed to restore riverine habitats, (2) biological benefits associated with each action, and (3) costs of restoration actions.

Dramatic declines of diadromous and freshwater fish populations have prompted substantial efforts to restore or rehabilitate riverine habitats. However, many river and watershed restoration projects fail to accomplish their objectives, and restoration efforts continue to achieve less than the desired outcomes (Bond and Lake 2003; Palmer et al. 2005; Roni et al. 2008, this issue). Specific causes of project failure vary, but include a misunderstanding of the natural potential of restoration sites (Muhar et al. 1995; Frissell 1997), a lack of understanding of geomorphological controls on habitat responses (Frissell and Nawa 1992; Kondolf 2000), nonnative species invasions (Klotzli and Grootjans 2001; Bond and Lake 2003), and presence of undetected water quality impairments (Cowx and Van Zyll de Jong 2004; Roni et al. 2008, this issue). Scientists and managers also have recognized that population declines are largely a result of attempts to manage individual species or habitat characteristics rather than whole ecosystems (Nehlsen et al. 1991; Doppelt et al. 1993; Frissell et al. 1997). Thus, scientists and managers now accept that river restoration is more likely to be successful at restoring individual or multiple species and preventing the demise of other species if there is careful consideration of the watershed or ecosystem context in which individual restoration actions are set (Lichatowich et al. 1995; Reeves et al. 1995; Beechie and Bolton 1999; Palmer et al. 2005).

Nevertheless, legal mandates (e.g., Clean Water Act or Endangered Species Act in the United States) drive the continuing focus of restoration plans on single species or water quality attributes instead of watersheds or ecosystems (Karr 1991; Beechie et al. 2003a). Moreover, the scientific literature on stream restoration typically focuses on isolated steps in the planning

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process (e.g., watershed analysis, project design, or prioritization of projects) and often lacks a clear explanation of linkages between steps (Beechie and Bolton 1999). It is within this context that stream and watershed restoration practitioners are commonly faced with the question, "What are your highest-priority restoration actions?" Not surprisingly, there is considerable confusion about how best to answer this question. This confusion appears to have three distinct sources. First, the importance of crafting a comprehensive goal is often ignored, so restoration groups approach watershed analysis and restoration prioritization without a solid grounding in their own objectives and values. Second, the steps for translating watershed analysis results into a list of necessary restoration actions remain somewhat vague, and restoration groups often conduct watershed assessments but do not explicitly use the assessment results to identify restoration actions needed to achieve their goal. Third, there has been no systematic review of approaches to prioritizing restoration actions, so practitioners have difficulty in defining prioritization and selecting an approach that suits their needs.

In this paper, we address these issues in two parts. First, we briefly review six common approaches for prioritizing restoration actions with the primary purpose of distinguishing the information needs and appropriate uses of each approach. We find that restoration practitioners typically have not been exposed to the variety of available prioritization approaches and therefore spend considerable time locating examples of prioritization methods and attempting to adapt the methods to suit their needs. However, readily accessible prioritization schemes are often incompatible with local goals and information gained from watershed assessments. Thus, many restoration groups enter the planning process without knowledge of common prioritization approaches and are frustrated by the apparent lack of suitable approaches. The purpose of this review is to give practitioners a broad overview of available approaches to consider before initiating restoration planning, thus allowing them to more efficiently identify a prioritization approach that matches their restoration goals and assessment capabilities.

Second, we describe a general protocol for linking restoration goals, watershed assessments, and prioritization into a coherent strategy for river restoration. The question "How should we prioritize our restoration actions?" implies that restoration actions have been identified and listed and simply need to be put in some priority order. However, we commonly find that restoration practitioners have not identified the necessary suite of actions and therefore are really asking the broader question, "What type of restoration should I do?" We break this broader question into its component parts, illustrating a four-step process for identifying and prioritizing restoration actions: (1) establish restoration goals, (2) choose a prioritization approach, (3) identify necessary restoration actions through watershed assessment, and (4) prioritize restoration actions. We focus on key analysis and synthesis elements within each step and illustrate the distinction between identifying and prioritizing actions. Finally, we summarize recommendations for prioritizing restoration projects based on the types and detail of information available, as well as the values encompassed in the goal statement.

Review of Prioritization Approaches

We identified six general strategies for prioritizing river restoration actions (Table 1). The first three strategies do not require detailed information about how watershed processes and habitats have changed or about how those changes affect important species. Rather, they employ simple logic tools to prioritize restoration actions that have been identified either opportunistically or through simplified restoration inventories. Hence, we refer to these as "logic" approaches. The last three strategies are based on analyses of habitat loss or degradation, changes in watershed processes, and importance of specific habitat losses to one or multiple species. We consider these to be "analytical" approaches.

Project Type

In the absence of detailed knowledge of factors limiting recovery, prioritizing restoration actions by project type can facilitate the logical sequencing of restoration actions based on their probability of success, response time, and longevity (termed a "hierarchical approach" by Roni et al. [2002, 2003]). In this approach, techniques that have a high probability of success, relatively quick response time, and long duration should be implemented before other techniques. Roni et al. (2002, 2008, this issue) suggested a sequence of projects that begins with the protection of high-quality habitats, as it is easier and more effective to maintain good habitat than to restore degraded habitat. The second priority is the reconnection of isolated off-channel habitats or blocked tributaries, which provides a quick biological response, is likely to last for many decades, and has a high likelihood of success (Pess et al. 2005). Third, watershed processes that create and sustain riverine habitat should be restored, including streamflows, water quality, sediment inputs, and riparian functions (Beechie et al. 2000; Beechie 2001). Other techniques,

TABLE 1.—Brief description of six general strategies for prioritizing stream restoration actions and selected citations for each approach.

