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Watershed Management and Pacific Salmon: Desired Future Conditions

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Abstract

Natural disturbances are an important part of the ecology of Pacific Northwest watersheds and create a diversity of aquatic environments to which different stocks of salmon (*Oncorhynchus* spp.) and other native fishes have adapted over time. Objectives for managing habitat should be focused on maintaining the full range of aquatic and riparian conditions generated by natural disturbance events at landscape scales large enough to encompass the freshwater life cycles of salmon and other species. Because streams are dynamic, establishing fixed habitat standards for such parameters as temperature, fine sediment concentration, woody debris abundance, or pool frequency (especially when applied to limited stream reaches) is not likely to protect the overall capacity of watersheds to produce fish or to recover from natural or anthropogenic disturbances. Attempting to make streams conform to an idealized notion of optimum habitat through legal regulations or channel manipulations will not easily accommodate cycles of disturbance and recovery, and may lead to a long-term loss of habitat and biological diversity. Desired future conditions can be derived by examining how natural disturbances influence the distribution of aquatic habitats and development of riparian communities within relatively pristine watersheds and by using these patterns as target conditions for watersheds in which management activities are planned. Although it is not feasible to return watersheds to a pristine state in most cases, a complete or nearly complete range of aquatic habitats can be maintained if anthropogenic disturbances are compatible with natural disturbances to the extent possible. Protecting the interactions between streams and surrounding terrain during disturbances (e.g., by maintaining river-floodplain connections and inputs of coarse sediment and organic material during fires, windstorms, and periods of high streamflow) is fundamentally important to maintaining the productivity and biodiversity of river systems. Analysis of watershed condition and development of management prescriptions should include a consideration of the eventuality of large, infrequent natural disturbances to ensure that when these events do occur, important transfers of organic and inorganic materials from terrestrial to aquatic ecosystems are not significantly altered and riparian recovery processes are not impeded.

Introduction

Loss of habitat has played a significant role in the reduction or extinction of many stocks of anadromous salmonids (*Oncorhynchus* spp.) in the Pacific Northwest (Nehlsen et al. 1991). Environmental degradation has resulted from a variety of human activities involving water use and land management adjacent to rivers, lakes, and estuaries. Only a small fraction of the river basins along the Pacific Coast in which anadromous salmonids occur has remained relatively free from habitat loss. In the central and southern range of Pacific salmon in North America, virtually no large river basins remain in a completely pristine state; thus, no clear set of benchmark conditions exist against which habitat degradation can be measured or toward which restoration can be aimed. Increasing human populations in the Pacific Northwest will continue socioeconomic pressures on natural resources of the region and virtually ensure that recovery of entire watersheds to pristine conditions will not occur (National Research Council [NRC] 1996). The rehabilitation of salmon habitat becomes an issue of determining not only what is desirable but also what is realistic and feasible (Lee 1993). An important management question then is "What should the specific objectives of habitat restoration be?"

Invocation of the Endangered Species Act to protect salmon and other species at risk of extinction has compelled economic interests, fish and wildlife agencies, and a concerned public to acknowledge the widespread failure of previous attempts to maintain sustainable populations in the face of intense and often conflicting management activities (Volkman and Lee 1994). The inability of many enhancement projects directed at individual salmon stocks or other declining species to achieve conservation objectives (Meffe 1992, Hilborn and Winton 1993) has fueled the call for an alternative, less species-oriented approach involving ecosystem management at a broader landscape level (Franklin 1993). Although these terms remain operationally vague (Tracy and Brussard 1994, Stanley 1995), the notion of managing large land areas for the purpose of preserving patches of ecologically functional habitat and restoring degraded habitats at geographical scales that make biological sense for whole communities of organisms has become an important priority. It was a fundamental cornerstone of the Forest Ecosystem Management and Assessment Team (FEMAT) recommendations for federal forests in the United States (US) Pacific Northwest (FEMAT 1993, Franklin 1994). Following the federal example, ecosystem management has been embraced by state and private natural resource organizations (Salwasser 1994), but whether implementation of the new paradigm (an ecosystem-based approach guided by watershed analysis together with adaptive learning [Naiman et al. 1992]) will lead to recovery of Pacific salmon habitat is unclear. Success in the long term will likely depend on the willingness of land and water managers to clearly identify the changes they wish to make, engage in large-scale controlled experiments over extended periods, monitor the results, and learn from successes and failures.

Herein we review the notion of desired future conditions, a concept that has emerged as an important element of ecosystem management in the Pacific Northwest. Taken generally, desired future conditions are those that will ensure the maintenance of biological diversity and sustainability of harvestable natural resources (FEMAT 1993). Upon this general goal there has been little debate, but in specific terms, desired future conditions often mean different things to different people. Difficulties in identifying habitat goals for fish and wildlife, and salmon in particular, often derive from a failure to clearly address the following questions: What is desired, what constitutes the future, and what are the conditions we wish to manage? Current approaches to watershed management often stress attainment of habitat standards at spatial and temporal scales that may be geomorphically inappropriate, fail to consider the natural disturbance history of watersheds, and ignore the dynamics and locally adapted life-history requirements of salmon populations. We propose a view of desired future conditions that is less rigid at small scales but explicitly considers a mix of habitats generated by natural processes across larger landscape areas, thereby providing a broader ecological context within which environmental planning can take place. Identifying desired future conditions over geographic areas relevant to salmon life cycles should become an important component of integrated watershed management—the process by which resources within a drainage basin are extracted, nurtured, and conserved with a balance between environmental, social, and economic concerns and with a consideration of future generations.

Habitat Standards

Enactment of the Clean Water Act in the mid-1970s specified that surface waters of the US be maintained as fishable and swimmable. This legislation, more than any other, initiated a system of environmental requirements resulting in important and substantial improvements in the water quality of rivers and lakes. The Clean Water Act enabled the US Environmental Protection Agency (EPA) to identify water-quality standards that must be met by anyone introducing effluents into receiving waters through point-source discharges. It also mandated states to develop their own point-source effluent standards and to develop further plans for reducing water pollution from non-point sources (i.e., land uses in which water-quality impairment did not originate at a single location such as the end of a pipe). Since the original goal of the Clean Water Act was to reduce the discharge of pollutants, principally from industrial and municipal sources, many of the substances addressed in both point- and non-point water-quality regulations have been toxic chemicals.

As water-quality standards were refined with additional research (EPA 1986), regulatory organizations began to develop additional standards for fish habitat. Among the objectives of these standards were the designation of hazard thresholds beyond which significant degradation could be expected, and the definition of habitat states considered optimum for fish. Examples of hazard thresholds that have been applied to salmon habitat include the maximum percentage of fine sediment present in spawning gravels or the maximum allowable temperature for a stream during summer (Bjornn and Reiser 1991). For purposes of regulation, human activities could be allowed to alter fine sediment concentration or increase temperature as long as hazard thresholds were not exceeded. Examples of the second objective of defining optimum habitat include specified frequencies of pool and riffle habitat or the number of pieces of large woody debris (LWD) per unit of stream length believed necessary for pool formation (Washington Forest Practices Board 1993).

