
The Aquatic Conservation Strategy of the Northwest Forest Plan

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Abstract: *Implemented in 1994, the Aquatic Conservation Strategy of the Northwest Forest Plan was designed to restore and maintain ecological processes for aquatic and riparian area conservation on federal lands in the western portion of the Pacific Northwest. We used decision support models to quantitatively evaluate changes in the condition of selected watersheds. In the approximately 10 years since strategy implementation, watershed condition scores changed modestly, but conditions improved in 64% of 250 sampled watersheds, declined in 28%, and remained relatively the same in 7%. Watersheds that had the largest declines included some where wildfires burned 30–60% of their area. The overall statistical distribution of the condition scores did not change significantly, however. Much of the increase in watershed condition was related to improved riparian conditions. The number of large trees (>51 cm diameter at breast height) increased 2–4%, and there were substantial reductions in tree harvest and other disturbances along streams. Whether such changes will translate into longer-term improvements in aquatic ecosystems across broader landscapes remains to be seen.*

Key Words: decision support models, ecosystem management, public lands, riparian management

La Estrategia de Conservación Acuática del Plan Forestal del Noroeste

Resumen: *Implementada en 1994, la Estrategia de Conservación Acuática del Plan Forestal del Noroeste fue diseñada para restaurar y mantener procesos ecológicos para la conservación de áreas acuáticas y ribereñas en terrenos federales en la porción occidental del Pacífico Noroeste (E.U.A.). Utilizamos modelos de soporte de decisiones para evaluar cuantitativamente los cambios en la condición de cuencas seleccionadas. En los casi 10 años desde la implementación de la estrategia, los valores de la condición de las cuencas cambiaron someramente, pero las condiciones mejoraron en 64% de las 250 cuencas muestreadas, declinaron en 28% y permanecieron relativamente iguales en 7%. Las cuencas con las mayores declinaciones incluyeron algunas en las que 30–60% de su superficie fue quemada por fuegos sin control. Sin embargo, la distribución espacial total de los valores no cambió significativamente. Buena parte del incremento en las condiciones de la cuenca se relacionó con el mejoramiento de las condiciones ribereñas. El número de árboles grandes (>51 cm diámetro a la altura del pecho) aumentó 2–4%, y hubo reducciones sustanciales en la cosecha de árboles y otras perturbaciones a lo largo de arroyos. Aun habrá que ver si tales cambios se traducirán en mejoramientos a largo plazo en los ecosistemas acuáticos en paisajes más extensos.*

Palabras Clave: gestión de ecosistemas, gestión ribereña, modelos de soporte de decisiones, terrenos públicos

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Introduction

The fauna of aquatic ecosystems, and particularly freshwater fish species, in the Pacific Northwest is characterized by relatively few species and relatively high rates of endemism (Moyle & Herbold 1987). More than 25% of these species are anadromous (Reeves et al. 1998), the best known being the Pacific salmon (*Oncorhynchus* spp.). Many fish species in the region are extinct, threatened, or endangered (Riccardi & Rasmussen 1999), and as in other parts of North America numerous aquatic ecosystems are degraded or altered to varying degrees by past and present human activities (Naiman & Turner 2000).

The Aquatic Conservation Strategy (ACS) of the Northwest Forest Plan (NWFP) is a regional strategy applied to aquatic ecosystems across the area inhabited by the Northern Spotted Owl (*Strix occidentalis caurina*). The ACS seeks to prevent further degradation of aquatic ecosystems and to restore and maintain habitat and ecological processes responsible for creating habitat over broad landscapes of public lands administered by the U.S. Department of Agriculture Forest Service (USFS) and the Bureau of Land Management (USDA Forest Service & BLM 1994). The foundation of the ACS was a refinement of earlier strategies: "The Gang of Four" (Johnson et al. 1991), PacFISH (USDA 1992), and the Scientific Assessment Team (Thomas et al. 1993). In the short term (10–20 years) the ACS is designed to halt declines in watershed condition and to protect watersheds that had good-quality habitat and healthy fish populations (FEMAT 1993). The long-term goal (100+ years) is to develop a network of functioning watersheds that supported populations of fish and other aquatic and riparian-dependent organisms across the NWFP area (USDA Forest Service & BLM 1994).

The ACS differs from previous conservation and management plans for aquatic ecosystems in its extent and complexity. Past attempts to recover fish populations were generally unsuccessful because they focused on good habitat in isolated stream reaches and not on watersheds (Williams et al. 1997). Also, previous plans focused riparian protection on relatively small portions of the aquatic ecosystem, generally within 30 m of fish-bearing streams, and over small geographic areas. In contrast, the ACS includes the entire riparian ecosystem, identifies watersheds that are meant to act as refugia for fish in the short term, and applies over a large area.

The ACS has five components through which to meet its goals and objectives: (1) watershed analysis, (2) riparian reserves, (3) key watersheds, (4) watershed restoration, and (5) standards and guidelines for management activities (USDA Forest Service & BLM 1994). Watershed analysis is an analytical process that determines the ecological characteristics and processes of watersheds and identifies potential management actions to address watershed-specific problems and concerns, includ-

ing possible adjustments to riparian reserve boundaries. Riparian reserves define the outer boundaries of the riparian ecosystem and are portions of a watershed most tightly coupled with streams and rivers. They provide the ecological functions and processes necessary to create and maintain habitat for aquatic- and riparian-dependent organisms over time, dispersal corridors for terrestrial organisms, and connectivity of streams within watersheds (FEMAT 1993). The boundaries are interim until a watershed analysis is completed, at which time they may be modified as suggested in the watershed analysis.

Two categories of key watersheds were identified: tier 1 key watersheds have strong fish populations or habitat, high restoration potential, or both; and tier 2 key watersheds provide sources of high-quality water. Watershed restoration is designed to recover degraded habitat and to restore critical ecological processes that create and maintain favorable environmental conditions for aquatic- and riparian-dependent organisms. Standards and guidelines are quantitative and qualitative objectives that guide management activities in riparian reserves and key watersheds and are not discussed here.