Strategy	General description	Source
Logic approaches		
Project type	Restoration progresses in the following order: (1) protect intact habitats, (2) remove migration barriers to intact habitats, (3) restore watershed processes (e.g., instream flows, sediment reduction, riparian areas), and (4) instream habitat enhancement	Roni et al. 2002, 2008, this issue
Refugia	Restoration first focuses on protecting intact habitats with relatively intact populations (refugia), then proceeds outward from refugia so that restored habitats are located near an established source of colonists	Reeves et al. 1995; Frissell and Bayles 1996
Decision-support system	Simple: the "score sheet" approach in which important values for each project (e.g., benefit, cost, certainty of success, land-owner impact, education value) are assigned weighted scores and the total score is used to rank project priorities; more complex: usually computer models that calculate total scores based on a more-complex suite of values and scores	Lewis et al. 1996; SRSRC 2004; Cipollini et al. 2005
Analytical approaches		
Single species	Relies on the use of models to estimate the magnitude and duration of project benefits to a focal species based on watershed, habitat, and population assessments; projects are ranked from greatest to least benefit to focal species	Reeves et al. 1991; Beechie et al. 1994; Greene and Beechie 2004
Multispecies	Includes two general types of targets: (1) focus on improvements in watershed processes and functions without direct consideration of species (aims to restore habitat conditions for many species) and (2) focus on a suite of focal species that broadly represent overall ecosystem function Highest-priority projects will most improve habitat abundance, habitat diversity, and focal species populations	Karr 1991; Reeves et al. 1995; Beechie and Bolton 1999; Bohn and Kershner 2002
Cost effectiveness	Ranks projects by cost effectiveness (change in biological measure divided by cost); biological measure may be either single species or multi species	Beechie et al. 1996; Beechie and Bolton 1999; Roni et al. 2002

such as wood or boulder placement in streams, are generally beneficial to some species but less beneficial for others. Such instream actions should be undertaken (1) after or in conjunction with reconnection of blocked habitats and other efforts to restore watershed processes or (2) when short-term increases in fish production are needed to prevent extirpation of a threatened or endangered species (Beechie and Bolton 1999; Roni et al. 2002). This logical sequence combines elements of cost effectiveness, refugia, and addressing causes before symptoms. However, it does not consider the relative importance of various restoration needs within a watershed or which actions might be most beneficial to local priority species or other local objectives (e.g., water quality impairment).

Refugia

The refuge approach is rooted in the idea of "protecting the best first" and expanding restoration outward from protected sites (Frissell and Bayles 1996; Ziemer 1997). This stems in part from island biogeography theory and the understanding that seed sources must be preserved to maintain the availability of colonists for occupying future restored sites (Gore and Milner 1990; Huxel and Hastings 1999). Indeed, population modeling studies indicate that restoration efforts focused near sources of colonists result in more-rapid species recovery (Huxel and Hastings 1999) and that recovery time increases with distance from colonization sources (Gore and Milner 1990). Refugia also provide some resilience against disturbance, allowing species and ecosystems to persist in the face of landscape changes (Sedell et al. 1990). Assigning the highest restoration priority to refugia may be most appropriate for situations in which at least one species is at high risk of extinction and the preservation of remnant populations or nodes of biodiversity is important. By contrast, watersheds with relatively stable populations and intact refugia might embark on a longer-term recovery strategy that expands habitat restoration outward from established refuge areas. Thus, distance to refuge and restorability are factors that influence restoration priorities. This approach has been illustrated in the Pacific Northwest, where a restoration strategy for a depressed stock of steelhead *Oncorhynchus mykiss* focused on first protecting and restoring subwatersheds that supported significant steelhead populations and then restoring more severely degraded subwatersheds in later years (Beechie et al. 1996). On a larger spatial scale, the Northwest Forest

Plan includes the identification of key watersheds for protection (Reeves et al. 1995). Advantages of this approach are twofold: (1) the focus on protection of relatively intact watersheds and populations is more cost effective than restoring degraded locations and (2) the likelihood of local extirpation of species is typically decreased. Its main disadvantage is that is that refugia in our present landscapes are often quite small, and small populations or ecosystems are more easily extirpated by either natural or human disturbances.

Decision Support Systems

The broad category of decision support systems includes an array of semiquantitative tools for prioritizing river restoration actions (Llewellyn et al. 1995; Verdonschot and Nijboer 2002). Such systems can be complex (Mobrand et al. 1997; Peters and Marmorek 2001) or can be simple scoring systems that help weigh the relative merits of various projects (WPN 1999; SRSRC 2004). In either case, the fundamental objective is to assemble and weigh information considered important to setting priorities (Cipollini et al. 2005). Simple scoring techniques are commonly used by local groups to rank restoration projects, most often in the form of a score sheet that addresses common evaluation criteria for stream and watershed restoration projects (e.g., number of species that are benefited, project cost, and educational value). Each question receives a score, and each score is weighted to reflect its level of importance in the suite of questions. The sum of scores reflects the overall priority of the project, and projects can be compared based on either the total score or component scores. Two important advantages of simple scoring systems are transparency and flexibility. Such systems are transparent to project proponents and project reviewers in two ways. First, the factors entering into project prioritization are readily apparent from the suite of questions that must be answered. Second, the relative importance of each factor is evident from its weighted contribution to the overall score. Such systems thus not only provide a means of prioritizing projects but also can help guide project selection over time to better match local restoration goals. These systems are also extremely flexible, as restoration planners can incorporate a wide variety of objective and subjective criteria tailored to local environmental and socioeconomic goals. A disadvantage of such systems is that there may be a high degree of subjectivity in developing the system and completing a scorecard. More-complex decision support systems may be quantitatively more rigorous and may thus be able to handle more-complex decisions. However, more-complex models often lose their transparency (i.e., project proponents or reviewers may not be able to see how complex computer models arrive at scores or decisions or the assumptions underlying those decisions). Other disadvantages to using more-complex models include increased uncertainty in model outcomes and a lack of data to populate the model (Beechie et al. 2003a; ISAB 2003).

