Watershed assessment techniques and the success of aquatic restoration activities, 185–201.

8. Watershed Assessment Techniques and the Success of Aquatic Restoration Activities

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Abstract.—A major challenge in planning and executing aquatic ecosystem restoration strategies is the need to make decisions without complete understanding of ecosystems or processes affecting their conditions. Information-gathering tools such as stream classification systems, riparian-growth and wood-recruitment models, watershed assessments, historical reconstruction, and decision-support models can help reduce uncertainty in defining a path for aquatic restoration activities. We demonstrate how these tools can be used to systematically gather information for achieving improved management decisions and restoration strategies. Two major sources of uncertainty are considered: inadequate knowledge of system behavior and natural variability. Uncertainty in assessing watershed and habitat conditions to be restored reflects the lack of prior knowledge of an ecosystem's status and functions as well as problems of coupling scientific principles with management objectives. These shortcomings arise from difficulties in defining and understanding complex ecosystem interactions and from not recognizing human limits in controlling natural environments. Additional uncertainty is due to rivers having geographically diverse and unique arrays of environmental problems and societal situations. We suggest that watershed restoration plans and efforts that incorporate uncertainty will have a greater chance of long-term success.

Introduction

Restoration can be defined as the reestablishment of the structure, functions, and natural diversity of an area that has been altered from its natural state (Cairns 1988; National Research Council [NRC] 1992). One primary goal of restoration is to reestablish interactions among ecosystem components and environmental disturbances. Our ability to successfully redirect the trajectory of aquatic ecosystems toward this goal is largely dependent upon clearly defined objectives that incorporate physical and biological processes (Cairns 1990; Collins and Pess 1997; Beechie and Bolton 1999). One of our greatest challenges is to synthesize new and existing process-based watershed information to strategically identify restoration actions. However, to use watershed information wisely, we need to understand its accuracy and precision, as well as its relationship to factors operating at various spatial and temporal scales (Frissell et al. 1986; Bauer and Ralph 1999; Chapter 6, this volume). Another challenge we face with planning and executing aquatic ecosystem restoration is the need to make decisions without complete understanding of ecosystems or processes affecting their conditions.

In this chapter, we demonstrate how different watershed assessment techniques can be used to systematically gather information for achieving improved management decisions and restoration strategies. Two major sources of uncertainty are considered: inadequate knowledge of system

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behavior and natural variability. Uncertainty in assessing watershed and habitat conditions to be restored reflects the lack of prior knowledge of an ecosystem's status and functions as well as problems of coupling scientific principles with management objectives. These shortcomings arise from difficulties in defining and understanding complex ecosystem interactions and from not recognizing human limits in controlling natural environments. Additional uncertainty is due to rivers having geographically diverse and unique arrays of environmental problems and societal situations.

There are several sources of uncertainty that are relevant to developing scientifically sound and cost-effective restoration strategies. The sources we considered here include natural variability, errors in identifying the causes of problems, inaccurate predictions, and socio-economic factors. We used several questions related to the source of uncertainty to help identify the type of information required to reduce overall levels of uncertainty involved in making decisions about restoration planning and actions:

- Identifying natural variability
    - Were the major sources of natural spatial and temporal variability of watershed processes identified?
    - How was this knowledge incorporated into the restoration actions?
- Identifying the causes of problems
    - What was the problem?
    - Were the correct problems or processes addressed in the watershed?
    - Were the causes of the problems fixed?
- Predicting outcomes
    - Was the predicted outcome of the restoration action similar to the expected outcome?
    - Did the prediction explicitly account for sources of uncertainty?

We review several assessment, inventory, and modeling techniques that systematically gather and use information to achieve improved management decisions. We describe these tools, their purposes, and how they have been used in the past. We also identify how these techniques can be used to display or reduce uncertainty. In adapting these approaches to illustrate uncertainty, we believe watershed restoration efforts can include aspects of uncertainty that help increase the long-term success of restoration activities.

A Context for Restoration

Despite the best of intentions of natural resource managers to address broader problems, many restoration efforts are scaled down because of land ownership, legal requirements, or limited funding or time. The broader geological and ecological context that a watershed-scale perspective brings can mean the difference between long-term success and failure. Following a review of aquatic restoration efforts across the country, the NRC (1992) found that many projects failed because proponents did not consider the broader scales necessary to understand the complexity and multidimensional nature of aquatic ecosystems. For example, repairing excessive stream-bank erosion along a downstream reach may be a waste of valuable resources if altered upstream or upslope conditions remain conducive to accelerated surface runoff, streamflows, and sediment production rates.

Better decisions associated with restoration initiatives are possible if ecosystem managers coordinate across multiple jurisdictions and land ownerships as well as integrate legal requirements such as the Clean Water Act, Endangered Species Act, National Forest Management Act, and National Environmental Policy Act. Multi-agency working groups, public/private partnerships, community stewardship, and watershed associations are some of the emerging vehicles for conducting ecosystem-scale management and bridging jurisdictional, ownership, and legal boundaries. Williams et al. (1997) and Keiter (1998) detail numerous recipes for successful partnerships and include case studies of community and watershed stewardship groups.

The increasing number of community and watershed associations has changed the role and responsibility of federal agencies (Dombeck et al. 1997). The Bureau of Land Management and U.S. Forest Service have created Resource Advisory Councils across the country to increase the input of local citizens in public land management. Federal agencies now assist local community and watershed associations by providing technical expertise, analysis procedures, resource data, and experience with restoration skills. Combining this technical information with funding facilitates decision-making at broader landscape scales. Increased integration of state and federal agencies with local communities also facilitates a longer-term perspective because private landowners tend to have a more enduring presence than do agency personnel. We suggest that a single agency or landowner that conducts restoration efforts should attempt to include a broader context of the river-basin scale for understanding the problems to be corrected and for proposing solutions. The river-basin context will be critical to establishment of restoration priorities, identification of needed partners in restoration planning, and successful implementation and monitoring.