Our primary objective was to identify expectations for the ACS in the first 10 years of implementation and to assess how well the ACS has met initial expectations. We summarize recently completed analyses on the NWFP and ACS and report on quantitative and qualitative assessments of available data and information.

Expectations and Results

Potential Listing of Fish Species and Population Segments

A primary motivation for developing the ACS was the anticipated listing of distinct population segments of various species of Pacific salmon, called evolutionarily significant units, and other fish species under the U.S. Endangered Species Act of 1973 (ESA). When the NWFP was developed in 1993, the Sacramento winter Chinook salmon (*O. tshawytscha*), the shortnose sucker (*Chasmistes brevirostris*), and the Lost River sucker (*Deltistes luxatus*) were the only listed fish in the NWFP area. Since then, 23 distinct population segments of five species of Pacific salmon and 3 population segments of bull trout (*Salvelinus confluentus*) found in the area have been listed. Twenty population segments of Pacific salmon and all bull trout population segments occur on federal lands managed under the NWFP (Table 1). Additionally, the Oregon chub (*Oregonichthys crameri*) was listed after the NWFP was implemented, and coho salmon (*O. kisutch*) on the Oregon Coast are a candidate for listing.

The NWFP was expected to aid in the recovery of ESA-listed fishes, particularly the anadromous salmonids, by increasing the quantity and quality of freshwater habitat (FEMAT 1993). It was not considered sufficient to prevent

Table 1. Estimated area of riparian reserve in which silvicultural activities occurred during the first 10 years of the Northwest Forest Plan.

<i>Administrative unit</i>	<i>Time period</i>	<i>Area thinned (ha)</i>	<i>Area of regeneration harvest (ha)</i>	<i>Total</i>
USDA ^a Forest Service				
Region 6				
Mt. Baker-Snoqualamie	1994-2000	446	0	446
Okanogan-Wenatchee	1994-2000	875	122	997
Gifford-Pinchot	1994-2004	243	0	243
Olympic	1994-2004	446	446	892
Mt. Hood	1998-2004			486 ^b
Deschutes	1997-2004	284	0	284
Willamette	1994-2004	2,673	51	2,724
Siuslaw	1994-2004	5,091	520	5,611
Umpqua	1994-2004	891	122	1,013
Siskiyou-Rogue River	2000-2004	770	0	770
Fremont-Winema	2003	162	0	162 ^c
estimated total		11,881	1,261	13,628
Region 5				
Klamath	1994-2004	1,862	316	2,178
Shasta-Trinity	1994-2004	689	209	898
Six Rivers	1994-2004	1,332	209	1,541
Mendocino	1994-2004	0	0	0
estimated total		3,883	734	4,617
Bureau of Land Management				
Oregon-Washington				
Salem	1995-2003			323 ^c
Coos Bay	1995-2003			1,326 ^c
Eugene	1995-2003			211 ^c
Roseburg	1995-2003			335 ^c
Medford	1995-2003			269 ^c
estimated total				2,464
California				
Arcata	1995-2004	34	0	34
Ukiah	1995-2004	0	0	0
estimated total		34		34
Estimated combined total				20,743

^aU.S. Department of Agriculture.

^bEstimated to be 40-81 ha/year with no breakdown of treatment type.

^cNo breakdown of treatment type provided.

the listing of any species or distinct population segment, because federal land management agencies have authority over fish habitat on federal lands, not the fish populations themselves. State agencies regulate activities that affect fish populations on all lands, and fish habitats on nonfederal lands. Factors outside the responsibility of federal land managers may contribute to the declines of many species and population segments and strongly influence their recovery. These factors include degradation and loss of lower-elevation freshwater and estuarine habitats, which are primarily on nonfederal lands, excessive harvest in commercial and recreational fisheries, migratory impediments such as dams, and loss of genetic integrity due to hatchery practices and introductions (National Research Council 1996).

Changes in Watershed Condition

The ACS was designed to halt further declines in watershed condition and to improve the ecological condition

of watersheds in the NWFP area over a period of several years to decades (FEMAT 1993). It was premised on preserving key ecological processes and recognizes that periodic disturbances may result in less than optimal conditions for fish for short periods but that these events are critical for maintaining long-term productivity of aquatic ecosystems. As a result the ACS did not expect all watersheds to have favorable conditions for fish at any particular time and does not expect any particular watershed to be in a certain condition over time. It did, however, recognize that significant results were not expected for several years to decades, because extensively degraded watersheds improve slowly (FEMAT 1993). Anadromous salmonid populations are assumed to have developed metapopulations with population centers historically occupying the most favorable habitats over time (Reeves et al. 1995). If the ACS and the NWFP are effective in improving habitat conditions, the proportion of watersheds in better condition should increase over time (Reeves et al. 2004). The ACS does not, however, identify a particular

desired or acceptable distribution of watershed conditions across the NWFP area.

An effectiveness monitoring program for the ACS was to be developed and implemented shortly after the signing of the Record of Decision (ROD) for the NWFP (USDA Forest Service & BLM 1994). The first two attempts to develop a monitoring plan failed because the involved agencies could not agree on a common vision for the NWFP or a common approach to the problem and methods. A monitoring program was finally developed and prototyped in 2000. Components of the program and the rationale for them are described in Reeves et al. (2004). The monitoring process illustrates the struggle the responsible agencies had implementing the ACS, and other parts of the NWFP, because of differences in legislative mandates and management philosophies.

The monitoring plan attempted to characterize the ecological condition of watersheds by integrating a suite of physical indicators and tracking condition trend in the population of watersheds (Reeves et al. 2004). The condition of watersheds was evaluated with decision support models that incorporated fuzzy logic (Zadah 1965). Such models are used for ecological assessment and analysis of ecological data (e.g., Equihua 1990) and for assessment of environmental conditions (e.g., Meesters et al. 1998). The ACS watershed condition models integrated riparian, upslope, and in-channel conditions of a watershed (Reeves et al. 2004). Watershed condition was estimated with only the riparian and upslope parameters, however, because in-channel data were not available for all watersheds.

