



Return to the River

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Return to the River: Strategies for Salmon Restoration in the Columbia River Basin

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“Fundamentally, the salmon’s decline has been the consequence of a vision based on flawed assumptions and unchallenged myths—a vision that guided the relationship between salmon and humans for the past 150 years. We assumed we could control the biological productivity of salmon and ‘improve’ upon natural processes that we didn’t even try to understand.” (p. 8)

—Jim Lichatowich. 1999. *Salmon without Rivers: A History of the Pacific Salmon Crisis*. Island Press, Washington, DC.

Introduction

The Columbia River today is a great “organic machine” (White 1995) that dominates the economy of the Pacific Northwest. Even though natural attributes remain—for example, salmon production in Washington State’s Hanford Reach, the only unimpounded reach of the mainstem Columbia River—the Columbia and Snake River mainstems are 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 and constrains conservation and restoration efforts for anadromous and resident salmonid fishes (Snake River Salmon Recovery Team 1993; Petersen 1995; NRC 1996; ISG 1999; NOAA 2004).

During more than a century of development in the Columbia River Basin (Figure 13.1), the region attempted to provide technological solutions for losses of salmon habitat and reductions in salmon survival, first through hatcheries (Figures 13.2 and 13.3) and fish ladders (Figure 13.4), then later through installation of screens at turbine intakes (Figure 13.5) and irrigation diversion screening (Figures 13.6 and 13.7), and finally barging and trucking of juvenile fish around the dams (Figures 13.8–13.10) (ISG 1998, 1999; Lichatowich 1999). The total amount of money spent maintaining and restoring salmon in the Columbia River Basin is difficult to determine, but it exceeds 3 billion dollars over the last two decades (General Accounting Office 1992, 2002). Despite these efforts, anadromous salmonids have continued to decline from their historical abundance (Figure 13.11). Total returns of cultured and wild anadromous salmonids reached an all-time low in 1995 of 750,000 fish (WDFW and ODFW 1996; 2001), although improved ocean conditions 2000 to 2004 brought increased adult returns to levels not seen in several decades. The returns are disproportionately composed of hatchery-raised fish. The total returns, and especially returns of wild fish, are still far short of historical numbers.

Prior to Euro-American development in the basin, the Columbia River may have supported more than 200 anadromous stocks, which returned 7 to 30 million adult salmon and steelhead to the river annually (Chapman 1986; NPPC 1986; Nehlsen *et al.* 1991). By the late-1990s, only nine salmon and steelhead stocks were considered healthy: Lewis River (Washington) and Hanford Reach (Washington) fall Chinook, Lake Wenatchee and Lake Osoyoos (Washington) sockeye, and five summer steelhead stocks in the John Day River (Oregon) (Huntington *et al.* 1996; Mullan *et al.* 1992). Recent increased adult returns, attributable largely to improved ocean conditions associated with the long-term productivity cycles in the Pacific Ocean (described in Chapter 10), have improved the abundance and status of many individual populations and stocks (Figure 13.12); however, extensive analyses

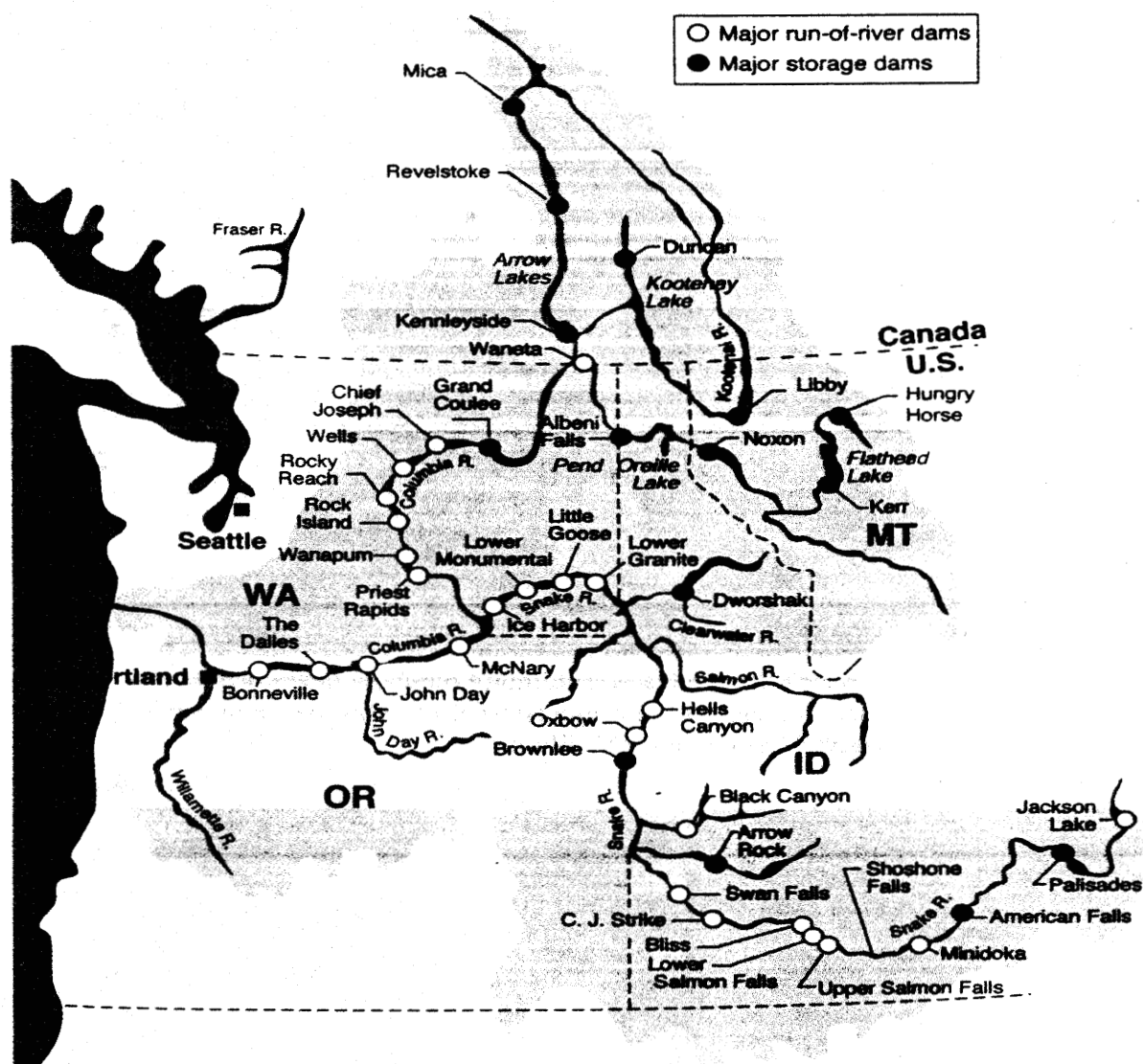


Figure 13.1 Map of the Columbia River Basin, showing major dams and lakes.

equivalent to the Huntington et al. (1996) study or NOAA Fisheries population status reviews (Busby et al. 1996; Gustafson et al. 1997; Johnson et al. 1997; Myers et al. 1998) have not been conducted within the past several years. Monitoring population abundance in years to come will determine whether these increases contributed to stock recoveries or were only momentary gains.

A consequence of the declines in salmon and steelhead has been a proliferation of legal challenges and endangered species listings and petitions. Presently, 13 “evolutionary significant units” comprising four species of salmon and steelhead that spawn in the Columbia River or its tributaries

