Return to the River:
Scientific Issues in the Restoration of Salmonid Fishes in the Columbia River

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ABSTRACT
The Columbia River once was one of the most productive river basins for anadromous salmonids on the West Coast of North America; however, its current runs total less than 10% of historic levels. The Independent Scientific Group (ISG) of the Northwest Power Planning Council reviewed regional salmon management actions described in the Columbia River Basin Fish and Wildlife Program and concluded that the current program is unlikely to recover declining salmon and steelhead stocks. Adoption of a salmon life history ecosystem concept as a guiding foundation is needed to recover depressed stocks. Increasing natural ecosystem processes and functions should rebuild salmon populations to more abundant, productive, and stable levels. Elements of a salmon recovery program that increase these normative conditions include restoration of habitat for all life history stages (including migrations), reduction of mortality sources (including harvesters), planning of hydropower mitigation measures in the context of the normative river concept, and empirical evaluation of mitigation for effectiveness in reaching fish restoration objectives. Salmon need to be managed for population and life history diversity, not just for harvest. Reserves that protect remaining core populations and intact habitats are needed to foster a step-by-step rebuilding of salmon abundance and productivity.

The Columbia River today is a great "organic machine" (White 1995:108) that dominates the economy of the Pacific Northwest. Although natural attributes remain (e.g., salmon production in Washington State's Hanford Reach, the only reach of the mainstem Columbia River that is not impounded), river basin management is dominated by technological operations supporting the region's economy (e.g., hydropower production, irrigation systems, flood control, commercial barging). Operation of the river via the hydropower system is driven largely by economic considerations of water usage in the basin; the associated management decisions constrain conservation and restoration efforts for anadromous and resident salmonid fishes [Bevan et al. 1993; Independent Scientific Group (ISG) 1996; National Research Council (NRC) 1996].

During more than a century of development in the Columbia River basin (Figure 1), the region attempted to provide technological solutions (first hatcheries and fish ladders, later screens at turbine intakes and irrigation diversions, then barging and trucking of juvenile

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fish around the dams) for losses of salmon habitat and reduced salmon survival. The total amount of money spent maintaining and restoring salmon in the Columbia River basin is not known but is surely in the billions of dollars. Despite these investments, anadromous salmonids have continued to decline from their historical abundance (Figure 2). Total returns of cultured and wild anadromous salmonids reached an all-time low in 1995 of 750,000 fish (WDFW and ODFW 1996). Prior to development in the basin, the Columbia River may have supported more than 200 anadromous stocks, which returned 7 million to 30 million adult salmon and steelhead to the river annually (Chapman 1986; NPPC 1986; Nehlsen et al. 1991). Today, only Lewis River and Hanford Reach fall chinook, Lake Wenatchee and Lake Osoyoos sockeye (all in Washington State), and five summer steelhead stocks in the John Day River in Oregon are considered healthy (Mullan et al. 1992; Huntington et al. 1996). A consequence of the declines of salmon and steelhead has been a proliferation of legal challenges and endangered species listings and petitions (Miller 1997; Wood 1998). For example, nearly all extant stocks of anadromous salmonids in Idaho are listed under the Endangered Species Act.

Development of the Fish and Wildlife Program

Since 1980 and enactment of the Pacific Northwest Electric Power Planning and Conservation Act by Congress (hereafter the Northwest Power Act), salmon restoration has been approached regionally through implementation of the Columbia River Basin Fish and Wildlife Program (FWP) of the Northwest Power Planning Council (NPPC). In the act, Congress charged the council with developing a plan to "protect, mitigate, and enhance" fish and wildlife affected by the Columbia River basin hydroelectric system.

The Northwest Power Act directs the NPPC to base the Fish and Wildlife Program on recommendations submitted by state fish and wildlife managers, Native American tribes, federal agencies, and other interested parties. Those recommendations are solicited, compiled, and discussed by the council in public hearings before being adopted. Consequently, the FWP is a collection of individual measures proposed by a diverse constituency. This approach to developing the FWP means that the final list of measures has not resulted in a coherent group of activities derived from a single *a priori* conceptual framework.

Thus, it is doubtful that the contributing institutions based their recommendations on a common scientific understanding of the physical and biological components of the Columbia River watershed and the ways those components interact to form a salmonid-producing ecosystem. The FWP actions to date represent a good-faith effort by the council and the region's fisheries managers to recover salmonids; however, those efforts have failed so far to stem the decline of salmonids in the basin. Salmon have declined since the early 1980s from almost 2.5 million to less than 1 million returning adults, most of which (>80%) are of hatchery origin. Wild fish abundance is approximately 1% of historical predevelopment abundance (NRC 1996).