Single-Species Approaches

More-quantitative and detailed approaches to prioritizing restoration actions typically require more-detailed information gathered through watershed assessments. Watershed assessments identify habitat constraints that inhibit recovery of one or more target species, as well as specific causes of those habitat constraints. Specific habitat bottlenecks that contributed to species' declines and now constrain the recovery of those species are usually identified through life cycle modeling (Greene and Beechie 2004; Scheuerell et al. 2006) or limiting factors assessments (Reeves et al. 1989, 1991; Beechie et al. 1994). Causes of habitat degradation are identified through watershed process assessments (e.g., migration barrier inventory, road sediment reduction inventory, or riparian function inventory; Beechie and Bolton 1999; Beechie et al. 2003b; Bartz et al. 2006). Prioritization among habitats may then be based on the estimated benefit of each action for priority species (Beechie and Bolton 1999; Roni et al. 2002). The prioritization of actions does not alter the types of actions that are needed to restore stream ecosystems but merely alters the sequence in which those actions are taken. Thus, the same list of restoration actions might be prioritized differently depending on the species of interest. A main advantage of this approach is that expected outcomes for each restoration action are quantified (e.g., number of fish that will be produced), which provides clear hypotheses for monitoring efforts. Disadvantages include relatively stringent data requirements, the difficulty of quantifying and communicating key model uncertainties (Greene and Beechie 2004), and the potential contribution of single-species management to declines in other nontarget species (e.g., Doppelt et al. 1993).

Multiple-Species Approaches

Where restoration objectives focus on conservation of multiple species or on biodiversity, alternative strategies for prioritizing restoration actions include approaches that use population viability analysis or species index models applied to multiple species (Akcakaya 2000; Cornutt et al. 2000; Lindenmayer et al. 2002) and approaches that focus mainly on suites of landscape processes considered necessary to conserve multiple species (Poiani et al. 2000; Holl et al. 2003). Such

TABLE 2.—Example of cost effectiveness calculations based on estimated total coho salmon smolt production over the life span of four different types of restoration projects in the Skagit River basin, Washington (adapted from Beechie et al. [1996]).

Site	Project type	Cost (US$)	Estimated smolt production	Cost per smolt ($)
Little Park Creek	Culvert (fish passage)	130,000	271,050	0.48
Boundary Creek	Culvert (fish passage)	81,000	129,375	0.61
Deepwater Slough	Reconnect side channel (fish passage)	242,000	205,875	1.18
Barnaby Slough	Reconnect side channel (fish passage)	80,000	363,600	0.22
Skinny Sauk Pond	Off-channel pond construction	37,700	45,300	0.83
Zander Pond	Off-channel pond construction	23,750	8,665	2.75
Finney Pond	Off-channel pond construction	25,000	7,690	3.25
Falls Creek	Wood placement	12,400	1,525	8.13
Circle Creek	Wood placement	4,700	340	13.82
Clear Beaver Creek	Wood placement	18,000	815	22.08

approaches are designed to help avoid conflicting priorities that inevitably arise when multiple species are separately targeted for conservation. Both types of approaches focus on the identification of critically important habitats, one from the perspective of species' needs and the other from the perspective of functional conservation areas and the hierarchical structure of important habitats. In the former, habitat needs of individual species are considered quantitatively (e.g., Filipe et al. 2004). The analysis of habitat needs is roughly equivalent among species, and priority conservation areas are identified through one of several weighting schemes that include such factors as the relative threats to each habitat type, the number of species a habitat can support, or habitats that are either rare or critically important to rare species. In this approach, the highest-priority projects are those that improve populations, either of multiple species or rare species. The latter approach focuses on the function of landscapes at the scale of species and ecosystems, prioritizing restoration actions based on the degree of impairment to processes or the rarity of specific habitat types. Advantages of these approaches are that they restore habitats for multiple species and have a greater likelihood of addressing causes of species declines rather than symptoms. A main disadvantage of a landscape process approach is the difficulty of assigning relative values across habitat types, whereas a disadvantage of the multispecies approach is the difficulty of finding a suite of species that effectively serve as a surrogate for all other species (Lindenmayer et al. 2002).

Cost Effectiveness

The cost effectiveness approach is typically invoked when funding agencies request that projects be prioritized to achieve the most restoration benefit at least cost. Cost effectiveness is defined as the cost per unit of measurable benefit achieved, such as cost per fish produced by a project (Beechie and Bolton 1999; Roni et al. 2002, 2003). Use of this approach requires the measurable benefit of restoration actions to be expressed in the same terms for each action type (Table 2). If anticipated benefits cannot be expressed in a common "currency" (e.g., number of fish produced), a true cost effectiveness approach cannot be used. If cost effectiveness can only be considered qualitatively (e.g., project type *x* typically produces many fish at relatively low cost), one of the logic approaches should be used for prioritizing actions. Advantages of the cost effectiveness approach include the following: (1) it is the most direct way of assessing where to spend limited funds and (2) priorities are easily understood by project proponents and funding agencies. The main disadvantage is that restoration benefits are often difficult to quantify for some action types.

Summary

The six prioritization schemes differ in information needs and, to some extent, in their basic philosophical approaches to restoration. The three logic approaches require the least quantitative information, as each can be used with only a list of actions to prioritize (Table 3). However, the decision support system can make use of more information if available. The project type approach is based largely on the average cost effectiveness of project types, whereas the refuge approach is based on the philosophy of protecting the best habitat first and subsequently restoring nearby habitats. Decision support systems codify suites of quantitative and qualitative criteria and score them to provide a logically consistent ranking of projects. The three analytical approaches require a more-detailed understanding of the causes of habitat and species declines and a means of predicting the probable outcome of restoration actions (Table 3). The single-species approach obviously focuses on improving the population performance of a species of interest, whereas multispecies approaches focus on restoration

TABLE 3.—Summary of information needs for six general methods of prioritizing stream or watershed restoration actions; X indicates required information and O indicates optional information. All approaches require a list of restoration actions, which is developed during the watershed assessment step.