Despite improvements in water quality resulting from the implementation of standards (NRC 1992), many Pacific Northwest streams still exist in a highly altered state in which neither the range of natural conditions is present nor the full expression of ecological interactions between aquatic and terrestrial ecosystems is permitted (Gregory et al. 1991, FEMAT 1993, NRC 1996). In the two decades since enactment of the Clean Water Act, the general trend continues toward increasingly degraded aquatic habitat (Bisson et al. 1992, Karr 1994), and the consensus of professional fishery scientists in the region is that habitat loss continues to contribute to the decline of salmon (Nehlsen et al. 1991, Cederholm et al. 1993, Gregory and Bisson 1996).

The inability of water-quality and habitat standards to reverse the overall trend of habitat loss has stemmed from several problems. In some cases, water-quality and habitat standards have simply not been enforced, either because the standards were unrealistic, violations went unnoticed or unreported, or resources for adequate enforcement were insufficient (NRC 1992, Sauter 1994). Parameters selected as standards for salmonid habitat such as temperature, sediment, flows, dissolved oxygen, or pool-riffle ratios were often relatively easy and cheap to measure, or simple to model, but may not necessarily have been the factors exerting the greatest influence on salmonid production (Fausch et al. 1988, Shirvell 1989). Standards may have been based on habitat requirements of single life-cycle stages of individual species and thus were only partially effective (Bisson et al. 1992).

Perhaps most importantly, habitat standards have generally not accounted for the dynamic nature of aquatic ecosystems in which patterns of disturbance and recovery provide the local evolutionary template to which salmonid stocks have adapted. Rather, such standards have often described a set of conditions representing a compromise among the perceived needs of different species or life-history stages. When applied to restoration projects, habitat standards have potentially reduced habitat diversity by eliminating some conditions, even those that may occur naturally (Fig. 1).

We do not advocate abandoning water-quality and habitat standards. They may serve as useful signals of severe environmental degradation. Instead, we suggest that habitat standards not be taken sensu stricto as desired future conditions. If conservation of functional ecosystems supporting naturally occurring assemblages of plants and animals, including salmon, is the principal goal of watershed management (Franklin 1993), then environmental planning and regulation should preserve the dynamic changes that accompany disturbance-recovery cycles and protect essential energy and material transfers that take place between aquatic and terrestrial ecosystems during disturbance events (Reice 1994). Habitat standards should not be taken as surrogates for ecological function; restoration of productive watersheds will require management activities that allow the natural range of conditions to be expressed.

Dynamic Populations in Dynamic Watersheds

Pacific salmon exhibit characteristics of complex metapopulations in which local reproductive groups (demes) spawn in different areas and exchange genes with other groups through adult straying (Riddell 1993). The structure of salmon metapopulations may vary for different species, depending on the geoclimatic features of a particular area and the species' life-history requirements, but salmon spawning in multiple locations within a river basin usually have strong and weak demes at any given time (Scudder 1989). Whether a particular deme is large or small depends on many factors, some of which are related to freshwater conditions and some to oceanic conditions.

At large spatial and temporal scales, extirpation of local demes in marginal habitats may be relatively common (Harrison 1991), especially in salmon populations. Straying is an important adaptation for recolonizing suitable habitat as populations expand. The centripetal flow of genes from marginal demes to large central demes during periods of population contraction is an important means of enriching genetic diversity (Scudder 1989). Even in watersheds relatively free

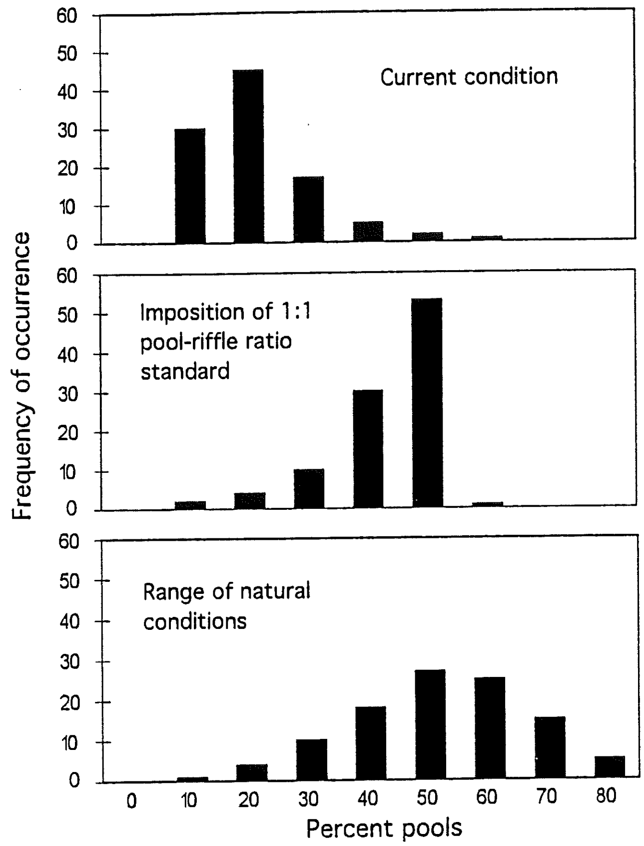

Figure 1. Three scenarios describing the frequency of pool habitat in streams within a hypothetical watershed. The graph at the top illustrates a situation in which pools have been lost due to widespread habitat alteration (e.g., Sedell and Everest 1991). The middle graph illustrates what might result from an attempt to rehabilitate altered streams to a pool-riffle ratio of 1:1 (some streams would likely fail to achieve this desired condition because of fundamental geomorphic constraints). The lower graph describes how pools might appear if the watershed were in a pristine state, where geomorphic controls and natural disturbance-recovery cycles have generated a wide range of pool frequencies.

of human influences, natural disturbances (Table 1) create a mosaic of habitat patches in various stages of post-disturbance recovery (Reice 1994). Particularly severe disturbances may extirpate local demes, while successional processes may generate exceptionally favorable conditions that promote survival and growth as habitat recovery occurs (Bisson et al. 1988, Minshall et al. 1989, Reice et al. 1990). Anadromous salmonids in the Pacific Northwest appear to be well adapted to reinvading areas of suitable habitat within their native drainage systems. Adults are strong swimmers with a relatively high fecundity for benthic spawning species, and juveniles often disperse over great distances from natal spawning sites in search of productive rearing habitat (Groot and Margolis 1991).

Table 1. Approximate occurrence rates of different types of natural and anthropogenic disturbances. Modified from National Research Council (1996), based on Swanston (1991).