Natural Variability

Successful restoration of aquatic ecosystem processes requires understanding a variety of physical and biological processes operating at various spatial and temporal scales. Physical processes that influence ecosystem conditions operate at small scales of streams (e.g., habitats and reaches) and short time intervals, as well as over large river basins and long timeframes (Figure 1). Physical processes help define the biological potential of watersheds (Figure 2). For example, interactions between hydrology, riparian zones, and stream channels influence the diversity, complexity, and distribution of stream habitats found in natural systems (Chapters 3, 4, 5, and 6, all this volume). The result of this complex array of interacting processes is tremendous variability in natural characteristics of habitat conditions and aquatic organisms.

An important question pertains to understanding how natural variations (e.g., disturbance regimes) in watershed and stream factors have determined watershed conditions (Benda et al. 1998). Many natural disturbance regimes can be inferred using historical information about large-scale disturbance mechanisms (e.g., fire and storm events) within relatively unaltered watersheds (e.g., Benda and Dunne 1997; Beechie 1998). Knowledge of natural disturbance regimes can facilitate assessments of how watersheds have been affected by human perturbations (Beechie and Bolton 1999). However, some watershed processes have been altered by human actions for long periods of time (e.g., years, decades), over large areas, such that natural disturbance regimes can no longer be identified (Bauer and Ralph 1999).

Classification Schemes and the Variability of Watershed Processes

One way to begin identifying and perhaps reducing uncertainties associated with natural variations in landscape processes and the habitats they form is to classify elements of riparian and stream ecosystems. Classification systems can categorize ranges of variability for structural characteristics (e.g., channel geomorphology) and imply process information. One type of classification stratifies physical factors that contribute to watershed characteristics and processes. Physiographic elements like geology and valley morphology that occur over large spatial scales (e.g., 10,000 km^2) and long time scales (100–10,000 years) usually cannot be influenced by human perturbations (Naiman et al. 1992; Beechie and Bolton 1999; Chapters 2 and 3, both this volume). Processes such as sediment supply, hydrology, development of plant communities, and wood recruitment, which occur at small to moderate spatial scales (100–1,000 km^2) and over short to moderate time

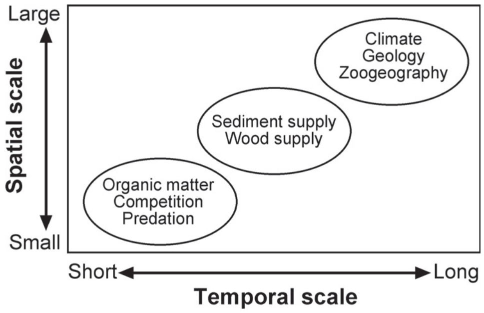

FIGURE 1.–Proximate versus ultimate variables that control habitat conditions. Adapted from Naiman et al. (1992).

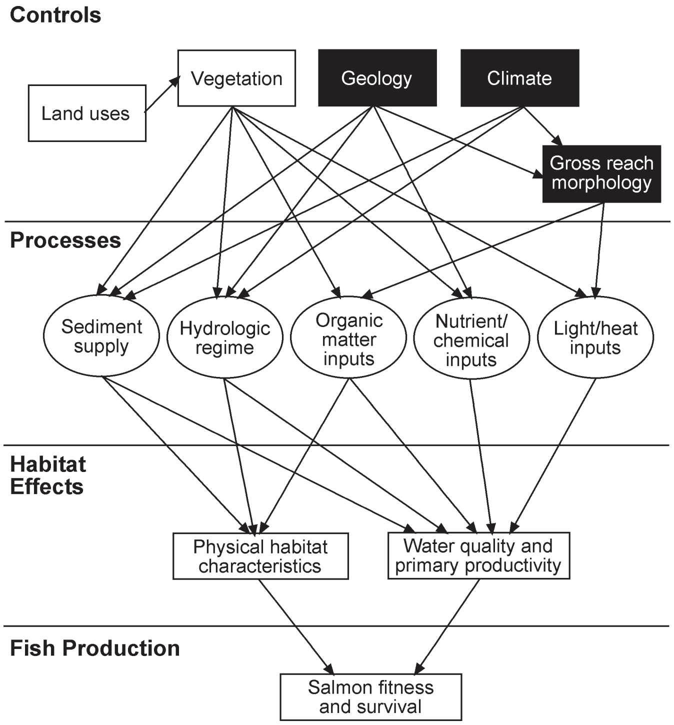

FIGURE 2.–Schematic diagram of relationships between landscape and land-use controls on habitat characteristics (via habitat-forming processes), and between habitat characteristics and salmon fitness and survival. Adapted from Beechie and Bolton (1999).

scales (decades to centuries), can be affected by human disturbance. Stratification of physical factors that affect watershed conditions can help us understand watershed processes, and can be a key component in developing meaningful restoration activities.

Classification schemes can minimize the number of parameters needed to categorize spatial variability and identify uncertainties (Bauer and Ralph 1999). For example, stream classification systems use the same suite of key variables such as geology, valley floor constraint, and channel slope to determine stream channel type over an entire watershed (Table 1). This reduces the number of variables and measurements needed to differentiate sites, allows for classification of spatial

TABLE 1.–Summary of contemporary spatial-scale classifications. Adapted from Bauer and Ralph (1999).