	Information needs			
Prioritization approach	Causes of impairment	List of actions	Biological benefit	Cost
Logic approaches				
Project type	O	X		
Refugia	O	X		
Decision support system	O	X	O	O
Analytical approaches				
Single species	X	X	X	
Multiple species–ecosystem	X	X	X	
Cost effectiveness	X	X	X	X

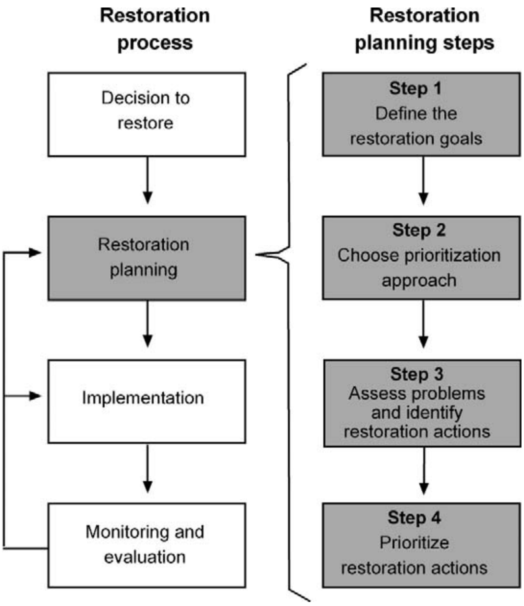


FIGURE 1.—Diagram of the river restoration process and four steps for identifying and prioritizing river restoration actions that are nested within this broader process.

efforts that benefit more than one species. The cost effectiveness approach considers not only which projects will have the greatest benefit for single or multiple species but also the cost of achieving that benefit.

General Protocol for Identifying and Prioritizing Restoration Actions

To help river restoration practitioners structure the process of identifying and prioritizing restoration actions, we propose a four-step process that connects watershed analyses to prioritization through (1) setting a clear goal for restoration activities, (2) choosing a prioritization scheme, (3) using watershed analyses to identify restoration actions necessary to meet the goal, and (4) prioritizing restoration actions based on assessment results (Figure 1). These steps fit within a broader restoration process that includes restoration planning, implementation, and evaluating the success of restoration actions. We presume for the purposes of this paper that the need for restoration has already been identified (often driven by a specific legal or resource issue), and our protocol describes the period after there is general agreement to pursue some level of river restoration. Implementing restoration actions and monitoring their success follow our protocol but are beyond the scope of this article.

Step 1: Set Restoration Goals

Goals are ideals or major accomplishments to be attained, whereas objectives are measurable targets that must be achieved to attain the goal (Barber and Taylor 1990; Tear et al. 2005). Both are important elements of identifying and prioritizing restoration actions, and both are influenced by stakeholder values. In the context of river restoration planning, the importance of clearly stated goals is often overlooked, perhaps because conflicting stakeholder values and uncertain predictions of restoration outcomes make the setting of goals a difficult task. Setting goals for river restoration involves considerable effort in gathering stakeholder opinions, negotiating restoration goals that most stakeholders can agree to, and specifying constraints imposed by conflicting socioeconomic goals (Stanford and Poole 1996; Hulse et al. 2004). Nevertheless, this step is critical to successful river management and restoration because it gives all parties a common understanding of management targets and tradeoffs (Barber and Taylor 1990; Stanford and Poole 1996; Baker et al. 2004). Moreover, clearly stated goals guide restoration practitioners in choosing how to identify and prioritize restoration efforts and in preventing drift in management objectives through time (Barber and Taylor 1990).

River restoration efforts typically focus on one of three types of goals: restoration of species, restoration of ecosystems or landscapes, and restoration of ecosystem services (e.g., recreation, clean water, and fish production; Parker 1997; Beechie and Bolton 1999; Ehrenfeld 2000). These general goals vary in complexity and purpose, yet each requires an understanding of how ecosystems have changed from their natural potential and what kinds of restoration are possible (Ebersole and Liss 1997). Thus, restoration goals should be stated in the context of landscape and aquatic processes that drive habitat degradation and species declines, as well as human constraints on recovery options (Frissell 1997; Slocombe 1998). We suggest that any goal statement should:

(1) identify the biological objective(s),
(2) address underlying causes of ecosystem degradation (Parker 1997; Beechie and Bolton 1999; McElhany et al. 2000), and
(3) acknowledge social, economic, and land use constraints (Slocombe 1998).

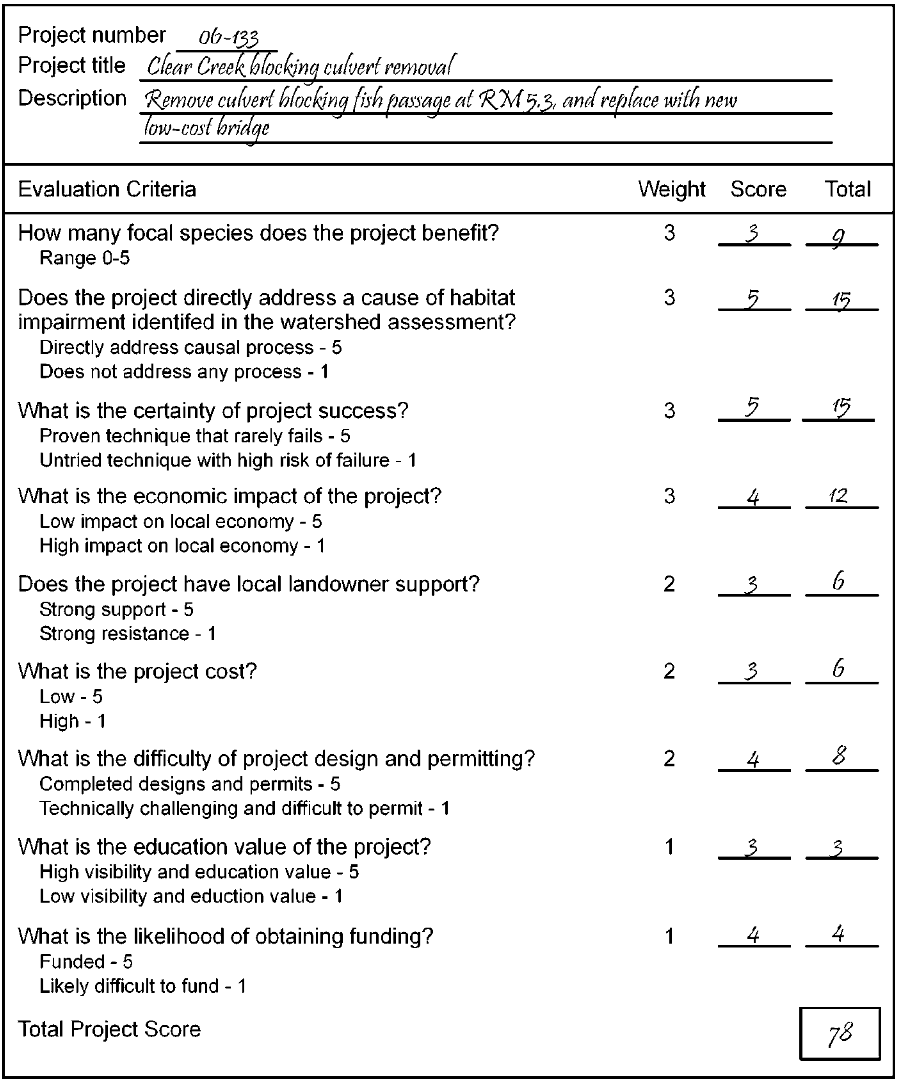
For example, a goal such as "support recovery of (species name[s]) through restoration of landscape processes that form and sustain riverine habitat diversity, while minimizing impacts to local (economic or landowner objectives)" contains each of these attributes. Goals phrased in this way are both realistic and explainable (Ehrenfeld 2000). They are realistic in their understanding that sustainable restoration will not be accomplished without a focus on driving processes and in their recognition of local land use constraints on the magnitude and pace of restoration. Such goals are also easily explained because they address focal species (identifying the need for restoration), causes of decline (targeting self-sustaining and low-maintenance recovery), and local social and economic interests (a recognition that humans are part of the present-day ecosystem).