Relations between parameters in these areas and watershed condition were defined based on empirical relations between individual parameters and watershed condition as established in the scientific literature and in the professional judgment of aquatic specialists from the national forests, BLM districts, regulatory agencies involved with the NWFP, and state fish-management agencies (Reeves et al. 2004). Models were built at the province and sub-province scales to account for ecological variability (Gallo et al. 2005).

Watershed condition was defined as "good" if the physical attributes were deemed adequate to maintain or improve biological integrity, primarily for native and desired fish species (Reeves et al. 1995, 2004). Physical attributes included age, size, and composition of riparian vegetation and quantities of roads, pools, and channel sediment (see Gallo et al. [2005] for complete list). Reeves et al. (2004) assumed that systems in good condition would recover if disturbed by a natural event or land-management activities. They emphasized the need to recognize that the natural condition of any watershed may vary widely over time, that those watersheds with little or no human activity would not necessarily have favorable conditions for fish all the time, and that at any point in time not every watershed would be in good condition. The focus of the monitoring program therefore was not on changes in indi-

vidual watersheds but rather on the statistical distribution of watershed condition scores across the NWFP area.

Two hundred and fifty sixth-field watersheds (i.e., sub-watersheds; 4,000–16,000 ha) with $\geq 25\%$ federal ownership were randomly selected from the 1,372 in the NWFP area that met the ownership criterion. Fifty watersheds a year were to be sampled over a 5-year cycle in a rotating panel design (Reeves et al. 2004). A wide variety of management conditions, from roadless and wilderness to intensive timber harvest and livestock grazing, occurred in these watersheds.

Because of funding limitations, in-channel conditions have been sampled in only 55 of the 250 selected watersheds (Gallo et al. 2005), and none have been sampled a second time. A thorough assessment of the ACS is not possible without more complete data. A limited assessment, however, compared changes in watershed condition between 1994 and 2003 based on only riparian vegetation and road parameters. Composition and size of conifers > 51 cm diameter at breast height in riparian areas were estimated using GIS layers developed to assess changes in late-successional and old-growth habitat (Moeur et al. 2005). Riparian areas were defined as the area within 46 m on each side of streams on the west side of the Cascade Range and within 28 m of streams on the east side of the Cascades (Gallo et al. 2005). The length of roads in watersheds was estimated from aerial photographs. The statistical distribution of watershed-condition scores did not change between 1994 and 2003 (Gallo et al. 2005) (Fig. 1).

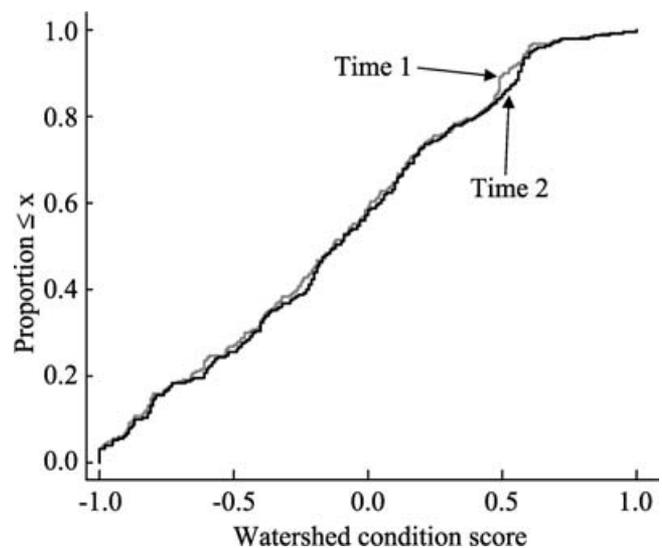


Figure 1. Statistical distribution of condition scores of watersheds sampled in 1994 and 2003 as part of the effectiveness monitoring program of the Aquatic Conservation Strategy of the Northwest Forest Plan (from Gallo et al. 2005).

In the short term (10–20 years), large improvements in the condition of individual watersheds or changes in the distribution of conditions were not expected because many watersheds were extensively degraded and because of the slow rate of recovery of natural systems (FEMAT 1993). At best, degradation would be slowed or halted and some minor to moderate improvements in watershed condition could result from implementing the ACS.

The proportion of watersheds with higher condition scores in 2003 than in 1994 compared with those with lower scores was greater than expected by chance alone ($p < 0.01$, Wilcoxon signed-rank test, Sokal & Rohlf 1969). Condition scores of about 18 of the 250 watersheds remained the same, 161 increased, and 71 decreased between 1994 and 2003 (Fig. 2). The average changes in scores were relatively small, 0.09 (SD 0.19) for those that increased and 0.14 (SD 0.3) for those that decreased. Decreases in watershed condition scores were not simply related to management activities. The four watersheds that exhibited the largest decline had 30–60% of their watershed area burned. The observed overall changes in condition scores suggest improvements in the condition of watersheds because of the ACS.

The ecological significance of this change is not yet known, however. Also, because multiple factors can influence watershed condition, a change in score can occur because of changes in one or more factors. How these factors interact needs further research.

The change in watershed condition scores during the first decade of the NWFP was attributable primarily to changes in riparian vegetation and more specifically to an increase in the number of large trees in riparian areas. The type, size, and distribution of vegetation in riparian and upslope areas influence the condition of aquatic

ecosystems (Burnett 2001); generally, the larger and more numerous the conifers, the better the condition of a watershed. The number of large trees in sampled watersheds increased an estimated 2–4% during between 1994 and 2003, most likely the result of tree growth into the >51 cm diameter at breast height category (Gallo et al. 2005). Concurrently, the amount of riparian area subjected to clearcutting on federal lands in Oregon and Washington in the NWFP area was one-seventh of that in 1988–1991 and even less compared with earlier periods (Gallo et al. 2005). Projections of tree size on federally managed lands in the central and northern Oregon Coast Range suggest that the number of large trees should continue to increase by 15–20% over the next 100 years under the current policy (Burnett et al. 2006; Spies et al. 2006).