Type of disturbance	Approximate recurrence interval (yr)		Physical and chemical factors influenced by the disturbance	Habitat effects
	Natural	Anthropogenic		
Daily and weekly precipitation and discharge patterns	0.01–0.1	0.001–0.1	Stream discharge, channel width and depth, storage and transport of fine particulate organic matter, fine sediment transport and deposition, nutrient concentrations, water current velocity	Minor alteration of particle sizes in spawning gravels, minor variations in rearing habitat, minor temperature change, altered turbidity, altered primary productivity
Seasonal precipitation and discharge, moderate storms, ice formation	0.1–1.0	0.01–1.0	Bank-full flows, moderate channel erosion, high base-flow erosion, increased mobility of sediment and woody debris, local damming and flooding, sediment transport by anchor ice, gouging of stream bed by ice movement, reduced winter flows with extensive freezing, seasonal changes in nutrient concentrations	Changes in frequencies of riffles and pools, changes in particle sizes in spawning gravels, increased channel width, flooding of side channels, removal (or sometimes addition) of cover, relocation of holding areas. In areas affected by ice: decreased water temperatures, lower primary and secondary productivity, egg dewatering or scour during anchor ice formation and breakup
Major floods, rain-on-snow events	10–100	1–50	Inputs of sediment, organic matter and woody debris from hillslopes, riparian zones and streambanks; localized scour and fill of streambeds; lateral channel movement; streambed mobilization resulting in redistribution of coarse sediment and flushing of fine sediment; redistribution of large woody debris (LWD); inundation of floodplains; transport of organic matter and LWD to estuaries	Changes in the frequencies of riffles and pools; formation of large log jams; burial of some spawning sites but creation of new areas suitable for spawning; increased amounts of fine particular organic matter for processing by the benthic community, resulting in increased secondary production; destruction or creation of side-channels along the floodplain; increased secondary production and cover habitat in estuaries
Debris flows and dam-break floods	100–1000	20–200	Large, short-term increases in sediment and LWD inputs; extensive channel scour; large-scale movement and redistribution of substrate, fine particulate organic matter, and LWD; damming and obstruction of channels at the terminus of the torrent track; accelerated streambank erosion, resulting in channel widening; destruction of riparian vegetation; very large short-term increase in suspended sediment; subsequent summer temperature increases from vegetative canopy removal	Extensive loss of pool habitat in the torrent track, loss of spawning gravels, loss of habitat complexity along edge of stream, destruction of side-channels and other overwintering areas, creation of new cover in the terminal debris dam, creation of new spawning areas in the sediment terrace upstream from the debris dam, short-term loss of aquatic invertebrates, possible damage to gills from heavy suspended sediment load, increased primary production

Table 1—cont.

Type of disturbance | Approximate recurrence interval (yr) Natural Anthropogenic | Physical and chemical factors influenced by the disturbance | Habitat effects

accelerated streambank erosion, resulting in channel widening; destruction of riparian vegetation; very large short-term increase in suspended sediment; subsequent summer temperature increases from vegetative canopy removal

sediment terrace upstream from the debris dam, short-term loss of aquatic invertebrates, possible damage to gills from heavy suspended sediment load, increased primary production

Table 1—cont.

Type of disturbance	Approximate recurrence interval (yr)		Physical and chemical factors influenced by the disturbance	Habitat effects
	Natural	Anthropogenic		
Beaver activity	5–100	0 (removal of beavers)	Channel damming, obstruction and redirection of channel flow, flooding of streambanks and side-channels, entrainment of trees from riparian zone, creation of large depositional areas for fine sediment, conditions that promote anaerobic decomposition and denitrification, resulting in nutrient enrichment downstream from the pond	Enhanced rearing and overwintering habitat, increased water volumes during low flows, refugia during floods, possible blockage to upstream migration by adults and juveniles, elevated summer temperatures and lower winter temperatures, local reductions in dissolved oxygen including areas under ice in winter, increased production of lentic invertebrates in pond, increased primary and secondary production downstream from pond
Major disturbances to vegetation				
1. Windthrow	100–500	50–150 (buffer strip blow-down)	Increased sediment delivery to channels, decreased litterfall, increased inputs of LWD, decreased riparian canopy, increased retention of sediment and fine organic matter in the channel	Increased pool habitat, localized sedimentation, increased in-channel cover, increased summer temperatures and decreased winter temperatures, creation of eddies and alcoves along channel margins, increased secondary production
2. Wildfire	100–750	40–200 (timber harvest rotation)	Increased sediment delivery to channels, inputs of large woody debris, loss of riparian canopy and vegetative cover, short-term increase in fine particulate organic matter and nutrients, decreased litterfall, increased peak discharge, short-term increase in summer flows from reduced evapotranspiration, short-term increase in biochemical oxygen demand in stream substrate	Increased sedimentation of spawning and rearing habitat, increased pool habitat and in-channel cover, increased water volume in summer, increased summer temperatures and decreased winter temperatures, increased secondary production, reduced dissolved oxygen in spawning gravels, scour of eggs and alevins in spawning gravels
3. Insects and disease	100–500	0 (chemical treatment)	Inputs of LWD, loss of riparian canopy and vegetative cover, decreased litterfall, short-term increase in summer flows from reduced evapotranspiration	Increased pool habitat and in-channel cover, increased summer temperatures and decreased winter temperatures, increased water volume in summer, increased primary and secondary production in treated areas, loss of secondary production due to toxicity of insecticides

Table 1—cont.

Type of disturbance	Approximate recurrence interval (yr)		Physical and chemical factors influenced by the disturbance	Habitat effects
	Natural	Anthropogenic		
Slumps and earthflows	100–1,000	50–200	Low-level, long-term contributions of sediment and LWDs to streams; partial blockage of channel; local base-level constriction below point of entry; shifts in channel configuration; long-term source of nutrients	Sedimentation of spawning gravels; scour of channels below point of entry; accumulation of gravels behind obstructions; possible blockage of fish migrations; increased pool habitat in coarse sediment and LWD depositional areas; destruction of side channels in some areas, creation of new side channels in others; long-term maintenance of primary productivity
Volcanism	100–1,000		Increased delivery of fine sediment and organic matter, scour of channels from mudflows, formation of mudflow terraces along rivers, destruction of riparian vegetation, damming of streams with creation of new lakes, increased nutrients	Sedimentation of spawning gravels, loss of pool habitat from mudflows but creation of pool habitat in areas with tree blowdown, creation of new overwintering habitat and side channels along mudflow terraces, short-term potentially lethal sediment and temperature levels during eruptions, long-term increases in primary and secondary production, formation of migration blockages, long-term benefits to lake-dwelling species
Climate change	1,000–100,000	10–100 (thermal discharges, riparian canopy removal, channelization)	Major changes in channel direction, gradient, and configuration; stream capture; long-term changes in temperature and precipitation regimes	Major changes in frequencies of dominant habitat types; shifts in species composition related to preferences for temperatures, substrates, and streamflows; faunal transfers during stream capture; reproductive isolation may lead to stock differentiation; founder effects

Salmon can exhibit multiple freshwater life histories, apparently a means of spreading the risk in uncertain environments (Schlosser and Angermeier 1995). Some juvenile coho salmon (*O. kisutch*) spend most of their time in freshwater close to natal spawning sites whereas others disperse downstream after emergence from spawning gravels to suitable but unoccupied habitats (Chapman 1962). In many river systems, juvenile coho occur throughout the drainage, including lowland sloughs and estuaries as well as headwater streams (Tschaplinsky and Hartman 1983). Some members of the population remain in headwater streams throughout the winter; others emigrate from headwaters to overwintering sites along riverine floodplains (Peterson 1982, Brown and Hartman 1988). Juvenile fall chinook salmon (*O. tshawytscha*) in Oregon's Sixes River have five distinctive rearing patterns with various periods of tributary, mainstem river, and estuarine residence (Reimers 1973).