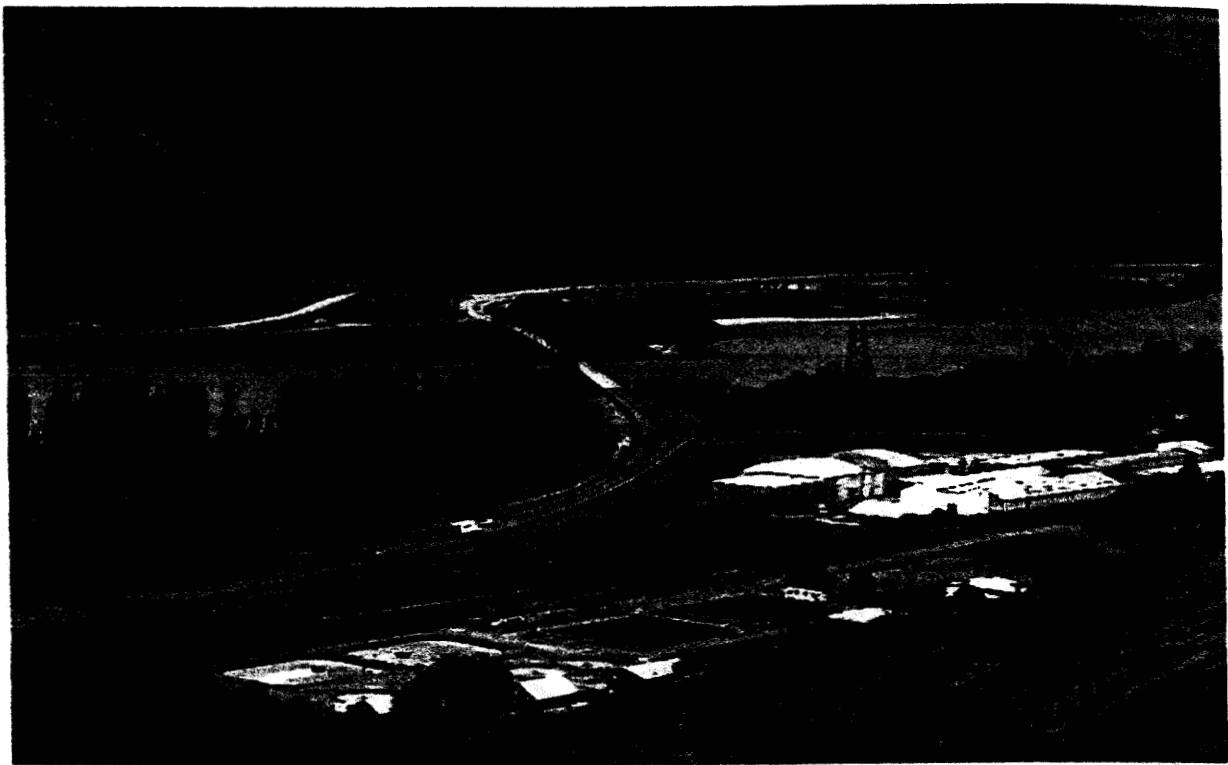


Figure 13.2 Photo of an upper Columbia River mitigation hatchery near Chelan, Washington, showing the proximity of the hatchery to the mainstem Columbia River and the constrained nature of the canyon geography. Photo by R. N. Williams.



Figure 13.3 Sorting of coho salmon prior to artificial spawning at Chiwawa Hatchery in central Washington. Photo by R. N. Williams.



Figure 13.4 The north (Washington shoreline) fish ladder and spillbays at John Day Dam looking south to the Oregon shore. Photo from U.S. Army Corps Digital Visual Library, website at <http://images.usace.army.mil/photolib.html>.

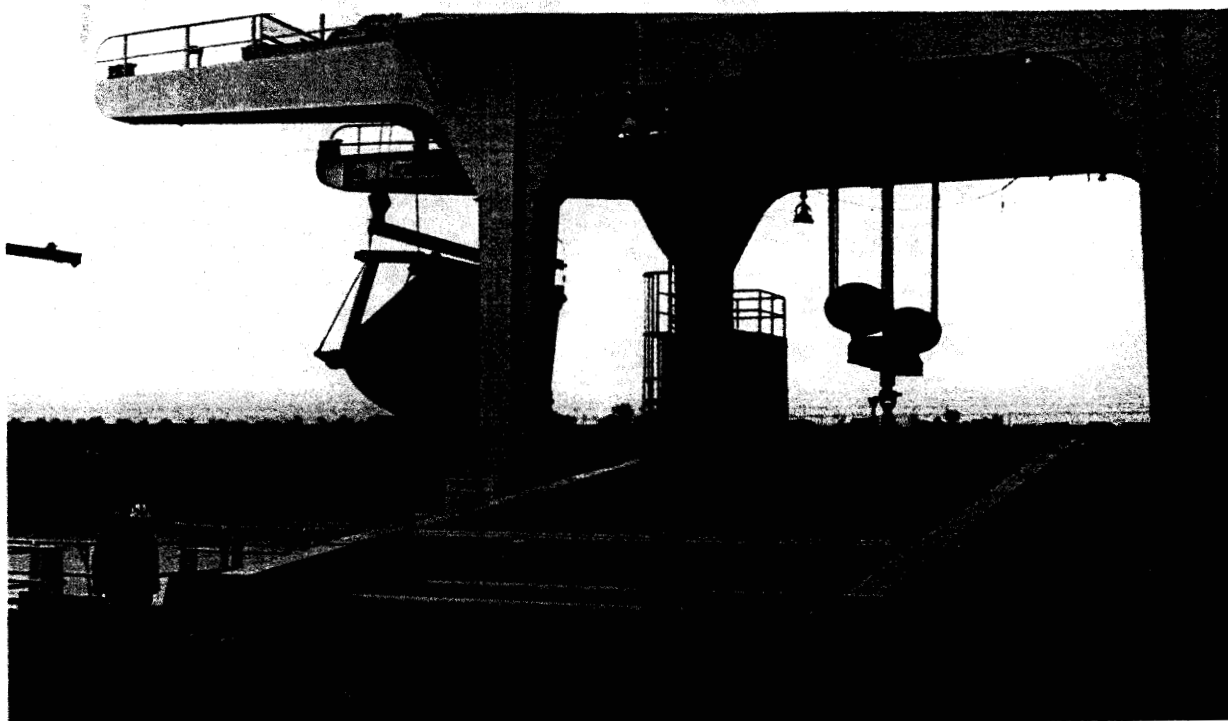


Figure 13.5 Installation of a turbine screen at McNary Dam. Photo from U.S. Army Corps Digital Visual Library, website at <http://images.usace.army.mil/photolib.html>.

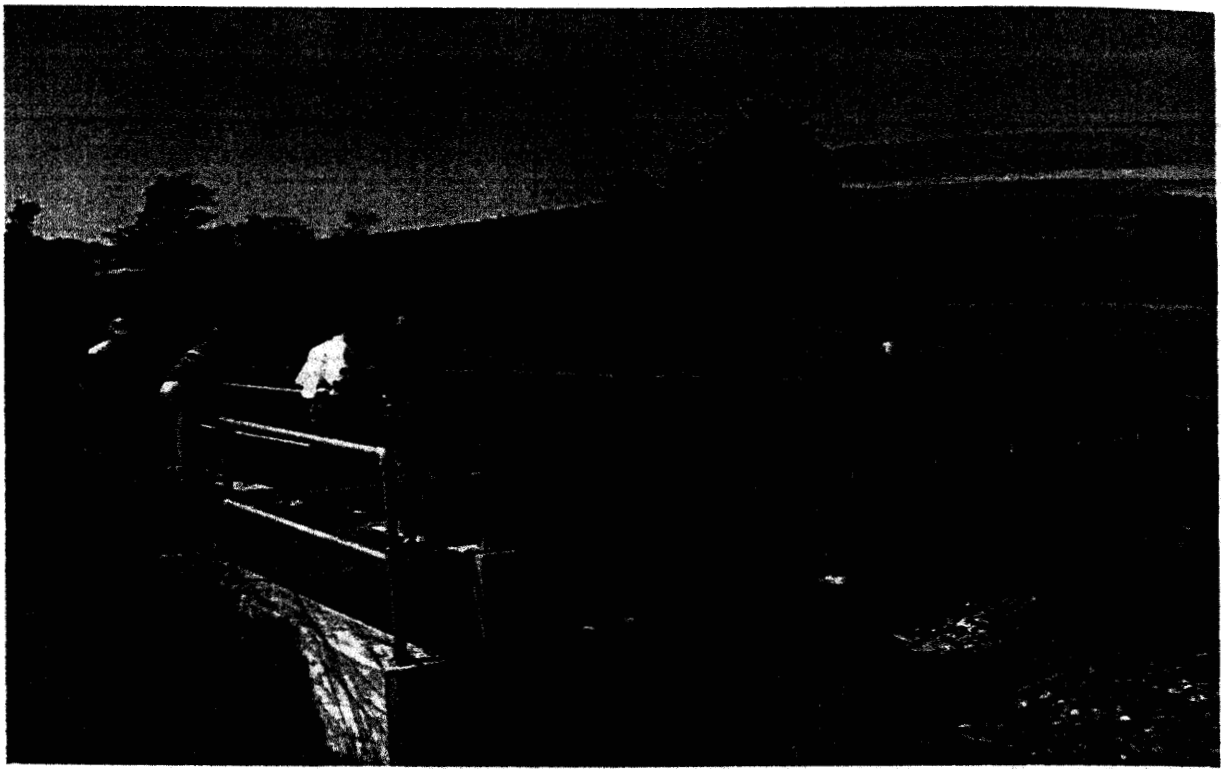


Figure 13.6 Irrigation diversion dam in a middle reach of Fifteenmile Creek near The Dalles, Oregon. Photo by R. N. Williams.



Figure 13.7 A rotating drum screen located on the water diversion ditch created by the irrigation dam on Fifteenmile Creek shown in Figure 13.6. The rotating drum screen passes water down the irrigation ditch but diverts any entrained juvenile and adult fish back to the creek. Photo by R. N. Williams.