	Spatial scales addressed by classification system						
Classification system	Eco-region	River basin	Water-shed	Sub-watershed	Valley segment	Stream reach	Habitat unit
Bisson et al. 1982							X
Frissell et al. 1986			X	X	X	X	X
Seaber et al. 1987		X	X	X			
Paustian et al. 1992				X	X	X	
Maxwell et al. 1995	X	X	X	X	X	X	
Rosgen 1994					X	X	
Montgomery and Buffington 1997						X	
Omernik and Bailey 1997	X	X	X				

variability by grouping channels across a watershed, and creates a consistent method that can be used on a larger scale across watersheds. Features used to identify common characteristics or patterns and classify channel reaches and valley segments can be relevant for developing restoration plans. For example, stream reaches with similar physical characteristics may exhibit similar responses to restoration actions.

Classification Schemes and Restoration Strategies

An assessment of historical and current watershed and stream habitat conditions in the Stillaguamish River drainage (1,770 km^2) of northwestern Washington State (Figure 3) identified culverts, small dams, and other structures that blocked fish access to habitats. These barriers hindered

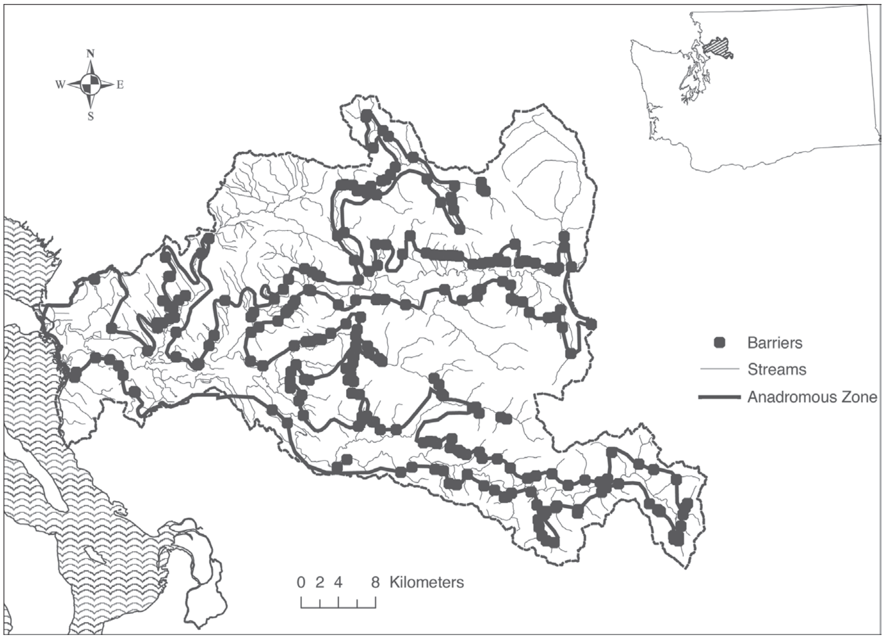

FIGURE 3.–Map of Stillaguamish River drainage, Washington State, with natural and anthropogenic salmonid barriers. Black circles denote natural (e.g., waterfalls) and anthropogenic (e.g., culverts, dams) barriers limiting salmon distribution.

or prevented adult and juvenile coho salmon *Oncorhynchus kisutch* passage and limited their reproduction and rearing in tributaries. Tributaries have been shown, historically and currently, to contain some of the most productive habitats in the Stillaguamish River (Figure 4; Pess et al. 1999). Ponds that connect with the main river channel and streams have also been identified as being important to juvenile coho salmon (Figure 4).

The Stillaguamish River watershed assessment identified over 500 culverts to determine whether they were blocking coho salmon passage at different life-history stages. Approximately 50 culverts were found to be blocking adult or juvenile passage. The assessment prompted stream restoration via (1) culvert modifications and removal and (2) the implementation of a stream monitoring program. The objective was to reconnect habitats within small, low-gradient tributary streams. The project was aimed at correcting impacts of human-made blockages on adult and juvenile coho salmon migration. The first phase identified and prioritized culvert barriers (1995) while the second phase corrected or eliminated blockages (1996). The last phase monitored the success of corrected culvert barriers by documenting adult and juvenile salmon use (1997 and 1998).

The purpose of the first phase of the culvert program was to prioritize for corrective actions based upon stream habitats (e.g., type, quality and quantity) above a culvert. However, many of the stream reaches above the culverts could not be quantitatively assessed because of limited monetary and human resources. This increased the uncertainty in prioritizing fish passage problems at the watershed scale. The problem was addressed by using watershed-scale information (e.g., gradient and confinement of stream channel) to identify which culvert modifications and replacements had a greater potential of benefiting juvenile and adult coho salmon.

The Montgomery and Buffington (1997) stream classification system was used to classify each stream reach above a blockage. This approach helped predict which streams had specific habitat characteristics based upon channel gradient and channel confinement. Specific channel types, such as pool–riffle and forced pool–riffle (e.g., channels that have pools due to obstructions like large wood), could potentially produce more coho smolts than other channel types. Pool–riffle and forced pool–riffle habitat sequences tend to have a greater proportion of pool area and gravel suitable for spawning than plane–bed and step–pool channels (Montgomery 1995; Montgomery and Buffington 1997). Our expectations were based on literature that identified these characteristics as being important to juvenile coho (Reeves et al. 1989) and observations of higher densities of spawning adult coho in pool–riffle and forced pool–riffle channel types compared with other channel types (Montgomery et al. 1999).