Within a river basin, streams cycle between productive and unproductive conditions in response to disturbances and subsequent periods of physical and biological recovery (Minshall et al. 1989, Reice 1994), forming a dynamic setting within which anadromous salmonids exist through such adaptations as multiple freshwater rearing patterns, straying, and extended run timing. As streams move into a productive state, conditions favoring large demes develop; as streams become unproductive, carrying capacity declines (Sousa 1984). Productive streams with large populations provide colonists for recovering streams with underutilized habitat (Sheldon 1987). Emigrants from large demes can occupy marginal habitat in which survival is normally low but which may under unusual circumstances be superior to normally preferred conditions (Scudder 1989). River basins and their fish populations can thus be seen as a mosaic of habitat patches in various disturbance-recovery states that are interconnected physically by fluvial processes and interactions between aquatic and terrestrial ecosystems, and as population subunits of different sizes that are interconnected biologically by gene flow among locally reproducing demes.

This view of watershed processes suggests that both habitat and salmon populations exist in a state of dynamic equilibrium that is self-buffering over time, but this is often not the case (Reice 1994). The scale and impact of some types of disturbances (Table 1) may be so great that watershed boundaries are transcended, creating large landscape mosaics in which whole river basins undergo long-term recovery cycles. Examples of such disturbances in the Pacific Northwest include the coastal floods of 1962, 1964, and 1996 in Oregon, the 1980 eruption of Mount St. Helens, and 1994 wildfires in eastern Washington and Idaho. The spatial impact of these large disturbances may extend well beyond the boundaries of locally reproducing demes, resulting in depression of entire populations. Interdecadal climate changes now known to have significant effects on ocean productivity (Francis and Sibley 1991; Pearcy 1992, 1996; Beamish and Bouillon 1993) introduce even more long-term variability into salmon populations. Although salmon are well adapted to dynamic and unpredictable environments, their abundance is rarely if ever stable at either local or regional scales. Studies of juvenile and adult anadromous salmonids extending 5 or more consecutive years suggest that interannual variations of 40–70% are the general rule for coho salmon, steelhead (*O. mykiss*), and sea-run cutthroat trout (*O. clarki*) in Pacific Northwest streams (Fig. 2).

The point of the foregoing discussion is to emphasize that neither stream channels nor salmon populations are stable but vary in response to a variety of forces. Management policies often oppose variation, thinking that variability is the enemy of sustainability (Botkin 1990). Instead, policies should recognize that variability is an inherent property of aquatic ecosystems

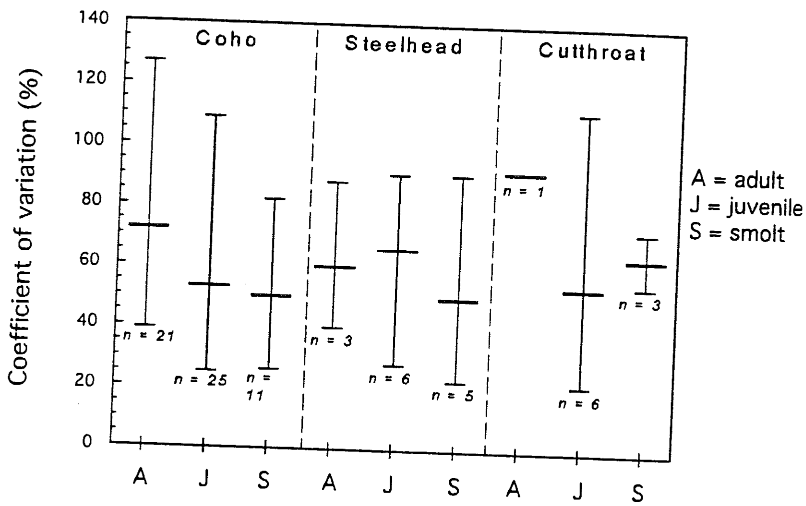

Figure 2. Comparison of the interannual variability (coefficient of variation [CV]) of coho salmon, steelhead, and cutthroat trout in western Oregon, Washington, and British Columbia streams, based on a compilation of published and unpublished studies in the Pacific Northwest where anadromous salmonid populations were censused for ≥5 consecutive years using consistent enumeration methods. Sample sizes refer to the number of studies examined. Horizontal lines represent averages and vertical lines represent the range of CVs for each species. Data sources: Johnson and Cooper (1986); Nickelson et al. (1986); Hall et al. (1987); Hartman and Scrivener (1990); Reeves et al. (1990); Ward and Slaney (1993); P.A. Bisson and R.E. Bilby, Weyerhaeuser Company, Tacoma, Washington, unpubl. data; S.V. Gregory, Oregon State University, Corvallis, unpubl. data; T.E. Nickelson, Oregon Department of Fish and Wildlife, Corvallis, unpubl. data; D. Seiler, Washington Department of Fish and Wildlife, Olympia, unpubl. data.

in the Pacific Northwest (Naiman et al. 1992, Stanford and Ward 1992), that habitat at any given location will change naturally from year to year, decade to decade, and century to century, and that the abundance of local breeding populations will similarly increase and decrease according to changes in freshwater and ocean conditions. Desired future conditions, then, must include variability as an integral and essential component of habitat and population objectives.

Disturbance-Recovery Cycles and Habitat Formation

The natural disturbance regime is the engine that drives habitat formation for salmon. Short-term impacts of natural disturbances on salmon populations are often negative. Death may result, habitat may be destroyed, access to spawning or rearing sites may be blocked, or food resources may be temporarily reduced or eliminated (Fig. 3). However, many types of natural disturbances introduce new materials into stream channels that are essential for maintaining productive habitat (Table 1). Mass soil movements such as earthflows and debris avalanches contribute coarse sediment and woody debris (Swanson et al. 1987). Wildfires and windstorms

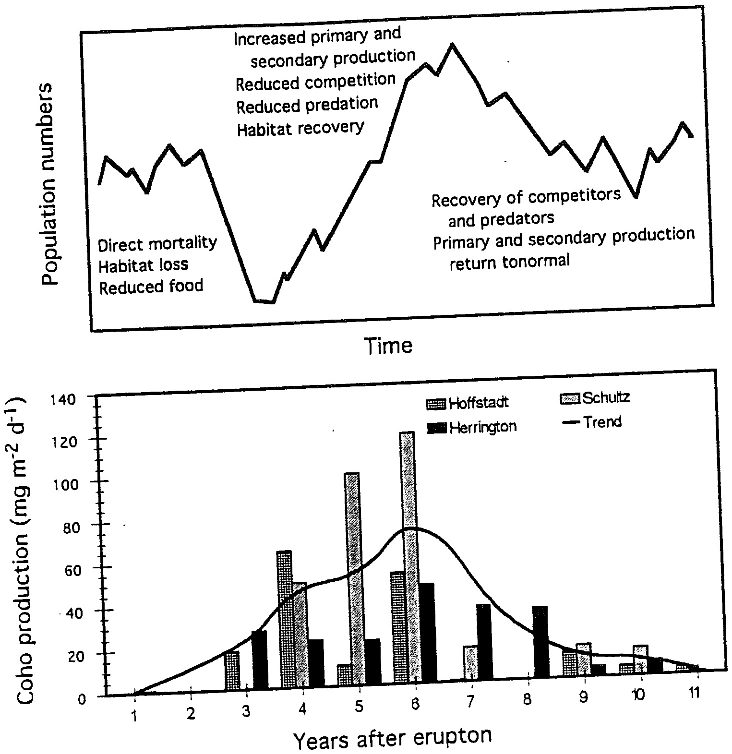

Figure 3. Top: factors potentially influencing the recovery of salmonid populations after large disturbances. Bottom: summer production of juvenile coho salmon in three 3rd-order streams impacted by the 1980 eruption of Mount St. Helens (Bisson et al. 1988; B.R. Fransen and P.A. Bisson, Weyerhaeuser Company, Tacoma, Washington, unpubl. data).

contribute both coarse and fine debris as well as nutrients (Minshall et al. 1989). Floods entrain nutrients, sediment, and particulate organic matter of all sizes (Bayley 1995). Volcanic eruptions create new soil, form new riparian terraces, and create new stream channels and lakes (Franklin et al. 1985).