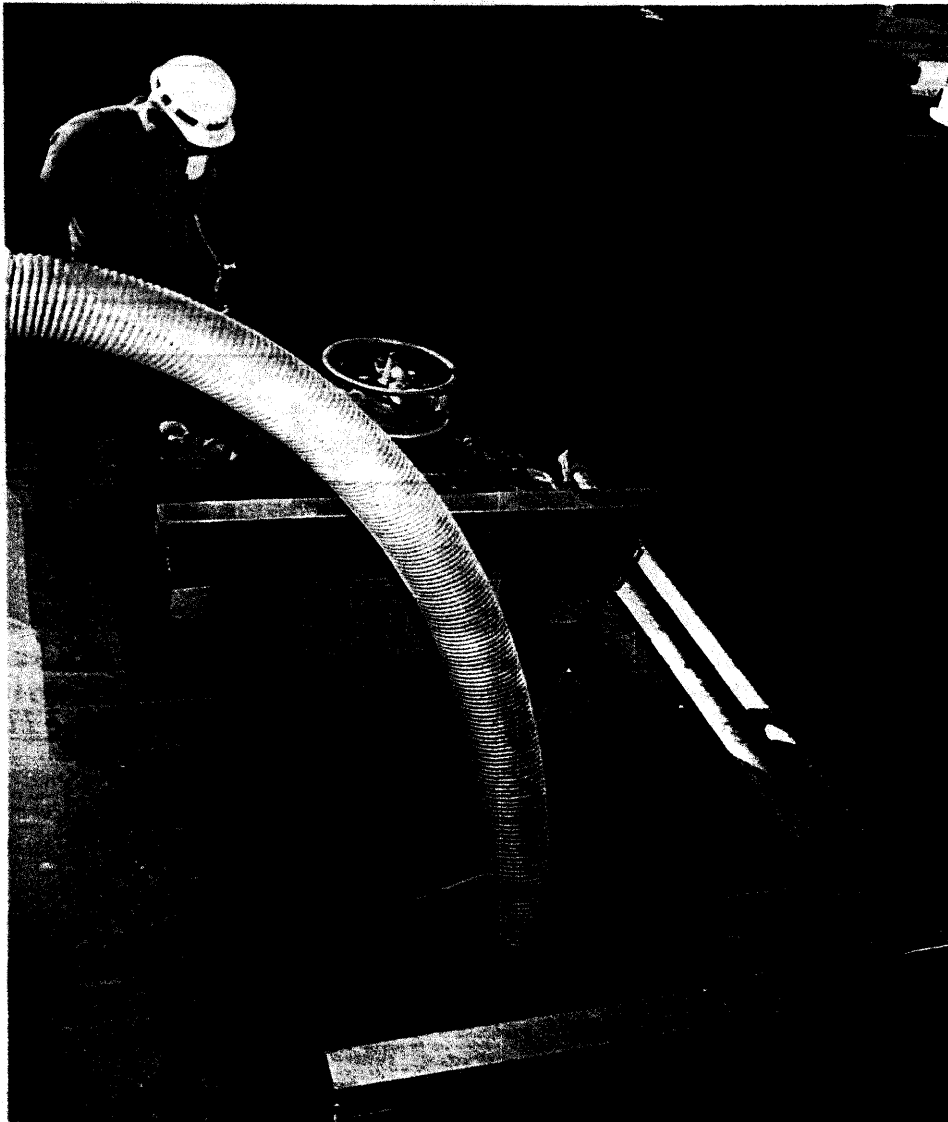


Figure 13.8 Loading juvenile salmon and steelhead captured in the bypass systems of Columbia and Snake River hydroelectric projects into a fish barge for transportation downriver and release below Bonneville Dam, the lowermost dam in the system. Photo from U.S. Army Corps Digital Visual Library, website at <http://images.usace.army.mil/photolib.html>.

have been listed as threatened or endangered under the Endangered Species Act (ESA). These include Snake River fall Chinook, Snake River spring/summer Chinook, Snake River sockeye, Snake River steelhead, upper Columbia River spring Chinook, upper Columbia River steelhead, middle Columbia River steelhead, lower Columbia River spring Chinook, lower Columbia River coho, lower Columbia River chum, lower Columbia River steelhead, upper Willamette River spring Chinook, and upper Willamette River steelhead. The federal role and responsibility for regional salmon recovery is complex and rapidly changing (see more detailed description in Chapter 12).

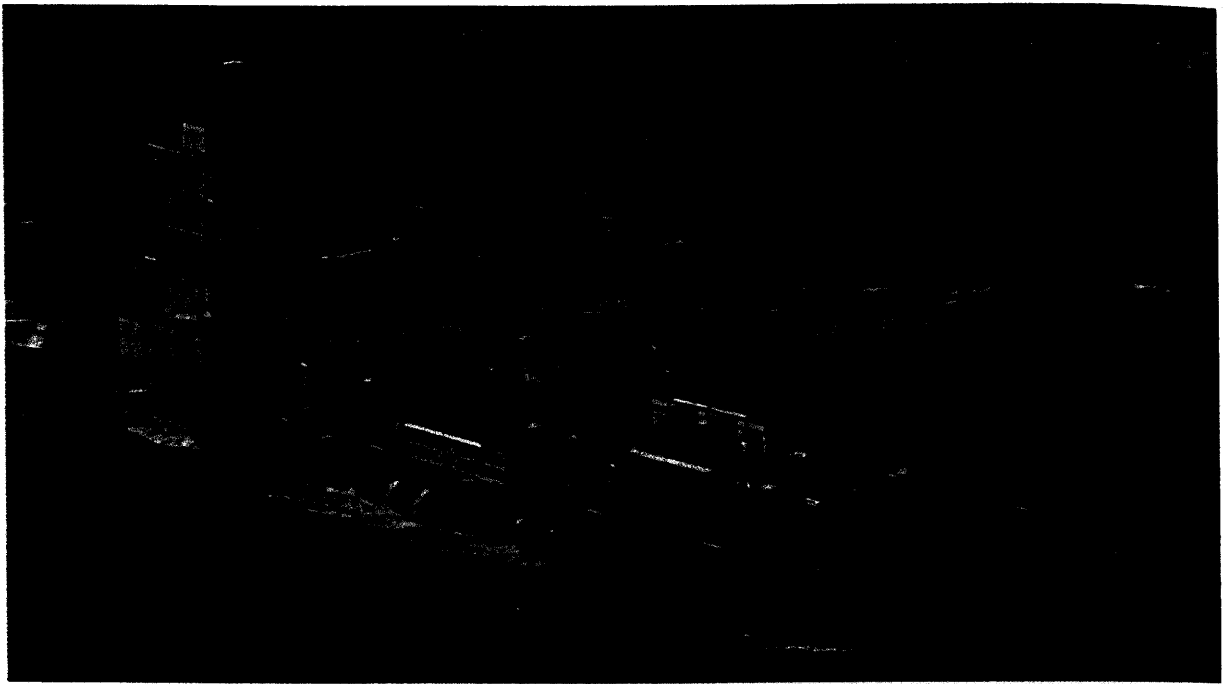


Figure 13.9 A U.S. Army Corps of Engineers' fish barge used in "Operation Fish Run" to transport juvenile salmon and steelhead around Columbia and Snake River hydroelectric projects. Photo from U.S. Army Corps Digital Visual Library, website at <http://images.usace.army.millphotolib.html>.



Figure 13.10 Idaho Department of Fish and Game tanker truck used to transport juvenile salmon and steelhead. Photo by R. N. Williams.

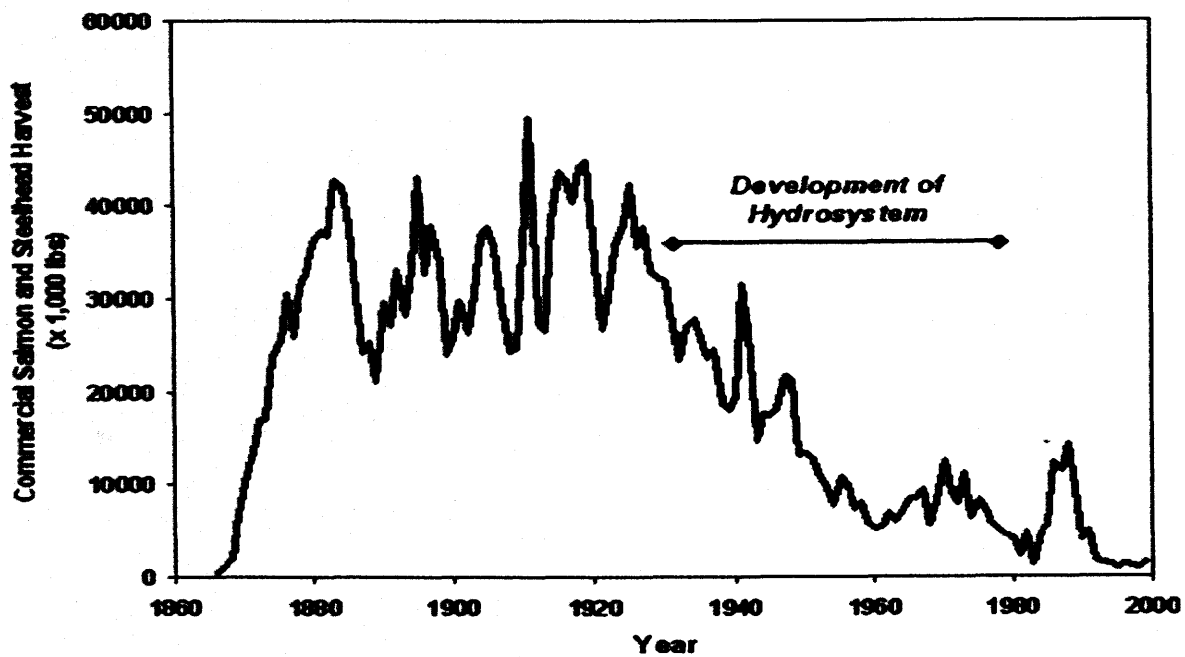


Figure 13.11 Commercial landings of salmon and steelhead in thousands of pounds in the Columbia River, 1866 to 2000. Figure courtesy of Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife (2001).