We recognize that stakeholders rarely share common goals for a river and its watershed, but this does not mean that goals cannot be set. In watersheds with diverse stakeholder values, recognition of socioeconomic values unrelated to river restoration becomes critical aspect of defining meaningful restoration goals that can guide the prioritization process. Where differences cannot be reconciled and a single concise goal cannot be reached, stakeholders can agree to list several diverse and conflicting goals or they can agree to express socioeconomic goals as constraints on river restoration (as in our previous example). Such suites of goals and constraints clearly portray stakeholder values and foster a rational means of setting priorities that benefit both the target species and the majority of stakeholders. Setting river restoration goals with diverse stakeholders may also benefit from models that predict environmental and socioeconomic outcomes of various strategies and policies (Baker et al. 2004; Bartz et al. 2006; Scheuerell et al. 2006). Such efforts give all stakeholders a common view of environmental and socioeconomic consequences of alternative futures and engender more-rational discussion of value tradeoffs and multiple resource goals (Baker et al. 2004; Hulse et al. 2004).

Once the goal statement has been constructed, objectives that must be met to achieve the goal can be defined. For river restoration, objectives might include specific fish population performance measures to be achieved, water quality standards to be met, or multispecies indicator scores to be attained (e.g., Harwell et al. 1999; McElhany et al. 2000; Tear et al. 2005). Ideally, each objective should be a measurable target against which restoration success can be assessed. Measurable targets are often either legally mandated standards (e.g., water quality standards) or specific performance measures for individual species or groups of species (e.g., population performance targets for threatened species; Tear et al. 2005). A variety of targets can be set for individual species, including population size, productivity, spatial structure, and diversity (McElhany et al. 2000). For multiple species, multimetric indicators such as the index of biotic integrity (IBI) or River Invertebrate Prediction Classification System (RIVPACS) can be used (Karr 1991; Wright et al. 2000).

Step 2: Choose a Prioritization Approach

When selecting an approach to prioritizing restoration actions, the most important criterion is that the prioritization approach be consistent with the stated goals. In the ideal planning sequence, practitioners will first establish their goals, then choose the prioritization strategy that best matches their goals, and finally choose watershed assessment tools that provide information needed to set priorities with the selected approach. In reality, setting goals and choosing prioritization schemes will often be interwoven to some degree, and both will probably draw upon information gained from previous watershed assessments. Hence, selection of a strategy for prioritizing restoration actions usually considers both the restoration goal and the types of information expected from watershed assessments. The restoration goal identifies the main values that should be considered in prioritizing actions, including important species or ecosystems, causes of habitat degradation, and socioeconomic constraints. However, the types of information to be obtained from watershed assessments may limit the number of restoration strategies that can be considered. For example, many restoration efforts do not have sufficient funding to conduct complex watershed and fish population assessments that include modeling of expected benefits to species or groups of species. In such cases, the watershed assessment might identify causes of habitat degradation (the most important element) but not biological outcomes or



Project number 06-133
Project title Clear Creek blocking culvert removal
Description Remove culvert blocking fish passage at RM 5.3, and replace with new low-cost bridge

Evaluation Criteria	Weight	Score	Total
How many focal species does the project benefit? Range 0-5	3	3	9
Does the project directly address a cause of habitat impairment identifed in the watershed assessment? Directly address causal process - 5 Does not address any process - 1	3	5	15
What is the certainty of project success? Proven technique that rarely fails - 5 Untried technique with high risk of failure - 1	3	5	15
What is the economic impact of the project? Low impact on local economy - 5 High impact on local economy - 1	3	4	12
Does the project have local landowner support? Strong support - 5 Strong resistance - 1	2	3	6
What is the project cost? Low - 5 High - 1	2	3	6
What is the difficulty of project design and permitting? Completed designs and permits - 5 Technically challenging and difficult to permit - 1	2	4	8
What is the education value of the project? High visibility and education value - 5 Low visibility and eduction value - 1	1	3	3
What is the likelihood of obtaining funding? Funded - 5 Likely difficult to fund - 1	1	4	4
Total Project Score			78

FIGURE 2.—Hypothetical example of a decision support system score sheet, which can be used to prioritize a list of river restoration actions. The set of evaluation criteria are scored on a scale of 1 to 5 and summed to a total score, which is then compared with the total scores of other potential restoration actions.

benefits, so options for prioritizing actions are best limited to one of the three logic approaches (project type, refugia, or decision support system; Table 3). To use either the project type or refuge approach, the watershed assessment must have identified intact and degraded areas, as well as specific restoration actions that are necessary to restore degraded habitats. The list of necessary restoration actions can be prioritized either by type of action (project type) or spatially (refugia). Neither approach requires information for assessing which actions are biologically most important.