Condition scores of watersheds as influenced by roads, which can significantly affect aquatic ecosystems (Trombulak & Frissell 1999), generally did not change with implementation of the NWFP (Gallo et al. 2005). It is estimated that 5360 km of roads (3.6% of the estimated total length) were decommissioned or closed on national forests in the NWFP area (Baker et al. 2006). An estimated 570 km of new roads were constructed during the same period (Baker et al. 2006). About 5000 km were “improved”; that is, actions were taken to reduce sediment delivery and improve stability or to allow more natural functioning of streams and floodplains, including improvements in road drainage, stabilization, and relocation. Current models of watershed condition do not take road improvements into account because, in part, data on them were not available in the federal agencies’ databases.

In general, it appears that the length of roads removed from any given watershed may have been insufficient to improve the condition scores or that roads were removed from parts of the watershed, such as ridge tops or nonriparian areas, that are less likely to directly affect aquatic ecosystems (Wemple et al. 2001). Watersheds with condition scores that increased had the most extensive road-decommissioning efforts (Gallo et al. 2005). Road restoration programs in these watersheds focused on removing roads from riparian areas and areas with high landslide hazard. The provincial and subprovincial watershed-condition models varied widely in how they accounted for road location. Some models considered location whereas others considered only road density (Gallo et al. 2005). Modification of models that do not consider road location may increase their sensitivity to restoration activities.

Because many watersheds are shared among federal and other ownerships, ecological assessment of an entire watershed often required consideration of conditions on nonfederal lands. The objectives and practices of these owners differed from those specified by the NWFP. Watersheds with more nonfederal ownership had the smallest changes in watershed condition scores (Gallo et al. 2005). Ownership patterns thus influenced the potential

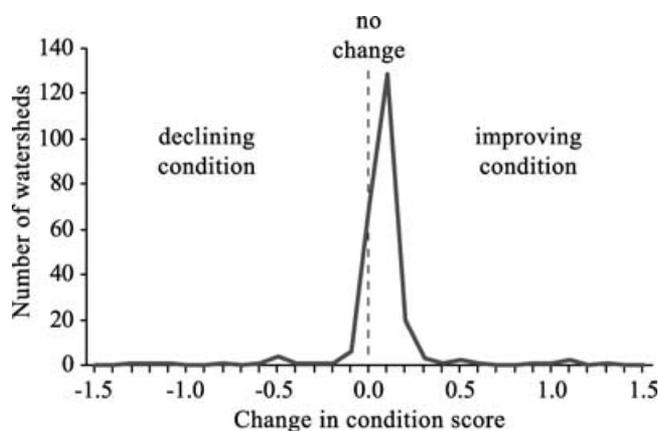


Figure 2. Changes in conditions scores of watersheds between 1994 and 2003 for the watersheds sampled as part of the effectiveness monitoring program of the Aquatic Conservation Strategy of the Northwest Forest Plan.

amount of change that can be expected in some watersheds and should perhaps be considered in future assessments of the effectiveness of the ACS.

Population numbers of many ESA-listed anadromous salmonids in the NWFP area, and other parts of the Pacific Northwest, have increased since the NWFP was implemented. It is not possible, however, to discern how much the NWFP has contributed to this increase. Conditions of freshwater habitats on federal lands have improved moderately under the NWFP (Reeves 2006) but not to an extent that could account for the current increases in the numbers of returning adults. Populations in areas outside the NWFP area have shown similar, and in some cases even larger, changes.

The real contribution of improved freshwater habitats and ecosystems to the persistence and recovery of anadromous salmonids in the region covered by the NWFP will be determined when conditions in the marine environment become less favorable as the Pacific Decadal Oscillation (Mantua et al. 1997) moves into a less-productive phase. The persistence of anadromous salmonid populations depends to a large degree on freshwater habitat during such times (Lawson 1993). Improvements in the quantity and quality of freshwater habitat should yield greater numbers of fish entering the ocean and thus increase the likelihood of persistence of many populations during periods of low ocean productivity.

Riparian Reserves

The riparian reserve network established by the ACS encompasses an estimated 1,053,000 ha and is a significant expansion from previous land-use plans. Before the ACS the riparian ecosystem was generally defined as 30.5 m on either side of fish-bearing streams or streams in some areas with high landslide risk (Fig. 3a). The riparian reserve network of the ACS is based on an "ecological functional" approach that identifies zones of influence rather than set distances and includes the entire stream network, not just fish-bearing streams. Consequently the riparian zone along streams was expanded to the height of two site-potential trees (the height of a site-potential tree is the expected height of various conifer tree species at a given location in 100 years) along fish-bearing streams and the height of one site-potential tree along permanently flowing and intermittent streams without fish (USDA Forest Service & BLM 1994) (Fig. 3b). The latter streams can be 90% or more of the stream network, and their inclusion undoubtedly was the primary reason for the larger area considered as the riparian ecosystem in the ACS compared with previous management plans. The ecological importance of these streams was once poorly understood. Now research results show the importance of headwater streams as areas of high amphibian biodiversity and sources of wood, sediment, cool water, and nutrients for

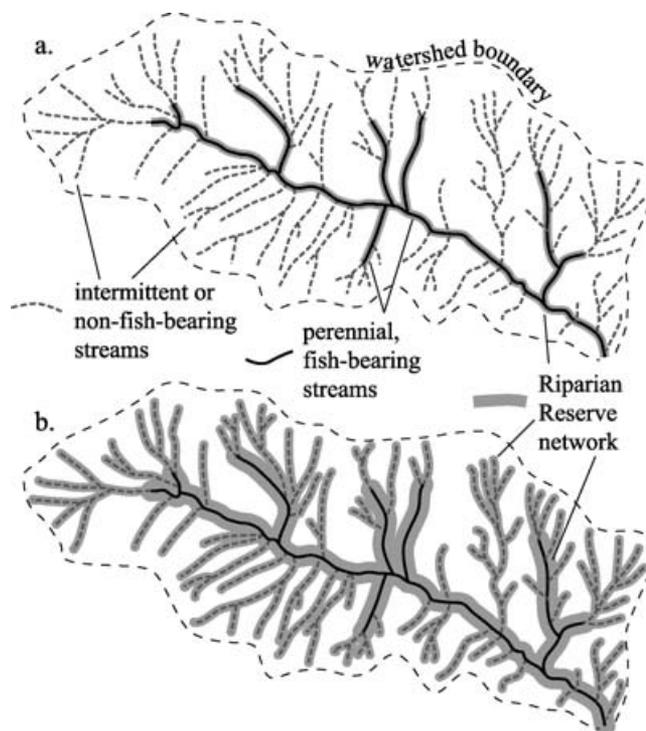


Figure 3. Generalized representation of the extent of the riparian reserve network (a) before and (b) under the Aquatic Conservation Strategy of the Northwest Forest Plan.

fish-bearing streams (reviewed in Reeves 2006). The difference in extent of riparian reserves between the ACS and previous plans was greatest in the steeper, more highly dissected landscapes, where stream density was highest (FEMAT 1993).