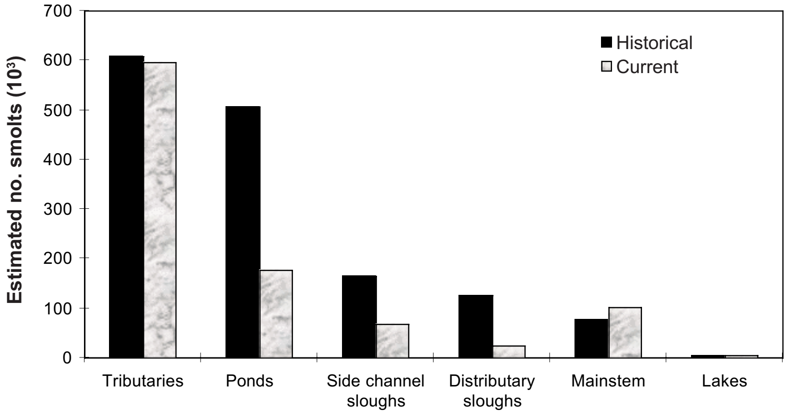

FIGURE 4.–Estimated historical (~1900s) and current (~1991) coho *Oncorhynchus kisutch* summer smolt population levels in the Stillaguamish River drainage, Washington. From Pess et al. 1999.

Barrier removal opened approximately 19 km of stream habitat for coho and chum *O. keta* salmon, steelhead *O. mykiss*, and sea-run cutthroat *O. clarki* by 1997. Coho spawning surveys, juvenile coho population estimates, and physical habitat surveys were conducted in stream reaches above the removed barriers for 2 years after fish passage was restored. Over 250 adult coho were observed spawning in 19 km of reconnected habitat during two consecutive spawning seasons. Juvenile salmonids were also observed in restored reaches, confirming the use of opened habitat beyond the spawning life-history stage.

Monitoring the restored stream reaches revealed that pool–riffle and forced pool–riffle channel types had a mean juvenile coho density (0.7 per m^2) two to four times greater than in plane–bed and step–pool channel types (Figure 5a). Comparison of the same channel types indicated mean redd numbers (~50 per km) were 35 times greater in pool–riffle and forced pool–riffle channel types (Figure 5b). The relative benefits to coho salmon of reconnecting pool–riffle and forced pool–riffle channel types appeared related to more complex and favorable habitat features for the

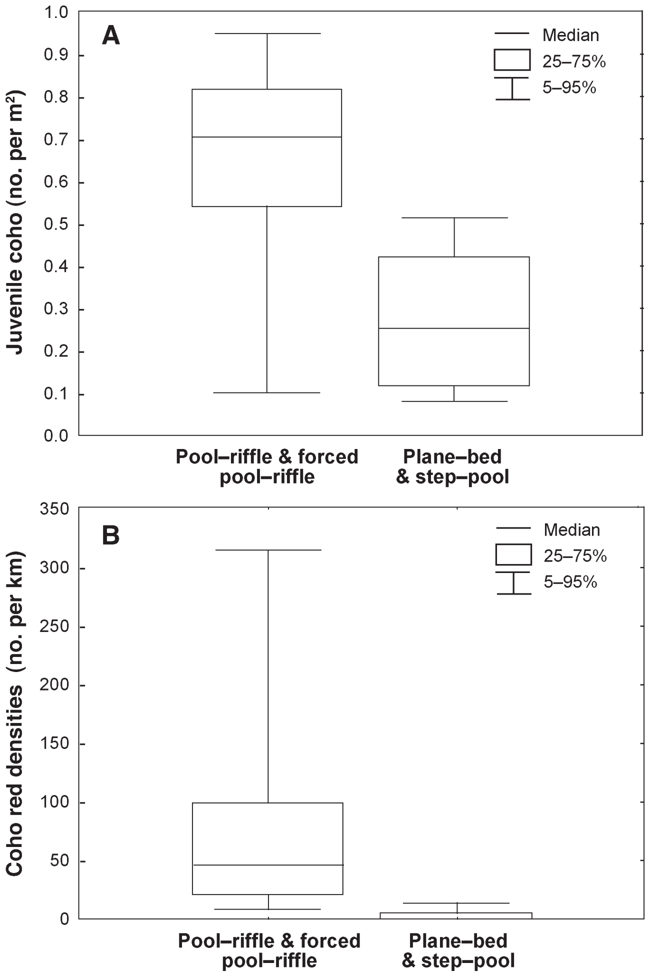

FIGURE 5.–Comparisons within the Stillaguamish River drainage, Washington State: (A) juvenile coho salmon densities (number per m^2) by channel type upstream of eliminated fish blockages, and (B) coho redd densities (number per km) by channel type upstream of eliminated fish blockages in 1997 and 1998.

fish. Juvenile and adult coho densities were greatest in pool–riffle and forced pool–riffle channels with stream gradients of less than 4%, a pool spacing of less than four channel widths per pool, and 4–5% of the total stream channel area in spawning gravels (Pess et al. 1998). These habitat characteristics were similar to what Montgomery et al. (1999) observed for adult coho and chinook *O. tshawytscha* salmon.

Stream classification systems do have limitations for identifying sources of variability and uncertainty within different stream reaches and habitat types. For example, classification systems that use channel-based indicators may not provide information about the uncertainty of proposed restoration projects and expected outcomes because of the natural variability of fluvial and geomorphic systems (Chapter 3, this volume; Reid and Furniss 1999). Stream channels may respond slowly and differently to changes in driving variables such as the routing of sediments in response to changes in stream discharge. Determining which stream characteristics may be most useful can require case-by-case investigations (Reid and Furniss 1999). In addition, many classification systems for stream channels only apply to structural information and do not incorporate temporal variability in channel conditions (Benda et al. 1998; Chapter 6, this volume). Regardless of these limitations, stream classification systems can be useful for prioritizing restoration actions because they enable identification of stream reaches likely to respond similarly to restoration treatments (Bauer and Ralph 1999).