Salmonid populations may rebound relatively quickly after large disturbances owing to their recolonizing abilities, temporarily abundant food, and a relative scarcity of competitors or predators (Fig. 3, top). Short-term recoveries of stream-dwelling salmonids have been observed after floods (Hanson and Waters 1974), volcanic eruptions (Fig. 3, bottom; Bisson et al. 1988), clearcut logging (Murphy and Hall 1981, Hawkins et al. 1983, Bisson and Sedell 1984, Holtby 1988, Bilby and Bisson 1992), and channelization (Chapman and Knudsen 1980). Quite often the recovery occurs unequally among species. One or two forms might be favored by altered habitat conditions and certain types of temporarily elevated foods while other species remain depressed (Waters 1983, Reeves et al. 1993).

Following a period of temporary superabundance, which seems to last ~3–15 years, salmonid populations typically decline to or below pre-disturbance levels as competitors and predators become reestablished and food levels return to normal (Fig. 3, top). Whether populations decline below pre-disturbance levels will be strongly influenced by the rate of habitat recovery. If the disturbance is such that stream channels remain depleted of important habitat elements such as LWD and coarse sediment, or if connections between the stream and its flood plain are disrupted, the carrying capacity of the watershed will probably be depressed until these elements are restored (Fig. 3, bottom; Bilby 1988, Gore and Shields 1995).

In many systems, periodic renewal of certain structural features of stream channels requires episodes of significant disturbance. Benda (1990, 1994) and Reeves et al. (1995) studied three streams in largely unmanaged watersheds of western Oregon with different time periods since their last major disturbance. They presented evidence that large quantities of coarse sediment and LWD eroded into streams after natural wildfires and accompanying landslides. Over periods of centuries, this material gradually washed out. A stream in an old-growth forest (330+ years old) that had not been significantly disturbed for a long time possessed a predominantly bedrock streambed with few deep pools or gravel riffles, a condition not particularly favorable for a high diversity of anadromous salmonids. Similarly, habitat diversity was relatively low in a stream of a watershed that had experienced a wildfire 90–100 years ago. This channel had deep sediment deposits from the post-fire erosion and was dominated by gravel riffles and deep but hydraulically simple pools. The greatest habitat diversity (and salmonid species diversity) was found in a third stream in which ~160–180 years had elapsed since the last major disturbance (a wildfire). In this watershed, the stream channel possessed the greatest array and most even distribution of substrate and habitat types. Some of the LWD and coarse sediment were still present from the erosion accompanying the wildfire and recruitment of new woody debris from the adjacent riparian zone was well underway (see also Grette 1985). Thus, diversity was greatest at an intermediate point in the long-term cycle of recovery after a major disturbance and was reduced at the beginning and end of the cycle.

The effects of debris flows differ somewhat from those of disturbances that simply add material to streams from adjacent riparian zones and hillslopes. In a debris flow, LWD and coarse sediment are scoured from the channel and concentrated at the terminus of the deposit, leaving in the wake of the flow a channel lacking in pool habitat (Sullivan et al. 1987, Swanson et al. 1987). Where mass wasting is a relatively common feature of the landscape, such as on the Queen Charlotte Islands of British Columbia, debris flow deposits constitute important nodes of complex habitat along the stream profile (Hogan 1985). In Oregon's Elk River, log jams created by debris flows trap gravels used extensively for both spawning and rearing by anadromous salmonids (G.H. Reeves, USDA Forest Service [Forest Service], Corvallis, Oregon, unpubl. data). As wood within a log jam decays and the matrix of sediment and smaller woody debris is washed out during subsequent storms, the debris deposit is breached, spreading woody debris and coarse sediment downstream to form new habitat. Very large log jams can be quite stable and can remain in place for centuries, depending on the size of the stream and its hydrologic regime. Although these jams may block upstream fish migrations, the material they contain will ultimately contribute to productive habitat when the log jam finally washes out.

The time required for new woody debris to be recruited to a stream channel or for a debris flow deposit to erode is far longer than the potential recovery time of a fish population after a disturbance, which may be a matter of only a few years (Fig. 3). Therefore, multiple cycles of population rebounding in response to small and intermediate-scale disturbances may be superimposed over much longer cycles of habitat change that accompany very large disturbances or long-term climate trends. Even if factors such as food availability are favorable for production,

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fish populations are limited to some extent by the amount of suitable habitat (Chapman 1966). Far greater production is possible if food resource abundance and habitat quality are high simultaneously than if one is elevated but the other depressed (Warren et al. 1964, Mason 1976). Response of salmon populations to smaller, more frequent disturbances (Table 1) is likely to be mediated by the overall condition of the stream and its watershed, which will itself be strongly influenced by large, infrequent natural disturbances (Frissell et al. 1986).

Land and water management actions often increase the frequency of small and intermediate disturbances, or they may increase the severity of impacts from natural disturbances (Table 2). In some cases, the magnitude of an anthropogenic disturbance (e.g., a dam) may be so great that irreversible changes to the aquatic community occur. The challenge facing natural resource managers is twofold: (1) where possible, to ensure that human activities do not increase the frequency or severity of disturbance events so greatly that the capacity of aquatic ecosystems to recover from either natural or anthropogenic disturbances is significantly impaired, and (2) to ensure that, when anthropogenic disturbances do occur, the essential linkages (e.g., coarse sediment and woody debris inputs, nutrient and fine organic matter transfers, floodplain connections) that promote habitat recovery are not disrupted.

In summary, we believe that the most important aspects of identifying desired future conditions are dealing with natural variability inherent in both habitat and fish populations, and accommodating the natural disturbance regime of a watershed. Spatial and temporal changes result from nested hierarchies of small-scale, short-term recovery cycles within very large-scale, long-term cycles. The dynamic nature of these processes suggests that prescribing desired habitat conditions at the scale of a stream segment or reach (the scale most often addressed in habitat restoration projects) may not be an appropriate or effective method of maintaining the ecological functions that govern productivity at the scale of entire watersheds or sub-basins. Attempting to engineer stream channels to conform to some idealized combination of pools, riffles, cover, substrate, depth, and water velocity is likely to be both prohibitively expensive and practically impossible (Sedell and Beschta 1991). In the following section, we propose an alternative approach that considers desired future conditions as ranges of states appropriate to the geomorphic setting and disturbance history of larger-order stream networks.

Identification of Desired Future Conditions

What Is Possible?

One of the first steps in defining desired future conditions is to identify geomorphic constraints imposed by the regional setting of a stream and its valley. At any given geographic scale, there exists a finite range of habitat conditions that can persist over time. These conditions may be affected by human activities but will nonetheless reflect the potential set of constraints dictated by the prevailing geoclimatic features of that particular river basin (Stanford and Ward 1992). Specific characteristics of a stream or lake and its associated riparian zone will be strongly influenced by a number of factors, including predominant rock type, substrate characteristics, and the degree of valley confinement; gradient; climate and flow regime; vegetative communities; natural disturbance history; and anthropogenic disturbance history.