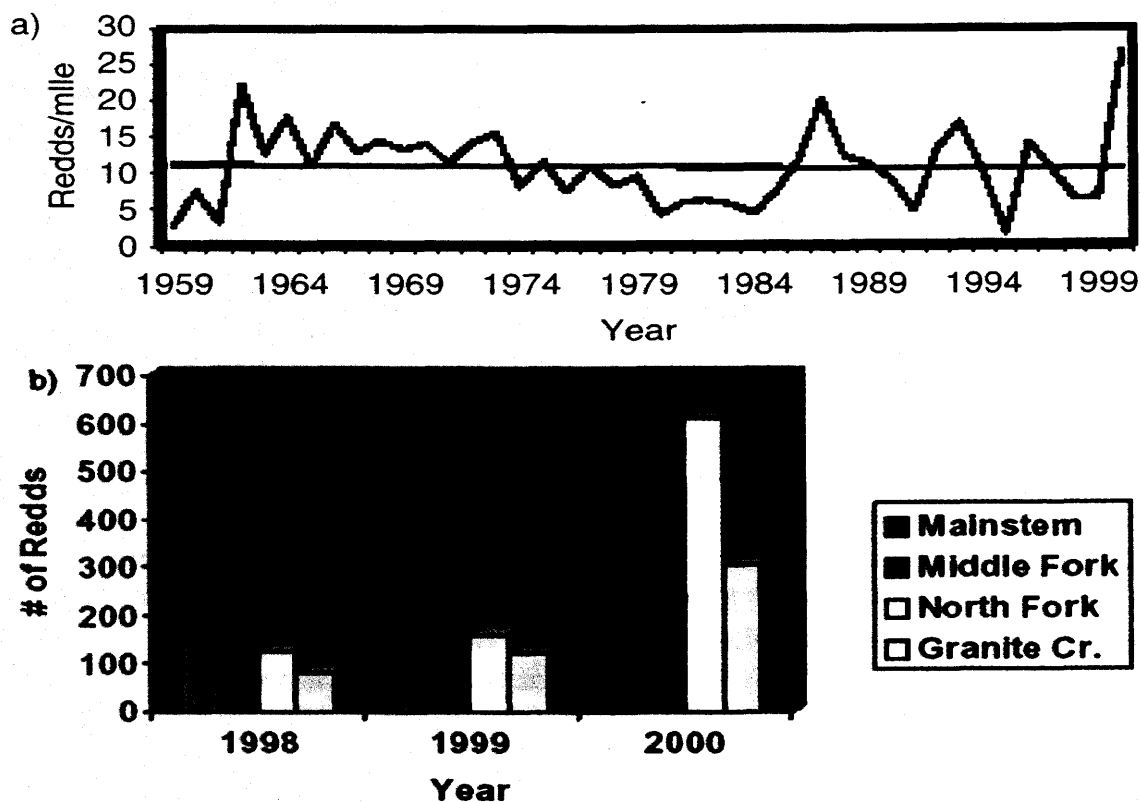


Figure 13.12 Status and trends of spring Chinook based on redd counts (a) in the John Day River overall from 1959 to 1999, and (b) from 1998 to 2000 for the John Day mainstem and the North Fork, Middle Fork, and Granite Creek tributaries. Graphs from the John Day Subbasin Management Plan (Columbia-Blue Mountain Resource Conservation and Development Area 2004).

Development of a Regional Fish and Wildlife Program

Since the early 1980s, salmon restoration has been approached regionally through implementation of the Columbia River Basin Fish and Wildlife Program¹ of the Northwest Power Planning Council (now called the Northwest Power and Conservation Council). The Northwest Power Act directed the Council to develop a plan to "protect, mitigate, and enhance" the fish and wildlife as affected by the Columbia River Basin hydroelectric system. The Fish and Wildlife Program was based on recommendations submitted by state fish and wildlife managers, Native American tribes, federal agencies, and other stakeholders. Those recommendations were solicited, compiled, and discussed by the Council in public hearings before being adopted into the program. Consequently, the Fish and Wildlife Program, in its early manifestations, represented a collection of individual, reactive measures (proposed by a diverse constituency), rather than a cohesive program derived from a single *a priori* conceptual framework. Thus, these recommendations did not share 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.

While the Fish and Wildlife Program actions to date represent a good faith effort by the Council and the region's fisheries managers to recover salmonids, those efforts have failed so far to stem the decline of wild salmonids in the basin, notwithstanding increases in adult returns from 2000 to 2004 when ocean conditions improved and salmonid marine survivals increased. Salmon returns have declined from almost 2.5 million annually in the early 1980s to less than 1 million returning adults in the late 1990s, most of which (> 80%) are of hatchery origin. Wild fish abundance is approximately 1% of historical pre-development abundance (NRC 1996). The Council's current fish and wildlife program aims to achieve a modest return of salmon and steelhead to the Columbia Basin of 5 million fish.

Recent iterations of the Council's Fish and Wildlife Program (NPPC 1997, 1998, 2000, 2004) include an integrated framework (NPPC 1997) and scientific principles (NPPC 1998) for fish and wildlife restoration, at least in part due to consistent critical advice by the Council's independent scientific advisory groups (ISG 1993, 1998, 1999; ISRP 1997, 1998, 1999). The Council's Fish and Wildlife Program, in concert with NOAA Fisheries Biological Opinions (NMFS 1995, 2000; NOAA Fisheries 2004), emphasize actions to increase survival of salmon and steelhead in the lower Snake River (i.e., downstream from Hells Canyon

¹Enactment of the Pacific Northwest Electric Power Planning and Conservation Act by Congress in 1980 (hereafter the Northwest Power Act) formed the Northwest Power Planning Council (renamed the Northwest Planning and Conservation Council in 2003) and directed it to develop a regional fish and wildlife plan.

Dam, Idaho/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 13.1). Major actions implemented so far include the following:

1. Modifying mainstem dam operations and facilities to improve upstream and downstream passage of adults and juveniles (Chapter 7)
2. Coordinating river operations to enhance spring and summer flows aimed at improving smolt survival (Chapters 6 and 7)
3. Reducing smolt predators (Chapter 7)
4. Constructing and operating hatcheries (Chapter 8)
5. Modifying existing artificial production operations, including supplementing naturally reproducing populations (Chapter 8)
6. Implementing best management practices for land use activities (Chapter 5)
7. Screening irrigation diversions (Chapter 5)
8. Improving habitat and other measures as well as research and monitoring designed to answer critical recovery questions (see Chapter 5 on habitat and Chapter 11 on monitoring).

Our collective review of the management of the Columbia River and its salmonid populations led to the conclusion that management over the course of the Council's Fish and Wildlife Programs (1982–2000) and the NOAA Fisheries Biological Opinions (1995, 2000, 2004) have been based on a conceptual foundation (i.e., a belief) that natural ecological processes comprising a healthy salmonid ecosystem can, to a large degree, be replaced, circumvented, simplified, and controlled by humans, while the production of anadromous salmonids is maintained or even enhanced (Chapter 2). In a review of the Pacific Northwest's use of salmon hatcheries, Meffe (1992) identified this approach to restoration (which he called "techno-arrogance") as the driver behind the region's reliance on large-scale hatchery technology to rebuild depleted salmon runs.

Salmonid Restoration in Regulated Rivers

Our alternative conceptual foundation (Chapter 3 specifically and Chapters 4–6 supporting) explicitly recognizes the Columbia River as a natural-cultural system, in which human development and its consequences are an integral part of the ecosystem. At the same time, the conceptual foundation also recognizes the critical function of natural biophysical processes in the creation and maintenance of healthy salmon habitat and fulfillment of life history functions (Chapters 3 and 5). The formation and maintenance of complex and interconnected habitats is fundamental to the expression of life history diversity and the spreading of the risk of mortality in variable

environments and, ultimately, to the realization of sustainable production (described more fully in Chapter 3). Human development in the Columbia Basin has weakened or eliminated the natural habitat forming and maintenance processes (Chapter 5), which together with inappropriate hatchery practices (Chapter 8) and overharvest (Chapter 9), have caused the depletion and extinction of salmon populations (Petersen 1995; NRC 1996; ISG 1998, 1999; Naiman and Bilby 1998; Stanford *et al.* 2005a). Thus, in highly developed natural-cultural ecosystems like the Columbia, there is an inescapable tension 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 (e.g., salmon and clean water) (Miller 1997; Blumm *et al.* 1998; Wood 1998; Lackey 1999; Lichatowich 1999). We recognize 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 (i.e., the "historical" river) in order to achieve salmon restoration. However, maintaining the current approach to salmon restoration will not achieve the Council's salmon restoration goals of returning approximately 5 million adult fish to the basin annually and is likely to continue the present trends of declining wild salmon abundance, local population extinctions, and proliferating ESA listings. A major conclusion embedded in our alternative conceptual framework (Chapter 3) is the need to restore a greater degree of "naturalness" to the river than exists today (see also Poff *et al.* 1997; Gregory *et al.* 2001; Stanford *et al.* 2005). With historical (i.e., pristine) conditions not attainable, what standard of naturalness is appropriate? An acceptable 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 or improve these attributes will also improve ecological conditions for salmon and aid in their restoration. Some examples of natural and artificial attributes that suggest possible management actions to improve conditions for salmon are shown in Table 13.1.