More than 800 of the 1100 organisms considered in FEMAT (1993) are associated with the riparian reserve network. The FEMAT (1993) suggests that the size of the riparian reserve in headwater streams be the distance equal to one-half the height of a site-potential tree, but it was changed to a full tree height in the ROD (USDA Forest Service & BLM 1994) to increase the likelihood of persistence of habitat for aquatic- and riparian-dependent organisms.

Initial widths of riparian reserves were expected to be interim and activities within them very restricted until a watershed analysis was completed. It appears, however, that the interim boundaries of the riparian reserves remained intact in the vast majority of watersheds (Baker et al. 2006). One reason given for this was that the burden of proof for adjusting the boundaries was too high. No explicit criteria for changing the boundaries were established by FEMAT (1993) or the ROD (USDA Forest Service & BLM 1994) other than to require that those proposing to undertake activities within the riparian reserves demonstrate that the actions would not have negative effects.

Tools are now available that identify the more ecologically important parts of the riparian and stream network from an aquatic perspective (such as Benda et al. 2006). Because watershed analysis is an interdisciplinary endeavor, however, changes in the riparian reserve boundaries need to consider nonaquatic factors such as terrestrial and social concerns. Only a few watershed analyses considered these factors and substantially adjusted the interim boundaries of the riparian reserves (e.g., Cissell et al. 1998).

Timber production, primarily precommercial thinning, occurred on an estimated 21,000 ha (2% of the estimated total area) of riparian reserve (Table 1). The volume of timber harvested is not known because agencies do not track trees cut outside of typical timber-production zones. Limited timber harvest was expected to occur in riparian reserves, but no level was specified by FEMAT (1993) or the ROD (USDA Forest Service & BLM 1994). Harvest from the riparian reserve was not part of the estimated probable sale quantity of the NWFP and was not counted toward it. Agency personnel thought that one of the primary reasons for the limited timber harvest in the riparian reserve was the difficulty in changing boundaries and in determining that there would be no adverse affects from the activities (Baker et al. 2006).

Watershed Restoration

Watershed restoration efforts were expected to catalyze recovery of key ecological processes that create and maintain aquatic habitat (FEMAT 1993). Restoration efforts were comprehensive, addressing both protection of existing functioning aspects of a watershed and restoration of degraded or compromised aspects. It was recognized that it may not be possible for restoration efforts to affect every watershed and that restoration would have only limited success in some watersheds because of the extensive level of past degradation. The results of restoration efforts were not expected to be large or immediately visible or measurable (FEMAT 1993). At the watershed scale it may take an extended time to observe the effects of restoration. Although it may appear that relatively large areas have been restored, in reality this represents only a small proportion of the total area previously degraded.

It is not possible to accurately assess the regional effect of numerous restoration efforts undertaken as part of the ACS. Gallo et al. (2005) highlight several successful restoration efforts, but the impact of those efforts could not be discerned at a regional scale. The length of streams restored or made accessible to fish was a relatively small fraction of the total length of streams. Watersheds that have the largest improvement in condition scores, however, are those that have relatively extensive road restoration programs (Gallo et al. 2005). Similarly, Baker et al. (2006) report that almost 27,600 ha of riparian reserve



Figure 4. Location of key watersheds of the Aquatic Conservation Strategy of the Northwest Forest Plan.

(2.6% of the estimated total area) were restored, primarily in Washington and Oregon, between 1998 and 2003. We expect that as the effects of these restoration efforts combine with those that may occur in the future, their results will be more discernable.

Key Watersheds

Tier 1 key watersheds (141, covering 3,300,000 ha, Fig. 4) were intended to serve as refugia for aquatic organisms

or to have high potential for restoration (USDA Forest Service & BLM 1994). Tier 2 key watersheds provide sources of high-quality water and comprise 23 watersheds covering about 405,000 ha (Fig. 4). Key watersheds are aligned as closely as possible with late-successional reserves of the NWFP (i.e., areas designated to protect late-successional and old-growth ecosystems) and other officially designated reserve areas to maximize ecological efficiency (USDA Forest Service & BLM 1994) and to minimize the amount of area in which timber harvest activities were restricted.

A primary objective for the tier 1 key watersheds is to aid in the recovery of ESA-listed fishes, particularly in the short term (FEMAT 1993). Tier 1 key watersheds currently in good condition were assumed to serve as centers for potential recovery of depressed populations. Those with currently degraded conditions were expected to have the greatest potential for restoration and to become future sources of good habitat.

Key watersheds had greater increases in condition scores than nonkey watersheds (Gallo et al. 2005). More than 70% of key watersheds improved compared with <50% of nonkey watersheds. The primary reason for this difference was that more than twice as many kilometers of roads were decommissioned in key watersheds as in nonkey watersheds. This result suggests that land-management agencies appear to have recognized key watersheds as priority areas for restoration.

Key watersheds were originally selected based on the professional judgment of fish biologists from the national forests and BLM districts covered by the NWFP. No formal evaluation of the potential effectiveness of the network watersheds was conducted during NWFP development or since it was implemented. Fish populations in need of attention are clearly identified now, and it would be useful to see whether the current system is beneficial to those fish in terms of the overall distribution and the suitability of individual watersheds.