Table 2. Spatial scales, recovery times, and some biological recovery mechanisms following natural and anthropogenic disturbances to aquatic ecosystems in the Pacific Northwest. Adapted from National Research Council (1996) based on Poff and Ward (1990).

Nature of disturbance	Spatial scale	Examples	Relative recovery time	Biological recovery mechanisms
Natural disturbance	Small	Flood of 1- to 3-year recurrence interval, local windstorm, minor landslide	Fast	Behavioral avoidance and refuge-seeking, increased growth among survivors, rapid recolonization of disturbed area
	Large	Major wildfire, dam-break flood (small streams), 50- to 100-year recurrence interval flood (large streams)	Slow to moderate	Adjustment of populations and community structure to new habitat conditions, migrations and establishment of new population units
Anthropogenic disturbance				
Acute				
Sublethal	Small	Minor landslide or streambank erosion, short-lived toxicant (local use), temporary water withdrawal	Fast	Behavioral and physiological avoidance, refuge-seeking, rapid recolonization
	Large	Short-lived toxicant (widespread use), various flood control practices	Slow	Physiological acclimation, selection for tolerant species, selection for species not dependent on floodplains, behavioral avoidance and refuge-seeking
Lethal	Small	Short-lived toxicant (e.g., spill), major debris torrent	Slow to moderate	Behavioral avoidance, recolonization; new species establishment
	Large	Introduction of pathogen to drainage system, channelization	Slow	Population and community adjustments, selection of tolerant species

Large	Introduction of pathogen to drainage system, channelization	Slow	Population and community adjustments, selection of tolerant species

Table 2—cont.

Nature of disturbance	Spatial scale	Examples	Relative recovery time	Biological recovery mechanisms
Anthropogenic disturbance—cont.				
Chronic				
Sublethal	Small	Gradual, small-scale sediment inputs, local thermal change; migration blockage in tributary	Slow to moderate	Local population and community adjustments, colonization by tolerant species, behavioral and physiological acclimation
	Large	Increased erosion at the watershed level, widespread loss of riparian vegetation, habitat simplification; multiple water withdrawals; dams	Slow	Population and community adjustments throughout system, selection of tolerant species, species migrations
Lethal	Small	Frequent discharges of long- or short-lived toxicants, chronic anoxia, temperature or flows beyond tolerance limits	Very slow	Selection of tolerant species
	Large	Frequent introductions of pathogens, frequent discharges of long- or short-lived toxicants, chronic anoxia, temperature or flows beyond tolerance limits	Very slow	Colonization by rare, resistant species

At the scale of a stream segment (reach), geomorphic classification systems (e.g., Rosgen 1985, Paustian 1992, Montgomery and Buffington 1993) assist in determining what is possible given the topographic constraints of a particular setting. Knowing the type and location of stream channels that are present in a watershed provides important clues to how different habitat types are likely to be distributed within the drainage (Frissell et al. 1986). In turn, the suitability of different channel segments for different species or their various life-cycle stages can be assessed if the frequencies of habitat types are known (Hankin and Reeves 1988).

The types of habitat available in individual streams and associated riparian zones change according to the watershed's history of natural and anthropogenic disturbances (Grant et al. 1990). Because watersheds exist in some phase of recovery from combinations of large and small disturbances (Reice 1994), it is likely that not all channels and riparian zones will look like those in old-growth forests, even in pristine watersheds. However, many watersheds in the Pacific Northwest have been altered by anthropogenic disturbances to such an extent that their channels possess the simplified appearance of streams in early post-disturbance recovery (Bisson et al. 1992), in which only one or two species have been favored and biodiversity has been significantly reduced (Reeves et al. 1993).

Determining what is possible is no easy task. There are few 4th- or 5th-order watersheds in pristine condition and no intact drainages of 6th-order and larger within the range of salmon south of Puget Sound that can serve as benchmarks. Much of the useful information on the range of natural conditions in the Pacific Northwest has come from surveys of small headwater streams (Naiman and Sedell 1979; Murphy et al. 1984; Bilby and Ward 1989, 1991; Hartman and Scrivener 1990). Descriptions of habitat in large rivers prior to human alteration are scarce (Sedell et al. 1984). Some of the best evidence has come from historical reconstruction of river channels and estuaries based on late 19th-century and early 20th-century maps, photographs, and stream surveys (Sedell and Luchessa 1982, Sedell and Froggatt 1984, Boulé and Bierly 1987, Sedell and Beschta 1991, Sedell and Everest 1991, Simenstad et al. 1992).

We believe it is imperative that a regional network of reference sites encompassing drainages of 5th- to 6th-order be established throughout the Pacific Northwest to determine the range of conditions over a variety of geoclimatic and disturbance regimes. These sites should contain substantial areas where stream channels have not been significantly altered by human activities or have recovered from such perturbations to the extent that they approximate conditions present in unmanaged watersheds (NRC 1996). Reference sites should be sufficiently large that the range of habitat conditions produced by natural disturbances is expressed and all or nearly all of the channel types found in the region are present.

Locating such sites will be difficult but not impossible. Some already exist in national and state parks. Large areas of the landscape have been designated as late-successional old-growth reserves, research natural areas, or key watersheds on federal forest lands (FEMAT 1993). Other examples of potential sites include large watershed areas designated as Watershed Administrative Units by the Washington Department of Natural Resources (Washington Forest Practices Board 1993), and the Class 1 Waters of the Aquatic Diversity Management Areas recently proposed for California by Moyle and Yoshiyama (1994) (i.e., those with the highest quality habitat and most intact native aquatic plant and animal communities).

Until a regional network of reference sites is established and systematic, long-term habitat monitoring programs are initiated, our knowledge of the range of conditions possible at a given location will be limited (Walters and Holling 1990). At present, we are forced to rely on the few existing studies of habitat in streams without significant anthropogenic influences and on the best professional judgment of watershed specialists. Information from a few small watersheds, while useful, may be so limited that the full range of potential states for all channel types throughout a region is poorly understood and cannot be applied to large streams. Without a more complete understanding of this range of possibilities, available evidence may lead us once again into embracing uniform sets of habitat standards that may be geomorphically inappropriate and that do not reflect naturally dynamic processes upon which aquatic productivity ultimately depends. We strongly urge land owners and resource management agencies to establish a regional network of reference sites and implement cooperative, long-term monitoring programs without delay. The information generated from such an effort will be essential to answering the following three questions.

What Is Desired?

A key goal of watershed management with respect to the protection of Pacific salmon and other members of aquatic ecosystems is to allow interactions between aquatic and terrestrial ecosystems to continue as unhindered as possible. Two of the most important steps to ensuring that ecological linkages will not be disrupted are (1) maintaining riparian zones of adequate width to mediate the full range of physical and biological exchanges of energy and materials between land and water, and (2) minimizing the occurrence of severe anthropogenic disturbances within these zones. These steps will enable natural disturbances to generate the changes necessary for habitat formation and long-term maintenance of aquatic productivity (Naiman et al. 1992). Although restoration of completely pristine conditions will not be possible in watersheds possessing a variety of human activities, management decisions should aim to maintain the range of conditions produced by natural disturbance regimes, including a frequency distribution of riparian forest successional stages that resembles those in unmanaged watersheds over long time periods.