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 (ISG 1998, 1999). The region will have to improve ecological 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 river, that is, attempting to restore salmon without restoring the natural river functions. In our dynamic ecosystem view, a cornerstone of salmonid restoration is protection and restoration of the natural processes that create and change habitat conditions (e.g., Reeves *et al.* 1995; Stanford *et al.* 1996; Beechie and Bolton 1999; ISAB 2003). Restoration of habitat-forming processes is crucial for re-establishing and

Table 13.1 Examples of natural and artificial conditions and approaches to salmon restoration.

Natural	Artificial
Natural spawning and rearing	Artificial propagation and rearing in man-made 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 are absent or 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

sustaining diverse salmonid populations and life histories (Healey and Prince 1995; Reeves et al. 1996; Ebersole et al. 1995). Knowing how to restore natural processes is exceedingly challenging in a landscape that has been subject to more than 100 years of human development and is highly fragmented, dominated by the inertia of established land and fish management practices, and in which public sentiment may not favor large-scale changes (e.g., reduced fire suppression and a more natural fire regime, re-regulation of rivers to achieve a more natural hydrograph) (Stanford et al. 1996; Miller 1997; Poff et al. 1997).

Along with protection and restoration of core habitats and habitat-forming processes, protection of core salmon and steelhead populations and their associated habitats should be of the highest priority (McElhany *et al.* 2000; Williams 2001). The Hanford stock of fall Chinook in central Washington and the free-flowing river habitat where they spawn are a particularly potent example of a core stock and its critical riverine habitat. Both should receive the utmost protection possible.

Improving Conditions for Salmon

Lessons from the Hanford Reach

Two important factors emerge from an examination of the Hanford Reach fall Chinook stock, one of only two truly robust fall Chinook population in the Columbia River Basin (the other being the healthy, but much smaller, Lewis River fall Chinook). First, the Hanford population originates in a series of linked habitats amid a free-flowing river section that provide suitable adult spawning habitat, successful incubation of eggs, and various juvenile rearing areas that are immediately adjacent to, or within a few kilometers downstream of, the spawning areas (Geist and Dauble 1998) (Figures 13.13 and 13.14). Second, fisheries regulations are appropriate to maintain adequate escapement of spawners to the Hanford Reach area.

While the 50-mile Hanford Reach is unimpounded and the Columbia River flows freely through this remarkable section, flows coming into the Hanford Reach are regulated by a number of upstream dams. In recent years, the Hanford Reach fall Chinook population has benefited from agreements to regulate river flows out of these upstream dams that take into consideration the spawning and rearing needs of the Hanford Chinook population. As a result of an agreement reached among affected parties (the three mid-Columbia public utility districts, the Bonneville Power Administration, the U.S. Army Corps of Engineers, the states of Washington and Oregon, and certain Treaty Tribes), flows are maintained while Chinook salmon are spawning to provide a stable boundary within which the redds are constructed. Following spawning, flows are maintained to protect the incubating eggs from dewatering. Finally, after the fry emerge from the redds, flows are stabilized to prevent stranding of juveniles, prior to their movement downstream (ISAB 1998). It is clear that the population has responded positively to these measures that have improved the functionality of the existing habitat. In addition, hatcheries at Priest Rapids and Ringold have also contributed to returning adults. The Chinook juveniles from the Hanford Reach are typical fall (ocean-type) Chinook, beginning and completing their migration to the sea during the first year after hatching. They move downstream

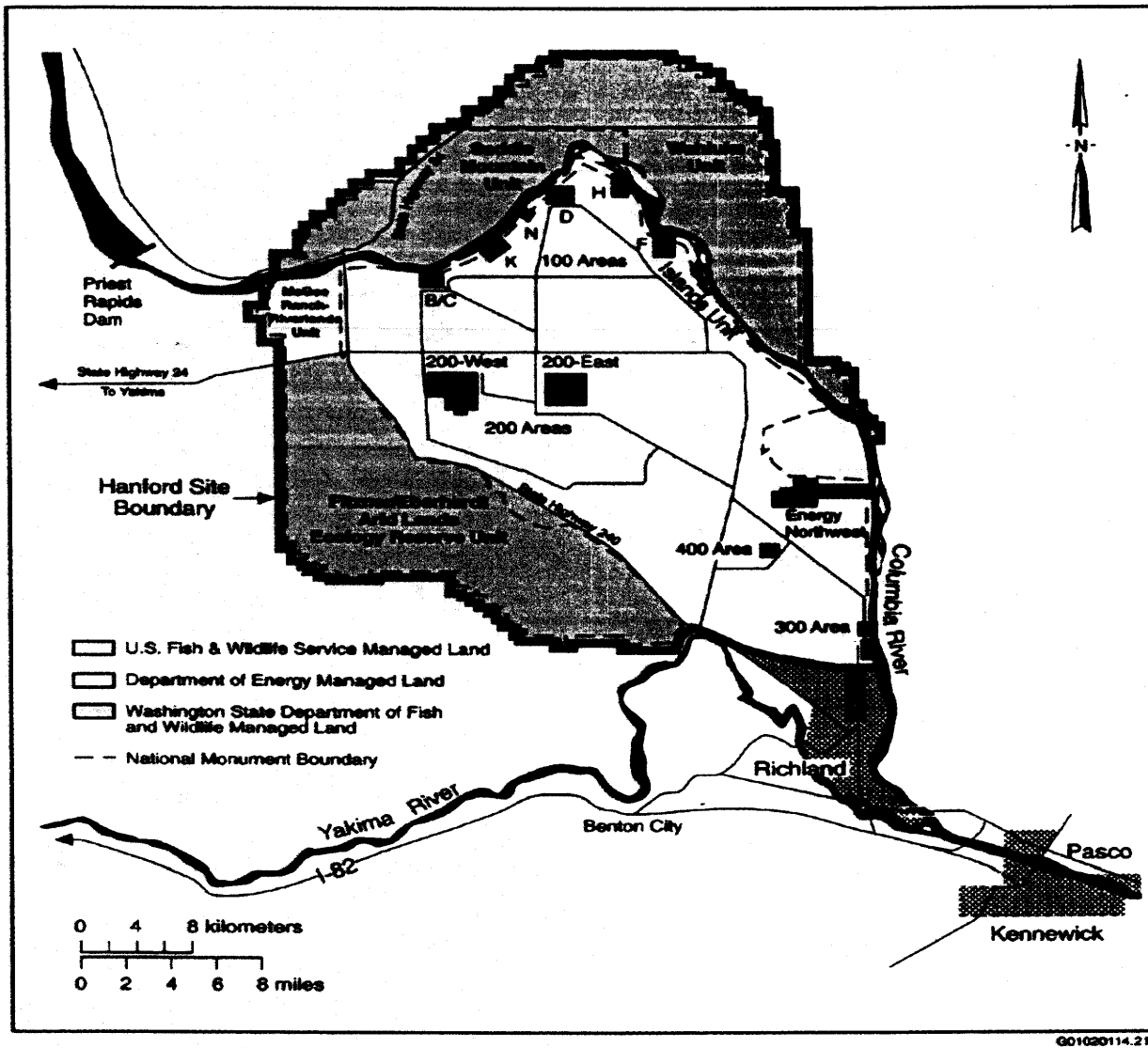


Figure 13.13 Map of the Hanford Reach in the Middle Columbia River showing its position adjacent to the Yakima River. Figure from U.S. Fish and Wildlife Service, <http://hanfordreach.fws.gov/fac.html>.

slowly, feeding and taking advantage of the excellent rearing habitat found in the lower portions of the Hanford Reach. Fall Chinook do not guide well with turbine intake screens. Like sockeye salmon, they are probably subject to higher mortality than spring Chinook or steelhead passage past the dams. Nevertheless, Hanford Reach fall Chinook are captured in ocean fisheries off the coasts of Washington, British Columbia, Alaska, and in the Columbia River. To date, passage mortalities on juveniles and these fisheries have not prevented attainment of the escapement goals in the Columbia River, although there are other stocks of fall Chinook that have not fared as well.