New techniques are now available to aid in this assessment. For example, Burnett et al. (2003) developed a process to identify the potential of a watershed or stream reach to provide habitat for coho salmon (*O. kistutch*) and steelhead (*O. mykiss*) based on topographic features. In an analysis of a portion of the northern Oregon Coast Range, areas with the highest potential to provide habitat for coho salmon (a candidate species for listing under the ESA) were primarily on private lands, whereas the best potential habitats for steelhead (which is not a listed species) were approximately evenly divided between public and private lands. Analysis of the entire Coast Range indicates that about 10% (540 km) of the stream length with the best potential to provide habitat for coho salmon is on federally managed lands (K. Burnett et al., unpublished data). A relatively small proportion of this habitat is found in key watersheds. Similar analyses in other areas could help determine the current effectiveness of key watersheds.

Watershed Analyses

Watershed analysis is designed to provide the context for management activities in a particular sixth-field watershed and the basis for developing project-specific proposals and determining restoration needs. Watershed analysis is envisioned in the ROD (USDA Forest Service & BLM 1994) as an analytical and not a decision-making process that involves individuals from a variety of scientific disciplines. Management agencies were expected to complete a watershed analysis before activities (except minor ones) were started in key watersheds or riparian reserves (USDA Forest Service & BLM 1994). The version of watershed analysis advocated in the NWFP differs from previous versions (e.g., Washington Forest Practices Board 1993) in involving multiple disciplines and issues other than those specifically aquatic. Since the ROD (USDA Forest Service & BLM 1994), several researchers have examined the watershed analysis process and framework (Ziemer 1997; Reid 1998), but these analyses are primarily from an aquatic perspective. A more comprehensive review and evaluation of watershed analyses could help improve processes and reduce costs while increasing the usefulness of the product.

No formal assessment of watershed analyses has been completed. Baker et al. (2006) estimate that about 500 watershed analyses existed by 2003, but their quality and effectiveness vary widely. The watershed analysis process should be reexamined so that it is conducted more efficiently and considers the appropriate spatial scales, including the watershed of interest and its context within the larger basin. The latter is particularly relevant if the NWFP is to be implemented effectively at a landscape scale.

Cultural Shifts within Land-Management Agencies

Implementation of the NWFP and ACS brought major changes to the way the affected land management agencies viewed and managed aquatic resources and watersheds. The NWFP and ACS changed the focus from small spatial scales (i.e., project areas) to larger landscapes. It appears that the implications of these changes have not been recognized fully or appreciated by the land-management and regulatory agencies or general public (Reeves 2006). It is difficult to accurately describe or quantify other changes. The ACS replaced local land-use plans that contained a variety of management directions and objectives with a common framework for managing aquatic and riparian resources on public lands. Additionally, it required a more comprehensive approach to the management of aquatic and riparian resources, including extensive cross-disciplinary coordination among staff, scientific assessment of watershed conditions before implementing activities, and a focus on restoring processes that maintain

Table 2. Changes in paradigms for managing aquatic and riparian resources that occurred as result of the implementation of the Northwest Forest Plan (NWFP) and Aquatic Conservation Strategy (ACS) (modified from Heller 2002).

<i>Old</i>	<i>New</i>
Management activities can occur unless unacceptable adverse impacts can be shown likely to occur	management activities must contribute to, or not retard, attainment of ACS objectives
A variety of individual approaches for the protection and restoration of aquatic and riparian dependent resources, often different between administrative units for no apparent reason	one consistent strategic approach for the protection and restoration of aquatic and riparian dependent resources across the entire plan area
Focus on the condition of individual streams or stream segments or sites, primarily on public land	management focus on process and function of whole watersheds, with special efforts to consider and coordinate activities across all ownerships
Effectiveness monitoring highly variable between administrative units; protocols inconsistent and preclude summarization and analysis across the NWFP area	a formal program, with consistent protocols, monitors effectiveness of the strategy across the NWFP area; data can be summarized and analyzed for the NWFP area
Federal agencies generally work independently; coordination often infrequent and driven by "problems"; efforts to involve all stakeholders occur but are not the norm	emphasis on coordinating the activities of federal agencies in the implementation and evaluation of the NWFP; special efforts made to include all stakeholders
Proposed actions came from "target" generally unrelated to ecosystem characteristics; analysis generally single disciplinary, single scale, and noncollaborative.	multiscale analysis of ecosystem form and function prior to formulating proposed actions

riparian and aquatic conditions. Table 2 summarizes these changes in agency culture, analysis, and analytical basis of management. In the view of many of the people responsible for the implementation of the ACS, these cultural changes are the primary successes of the NWFP. Results of a survey of USFS personnel involved with the implementation of the ACS show that most believe that the ACS was appropriate and that it has led to improved and proactive management of aquatic resources (Heller et al. 2004).

Summary and Considerations

Quantitatively assessing ACS effectiveness continues to be challenging because of data availability and quality. First, the accuracy and quality of data on some activities are questionable. Data on important indicators of effectiveness, such as the amount of streams on federally managed lands with water quality and quantity problems and the volume of timber harvested in riparian reserves, are not regularly reported. Watersheds degraded by management activities before the NWFP was implemented were expected to take several years or decades to recover (FEMAT 1993). Thus it is not too late to assemble credible data on activities and actions done under the ACS. The condition of watersheds is being improved by removing or improving roads, conducting in-channel restoration projects, and restoring riparian areas. Land-management agencies could require field units to report on selected key activities and have the data assembled and accessible in a central location. Availability of such data would facilitate a more complete and defensible assessment of the effectiveness of the ACS.

The ACS met its expectation that watershed condition should begin to improve in the first decade of the NWFP.

Conditions of watersheds in the NWFP have improved at least somewhat since the NWFP was implemented and the proportion of watersheds with improving conditions was significantly greater than those that declined. A primary reason for this improvement was an increase in the number of large trees in riparian areas and a decrease in the extent of clearcut harvesting in riparian zones. This general trend should be expected to continue, and may actually accelerate in the future, if the ACS continues to be implemented as originally intended.