The NPPC's Fish and Wildlife Program emphasizes actions to increase survival of salmon and steelhead in the Lower Snake River (i.e., downstream from Hells Canyon Dam in Idaho and Oregon, which is a barrier to upstream adult migration), the middle and lower reaches of the mainstem Columbia River (i.e., downstream from Chief Joseph Dam, Washington), and their tributaries (Figure 1). Actions implemented so far include the following:

(1) modifying mainstem dam operations and facilities to improve upstream and downstream passage of adults and juveniles;
(2) coordinating river operations to enhance spring and summer flows to improve smolt survival;
(3) reducing smolt predators;
(4) constructing and operating hatcheries;
(5) modifying existing artificial production operations, including supplementing naturally reproducing populations;
(6) implementing best management practices for land use activities;
(7) screening irrigation diversions; and
(8) improving habitat and other measures as well as research and monitoring designed to answer critical recovery questions.

The NPPC's Fish and Wildlife Program includes a scientific review group [then called the Independent Scientific Group (ISG); now called the Independent Scientific Advisory Board (ISAB)], a panel of 11 scientists charged with conducting independent review of the

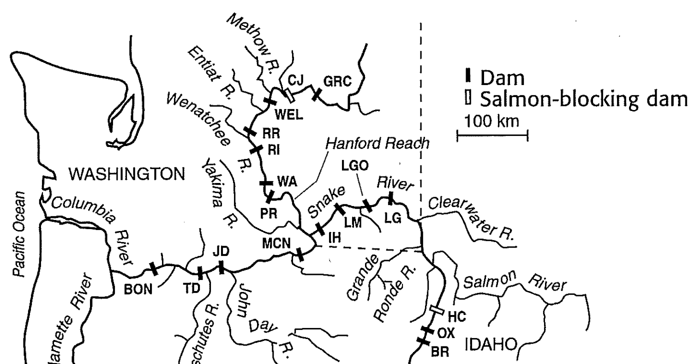

Figure 1 shows major features of the Columbia River basin hydropower system, including tributaries and dams. There is no fish passage upstream of Chief Joseph and Hells Canyon dams. (Dam identifiers are BON=Bonneville, TD=The Dalles, JD=John Day, MCN=McNary, PR=Priest Rapids, WA=Wanapum, RI=Rock Island, RR=Rocky Reach, WEL=Wells, CJ=Chief Joseph, GRC=Grand Coulee, IH=Ice Harbor, LM=Lower Monumental, LGO=Little Goose, LG=Lower Granite, HC=Hells Canyon, OX=Oxbow, BR=Brownlee).

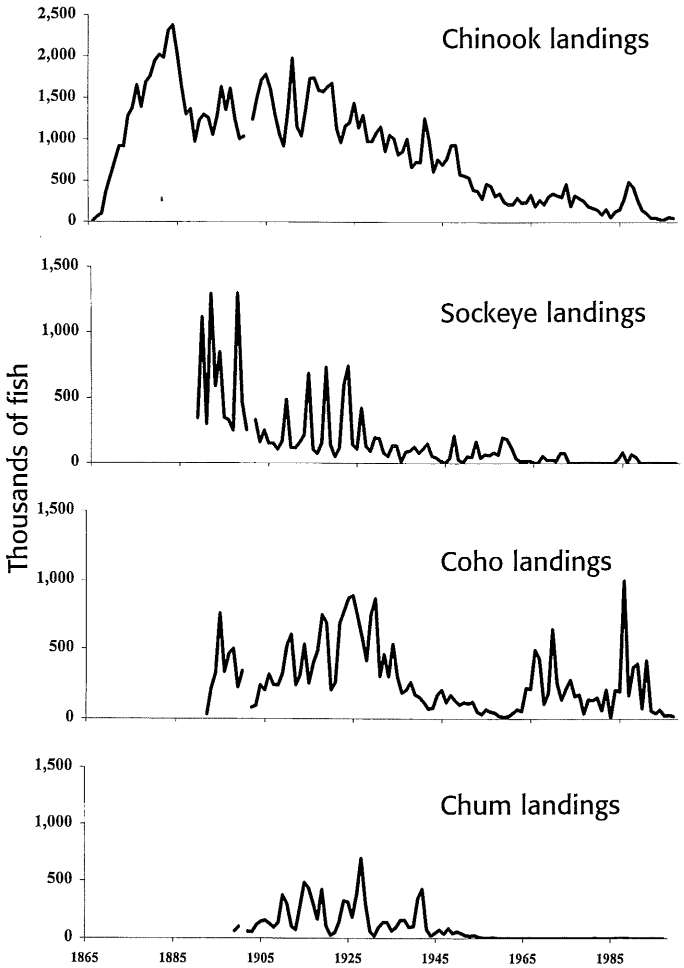

Figure 2 depicts Columbia River commercial salmon fishery landings from 1866 to 1994.