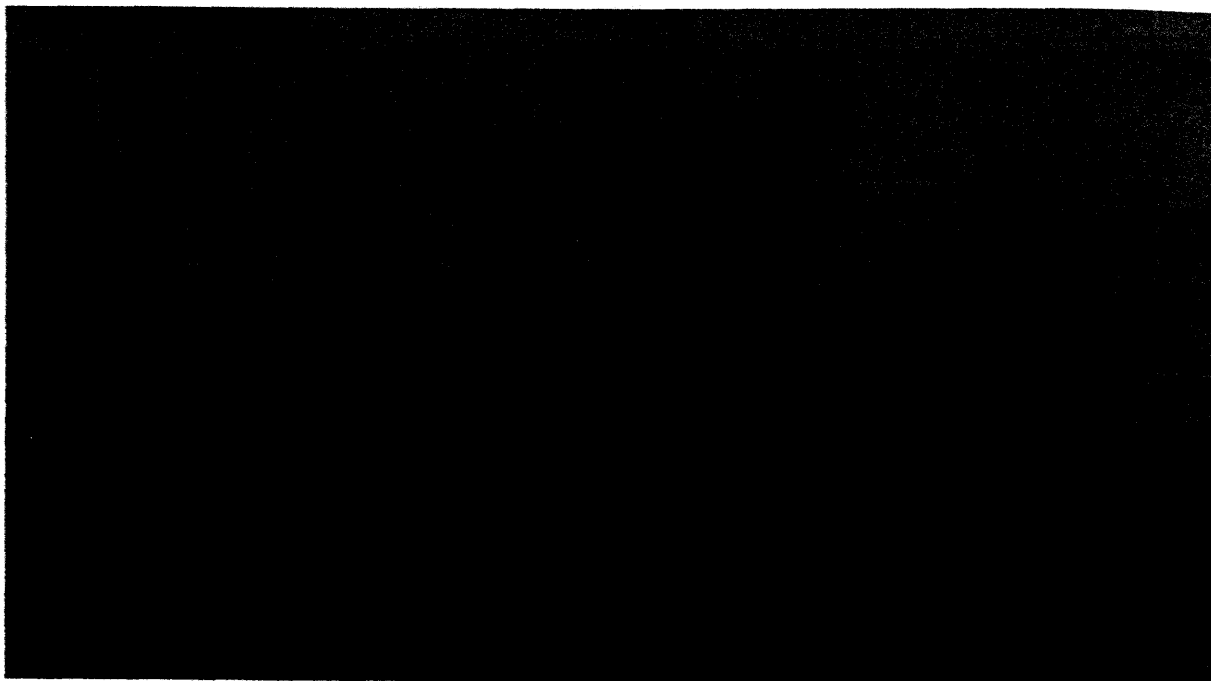


Figure 13.14 Beach seining for juvenile fall Chinook at Hanford Reach, showing typical shoreline habitat within the Hanford Reach National Monument. Photo courtesy of D. Geist.

Salmon and Habitat in the Mid-Columbia and Lower Snake Rivers

Areas in the mid-Columbia, adjacent to the Hanford Reach and extending downstream to below The Dalles, were historically highly productive spawning and rearing habitats for salmon, particularly fall Chinook (Figure 13.15). The forested upper reaches of the Snake River Basin and its many tributaries (the Boise, Payette, Weiser, Owyhee, Bruneau, Salmon, and Clearwater Rivers) produced the majority of the Columbia River Basin's spring Chinook salmon. The lower Snake River (the site of the four lower Snake River dams) (Figure 13.1) is largely constrained through a high desert canyon, yet also was a historically productive river reach for fall Chinook salmon. The Columbia River, from its confluence with the Snake River in eastern Washington, downstream to below The Dalles, was characterized by a shallow river gradient replete with complex and diverse riverine habitats that were used extensively by spawning fall Chinook salmon, including the large and storied "June hogs" and today's "upriver brights." The entire area was also used as rearing habitat for juvenile fall Chinook and as resting and feeding habitat for outmigrating spring Chinook and steelhead from the upper basin (Chapter 6).

While the mid-Columbia area near Washington's Tri-Cities (Richland, Kennewick, and Pasco) and John Day and McNary Dams is extensively developed for hydroelectric generation, barge transportation of inland goods, and large-scale pump-fed crop irrigation, the adjacent Hanford Reach holds great

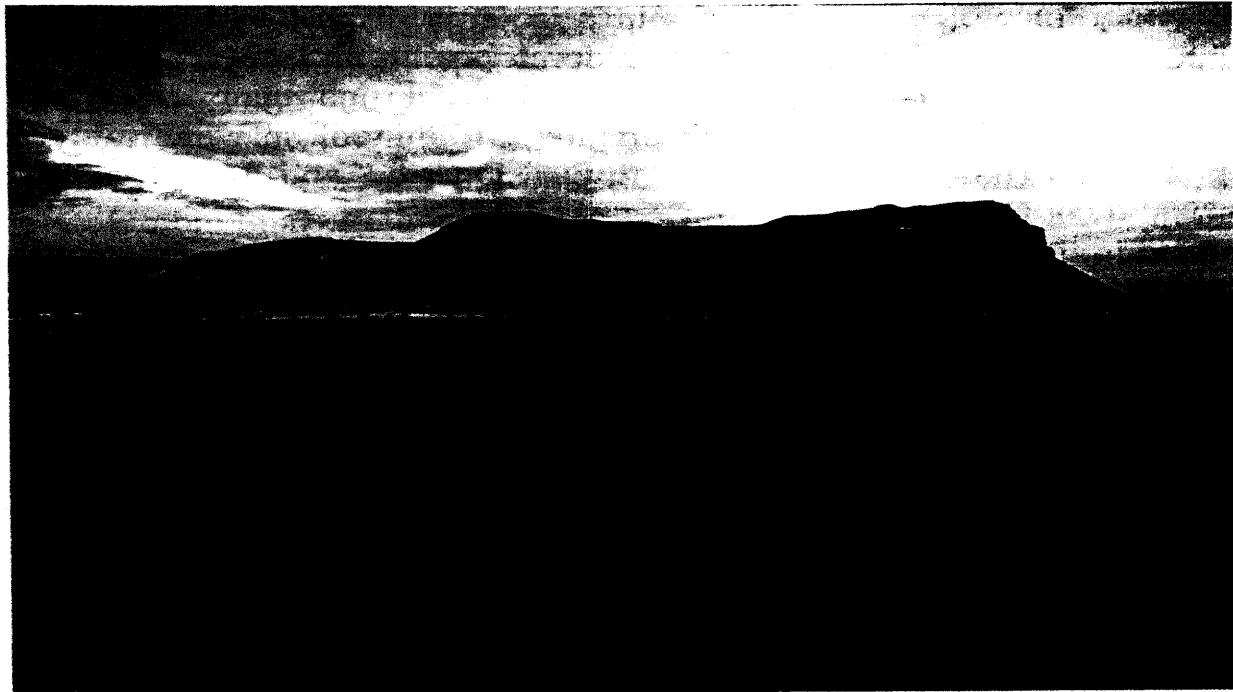


Figure 13.15 View of the mid-Columbia River near Vantage, Washington, showing the broad valley and shorelines habitats typical of the mid-Columbia region. Photo by Mike Pinney, www.photobymike.com.

potential for restoration of salmon-bearing habitat and increasing salmon abundance in the basin. Nevertheless, large-scale restoration of salmon habitat in the mid-Columbia area would necessitate major modification of the Columbia River federal hydroelectric system, something not currently considered in the 2004 NOAA Fisheries Biological Opinion (NOAA 2004), nor supported by the Northwest Regional Congressional delegation. An earlier version of the Biological Opinion (NMFS 2000) had decision points where modification of the hydrosystem, including the possibility of partial removal of the four lower Snake River dams, would have been considered if explicit restoration steps did not achieve numerical targets by 2008. Recent federal actions and the new 2004 Biological Opinion removed any consideration of dam removal or major modification to the hydrosystem from the federal planning process (Chapter 12); however in May 2005, the 2004 Biological Opinion was rejected by the federal courts after determining that it violated the Endangered Species Act. In June 2005, Judge Redden ordered summer spill to occur at selected Snake and Columbia River dams after noting that “irreparable harm results to listed species as a result of the action agencies’ implementation of the updated proposed action” (Judge James A. Redden, p. 9; Injunctive Order and Opinion for Case CV 01-640-RE, June 10th, 2005).

In spite of the current federal position constraining modification of the Snake or Columbia River hydrosystem, several recent studies have examined

the importance of geomorphic features in large rivers (Geist and Dauble 1998) and assessed the impacts of development and operation of the Columbia and Snake River hydroelectric system on mainstem riverine processes and salmon habitats—primarily on fall Chinook spawning and rearing habitats (Battelle's Pacific Northwest Division and U.S. Geological Survey 2000; Dauble *et al.* 2003).

Among the findings from the study are that only about 13% and 58% of the historical mainstem Columbia and Snake Rivers, respectively, are still riverine in nature (as opposed to the lacustrine nature of the impounded reaches). The largest loss of riverine habitat in the Columbia River occurred downstream of the Snake River confluence where only about 3% of the historical riverine habitat between the confluence and Bonneville Dam still exists, mostly in the tailraces downstream of hydroelectric projects (Figure 13.16). Other recent studies have shown remnant fall Chinook populations utilizing these specific habitats for spawning (Garcia *et al.* 1994). In the upper Snake River, nearly 70% of the historical mainstem riverine habitat still remains; however, it lies upstream of Hells Canyon Dam (Figure 13.1) and is no longer accessible to anadromous salmonids.