One clear success of the ACS is a change in the general expectation of trends in aquatic conditions across the NWFP area. It is generally accepted that aquatic conditions deteriorated in the period of intensive federal timber harvest and road building before the NWFP, and these declines were predicted to continue under many of the land-use plans that the NWFP replaced. Several land-use plans that were to be implemented before the NWFP acknowledged that aquatic habitat would decline (e.g., the Siuslaw National Forest, Oregon) or have a high probability of declining (e.g., Umpqua and Siskiyou national forests, Oregon). Many of the activities that could have had negative effects on aquatic ecosystems, however, have subsided under the NWFP. The amount of timber harvest in riparian areas decreased substantially. Implementing the ACS appears also to have influenced the rate at which roads were built in the NWFP area. The length of roads decommissioned was nine times greater than the length built between 1995 and 2002, which is the opposite of the pre-NWFP trend. The ACS and NWFP appear to have prevented further degradation of watersheds that would have been likely under previous forest plans.

The science emerging since the NWFP was developed supports the framework and components of the ACS, particularly for the ecological importance of smaller, headwater streams (see Reeves [2006] for a more detailed

discussion). Also, a growing body of science about the dynamics of aquatic and riparian ecosystems could provide a foundation for refining management approaches and policies. Scientifically based tools for aiding watershed analysis are also available and could be used by the various agencies.

The interaction of processes operating at multiple spatial and temporal scales is difficult to understand and even more difficult to incorporate into a coherent management strategy such as the ACS and the NWFP. Understanding the relationships among different spatial scales is necessary to successfully assess the effects of management policies and activities on aquatic ecosystems in the future. The challenge is to develop a process that not only considers current aquatic conditions but also (1) broadly determines the spatial context, (2) historically assesses past trajectories of the systems and natural history, and (3) looks ahead to identify potential threats and expectations. This wider perspective would allow for a more integrated response to basic questions such as Where are we presently? Where do we want to go in the future? and How do we get there? Watershed analysis is a logical forum for exploring these questions.

The view of aquatic ecosystems as dynamic entities has implications for the network of key watersheds and the potential long-term success of the ACS. First, an underlying assumption about key watersheds was that streams in old-growth forests contained the best habitats for fish. Many of the key watersheds in the ACS were associated with late-successional reserves. Reeves et al. (1995) suggest that streams in mid-successional forests were more productive than those in old-growth forests in the Oregon Coast Range. Whether this pattern occurs in other areas is unknown at present and could be a future research emphasis. The second implication of treating aquatic ecosystems as dynamic entities deals with the expectations of reserves in dynamic landscapes. Reserves in such a setting cannot be expected to persist for long periods. How watersheds with high-quality habitat will develop and where in the landscape they will occur are key questions for managers, regulators, and researchers to consider now.

Although results are preliminary, it appears that land-management agencies altered their direction in ways that improved the ecological condition of aquatic and riparian systems and increased their capacity to support high levels of biodiversity that depend on these habitats. Although it is appropriate to examine ways to refine the ACS, including improving the effectiveness of watershed analysis and examining the impacts of wildfire on aquatic systems, we emphasize the importance of maintaining a comprehensive strategy that focuses on a variety of spatial and temporal scales.

The future of the ACS is uncertain at this time, in part, because of an ongoing court challenge. The ACS was amended by the USFS and BLM in 2004 (USDA Forest Service & BLM 2004) to indicate that project-level consistency with the ACS is not required and that consistency will be evaluated at the fifth-field watershed (an individual watershed within a hydrological unit). These agencies asserted that it was acceptable to undertake management activities such as stream restoration projects and some timber harvesting that may cause short-term negative effects but attain the ACS objectives in the long term. A coalition of groups representing environmental and fishing interests, however, filed a court challenge. They argued that the amended ACS failed to meet the requirements of the ESA and the U.S. National Environmental Policy Act of 1969. The plaintiff's rationale included that the amended ACS did not provide for a meaningful cumulative effects analysis because it failed to require assessment of how well individual projects met the ACS. Whether the ACS will be implemented in its original or amended form and what implications this has for management of aquatic ecosystems in the NWFP area are unknown until the court case is settled.

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Literature Cited

- Baker, D., C. Palmer, and T. Tolle. 2006. The Northwest Forest Plan—the first ten years (1994–2003). Implementation monitoring: accomplishments and compliance with plan requirements. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. Portland, Oregon.
- Benda, L., D. Miller, K. Andras, and G. H. Reeves. 2006. A coupled landscape-riverine terrain characterization and analysis system. *Forest Management*: in press.
- Burnett, K. M. 2001. Relationships among juvenile anadromous salmonids, their freshwater habitat, and landscape characteristics over multiple years and spatial scales in Elk River, Oregon. Ph.D. dissertation. Oregon State University, Corvallis.
- Burnett, K. M., G. H. Reeves, K. Christiansen, S. Clarke, D. J. Miller, and K. Vance-Borland. 2006. Distribution of salmon habitat potential relative to land use and forest cover in a multi-ownership province. *Ecological Applications*: in press.
- Burnett, K. M., G. Reeves, D. Miller, S. Clarke, K. Christiansen, and K. Vance-Borland. 2003. A first step towards broad-scale identification of freshwater protected areas for Pacific salmon and trout in Oregon, U.S.A. Pages 144–154 in J. P. Beumer, A. Grant, and D. C. Smith, editors. Protected areas: what works best and how do we know? Proceedings of the world congress on aquatic protected areas, Cairns, Australia, 2002. Australian Society for Fish Biology, North Beach.
- Cissell, J. H., et al. 1998. A landscape plan based on historical fire regimes for a managed forest ecosystem: the Augusta Creek study. General technical report PNW-GTR 422. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- Endangered Species Act of 1973 (as amended Pub. L. 93-205, 16 USC 1531 et seq.).