program and its implementation (e.g., Meffe et al. 1998). In May 1995 the council asked the ISG to review the scientific basis for the FWP, particularly its conceptual framework. The ISG completed its assignment in September 1996 with a 584-page prepublication report, "Return to the River: Restoration of Salmonid Fishes in the Columbia River Ecosystem." The group presented its recommendations to policy makers and citizens throughout the Pacific Northwest. Additionally, the council solicited public and technical comments through June 1997. The ISG now is revising its report.

Conceptual foundation

A key element in the report was the specification of a conceptual foundation that the ISG thought was essential for setting direction and evaluating results of Fish and Wildlife Program actions. Conceptual foundations (Anderson 1991) are the set of scientific principles and assumptions that direct management activities (e.g., Bisbal and McConnaha 1998), including restoration programs such as the FWP. A conceptual foundation determines how information is interpreted and which problems (e.g., limitations on fish production) are identified, thus establishing the range of appropriate solutions (Lichatowich et al. 1996). Because it influences how we interpret information, identify problems, and select approaches to their resolution, the conceptual foundation is a powerful scientific element of management and restoration plans, one that can determine the success or failure of those plans. The assumptions and principles (conceptual foundation) underlying management and restoration programs are rarely explicitly stated.

Like most salmon management and restoration programs, the FWP lacks an explicitly described conceptual foundation. Because the council's FWP is made up of measures originally proposed by constituent agencies, institutions, and interest groups, the FWP probably was derived from various unstated conceptual foundations, some of which contradicted or were inconsistent with each other and current scientific knowledge.

We attempted to identify the FWP's implied conceptual foundation. We reviewed the measures in the plan and their implementation, and then constructed a set of assumptions consistent with those measures. In other words, we asked the question, If these are the measures that are being implemented, what underlying assumptions are consistent with them?

We concluded that management of the Columbia River and its salmonid populations has been based on the belief that natural ecological processes comprising a healthy salmonid ecosystem can, to a large degree, be replaced, circumvented, simplified, and controlled by humans while production is maintained or even enhanced. Meffe (1992), in a review of the use of salmon hatcheries in the Pacific Northwest, identified this belief (which he called *techno-arrogance*) as the driver behind the region's reliance on large-scale hatchery technology to rebuild depleted salmon runs.

We identified three global assumptions that form the conceptual foundation in the FWP (ISG 1993):

(1) The number of adult salmon and steelhead recruited is primarily a positive response to the number of smolts produced. This assumes that human-induced losses of the natural production capacity can be mitigated by actions to increase the number of smolts that reach the ocean, for example, through barging, the use of passage technology at dams, and hatchery production.

(2) Salmon and steelhead production can be maintained or increased by focusing management primarily on in-basin components of the Columbia River. Estuary and ocean conditions are ignored because they are largely uncontrollable.

(3) Salmon species can be effectively managed independently of one another. Management actions designed to protect or restore one species or population will not compromise environmental attributes that form the basis for production by another species or population.

These assumptions drive managers toward solutions that attempt to use technologies as substitutes for ecosystem functions (Lichatowich et al. 1996). Current implementation of the FWP focuses primarily on use of hatcheries in tributary streams and improved survival of juvenile and adult salmonids that pass through the mainstem hydroelectric projects. Survival of salmon migrating past dams is an important problem that deserves attention, but passage must be considered in the context of a salmon's entire life history, behavior, and ecosystem. Much passage work has focused on achieving incremental improvements in the established technologies of passage for a few predominant life history types while ignoring the broader context of salmonid life history diversity, behavior, and habitat (Whitney et al. 1997). Artificial production has been an essential component of salmon recovery in the Columbia basin, one that has been used primarily to circumvent natural processes lost or degraded through development (Meffe 1992; Scientific Review Team 1998). In view of the continuing decline in salmon, the FWP's conceptual foundation and implementation of measures derived from it have failed to reverse the decline of salmon in the basin. A different foundation is needed.