Dauble *et al.*'s (2003) analysis of historical spawning areas for fall Chinook was coupled with model-based analysis of river reach geomorphology and concluded that historical fall Chinook spawning areas were primarily associ-

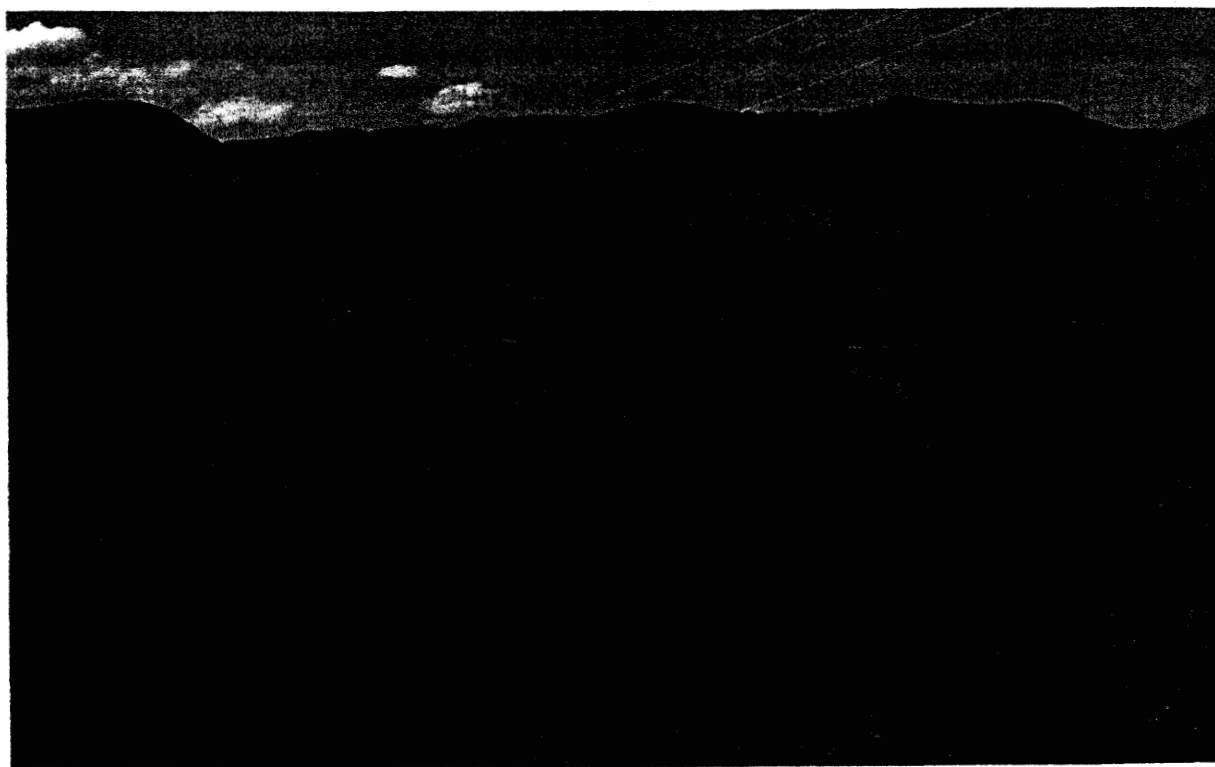


Figure 13.16 The Snake River immediately below Hells Canyon Dam on the Idaho-Oregon border, showing fall Chinook spawning habitat. Photo by R. N. Williams.

ated with the wide alluvial flood plains that were once common in the mainstem Columbia and Snake Rivers (Battelle's Pacific Northwest Division and U.S. Geological Survey 2000; Dauble et al. 2003). From the analysis, they identified three river reaches with the highest potential for restoration of riverine processes: (1) the Columbia River upstream of John Day Dam, (2) the Columbia-Snake-Yakima River confluence, and (3) the lower Snake River upstream of Little Goose Dam.

The John Day pool lies immediately downstream of McNary Dam. The upper portion of the pool also lies downstream of the confluence of the Snake and Columbia Rivers and contains what was formerly a large alluvial reach that served as a highly productive area for mainstem spawning Chinook salmon populations. Populations in this area may have been linked together into a regional metapopulation. The large mainstem spawning population may have served as the core of the metapopulation, and it may have stabilized Chinook salmon production in the mid-Columbia and its tributaries. Restoration and revitalization of the upper John Day pool as a free-flowing river segment might assist in the re-establishment of Chinook salmon production and metapopulation structure through straying and dispersal from the upstream Hanford Reach Chinook. Dauble et al. (2003) examined three different river management options for the John Day reservoir: (1) natural river drawdown, (2) spillway crest drawdown, or (3) normal pool conditions; and found that up to 53%, 22%, and 3% of the total reservoir area would be potentially suitable as spawning area for fall Chinook, respectively (Figure 13.17). Because of the shallow river gradient in the Columbia River below the confluence with the Snake River, the John Day Dam pool is one of the longest reservoirs on the Columbia River at more than 70 miles in length. As suggested by one scenario in the Dauble et al. (2003) study, drawing the John Day Dam pool elevation down 40 feet to spillway crest would reduce the reservoir length by half, exposing about 35 miles of river that was inundated when the dam was built. The resulting river would be shallow and braided: ideal spawning and juvenile rearing habitat for fall Chinook (e.g., Figure 13.18).

In the lower Snake River, Dauble et al. (2003) concluded that the majority (74%) of the 266-km study area was classified as alluvial or partially alluvial habitat. They estimated that approximately 55% of the study area may have been suitable as fall Chinook spawning habitat prior to hydroelectric development. Of particular interest is the river section between Little Goose Dam and Lower Granite Dam, in which 87% of the lineal river distance was predicted to be suitable fall Chinook spawning habitat.

Lessons from the Salmon Themselves

While it is important to look at historical distribution and abundance patterns of salmon in the basin as one means of identifying potential restoration

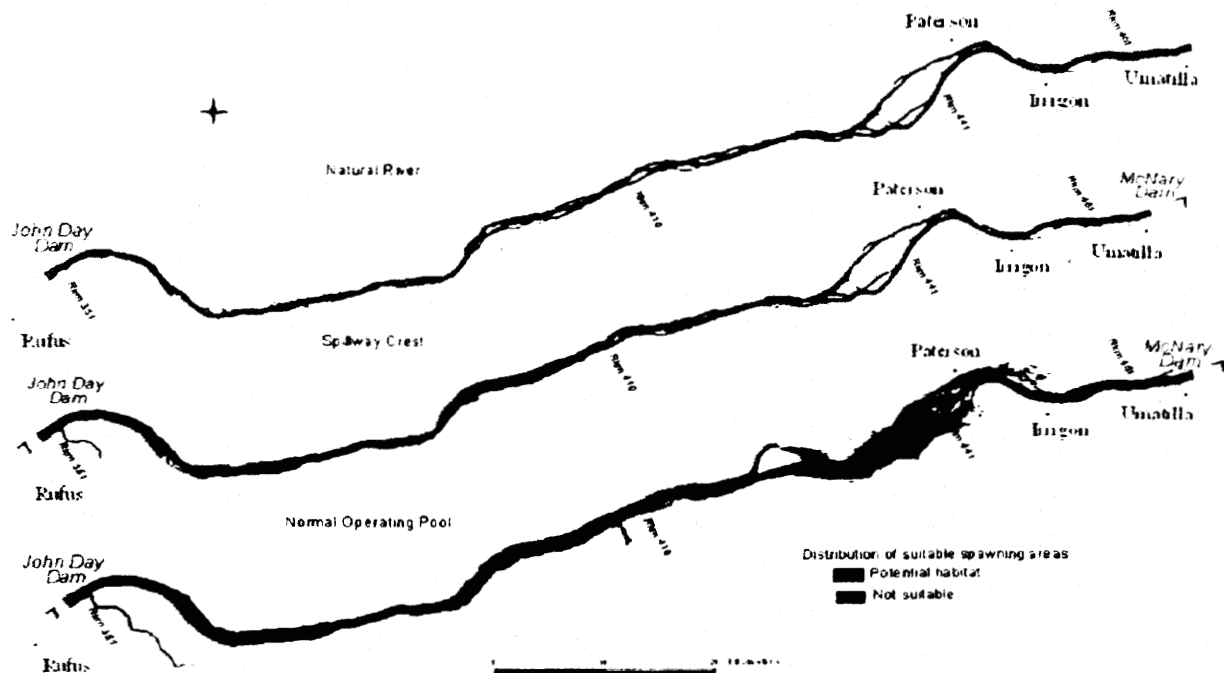


Figure 13.17 Distribution of suitable (red) and unsuitable (blue) fall Chinook spawning habitat in the John Day pool area based on water depth and velocity for three operational scenarios: natural river (top), spillway crest drawdown (middle), and normal operating pool (bottom). Figure from draft final report by Battelle's Pacific Northwest Division and the U.S. Geological Survey (2000), courtesy of D. Dauble.

sites and opportunities, we also need to look closely at current distribution and abundance patterns, as these indicate how salmon are adapting to and using the present system. One of the most interesting distribution patterns to emerge from recent surveys of the Columbia and Snake River mainstems is the persistent use of tailwater areas below hydrosystem projects by fall Chinook salmon as spawning areas (Garcia et al. 1994; Fish Passage Center website, www.fpc.org). Remnant fall Chinook populations have been observed below nearly all projects in the mainstem Columbia and Snake Rivers, attesting to the dispersal ability of fall Chinook, as well as to their ability to find and colonize suitable available spawning habitats. We view this response by fall Chinook to these habitats as evidence of the effectiveness of the normative river concept (Chapter 3) as a restoration strategy for increasing salmon abundance and productivity.