- Equihua, M. 1990. Fuzzy clustering of ecological data. *Journal of Ecology* **78**:519–534.
- FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the FEMAT. U.S. Government Printing Office, Washington, D.C.
- Gallo, K., S. H. Lanigan, P. Eldred, S. N. Gordon, and C. Moyer. 2005. Northwest forest plan: the first 10 years (1994–2003). Preliminary assessment of the condition of watersheds. General technical report PNW-GTR 647. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- Heller, D. 2002. A new paradigm for salmon and watershed restoration. U.S. Department of Agriculture Forest Service, Pacific Northwest Region, Portland, Oregon.
- Heller, D., B. McCammon, and B. Roper, B. 2004. Aquatic strategies in Region 6—are they working. U.S. Department of Agriculture Forest Service, Pacific Northwest Region, Portland, Oregon.
- Johnson, K. N., J. F. Franklin, J. W. Thomas, and J. Gordon. 1991. Alternatives for management of late-successional forests of the Pacific Northwest. Report. Agriculture Committee and the Merchant Marine Fisheries Committee of the U.S. House of Representatives, Washington, D.C.
- Lawson, P. W. 1993. Cycles in ocean productivity, trends in habitat quality, and restoration of salmon runs in Oregon. *Fisheries* **18**:6–10.
- Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bulletin of the American Meteorological Society* **78**:1069–1079.
- Meesters, E. H., R. P. M. Bak, S. Westmacott, M. Ridgley, and S. Dollar. 1998. A fuzzy logic model to predict coral reef development under nutrient and sediment stress. *Conservation Biology* **12**:957–965.
- Moer, M., T. A. Spies, M. A. Hemstrom, J. Alegria, J. Browning, J. H. Cissel, W. B. Cohen, T. E. Demeo, S. Healy, and R. Warbington. 2005. The Northwest Forest Plan—the first ten years (1994–2003): status and trends of late-successional and old-growth forests. General technical report PNW-GTR-646. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- Moyle, P. B. and B. Herbold. 1987. Life history patterns and community structure in stream fishes in western North America: comparisons with eastern North America and Europe. Pages 25–32 in W. J. Matthews and D. C. Heins, editors. *Community and evolutionary ecology in North American stream fishes*. University of Oklahoma Press, Norman.
- Naiman, R. J., and M. G. Turner. 2000. A future perspective on North America's freshwater ecosystems. *Ecological Applications* **10**:958–970.
- National Environmental Policy Act of 1969 (Pub. L. 91-190, 42 USC 4321-4347).
- National Research Council. 1996. *Upstream: salmon and society in the Pacific Northwest*. National Academy Press, Washington, D.C.
- Reeves, G. H. 2006. The Aquatic Conservation Strategy of the Northwest Forest Plan: an assessment after ten years. General technical report PNW-GTR-577. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- Reeves, G. H., P. A. Bisson, and J. M. Dambacher. 1998. Fish communities. Pages 200–234 in R. J. Naiman and R. E. Bilby, editors. *River ecology and management: lessons from the Pacific coastal ecoregion*. Springer-Verlag, New York.
- Reeves, G. H., L. E. Benda, K. M. Burnett, P. A. Bisson, and J. R. Sedell. 1995. A disturbance-based ecosystem approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmonids in the Pacific Northwest. Pages 334–349 in J. Nielsen, editor. *Defining unique units in population conservation*. Symposium 17. American Fisheries Society, Bethesda, Maryland.
- Reeves, G. H., D. B. Hohler, D. P. Larsen, D. P. Busch, K. Kratz, K. Reynolds, K. F. Stein, P. Hays, and M. Tehan. 2004. Effectiveness monitoring for the aquatic and riparian component of the Northwest Forest Plan: conceptual framework and options. General technical report PNW-GTR-577. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oregon.
- Reid, L. M. 1998. Cumulative watershed effects and watershed analysis. Pages 476–501 in R. J. Naiman and R. E. Bilby, editors. *River ecology and management: lessons from the Pacific coastal ecoregion*. Springer-Verlag, New York.
- Riccardi, A., and J. B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. *Conservation Biology* **13**:1220–1223.
- Sokal, R. R., and F. J. Rohlf. 1969. *Biometry*. W. H. Freeman, San Francisco.
- Spies, T., B. C. McComb, R. J. Pabst, R. Kennedy, M. McGrath, and K. Olsen. 2006. Potential effects of forest policies on terrestrial biodiversity in a multi-ownership province. *Ecological Applications*: in press.
- Thomas, J. W., M. G. Raphael, R. G. Anthony, E. D. Forsman, A. G. Gundersen, R. S. Holthausen, B. G. Marcot, G. H. Reeves, J. R. Sedell, and D. M. Solis. 1993. Viability assessments and management consideration for species associated with late-successional and old-growth forests of the Pacific Northwest. U.S. Department of Agriculture Forest Service, Portland, Oregon.
- Trombulak, S. C. and C. A. Frissell. 1999. Review of the ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* **14**:18–30.
- USDA (U.S. Department of Agriculture). 1992. Background report for development of the Forest Service management strategy for Pacific salmon and steelhead habitat. USDA, Washington, D. C.
- USDA (U.S. Department of Agriculture) Forest Service and BLM (Bureau of Land Management). 1994. Record of decision (ROD) for the amendments to Forest Service and Bureau of Land Management Planning documents within the range of the northern spotted owl. USDA Forest Service and BLM, Washington, D.C.
- USDA (U.S. Department of Agriculture) Forest Service and BLM (Bureau of Land Management). 2004. Record of decision. Amending resource management plans for seven Bureau of Land Management Districts and Land and Resource Management Plans for nineteen National Forests within the range of the northern spotted owl: Decision to clarify provisions relating to the Aquatic Conservation Strategy. USDA Forest Service, Portland, Oregon, and BLM, Moscow, Idaho.
- Washington Forest Practices Board. 1993. Standard methodology for conducting watershed analysis. Version 1.2. Washington Forest Practice Board, Olympia.
- Wemple, B. C., F. J. Swanson, and J. A. Jones. 2001. Forest roads and geomorphic process interactions, Cascade Range, Oregon. *Earth Surface Processes and Landforms* **26**:191–204.
- Williams, J. E., C. A. Wood, and M. P. Dombeck, editors. 1997. *Watershed restoration: principles and practices*. American Fisheries Society, Bethesda, Maryland.
- Zadah, L. A. 1965. Fuzzy sets. *Information and Control* **8**:338–353.
- Ziener, R. R. 1997. Temporal and spatial scales. Pages 80–95 in J. E. Williams, C. A. Wood, and M. P. Dombeck, editors. *Watershed restoration: principles and practices*. American Fisheries Society, Bethesda, Maryland.