An alternative conceptual foundation

After reviewing the science behind salmon restoration and the persistent trends of declining abundance of Columbia River salmon, we concluded that the FWP's implied conceptual foundation did not reflect the latest scientific understanding of ecosystem science or salmonid restoration. While we can trace some integration of modern ecological thought in the evolution of the council's FWP (NPPC 1984, 1987, 1994) through increasing emphasis on adaptive management, concerns about genetic issues, and a recent emphasis on watershed science, the basic assumptions that direct the program (i.e., its conceptual foundation) appear to remain unchanged and generally unchallenged.

Because we do not believe the FWP's implied conceptual foundation reflects the latest scientific understanding of ecosystem science or salmonid restoration, we developed an alternative conceptual foundation for the council and region to consider. Our alternative conceptual foundation was derived from a synthesis of riverine geomorphology, a riverine ecological theory, and an understanding of salmonid life histories, behavior, habitat requirements, and genetic diversity in the context of a dynamic and variable environment. Our alternative conceptual foundation is necessarily general and large-scale in its approach. A significant future challenge will be for fisheries scientists and land and fisheries managers to collaboratively apply these principles at smaller scales such as a subbasin or specific subbasin tributary and to define specific implementation actions.

The alternative conceptual foundation is based on three fundamental principles or assumptions:

I. *Restoration of Columbia River salmonids must address the entire natural-cultural ecosystem, which encompasses the continuum of freshwater, estuarine, and ocean habitats where salmonid fishes complete their life histories.*

A natural-cultural system includes all the ecological and social processes that link organisms, including humans, with their environments. The natural-cultural system of Columbia River anadromous salmonids extends from headwater tributaries into the northeast Pacific Ocean. It includes the uplands and riparian corridors as well as surface and subsurface water flow pathways and processes. Restoration of Pacific salmon in the Columbia River has to take into account both natural and cultural components of the ecosystem. Recovery plans will need to be both scientifically valid and socially acceptable for restoration to occur. The region will not implement plans that are not socially acceptable, and plans that are not scientifically valid are foreordained to failure. The Columbia basin has been extensively developed for human uses, and developed rivers are important components of the region's economy. Viewing the Columbia basin in a natural-cultural context means restoration programs must be preceded by open public debate and a complete airing of community values followed by a rational process of reconciling divergent views.

II. *A productive salmonid system requires a network of complex and interconnected habitats that are created, altered, and maintained by natural physical processes in freshwater, estuary, and ocean environments. These diverse and high-quality habitats, many of which have been extensively altered by human activities, are crucial for salmonid spawning, rearing, migration, maintenance of food webs, and predator avoidance. Ocean conditions, always variable, are important in determining the overall patterns of productivity of salmonid populations.*

The Columbia, like all large gravel-bed rivers, is a complex, dynamic gradient of habitat types from headwaters to estuary. Salmonids and all other riverine flora and fauna are distributed rather predictably along that gradient according to the requirements of each stage in their life cycle

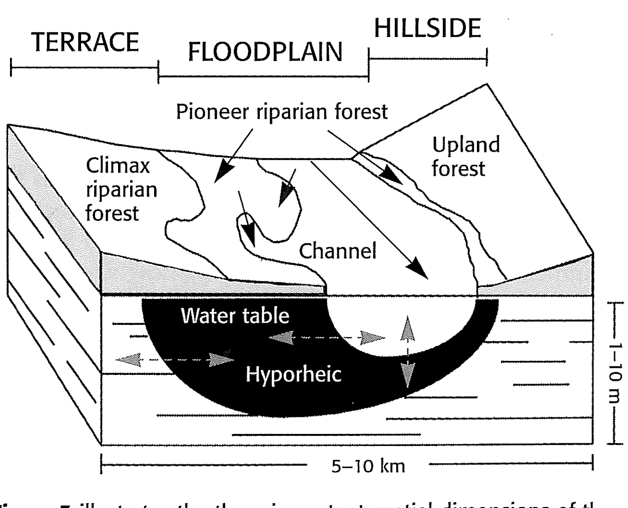

Figure 3 illustrates the three important spatial dimensions of the alluvial river ecosystems: (1) the riverine or longitudinal channel habitats (runs, riffles, and pools); (2) the riparian or horizontal habitats between terrace, floodplain, and hillslope; and (3) the hyporheic or vertical habitats below the level of the water table where the river water flows through the bed sediments. Arrows show the direction of water movement. Figure modified from Stanford (1996), reprinted by permission.