The third logic approach (decision support system) is considerably more flexible and can be tailored to incorporate a wide range of local values in prioritizing restoration actions. However, it must have a list of identified actions to prioritize. The simplest and most transparent form of a decision support system is a scoring system, in which a set of evaluation criteria are scored and summed to a total score. These scores can then be used to prioritize the list of restoration actions. When using such systems, it is important that evaluation criteria reflect the values embodied in the goal statement developed by local stakeholders. For example, evaluation criteria related to our earlier goal statement should include some consideration of species that benefit from restoration, the degree to which restoration actions address causal processes, and how the project accommodates local socioeconomic goals (Figure 2). More-complex models may also be used to integrate information into project rankings but often with some loss of transparency. That is, end users (e.g., funding agencies or implementers) of a prioritized list of restoration actions generated by complex models may have difficulty in understanding why some projects rank unexpectedly high or low or even in understanding the rules and assumptions used to determine these rankings. Nevertheless, even a complex computer model for ranking projects is flexible and easily tailored to local needs.

The three analytical approaches can be used when detailed watershed assessments have been or will be completed. Prioritizing actions based on the needs of a single species may be one of the most common means of prioritizing restoration actions. This approach requires an understanding of the causes of habitat change and the importance of habitat changes to the species of interest (Table 3). Both types of information are provided by watershed assessments, and prioritization procedures typically combine quantitative analyses and qualitative judgments made by local experts and stakeholders (Bartz et al. 2006; Scheuerell et al. 2006). Prioritizing actions for multiple priority species with conflicting habitat needs (e.g., more than one endangered species) can be based on likely improvement in a multimetric indicator of stream health (e.g., IBI or RIVPACS; Karr 1991; Wright et al. 2000) or on restoring ecosystem processes and functions with the greatest need for restoration (e.g., the most disturbed sites or sites with little remaining functional habitat). Either approach can be extended to the cost effectiveness approach when project costs can be estimated. Despite significant model uncertainties in estimating how much any suite of actions will improve the status of focal species, these approaches often give funding agencies more confidence that restoration funds will be spent cost effectively.

Step 3: Identify Restoration Actions

Restoration actions are identified based on a watershed assessment combined with an inventory of potential actions. First, we describe the purposes of and techniques for conducting a watershed assessment, which is generally defined as an assessment approach for understanding watershed processes, their effects on riverine habitats and biota, and the roles of people in modifying or restoring such processes (Beechie et al. 2003a). We then describe how watershed assessment results guide an inventory of potential restoration actions. This inventory is separate from the general watershed assessment and is specifically designed to locate and describe restoration options.

Conduct watershed assessment.—Watershed assessments provide most of the information used to identify and prioritize actions and should be explicitly and carefully designed to support the goals and prioritization scheme. Watershed assessments must address three main questions: (1) What restoration actions are necessary to restore habitat availability, quality, and diversity? (2) Which restored habitats will most improve biological populations, communities, or ecosystems? (3) How will land use and economic constraints limit the pace and extent of restoration?

Focusing watershed assessment procedures on these questions will help identify cause–effect linkages among land uses and habitats and among habitats and biological responses (Figure 3). Critical objectives of these assessments are to gain an understanding of natural potentials and determine the degree to which restoration efforts can move habitats toward a re-expression of natural habitat capacity and quality (Poff and Ward 1990; Ebersole and Liss 1997; Frissell et al. 1997; Pess et al. 2003). The degree to which natural habitat conditions can be expressed will inevitably be limited by socioeconomic factors, and natural forces such as climate change may shift natural capacity over time. Hence, assessments should also consider such factors to the extent possible.

The first question addresses causal processes and the identification of restoration actions needed to restore riverine habitats (Beechie et al. 2003b). A minimum set of landscape processes and functions addressed in a watershed assessment should include hydrology, sediment supply, riparian functions, channel–floodplain interactions, habitat connectivity, and delivery of pollutants (Table 4). This suite of factors encompasses most processes that alter habitat availability, quality, and diversity, although the types and complexity of each assessment varies with geographic setting. Other authors provide detailed summaries of the general approach for conducting watershed assessments and the specific procedures for assessing each watershed process or function (e.g., Kershner 1997; WPN 1999; Beechie et al. 2003a, 2003b); therefore, we do not describe detailed methods here.

Assessing each watershed process or function includes two levels of detail. The first is a general assessment of changes in habitat condition and the land use factors that have caused those changes; the second is an inventory of specific restoration actions that can be taken (Beechie et al. 2003b). Assessments of land use impacts on watershed processes and habitats can be accomplished through a combination of remote sensing

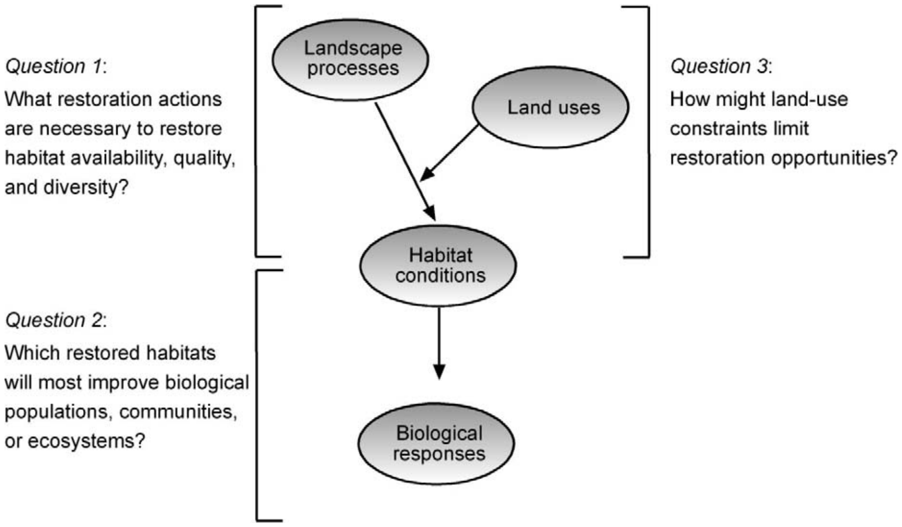


FIGURE 3.—Diagram of conceptual linkages and questions to be addressed in watershed assessments that are used to identify and prioritize river restoration actions.