Identifying the Causes of Problems

Watershed assessment techniques can help identify causes of watershed-scale problems, sources of uncertainty, and possible negative impacts on restoration activities. Information obtained from assessments gives natural resource managers a better understanding of how their management and restoration actions can affect system response. Understanding the cause-and-effect relationship between management action and response can be important because it provides the basis for adaptive management and decision making (Chapter 9, this volume).

Watershed-Scale Problems

Over the last decade, different watershed procedures have been developed that examine the cumulative impacts of human activities on the condition of aquatic systems (Reid 1998). These tools are generally referred to as watershed assessments or analyses. The general goal of many watershed assessments is to identify disrupted watershed processes, and the location and timing of land-use effects on those processes (Beechie and Bolton 1999). Some watershed processes include the delivery and routing of water, wood, and sediment within different parts of the channel network. Predicting responses of stream habitats to human actions can be accomplished by examining the effect of management actions on these processes. For example, road construction on unstable slopes may dramatically increase sediment delivery to a channel, altering channel characteristics downstream. Also, removal of riparian vegetation can change rates and types of wood and other organic material delivered to the channel and alter channel forms and trophic dynamics of streams.

Watershed assessments generally include procedures for identifying locations prone to mass wasting and surface erosion, as well as protocols for evaluating the sensitivity of riparian areas, susceptibility to hydrologic alterations, floodplain functions, and connectivity of habitats. Understanding watershed conditions can help us determine the sensitivity of specific locations to human disturbance, better predict cumulative effects of land-use activities on watershed processes, and provide a screening tool to determine which specific processes, locations, and habitats may be most important to protect and restore for salmonid recovery (Collins and Pess 1997).

The advent of geographical information system (GIS) technology and spatially referenced databases has greatly enhanced our ability to conduct watershed assessments. For example, the Skagit Watershed Council developed an approach to estimate changes in sediment supply due to land use by extrapolating from sediment budgets in representative tributary watersheds of the Skagit River drainage in northwestern Washington State (Paulson 1997). Natural sediment supply rates of four geology classes and the alpine zone were assigned under mature forest conditions (Paulson 1997). Sediment production from each geology class was then assigned an empirically derived multiplier to each vegetation cover class based on the type and age of current vegetation. Sediment supply rate in any watershed without a sediment budget was estimated by averaging the sediment supply rates from all the geology–vegetation polygons. This method identified sediment supply classes as either similar to the natural background rate, or significantly higher than the background rate in 8 of the 10 sub-watersheds where sediment budgets had been constructed. This procedure can be used to predict areas that will produce the largest change in sediment supply due to land-use activities.

One common shortcoming of watershed assessments can be the minimal use of historical information to describe watershed processes and conditions prior to the arrival of Europeans. Watershed assessments can identify conditions of watersheds using aerial photos that date back to the 1930s (Collins and Pess 1997). Aerial photo studies combined with extensive field and archival investigations that date back prior to European settlement can provide an indication of initial watershed conditions in the absence of large-scale human impacts. Most watersheds used for industry, timber, agriculture, and transportation throughout the United States usually experienced intensive disruptions to watershed processes (e.g., floodplain connectivity, sediment supply, wood recruitment, and habitat conditions) prior to the 1930s (Beechie et al. 1994; Collins 2000). These assessments can provide a better understanding the overall effects of land management (Beechie et al. 1994; Collins and Pess 1997; Collins 2000).

Historical Reconstruction

Historical reconstruction of watershed conditions can be a critical tool that reduces the uncertainty of restoration activities. Various types of information can be derived from historical sources (e.g., maps and field notes): for example, the presence and absence of stream channel habitats, riparian vegetation, and beaver ponds. Retrospective studies of vegetation and channel conditions have been completed for several Northwest watersheds (Wissmar et al. 1994; Wissmar 1997; Collins 2000; Collins et al. 2001). Comparing these reconstructions with current conditions provides a solid basis for identifying habitat types and processes that have been most seriously affected by European settlement. This information, in conjunction with the general knowledge of the habitat needs of the species of interest, can provide a starting point for developing restoration priorities (Beamer et al. 2000). For example, historical reconstructions, combined with assessments of Puget Sound watersheds, identified a number of habitat features and priorities for restoration (Beechie et al. 1994; Pess et al. 1999; Collins 2000; Collins et al. 2001; Haas and Collins 2001). These priorities can be separated into three action categories: restore access to habitats, improve the quality of existing habitats, and influence upstream watershed processes in a way that improves downstream stream habitat conditions that may be critical to different fish and wildlife species.

Historical analyses and data can indicate the natural distribution of conditions across a watershed. In such cases, restoration targets and strategies can be developed that account for natural variations in habitat conditions. Some examples of restoration strategies include the following:

1. opening disconnected habitats in floodplains and estuaries of large rivers (Beechie et al. 1994; Gore and Shields 1995; Slaney and Zaldokas 1997; Haas and Collins 2001),
2. removing unnatural stream-bank protection materials to increase fish use in a given stream reach (Sedell et al. 1990; Sear 1994; Haas and Collins 2001),

3. reducing sediment inputs to stream channels from roads and other land uses (Sedell et al. 1997), and
4. undertaking active riparian restoration in stream reaches to improve temperature regimes of rivers and tributaries (NRC 1992; Gurnell 1995; Mesick 1995).

Predicting Outcomes

Many potential restoration actions lack precedents to follow in terms of expected responses of systems after treatment. Thus, predicting outcomes of restoration actions should be a necessary step toward reducing uncertainty in planning the restoration of watersheds and in identifying what types of information are needed to ensure greater reliability in future restoration actions. Excellent examples of such tools are forest growth and riparian wood recruitment models that identify which suites of riparian management actions might attain the desired restoration objectives.