(Vannote et al. 1980; Power et al. 1997). Similar to other river ecosystems, the Columbia has three important spatial dimensions (Figure 3) (Ward 1989; Gregory et al. 1991; Naiman et al. 1993): (1) *riverine*: a longitudinal continuum of habitats of varying geometry from headwaters to mouth; (2) *riparian*: a lateral array of aquatic and terrestrial habitats from the edge of the main channel through various side and flood channels and wetlands to floodplains, including stream-side vegetation and associated faunal assemblages; and (3) *hyporheic*: a latticework of underground habitats associated with the flow of river water through the alluvial sediments of the channel and flood plain. These three interconnected habitat dimensions are constantly being reconfigured by physical (e.g., flooding) and biological processes (e.g. salmon digging redds, beaver activity, and vegetation growth). Critical habitats for the various life stages of salmonids exist in all three dimensions.

The importance of a complex and dynamic continuum of habitats in the Columbia River system is a central tenet of our conceptual foundation. The diverse habitats found in floodplain and gravel-cobble segments (e.g., alluvial reaches such as the Hanford Reach) are especially important because they provide the connected, necessary habitats for salmonid spawning and rearing. Historically, alluvial reaches were probably the biological hot spots for salmonid production in the Columbia basin. Not surprisingly, these areas also are frequently the centers of human activities within watersheds (Amoros et al. 1987; Petts et al. 1989; Wissmar et al. 1994). Dams also have flooded many reaches, such that habitat complexity has been reduced and replaced by the uniformity of regulated reservoirs with more lake-like characteristics.

The salmon's oceanic habitats are dynamic, changing in response to physical processes. Atmospheric and oceanic processes, responding to fluctuations in the global heat budget, change the physical environment and the composition of assemblages of marine biota. In effect, they reset ecological conditions on local and regional scales. The new conditions may be sufficient to qualitatively change the relationship between a species and regularly occurring environmental phenomena such as coastal upwelling. In addition, harvest, hatchery, and habitat management practices that reduce life history and genetic diversity in salmon populations leave them more vulnerable to mortality in fluctuating marine and freshwater environments. Stock and life history diversity spreads the risk of mortality (extinction at the population and species levels) in fluctuating environments across a diverse suite of populations, in which some populations are more likely to survive than others in any given set of environmental conditions.

Historically, salmon managers treated ocean productivity as a constant in the development of management and restoration plans as well as in the population models they used to set escapement and harvest levels. However, recent understanding of phenomena such as El Niño have led us to appreciate that changes in the Pacific Ocean can dramatically alter both freshwater and marine conditions for Pacific salmon. Thus, management activities should be flexible and broad-based so they can accommodate changing oceanic conditions. For example, reducing the number of smolts released from hatcheries during periods of decreasing marine survival may be desirable if the numbers of smolts released are thought to exceed near-shore ocean carrying capacities (Beamish and Bouillon 1993; Francis 1997). However, Pearcy (1992) noted the difficulty of assessing near-shore ocean productivity and its relationship to salmon production.

III. Life history diversity, genetic diversity, and metapopulation organization are ways salmonids adapt to their complex, interconnected, and variable habitats. Diverse adaptations contribute to the ability of salmonids to cope with environmental variation typical of freshwater and marine environments.

Thus, habitat complexity and connectivity as generated, altered, and maintained by complex natural-river processes act as templates on which salmonid life history diversity, stable multi-stock productivity, and long-term continuity are expressed and on which they depend (Moyle and Leidy 1992; Moyle et al. 1998).

Freshwater habitats change in response to fluctuations in the environment on daily, annual, and decadal cycles and in response to disturbances such as record floods and droughts, fire, volcanic eruptions, landslides, and other geomorphic processes. Ocean conditions favorable or unfavorable for salmon growth and survival vary on decadal cycles and short-term events (El Niño events of one to several years). Complex, interconnected habitats facilitate the expression of life history diversity (Angermeier and Schlosser 1995; Bisson 1995; Reeves et al. 1995). In turn, life history diversity spreads the risk of mortality in fluctuating environments (den Boer 1968; Schlosser 1985; Scudder 1989).

Widespread habitat loss within the Columbia River basin and fragmentation of remaining high-quality habitats has been especially damaging to species with relatively little potential for freshwater life history diversity and limited capacity to adapt to changing conditions. While large-scale restoration and reconnection of degraded and fragmented habitats have not yet been undertaken in the Pacific Northwest, smaller-scale projects such as in California's Owens River Gorge (Hill and Platts 1998) have positively benefitted fisheries and aquatic communities.