The goal is not to maintain all streams in the same state over time but to allow disturbance and recovery processes to take place as normally as possible. Even streams with high-quality habitat (i.e., habitat that appears exceptionally favorable for a particular species of interest) will change over sufficiently long intervals. Disturbances that temporarily transform habitats favorable for salmon into unfavorable habitats need not necessarily be viewed as greatly harmful as long as other streams with productive conditions are readily available within the drainage system. The metapopulation structure of salmon stocks permits the strength of locally reproducing population units to expand and contract in response to habitat recovery cycles (Reeves et al. 1995). An appropriate goal might be to ensure that some biologically productive streams are always present in the drainage system and that their frequency approaches what might be expected in undeveloped but otherwise similar watersheds. Establishing a mix of streams in different stages of recovery from natural disturbances is, we believe, most appropriate at landscape scales encompassing intermediate to large watersheds (i.e., >1,000 ha). Drainages of at least 4th- to 6th-order may be the minimum size landscape units within which habitat goals can properly be matched to the life cycles of salmon populations (i.e., they may be the minimum size necessary to contain summer and winter habitats as well as migration corridors).

We caution habitat managers against basing restoration decisions solely on the needs of individual salmon species or life stages. Streams in the Pacific Northwest are often classified according to their potential use by adult or juvenile salmonids. Stream segments may be termed "steelhead streams" or "coho streams," or classified according to use by certain life-cycle stages such as "spawning areas" or "overwintering sites." While these descriptions may accurately reflect current utilization, the danger is that habitat improvement projects may be designed solely to enhance the characteristics of the channel that favor these particular species or life-history stages. Such projects may be successful in the short term for the limited purpose for which they were intended, but they often lead to unnatural channel characteristics that may impede successional changes ultimately favoring other species (Sedell and Beschta 1991). As a general rule, we recommend that objectives include a diversity of habitat types within a watershed sufficient to support complete assemblages of native species. These assemblages should include both salmonid and non-salmonid fishes as well as other aquatic vertebrates, invertebrates, and plants (Pister 1995).

What Conditions Should Be Managed?

Emphasis should be placed on protecting watershed processes that provide materials essential for maintaining the structure and functional properties of aquatic ecosystems. Key elements of ecologically healthy watersheds include fully functional riparian zones, unaltered streamflow regimes, floodplains connected with river channels, uninterrupted hyporheic zones, and natural input rates of sediment, organic matter, and nutrients (Naiman et al. 1992, Stanford and Ward 1992). Because most human activities change these elements to some extent, the objective should be to minimize adverse changes, restore biophysical connections where possible, and preserve remaining ecologically functional areas in which a range of habitats exist. By allowing natural disturbances to occur with a minimum of human intervention, and by providing the raw materials upon which these disturbances can act, it should be possible to maintain patches of productive habitat across the landscape that are spatially arrayed in a manner that provides for the needs of salmon populations.

Restoration of ecological functions in Pacific Northwest watersheds will require considerable time and patience on the part of natural resource managers (Bisson et al. 1992), but the current plight of many salmon stocks may call for short-term intervention to improve habitat. In theory, recovery can be accelerated by adding structures to streams to increase pool habitat (House and Boehne 1986), creating missing habitat types such as overwintering ponds (Cederholm et al. 1988), or actively managing riparian vegetation to speed development of late-successional coniferous forests (Bilby and Bisson 1991). If instream habitat improvement efforts are undertaken, care should be taken to utilize or mimic to the greatest extent possible the size and composition of material that would occur at the site naturally, the locations where the material is most likely to enter the channel and stabilize, and the ability of structures to interact dynamically with water flow, streambed, and streambanks. In practice, this will mean using native tree species and inorganic materials typical of those produced by local site characteristics, including whole trees with intact rootwads and branches, irregular spacing of structures similar to streams in pristine watersheds with similar channel types, limited use of exotic materials such as wire mesh and geotextile fabrics, and a minimum of anchoring to the streambed or streambanks.

Anchoring systems such as steel cables to prevent fluvial transport of introduced woody debris are often used to prevent damage to bridges, homes, and other capital structures downstream; however, anchored debris often does not function in the same way as do naturally produced materials, their failure rates may be high (Frissell and Nawa 1992), and their effectiveness in significantly increasing ecosystem productivity remains largely unproved.

WHAT CONSTITUTES THE FUTURE?

We suggest that the minimum planning horizon for watershed rehabilitation should be 100 years, a time period representing about 20–50 salmon generations. This interval should be long enough to allow natural disturbances and other ecological processes to provide genuine gains in overall watershed productivity. Planning efforts should recognize the likelihood that, over a century or more, very large disturbances will occur in most areas. When these events take place, the future capacity of watersheds to produce salmon will be strongly influenced by changes accompanying the disturbances. Taking steps to ensure that watersheds possess the full range of vegetative characteristics and hydrologic connections in appropriate locations upon which disturbances can eventually act is, we believe, more important for restoring the long-term capacity of drainage systems to produce salmon than modifying channels is to rehabilitating degraded habitat. Relying strictly on instream projects to increase salmon production, however well-intentioned, without a comprehensive plan for improving ecological functions and processes at the watershed scale will not achieve the diversity of channel characteristics upon which Pacific salmon depend and to which their population structure and life cycles are matched.

Tracking long-term changes in freshwater and marine environments facilitates a better understanding of interdecadal cycles of salmon abundance and the need to adjust management policies appropriately. The inverse relationship between marine survival of northern and southern salmon populations along the Pacific coast of North America (Beamish and Bouillon 1993, Francis 1996) illustrates the great importance of changing ocean conditions; yet, while ocean productivity may be low in some years and high in others the need for good land and water stewardship always remains (Pearcy 1992, Lawson 1993). For example, it seems prudent to ensure that salmon have access to all available productive freshwater habitat when ocean survival is relatively low (Lawson 1993). Success during spawning and juvenile rearing phases of the life cycle may help compensate for less than favorable marine conditions by maintaining a high rate of smolt production for each returning female salmon. High rates of freshwater survival and growth should help maintain relatively small demes during periods of weak marine production and support large, abundant demes during periods of strong ocean production.

Long-term vision is also needed in order to properly interpret the results of salmon enhancement programs in an adaptive learning context. Habitat managers should be careful not to proclaim habitat enhancement projects successful based on short-term increases in fish populations (Hilborn and Winton 1993), especially when those increases may have been caused by factors unrelated to freshwater habitat (e.g., reduced fishing rates or increased ocean survival). Recovery of ecosystem functions at large landscape scales will be gradual. The high interannual variability in salmon abundance (Fig. 2) will make it difficult to detect long-term, consistent improvement in the productivity of a watershed for various species. Even large increases in salmonid populations caused by habitat improvement projects are likely to require decades for statistical detection (Fig. 4).