Riparian and Wood-Debris Models: Predictions of Responses to Restoration

Wood-debris models in combination with stand-growth models can be used to quantify changes in wood abundance and pool–riffle morphology resulting from changing riparian conditions. One such tool, Riparian-in-a-Box (RIAB), was developed to help land managers identify and predict, on a channel reach/valley segment scale, (1) the linkages between riparian forest condition and aquatic habitat condition, and (2) what types of change in aquatic condition may occur under different restoration scenarios (Kennard et al. 1998; Beechie et al. 2000; Chapter 5, this volume). The RIAB model has been used to determine the effect of various riparian restoration efforts on stream channel response with different channel slope, channel width, and riparian successional pathways (Beechie et al. 2000).

Site-specific restoration strategies (e.g., stand manipulations at the stream-reach scale) are important to riparian restoration because of the large amount of variability in riparian condition that occurs among stream reaches in different watersheds (Beechie et al. 2000). At the larger watershed and landscape scale, more general trends in riparian condition resulting from historical and current land-use practices are also important (Pollock 1998). Patterns of change in channel response to riparian conditions lend themselves to development of general guidelines (Kennard et al. 1998; Beechie et al. 2000). The RIAB model identified that understory thinning of riparian stands along large stream channels (channel widths >20 m) will result in fewer but larger trees over time (Kennard et al. 1998). However, thinning along smaller stream channels (width <20 m) may actually decrease short-term recruitment of smaller trees that function to create pools. In contrast, streams larger than 20 m in width need larger wood pieces, and thinning in adjacent riparian stands can accelerate production of wood of sufficient size (Beechie et al. 2000). Riparian models can reduce uncertainty by quantifying the relative amounts of wood recruitment over time and comparing different management scenarios to attain specific management objectives. This greatly reduces uncertainty in management decisions because it predicts what may occur before actual implementation.

Limitations of such models should be fully understood when used for restoration or protection planning. For example, RIAB does not accurately represent absolute wood abundance in channels because the model (1) assumes no lag time between death of a tree and its function in the channel, (2) does not consider breakage of fallen trees, and (3) does not include variation in depletion rate (e.g., losses through stream channel transport) between different channel widths and wood size (Beechie et al. 2000). Therefore, absolute number of wood pieces predicted by the model may be in error by a factor of 2 or more. However, comparisons of relative amounts among different management options are more reliable (Kennard et al. 1998; Beechie et al. 2000). Models such as RIAB, which suggest relative abundance of wood in channels, can be used to evaluate different restoration actions. The application of such models should improve understanding of the possible consequences of restoration and reduce uncertainty.

Restoration Planning Case Studies

Many watershed procedures discussed here and associated assessment tools need to be integrated with local restoration goals that include socio-economic objectives and regulatory obligations (Regional Interagency Executive Committee 1995). Such integrated tools can be used to evaluate expected results of restoration and potential socio-economic costs and benefits. This section discusses an application of various tools by the Skagit Watershed Council. A second example from the Rogue River drainage, Oregon, describes how another community attempted to answer similar questions using different assessment tools.

Skagit Watershed Council Strategy

Local volunteer groups that conduct habitat restoration often have disparate interests. Their actions tend to be uncoordinated and lack long-term strategic planning. Additionally, there may be little guidance from state or federal agencies for planning watershed and aquatic habitat restoration. These factors result in little consistency in the direction taken by local restoration groups. Without guidance, volunteer groups tend to rely on “standard” techniques for improving habitat that may not be effective or desirable when applied in inappropriate physical or biological settings. However, there can be more consistency in management actions on forestlands where habitat recovery approaches follow Habitat Conservation Plans and federal strategies (e.g., Northwest Forest Plan).

Recognizing that restoration actions were likely to fail without scientific guidance and additional information describing the watershed context, the Skagit Watershed Council (the “Council”) developed a habitat restoration and protection strategy for the Skagit River drainage. The goal was to “assist and encourage the voluntary restoration and protection of natural landscape processes that formed and sustained habitats to which salmonid stocks are adapted” (Skagit Watershed Council 1998). The strategy was based on Council members’ desire to attain a better understanding of how habitat-forming processes (1) functioned prior to recent alterations, (2) have been disrupted by land uses, and (3) might be restored and promote fish recovery (e.g., Beechie et al. 1996; Beechie and Bolton 1999).

The Council has developed a set of analyses designed to answer these questions for flooding, sediment supply, riparian functions, floodplain functions, and connectivity of habitats (Skagit Watershed Council 1998, 2000). It has applied results of these analyses in two stages. Initially, the information has been used to filter project proposals based on whether they address basic causes of habitat degradation. Projects that do not address causes of habitat change were considered unlikely to succeed over the long term and were not included in funding proposals put forth by the Council. This procedure increases the likelihood that completed projects would improve habitats (Skagit Watershed Council 2000). Assessments of causes of habitat loss facilitate prioritization of actions necessary to restore habitat-forming processes. Decisions for proposed actions were prioritized by anticipated project effectiveness relative to costs and higher likelihood of success (Beechie et al. 1996; Skagit Watershed Council 2000).

The Council’s analyses enabled identification of (1) disturbance issues such as riparian function along specific river reaches and (2) watershed-level processes such as sediment supply or hydrology. Reach-specific disruptions may affect functions in other reaches. Reach-level effects were summed to estimate the total amount of disturbed area for any process. Watershed-level processes that were analyzed cumulatively accounted for disturbances that could affect downstream reaches.