The Normative River: a system suitable for salmon and humans

Our alternative conceptual foundation recognizes that the Columbia River is a natural-cultural ecosystem. Therefore, human development and its consequences are integral parts of this ecosystem. At the same time, the conceptual foundation recognizes the critical function of natural biophysical processes in the creation and maintenance of salmon habitat and fulfillment of life history functions. Human development in the Columbia basin has weakened or eliminated natural habitat-forming and maintenance processes that, together with overharvest and hatchery practices, have caused depletion and extinction of some salmon populations. In a highly developed natural-cultural ecosystem such as the Columbia, an inescapable tension exists between the benefits derived from development and the costs of that development in terms of lost goods and services naturally produced by a healthy ecosystem (salmon and clean water, for example). We recognized this tension between development and salmon production in our conceptual foundation.

It is not possible to return the Columbia River system to a completely natural state to achieve salmon restoration. However, maintaining the current approach to salmon restoration will not achieve the council's salmon restoration goals (to double abundance without harming diversity) and is likely to continue the trends of declining salmon abundance, local population extinctions, and proliferating Endangered Species Act listings. A major conclusion embedded in the alternative conceptual foundation is the need to restore a greater degree of "naturalness" to the river than exists today. With historical (i.e., pristine) conditions not attainable, what standard of naturalness is appropriate? We believe a level of naturalness rests somewhere between the current developed state and a completely natural river. The ecological and biophysical attributes of the pre-development river represent the norms or standards under which salmon in the Pacific Northwest evolved. Management actions that restore these attributes or bring them into higher relief in the basin, thereby increasing normative conditions for salmon, should aid salmonid populations. Some examples of natural and artificial conditions that illustrate possible management actions to increase normative conditions for salmon are shown in Table 1.

We believe an ecosystem with a mix of natural and cultural features such as the Columbia River can still sustain all life stages of a diversity of salmonid populations. However, this is not currently occurring. The region will have to increase normative conditions in the river system before sustained salmon recovery is possible. This is a major change in approach to salmon recovery from the current approach, which has emphasized activities and actions that circumvented the natural ecological attributes of the basin rivers, i.e., attempting to restore salmon without restoring natural river functions.

The region, through its policy representatives, must decide how far it is willing to restore the river based on its economic, cultural, and ecological values. If the region concludes it cannot or will not increase the normative conditions needed to achieve the council's current salmon recovery goals, then those goals must be changed. The challenge is to reach agreement on the extent to which numerous social and biophysical constraints on the Columbia River can be relaxed or removed. Defining what the river must be and moving the ecosystem to that point is the only way to achieve the FWP's salmon restoration goals.

Conclusions and recommendations

Salmon restoration in the Columbia River is based on the prevailing belief that the primary problem for anadromous fish is mortality associated with juvenile passage through the mainstem dams and reservoirs. The prevailing solution involves combining hatchery technology (to maximize the number of smolts produced) with flow augmentation and juvenile transportation via barges to move the

Table 1 shows examples of natural and artificial conditions and approaches to salmon restoration.

Natural	Artificial
Natural spawning and rearing	Artificial propagation and rearing in artificial structures; population relocations or stock transfers
Unimpeded passage to and from spawning and rearing sites	Migrations blocked or hindered by anthropogenic factors such as instream structures (dams and other migration barriers), water withdrawals, water pollution, or unfavorable flows; artificial migration pathways that don't mimic natural features
Flow regimes produced by local and regional climates, unencumbered by regulation	Regulated flow regimes in which natural patterns of seasonal and diurnal discharge do not occur, and characteristics of naturally flowing water (e.g., turbulence) are limited.
Riverine habitats formed and maintained by natural processes through the interactions between flowing water and the surrounding landscape	Replacement of free-flowing river channels with impoundments; substitution of artificial habitats for habitats formed by natural disturbance processes
Community interactions dominated by species with which native salmonids co-evolved	Introductions of non-native plants and animals, including other game fishes, which have altered survival, growth, and behavior of native salmonids
Survival rates that permit enough adults to return so that (1) naturally spawning populations are capable of sustaining and rebuilding themselves; (2) sufficient numbers exist to repopulate favorable but currently vacant habitats; and (3) sufficient marine-derived nutrients are returned to maintain aquatic and riparian productivity	Anthropogenic mortality, including harvest, is sufficiently high that (1) populations are incapable of sustaining or rebuilding themselves; (2) there are insufficient adults and juveniles to recolonize favorable habitats and interbreed with other locally reproducing populations; and (3) not enough nutrients are returned to maintain aquatic and terrestrial food webs dependent on salmon carcasses

fish as rapidly and efficiently as possible past the dams. This strategy is reflected in restoration expenditures (General Accounting Office 1992) and in the measures supported by management agencies and tribes (Independent Scientific Review Panel 1997).