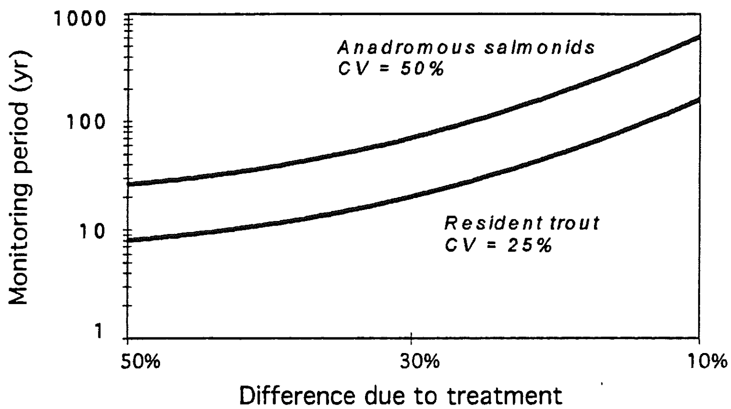

Figure 4. Years of monitoring required to be 80% certain of detecting true treatment differences at a Type 1 error level of $p \leq 0.05$ (Sokal and Rohlf 1981) for an anadromous salmonid population having an interannual coefficient of variation (CV) of 50% and a resident salmonid population having an interannual CV of 25% (based in part on population studies summarized in Fig. 2).

For these reasons we argue that planning horizons should extend well beyond the normal scope of long-term plans, which are more often on the order of decades rather than centuries. Large disturbances and long-term climate changes are usually impossible to forecast, but planning should proceed with the certainty that they will eventually occur and that they will create a mosaic of conditions on the landscape. We do not suggest that human activities must create no disturbances, but rather that the type and frequency of disturbances match to the extent possible those that exist naturally. With the advent of geographic information system technology and other new modeling tools, comprehensive views of current and proposed watershed characteristics can assist planners in designing management activities that better resemble natural disturbances and are more compatible with natural successional processes and hydrologic regimes. Such an approach was used by the FEMAT as an example of how timber harvest in the Augusta Creek (Oregon) watershed could simulate historical patterns of wildfire (FEMAT 1993).

Need for a Better Landscape Context

We have avoided specific recommendations for desired future conditions because in most cases our knowledge of the natural disturbance history of Pacific Northwest watersheds is far from complete. Although some habitat trends are abundantly clear and do not require additional verification before restoration can begin (e.g., loss of floodplain habitat, loss of late-successional and old-growth riparian forests, loss of lowland sloughs and estuaries, accelerated erosion, and highly altered streamflows), information on the distribution of aquatic and riparian habitat in various recovery states following natural disturbances is usually lacking. Without such information, our ability to provide a landscape context for establishing refugia or determining appropriate restoration strategies for extensively altered stream networks will lack the spatial and temporal dimensions needed to match salmon population dynamics (Gregory and Bisson 1996). The locations of favorable habitats within watersheds will change over time and management plans should be cognizant of these changes. For example, we should know the location of important overwintering sites for different species within a river system and be able to predict how proposed management activities will likely influence their condition and accessibility in the event of a large flood. As a better understanding of basic watershed processes is developed, our ability to identify desired future conditions appropriate to specific watersheds will improve. This understanding should begin with a careful examination of the local disturbance regime.

Watershed analysis, a procedure for assessing the current condition of streams with respect to biophysical watershed processes, aquatic resource values, and their vulnerability to disruption by forestry operations (Washington Forest Practices Board 1993, USDA Forest Service 1994) provides an opportunity to incorporate disturbance history into landscape planning. The NRC report on the protection and management of anadromous salmonids in the Pacific Northwest (NRC 1996) strongly endorsed the importance of recognizing natural disturbance patterns in the watershed analysis process. The NRC report identified four major categories of information to be addressed when describing current conditions and management objectives: (1) the spatial context of the watershed (i.e., the location and geomorphic setting of channel characteristics such as constrained versus unconstrained, sinuous versus braided, incised versus unincised, bedrock-controlled versus alluvial floodplains), (2) the temporal context and natural disturbance history of the watershed (i.e., its annual flow regime and sediment yield, long-term channel changes, climate trends, forest successional patterns, fire history, and other significant natural disturbances), (3) the range of riparian vegetation and availability of reference sites within the watershed (i.e., the variation in riparian community composition and the presence of unmanaged areas within the watershed or nearby that can be used as reference sites for identifying natural conditions), and (4) the history of human impacts within the watershed (i.e., the institutional, scientific, and social records of anthropogenic changes to the watershed's ecosystem).

A watershed analysis procedure that addresses the dynamic aspects of watershed processes in the context of spatial and temporal disturbance history will be very useful for determining the extent of habitat alteration caused by land management and for providing a rational framework for establishing target ranges of future conditions (Peterson et al. 1992). The protocols of Washington State (Washington Forest Practices Board 1993) and federal watershed analysis (USDA Forest Service 1994) are geomorphically based and recognize different types of natural and anthropogenic physical disturbances, particularly those related to erosional events. Analysis of physical watershed processes in both procedures explicitly acknowledges long-term changes in the sediment and woody debris properties of stream channels, yet a similarly dynamic perspective is often not applied in watershed analysis for the assessment of biological communities and their habitats (Karr 1994). Stream reach-specific habitat ratings (good, fair, or poor) rely on habitat standards relevant to certain salmonid species or life cycle phases (Table F-1, p. F-22 in Washington Forest Practices Board 1993). Stream segments are classified according to use by the predominant salmonid species with little consideration for long-term changes in population distribution (Figure F-2, p. F-13 in Washington Forest Practices Board 1993). Habitat parameters are considered individually without the possibility of synergism among elements (Table F-1, p. F-22 in Washington Forest Practices Board 1993; p. 2-112 in USDA Forest Service 1994), and fish population objectives do not adequately consider natural variability (p. 2-103 in USDA Forest Service 1994).

As watershed analysis protocols are further refined, we hope they will place less emphasis on enforcing reach-specific standards that benefit a few salmonid species, possibly for only a limited time, and more emphasis on restoring an appropriate range of natural aquatic-riparian ecosystem states throughout watersheds. For example, a large increase in fine sediment or large decrease in shade in a single stream segment might be less alarming than small to moderate increases in sediment or temperature throughout the entire watershed if other streams with favorable habitat are present in the drainage. Relatively severe but localized disturbances are part of a watershed's history, but widespread gradual changes may not be representative of the natural disturbance regime.

We conclude our discussion of desired future conditions with the observation that existing knowledge of natural disturbance regimes and aquatic-riparian habitat is often highly imperfect and, therefore, we must make many assumptions and inferences with regard to what target conditions should be. Because pristine watersheds are rare in the Pacific Northwest, because a regional network of reference sites has not been established, and because current knowledge of the response of aquatic and riparian ecosystems to disturbance is incomplete, we cannot define desired future conditions with certainty at regional or watershed scales. Natural resource managers should not be afraid to implement bold and innovative approaches to restoring functional aquatic and riparian ecosystems, provided the effects are carefully monitored and evaluated (Walters et al. 1988). Although it is impossible to describe in detail how desired future conditions should appear, we do not believe land-use planners should be deterred from attempting to restore functional ecological linkages between streams and their watersheds and, especially, from designing management actions that better simulate the effects of natural disturbances. The current status of many salmon stocks calls for conservative habitat protection, yet we argue that to ignore the historical disturbance context within which these and other aquatic organisms evolved is to ignore some of the most important processes upon which they depend.

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