For example, a small paved area near a stream may not have a noticeable effect on storm runoff in the adjacent reach or elsewhere in the stream network, but the accumulation of impervious surface areas in a basin may dramatically alter peak flows and habitat quality when the cumulative area exceeds 10% (Leopold 1994).

The Skagit Watershed Council implemented a habitat barrier inventory organized by subbasins or tributaries within the Skagit River drainage. Field inventories and analyses of stream passage structures dealt with several main issues or questions related to uncertainty, including (1) were all structures examined? (2) was a consistent definition of barrier used? and (3) could all structures be classified in a barrier category? The inventory was based on an earlier analysis of natural anadromous fish passage barriers within the Skagit drainage and included fish-bearing tributaries that were downstream of natural and man-made barriers (culverts, bridges, dams, dikes, tidegates, etc.). Inventory information for each subbasin was mapped prior to the inventory of the next subbasin. A clearly defined set of barrier criteria (WDFW 1998) was used to determine barrier status, reducing the potential subjectivity of the barrier categories and determination. Structures were binned into two categories: structures that were clearly barriers and did not meet criteria, and structures that were not barriers. These provisions reduced uncertainties related to survey coverages and allowed managers to effectively target restoration activities and identify intact areas that should be protected.

For total structures surveyed (1,755 structures), 84% fell into one of the above barrier categories. Structures that fell into the barrier category were further delineated into full and partial barriers. Full barriers block all salmonid access while partial barriers block movements of most fish life-history stages. Restoration efforts were focused on these structures. Table 2 shows examples of major fish blockages (e.g., juvenile and adult salmon), project sites, and cost effectiveness prioritized by the Skagit Watershed Council (1998, 2000). Cost effectiveness for restoring stream-crossing structures ranged from 13 m^2 to 609 m^2 per $1,000.

Culverts that did not fall in any of the preceding categories were the main sources of uncertainty.

TABLE 2.–Cost effectiveness for restoring stream-crossing structures of tributaries in the Skagit River drainage. Cost effectiveness (m^2 per $1,000) for structures was based on the habitat area (m^2) upstream of the project divided by the project cost. The lifespan of all new structures was assumed to approach 50 years. Stream-crossing structures needing restoration were identified according to criteria for fish passage of the Washington Department of Fish and Wildlife (WDFW 1998). The projects represent major fish blockage sites (juvenile and adult salmon) prioritized by the Skagit Watershed Council (1998, 2000).

Project site	Stream number	Wetted width (m)	Reach length (m)	Wetted area (m^2)	Estimated project cost	Cost effectiveness (m^2 per $1,000)
Careys Slough at Pettit Rd.	03.0354	45	1,354	60,930	$100,000	609
Red Cabin Cr. at Hamilton Cemetery Rd.	03.0343	5.8	5,345	31,001	$100,000	310
Careys Cr.	03.0354	4	1,000	4,000	$30,000	133
Unnamed	03.0286X	6	620	3,720	$30,000	124
Davis Slough at So. Skagit Hwy	03.0176G	4	3,200	12,800	$250,000	51
Careys Cr. at Maple St.	03.0354	4	890	3,560	$100,000	36
Unnamed	04.0384X	1.9	495	941	$30,000	31
Gilligan Cr. at So. Skagit Hwy	03.0281	6	750	4,500	$250,000	18
Unnamed	03.0293B	2.5	170	425	$30,000	14
Unnamed	04.0373	2.2	173	381	$30,000	13

Many of these culverts were located within the Skagit River floodplain or at dike tidegates in the Skagit delta. Such structures were difficult to categorize because they often appeared to be passable but impeded fish differently under different flows. These structures also reduced the amount of habitat available upstream and altered riverine and tidal processes that create and maintain floodplain and estuarine habitats. In many situations, it was difficult to assess the actual impact solely based upon the amount of isolated habitat.

The Council is currently developing a method to deal with some of these “unknown” barriers. In tidally influenced areas, they are reviewing historical maps or photos of select areas to estimate the extent of habitat in blocked areas prior to diking. This approach will allow estimates of the amount of habitat potentially available in the future if blockages and other impediments to habitat formation are removed. The Council will also be able to measure the amount of habitat currently available to make more accurate estimates. A comparison between full and partial blockage removal could then be made to determine habitat benefit.

Rogue River Basin, Oregon

Planning and implementing restoration at the drainage scale introduce many sources of uncertainty and complexity. Large landscapes typically include multiple agency jurisdictions and land ownerships, often with different interests. There is a need to integrate these interests, as well as coordinate and prioritize restoration activities among tributary watersheds. Habitat conditions and restoration needs vary among watersheds because of relative locations in river drainages, land ownership, past history, and use of natural resources (e.g., agriculture vs. timber production). Quality and quantity of available information about habitats are usually inconsistent across large spatial scales.

In the Rogue River Basin of southwestern Oregon, interagency coordination has addressed habitat needs in several ways. Restoration efforts in this system have been tied to two government plans—one federal and one state. The Northwest Forest Plan (Forest Ecosystem Management Assessment Team 1993) provides the basis for management decisions on all federal lands in the Pacific Northwest, with emphasis on protecting and restoring late-successional and old-growth forests and riparian areas. The Oregon Plan for Restoring Salmon and Watersheds (1995) aims to return fish populations to sustainable and productive levels, improve water quality, and involve local communities in land management through a network of watershed councils.