Unfortunately, the restoration program based on the current set of assumptions has failed to curtail the decline of salmonids. Moreover, it may be actively interfering with conservation efforts for resident fishes or other management goals in headwater areas not accessible to salmon, e.g., eutrophication controls in Flathead Lake are negated by discharges from Hungry Horse Reservoir made to accommodate late-summer smolt movement in the lower Columbia River (Stanford and Hauer 1992).

Without a fundamental change in our approach to salmon restoration, more extinctions of salmon populations are likely, and progress toward the regional rebuilding goal unlikely.

Based on reviews of the existing (implied) conceptual foundation and the science related to salmonid restoration as well as the council's FWP, the ISG developed three recommendations (1–3 below) and six recommendations (4–9 below).

(1) *Progress toward salmon recovery in the Columbia basin is impeded by the lack of an explicitly defined conceptual foundation based on ecological principles. We recommend that the region adopt an explicitly defined conceptual foundation based on ecological principles.*

Without a fundamental change in our approach to salmon restoration, more extinctions of salmon populations are likely, and progress toward the regional rebuilding goal unlikely.

(2) *The potential social, economic, and biological tradeoffs that will accompany a shift in the Columbia River toward normative conditions are not known. Identifying and quantifying those tradeoffs where possible is a high priority.*

(3) *Although uncertainty exists regarding our restoration approach, it offers an opportunity to move from the continued pattern of decline and to boost recovery of salmon and the goals of the FWP.*

A rigorous program of evaluation, monitoring, research, and adaptive management will be required. An approach based on the re-establishment of more natural riverine processes, combined with an implementation program governed by the principles of adaptive management, offers the best hope for preventing large-scale extinction of salmon in the basin. The normative approach might be tested and evaluated at the subbasin level as a first step (see Hill and Platts 1998).

(4) *Recognize explicitly that salmonid fishes in the Columbia River exist naturally as aggregates of local populations, possibly organized as metapopulations, and manage for life history and population diversity essential to increased survival and total production.*

Although much of the natural diversity of salmonid fishes has been lost (Nehlsen et al. 1991; Huntington et al. 1996), we believe salmonids retain some capacity to re-express life history and population diversity if opportunities for access to suitable habitat are provided (Quinn and Unwin 1993; Healey 1994). As habitats improve in the Columbia basin, metapopulation structure may develop from the natural expansion of remaining wild core populations (e.g., fall chinook in the Hanford Reach).

(5) *Freshwater habitat for all life history stages must be protected and restored with a special emphasis on key alluvial river reaches and lakes. Protecting healthy habitat, restoring degraded habitat, and providing access for salmonids to diverse habitats should be management priorities. These activities should encourage the re-expression of phenotypic diversity in salmonid populations.*

At least three generalized actions could begin to rebuild habitat quantity and quality of the mainstem and tributaries: (a) reregulate flows to restore the spring high-water peak to revitalize the mosaic of habitats in alluvial riverine reaches; (b) reregulate flows to stabilize daily fluctuations in flow (caused by the practice of "power peaking") to allow food web development in shallow water habitats; (c) provide incentives for watershed planning that emphasize riparian and upland land use activities supportive of natural interactions between land and water, and insist on empirical evaluation of the effectiveness of management practices.

(6) *Reduce sources of mortality in the mainstem of the Columbia and Snake rivers, and improve the effectiveness of mitigation activities within the hydroelectric system. These goals include managing stocks with a more complete understanding of their migratory behavior and ways this behavior is affected by various modes of river regulation. Mitigation measures should be directed toward increasing natural riverine processes and functions needed by salmon for spawning and rearing.*

We identified four areas or activities that would improve salmon survival in the mainstems of the Columbia and Snake rivers: (a) couple seasonality of flow with spill rates over the dams that efficiently bypass juveniles and adults around mainstem dams and behaviorally cue (rather than physically flush) the juveniles through the mainstem; (b) reduce mortality from gas bubble trauma via field research on causes of the problem and installation of devices that reduce nitrogen gas supersaturation; (c) transport (barge) juvenile salmon around mainstem dams only if all life history types are included, if the currently perceived benefits of transportation are real for all life history stages, and if natural habitats in the mainstems clearly cannot be restored; and (d) restore mainstem habitats to more natural conditions to reduce predation rates on migrating juvenile salmon.