and field data; these assessments typically include such analysis techniques as sediment budgets, mapping of riparian conditions, or quantification of habitat areas above man-made migration barriers (Table 4). Such assessments identify how land uses have altered habitat conditions at the watershed scale and suggest the types and magnitude of restoration effort needed for each type of impact. However, these assessments typically are not of sufficient detail for generating lists of potential restoration actions. Identifying specific restoration actions (e.g., which culverts to replace, where riparian fencing is needed, or where road erosion can be reduced) requires field assessments (Table 4).

The second question addresses the biological significance of restoration actions. Answering this question includes assessing habitat loss or degradation and estimating the effect of those changes on one or more species. Diagnostics of habitat degradation include assessments of habitat structure and quality (e.g., habitat surveys and water quality sampling) and a wide variety of variables that indicate deviations from regulatory thresholds or expected habitat conditions (e.g., water quality standards, pool area or frequency, abundance or size of woody debris, and substrate characteristics; Bauer and Ralph 2001). Two basic approaches to understanding the importance of different habitat changes on biota include models that assess where habitat changes will most benefit species (e.g., Reeves et al. 1991; Beechie et al. 1994; Greene and Beechie 2004) and empirical sampling of suites of biota that can be correlated with landscape or habitat changes (Karr 1991; Wright et al. 2000). The purpose of either methodology is to identify which habitat changes have the most significant effects on aquatic biota.

TABLE 4.—Examples of assessments and inventories used to identify river restoration actions. More-complete summaries of these methods are provided by Beechie et al. (2003a, 2003b) and Watershed Professionals Network (WPN 1999).

Watershed process or function	Assessment techniques	Inventory procedures
Sediment	Sediment budget, mass-wasting models, and surface erosion models	Inventory forest roads, zonation of mass-wasting hazard areas, and mapping of agricultural sediment sources
Flood hydrology	Models, empirical methods, and impervious areas	Water routing by roads and other impervious area sources
Low-flow hydrology	Empirical assessment of withdrawals or diversions	Inventory of diversions, dams, and quantities of withdrawal
Riparian functions	Regional assessment of riparian conditions with remote sensing and aerial photography	Inventory of specific riparian segments to identify need for fencing, buffer establishment, or buffer management
Habitat connectivity	Remote sensing and mapping of disconnected habitats	Inventory of migration blockages and the available habitats above them
Delivery of pollutants	Empirical assessments of point and non-point sources of pollutants (e.g., pesticides, fertilizers, and metals)	Inventory of development and agriculture patterns; documentation of current-use pesticides by land use class

TABLE 5.—Example of a summary of process impairments identified by watershed assessment in four subbasins; ratings of high (H), moderate (M), and low (L) indicate the degree to which each impaired process alters riverine habitat conditions. Each impairment is translated into necessary restoration actions (see Table 6) through field inventories that identify specific problems (e.g., roads that deliver sediment, culverts that block migration, or levees that constrain floodplain functions).

Process–function	Specific cause of problem	Subbasin 1	2	3	4
Hydrology	Drainage systems increase peak flow	M	M	L	L
Sediment	Road surface erosion	L	M	M	H
Riparian	Reduced large woody debris delivery	M	M	H	H
	Lack of shade	H	M	L	L
Channel	Bank armoring constrains the channel	H	M	L	L
	Simplified habitat due to wood removal	H	H	M	L
	Impassable culverts	L	L	M	M
Floodplain connectivity	Levees disconnect channel from floodplain	H	M	M	L
Water quality	Pesticide input from agriculture and urban zones	M	L	L	L

The third question addresses constraints on restoration options. Many restoration efforts are located in heavily managed watersheds or areas within watersheds (such as urban or agricultural zones); as a result, restoration activities may not fully restore stream or watershed functions to their natural potential. Therefore, watershed analysis should also identify socioeconomic constraints on restoration (Geist and Galatowitsch 1999). Results of these analyses help to identify habitats that may not be restorable or that may require expensive restoration techniques. Tools for assessing socioeconomic constraints include surveys or public meetings to assess landowner willingness to participate in restoration, mapping of obvious infrastructure constraints that have a low likelihood of removal (e.g., major dams, highways, or other structures), and modeling of future scenarios that account for population growth and shifts in management policies (Baker et al. 2004). Anticipated climate change may also constrain restoration options if future habitat conditions are likely to fall outside tolerance limits of target species (McCarty 2001). Anticipating such future constraints requires scenario modeling that includes effects of climate change on habitats and modeling of species responses to habitat change.

List restoration actions.—The final and most important step in identifying watershed restoration actions is translating watershed assessment results into a list of necessary actions (Beechie and Bolton 1999). A list of restoration actions should be spatially explicit and should identify actions as specifically as possible. Reaches or subwatersheds should be assessed separately, and the location of each restoration action should be specified. Moreover, the watershed assessment summary should clearly identify which processes or functions are most impaired and most responsible for habitat degradation, so that limited restoration funds can be focused on actions that will have the greatest impact and locations that will receive the greatest benefit. Summarizing which processes cause degradation of habitats or species can be ordered in a simple table listing important watershed processes and identifying the degree to which each process or function is impaired within each area of the watershed (Table 5). Important attributes of the summary are that it separately addresses each subbasin or reach and that it rates the level of impairment for each watershed process to indicate which impairments have the largest habitat effects in each subbasin or reach.