In April 1999, 25 state and federal agencies signed a Memorandum of Understanding (MOU) with two primary goals. The first goal was to develop a coordinated, consistent, and streamlined approach to river drainage restoration planning, implementation, and monitoring. The second was to provide a range of expertise and technical assistance across the multiple jurisdictional boundaries to aid public and private landowners in implementing the MOU approach to restoration. The agencies accomplished these goals by establishing the Rogue Basin Restoration Technical Team (“Team”) and the Rogue Basin Restoration Technical Pool (“Pool”). Together, these two groups were to implement the MOU by documenting conditions and directing collaborative efforts across the entire river drainage, which consists of 5 subbasins, 37 watersheds, and 204 sub-watersheds (Maxwell et al. 1995).

The Team’s first step was to ensure that agencies and landowners participated in the restoration planning phase. To help accomplish this, Team members asked private landowners and government agencies to identify problems, needs, and opportunities (e.g., lack of information, consistent data across broad landscapes) for developing management plans and implementing restoration.

The Team also dealt with definition and data issues. Previous assessments of the Rogue River Basin were usually conducted at sub-watershed and watershed scales by agencies and private landowners. Such uncoordinated and fragmented approaches often resulted in using very different assessment tools to collect various types of data on small land areas. As a result, three critical sources of uncertainty emerged: (1) varying definitions of watershed health at different scales, (2) lack of consistent assessment data across spatial scales, and (3) quality of assessment data.

Using the approaches and assumptions of Kolb et al. (1994) and D. Whitall and others (USDA Forest Service, Medford, Oregon, unpublished data), the Team defined a healthy drainage as possessing (1) physical structures and biotic resources that support productive ecosystems, (2) ecosystem capacity to quickly recover from episodic and chronic disturbances, and (3) availability of essential resources (e.g., water, nutrients, light, growing space) that allow the natural development of ecosystem functions and structures (e.g., plant succession, diversity of aquatic habitats).

The Team then evaluated data and indices representative of drainage health using indicators for four ecosystem components: physical, chemical, biological, and social. The Team used a “nominal group technique” (discussion and ranking) to select indicators according to the following evaluation criteria: relevancy, sensitivity, availability, measurability, defensibility, extent of spatial coverage, cost effectiveness, and ability to help distinguish human-caused changes from natural variability.

This screening allowed the Team to focus on 12 habitat indicators. The “Ecosystem Management Decision Support” (EMDS) model (Hohler et al. 2000) was used to apply indicators and determine conditions throughout the drainage. The EMDS, an information model based on professional judgments, interprets biological and physical indicators. The model attempts to classify conditions of ecosystems that can be understood by different interest groups (Hohler et al. 2000).

Application of the EMDS model demonstrated that some indicators had to be more precisely defined and others were unavailable or inappropriate. This produced different core groups of indicators stratified by sub-watersheds. These groups included upland seral stage, riparian seral stage, floodplain connectivity, erosion rates, and several stream indices. Major indices included water temperature, key pieces of large wood, pool spacing, percent fine sediments in riffles, percent habitat area above fish passage barriers, fire condition class, and ratio of water allocation to summer water yield. Most indicators were defined by multiple parameters. For example, indices of riparian vegetation seral stage were defined by cover type, species mix, single or multi-story canopy, size class, and crown closure. Indices of erosion rates included miles of road on critical slope gradients, number of stream crossings, and miles of roads in riparian areas.

For each stream indicator, such as key pieces of large wood, the Team defined good, fair, and poor habitat conditions by using reference data from the Oregon Department of Fish and Wildlife’s stream habitat condition report for western Oregon (Thom et al. 1999). Following the EMDS model, these reference data were then translated into a series of truth statements ranging from -1.0 (absolutely false) to +1.0 (absolutely true) to determine whether habitat quality was good. The EMDS model used formal logic that combines truth statements with the network of indicators to arrive at a determination of how well each sub-watershed meets the definition of health.

The EMDS model allowed assessment of habitat and basinwide health conditions without using data from every indicator. The model was most useful when data were entered at different intervals (e.g., every 3 years) so that trends were revealed. Additionally, while two sub-watersheds may have had the same score, the model showed how each indicator contributed to that score and suggested the appropriate restoration actions throughout the Rogue River drainage. Monitoring needs were also revealed as relevant data gaps appeared.

The Pool group used the EMDS model to identify priority restoration needs. They also provided technical assistance (e.g., engineering, hydrology, biology, project design, implementation, and monitoring) to implement on-the-ground restoration activities in a consistent and cost-effective manner. The Team facilitated private and public land restoration projects through landowner assistance, site surveys, and interactive website information (www.restoretherogue.org). The website was provided by a local, non-governmental server to increase acceptability to landowners and watershed councils. The Team will continue to assist in developing (1) a common understanding among landowners and, eventually, (2) an increased civic capacity for restoring the health of natural systems and local communities.

Conclusions

Natural variability, a lack of problem identification, an inability to predict restoration outcomes, and socio-economic factors can increase uncertainty and lead to poor decisions in restoration planning and actions. Tools such as stream classification systems, watershed assessment, historical reconstructions, predictive models, and the development of large-scale restoration strategies facilitate the reduction of sources of uncertainty in making decisions. Subsequent documentation of decisions and monitoring response allows managers to formally adopt adaptive management plans that further address uncertainty in restoration actions (Chapter 9, this volume). Linking science with management and social objectives and treating each action as an experiment will ultimately lead to a greater understanding of how aquatic ecosystems and watersheds function and can be rehabilitated. Successful watershed and habitat restoration requires clear and specific goals, objectives, and decision criteria that will allow for accountability and project evaluation (Halbert 1993; Collins and Pess 1997). Specific restoration objectives should include not just desired habitat characteristics but watershed and habitat processes. Strategies need to relate to space and time scales appropriate to definitions of uncertainties and documentation of resource responses (Cairns 1990), and should be based on science in order to answer questions and formulate testable hypotheses (Collins and Pess 1997).

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