(7) *Reduce inadvertent harm and improve effectiveness of mitigation actions associated with harvest management, artificial propagation, and habitat restoration. Planning and implementing mitigation measures should occur within the context of an explicitly defined conceptual foundation and the normative river concept. Measures should be evaluated for effectiveness in reaching stated objectives.*

Habitat restoration in both mainstem and tributaries must receive high priority and be directed at providing habitat opportunities that historically supported salmonids in their natural state (Healey 1994; Moyle et al. 1998). Appropriate harvest control also is necessary for successful salmon conservation, with full accounting for harvest (both direct and indirect) to ensure the persistence of salmon populations. Artificial propagation must be viewed as an experiment to be implemented within an adaptive management framework (NRC 1996). It will be difficult to determine if it is possible to integrate hatchery operations with natural production in the basin (Scientific Review Team 1998). The role and scale of artificial production at the subbasin level should be consistent with the rebuilding goals for natural production. Monitoring, and especially evaluation, remain inadequate for current needs.

(8) Recognize estuary and ocean dynamics as controllers of salmon productivity. This will require responses in management actions for all other aspects of the life cycle under human control such as harvest, hatchery operations, and hydrosystem operations. Management activities should increase or maintain biodiversity in salmon populations to minimize the effects of fluctuating marine environments. Better understand estuarine and oceanic food webs.

Estuarine habitats and the Columbia River plume can be improved by pollution abatement and continuing enhancement of the spring freshet associated with restoration of a normative flow regime (Cury and Roy 1989; Bottom and Jones 1990; Lawson 1993). Numbers of smolts released from hatcheries should take ocean productivity into account; managers may be prudent to limit releases during periods of low ocean survival and growth (Francis 1997). Management actions affecting freshwater parts of the salmon's life cycle should emphasize the linkages between habitat and biological diversity since a biologically diverse suite of salmon and steelhead populations are likely to be buffered against fluctuating ocean conditions (Bisbal and McConnaha 1998).

(9) It is critical to protect remaining core populations and to restore habitats with the potential to reestablish core populations at strategic locations within the basin. One approach would be to reevaluate the concept of salmonid reserves. Reserves could protect habitats that support remaining viable core populations. They could serve as foci for rebuilding salmonid abundance and metapopulation structure throughout the Columbia basin. Specifically, the region should give priority to evaluating the potential for a salmon reserve near the confluence of the Snake and Columbia rivers, including the Hanford Reach.

Establishing a salmon reserve from the Hanford Reach to the confluence of the Columbia and Snake rivers, combined with flow regulation and improved habitat quality in the lower reaches of adjacent tributaries, would provide the basis for testing the normative concept. In addition, the region should search for other candidate areas such as the John Day River where spawning and rearing habitat can be restored and natural population and metapopulation structure reestablished (Rahr et al. 1998).

The challenge ahead

Returning the river to a more-natural state runs counter to the philosophy that has guided salmon restoration in the Columbia River basin for much of this century. For this reason, restoring natural ecological processes and functions will require an examination of the values that underlie Columbia River management. However, the conceptual foundation outlined here provides a scientific basis for that debate. Recently, failure of the scientific community to resolve key restoration issues often was used to justify the status quo and avoid necessary public debate about the social and economic costs of salmon recovery (Volkman and Lee 1994).

If the region is serious in its desire to restore Pacific salmon, the status quo is not an option.

Maintaining the current approach is unlikely to significantly improve the status of Pacific salmon in the Columbia River and is likely to result in further salmon declines and extinctions. If the region is serious in its desire to restore Pacific salmon, the status quo is not an option. However, the 1994–1998 Biological Opinion for the Federal Columbia River Power System Operations, recently upheld in *American Rivers v the National Marine Fisheries Service* (NMFS), does not require the Corps of Engineers or Bureau of Reclamation to significantly change current hydroelectric operations. Instead, it calls on river operators to make relatively minor, albeit expensive, modifications that leave the altered flow regime in place. While a more-natural river can be made somewhat compatible with other uses of the river, it cannot be achieved without significant changes in the way the river is managed.

Clearly, the first step is to develop a scientific description of conditions needed for salmon relative to the council's existing goals. The next step is to determine what changes in the federal hydropower system and other river uses are needed to achieve these conditions. The difficult job of debating costs and benefits of salmon restoration follows that step.

Significant changes will, in many cases, require painful decisions, perhaps even congressional alteration of federal hydrosystem project operations. Other changes such as drawdown of reservoir elevations would limit, although not eliminate, the region's ability to use the Columbia River as a navigation corridor and to supply some irrigation needs.

"Return to the River" and other recent reviews of the salmon problem (NRC 1996; Stouder et al. 1997) provide a scientific foundation for salmon recovery. Consequently, the biggest challenge facing the region is not the biological uncertainties associated with salmon recovery efforts, but whether the region is willing to significantly change the status quo.

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