The summary of impairments is then translated into a list of restoration needs, which includes types of restoration actions, their locations, and approximate levels of effort needed to address each of the impaired processes (Table 6). Restoration actions are identified based on matching the feasibility and appropriateness of various restoration techniques to each problem. Finally, field assessments of potential restoration sites are needed to generate a list of actions that can be prioritized in step 4 (e.g., which culverts can be removed to allow fish migration, which riparian areas need fencing or silvicultural treatment, or which levees could be set back to reconnect a river to its floodplain; Table 7). For example, if the watershed assessment finds that sediment supply to specific reaches is elevated, a field inventory of sediment sources and appropriate treatments is needed to specify individual projects and estimate restoration costs.

Step 4: Prioritize Restoration Actions

Ideally, the prioritization of restoration actions simply involves following through on the approach chosen in step 2, based upon the information collected in step 3. In reality, the sequence of decision making often follows the order of implementation (i.e.,

TABLE 6.—Example of a list of restoration needs developed from a watershed assessment; ratings of high (H) and moderate (M) indicate the importance of the action based on the level of impairment for each process in Table 5. Specific restoration actions that address each need within each subbasin (Table 7) are identified through targeted field assessments.

		Subbasin			
Process–function	Restoration action	1	2	3	4
Hydrology	Disconnect roads and drainage systems from stream network	M	M		
Sediment	Reduce surface erosion from unpaved roads		M	M	H
Riparian	Manage riparian forests for increased growth	M	M	H	H
	Plant riparian buffers for shade	H	M		
Channel	Remove rip-rap to allow channel migration	H	M		
	Increase channel complexity	H	H	M	
	Remove or fix migration barriers			M	M
Floodplain connectivity	Set back or remove levees	H	M	M	
Water quality	Reduce input of pesticides in agricultural and urban zones	M			

assessments are conducted before goals are set and before a prioritization approach is selected), and practitioners attempt to retrofit a prioritization scheme to existing assessment information. Selection of an approach in this situation is obviously influenced by the values expressed in the goals; however, it is also influenced by the amount of information available from watershed assessments. The analytical approaches (single species, multispecies, and cost effectiveness) can only be applied in cases where assessments provide information on causes of habitat change, actions needed for habitat restoration, anticipated biological responses, and estimated costs for each action. If these kinds of information are not available from the assessments, then either additional assessments must be conducted to fill in missing information or another prioritization scheme must be selected (ISAB 2003). When an analytical approach is used, it is important to revisit the ideal sequence of planning steps: (1) setting goals, (2) selecting the preferred analytical approach to prioritizing restoration actions, (3) conducting additional components of watershed assessment to fill in missing information and create the list of necessary restoration actions, and (4) prioritizing actions by use of the chosen approach.

In cases where biological benefits of listed actions have not been or cannot be estimated, one of the logic approaches (project type, refuge, or decision support system) can be used to set priorities (e.g., Table 7). Of these approaches, the most flexible option is a simple decision support system that scores projects based on values held by stakeholders and expressed in the restoration goals. These can be tailored to incorporate a wide range of values that can be weighted and scored for each project, including anticipated biological benefits, certainty of success, socioeconomic impacts, and educational values. Such values are often expressed in statements of goals and constraints for river restoration but are difficult to quantify in concrete terms. Hence, this approach is often applied where stakeholder values are generally understood but available or anticipated watershed assessment informa-

TABLE 7.—Hypothetical prioritized restoration project list based on watershed assessment results (Tables 5, 6) and the project scoring approach illustrated in Figure 2. Priorities are not given in order of importance (low [L], medium [M], and high [H]; from Table 6), because other factors (e.g., project costs and socioeconomic impacts) influence priority scores.

Project	Subbasin	Importance	Priority score
Replace impassible culvert at Jones Road, mile post (MP) 3.6	3	M	79
Replace impassible culvert at Road 1341, MP 1.2	4	M	78
Riparian planting along mainstem, river kilometer (rkm) 1.2–1.6	1	H	68
Levee setback on main stem, rkm 0.0–1.1	1	H	65
Riparian planting and fencing along tributary A, rkm 0.2–1.1	2	M	58
Replace impassible culvert at Smith Road, MP 1.3	2	L	53
Road erosion reduction at Jones Road, MP 1.1–2.5	3	M	37
Road erosion reduction at Road 1341, MP 0.2–1.5	4	H	35
Wood placement in main stem, rkm 6.4–7.2	3	M	35
Road erosion reduction at Road 1341, MP 1.6–2.3	4	H	34

tion is not sufficient to support one of the analytical prioritization approaches.

Conclusions

Distinguishing between the questions "What should I restore?" and "How should I prioritize restoration actions?" is fundamental to effective restoration planning for aquatic ecosystems. The first question leads a restoration practitioner to identify the types of restoration actions necessary to achieve a restoration goal, whereas the second question addresses the sequence of restoration actions that most efficiently progresses towards the goal. An understanding of this distinction and the importance of clearly defined goals suggests a four-step protocol for restoration planning: (1) identify restoration goals, (2) select a prioritization approach consistent with goals, (3) use watershed assessments to identify needed actions, and (4) prioritize the list of actions based on evaluation criteria that reflect stakeholder-defined restoration goals. Restoration goals should identify biological objectives of restoration, address causes of ecosystem degradation, and recognize that local land use and resource management objectives or economic constraints may limit some restoration opportunities. Watershed assessments should focus on identifying necessary restoration actions and produce the information needed to prioritize actions. When watershed assessments provide an incomplete understanding of restoration needs, simple decision support systems (e.g., a scorecard approach) are the simplest option for prioritizing restoration actions. This approach is flexible and transparent, allowing local groups to easily adapt a scoring system to local restoration objectives and constraints. More-complete watershed assessments allow more-comprehensive analyses for identifying the restoration actions that will provide the greatest benefit. Use of cost effectiveness analysis will give funding agencies greater confidence that limited restoration funds will be spent efficiently.

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