The most striking example of fall Chinook use of tailwater habitats immediately below a hydroelectric project occurs below Bonneville Dam around Pierce and Ives Islands. Lower Columbia River chum salmon, an ESA-listed threatened species, have also used the area for spawning since the 1960s, or earlier. The first recorded stream survey of the area (Hamilton Slough on the north bank of the Columbia) occurred in November 1967 by Washington Department of Fish and Wildlife personnel, where they counted 63 chum

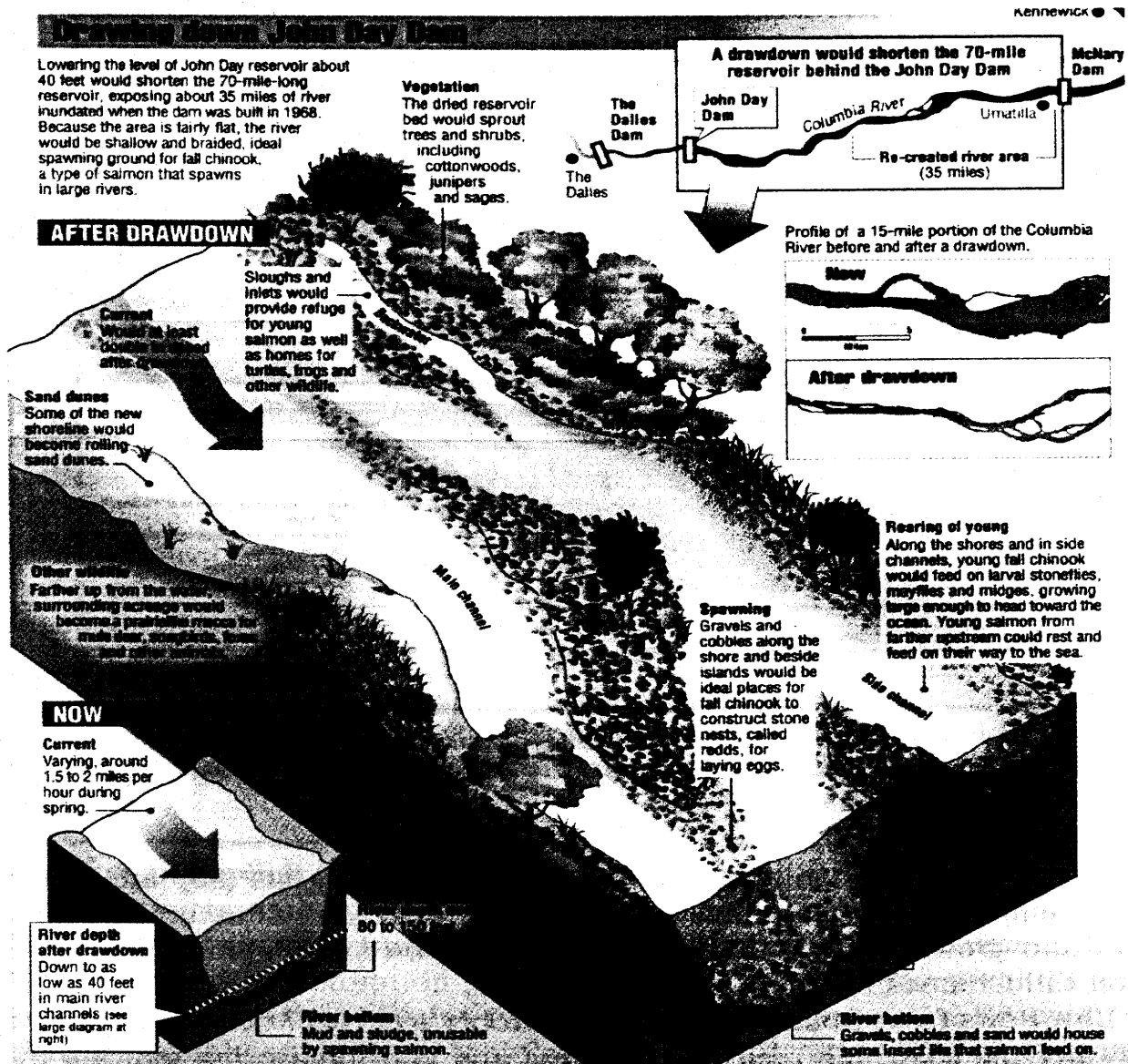


Figure 13.18 An example of how ecological conditions would be improved by restoring free-flowing river conditions to the upper John Day pool area through a permanent drawdown of John Day Reservoir to spillway crest. Graphic design provided by Molly Swisher and Jonathan Brinckman, *Oregonian* staff.

salmon adults. Another survey in the fall of 1976 noted 13 chum salmon and 75 redds at the upstream end of Pierce Island. In spite of these records, the area was not systematically surveyed until the late 1990s.

In November 1993, fall Chinook were observed in the area by WDFW personnel. Surveys in December 1994 counted more than 150 spawning fall Chinook salmon. More extensive surveys in 1997 and 1998 counted over 1,000 adult fall Chinook in the Pierce and Ives Islands and the Hamilton slough area. Figure 13.19 shows the distribution of fall Chinook and chum salmon redds in the Hamilton Slough area in late November 1999. Genetic

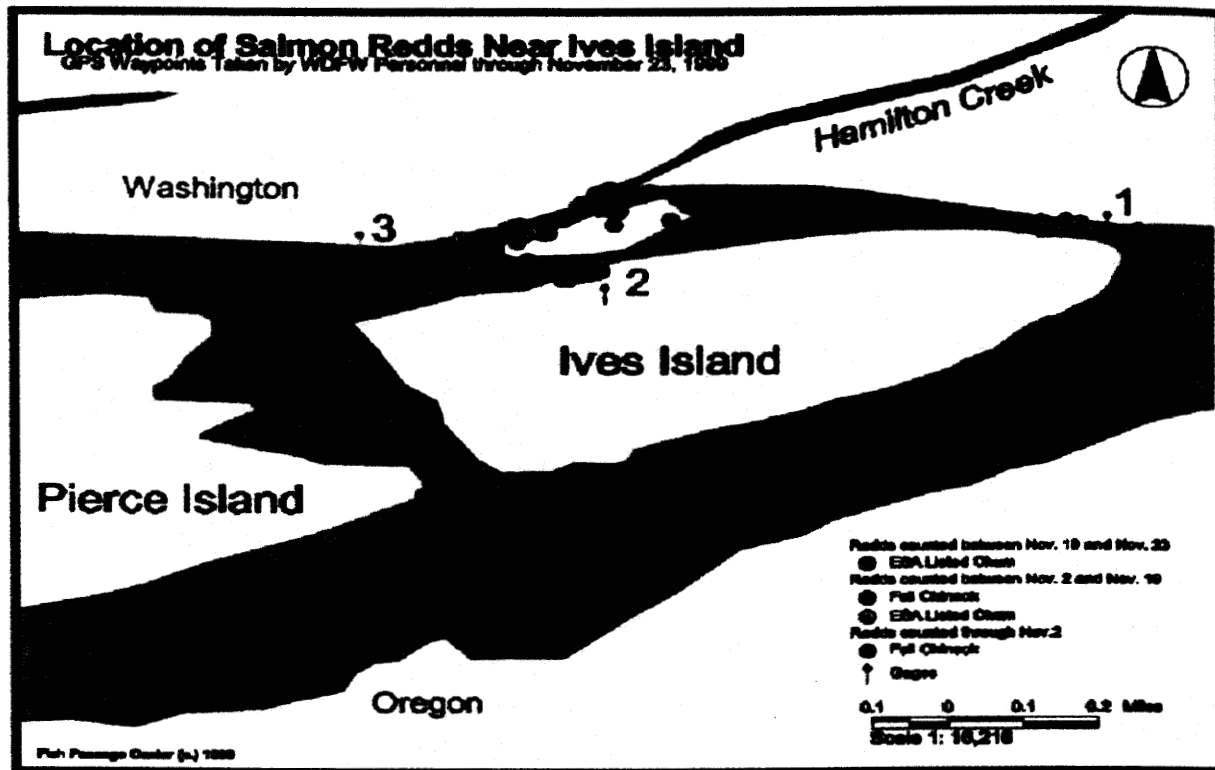


Figure 13.19 Map showing chum and fall Chinook salmon redds in normative habitats surrounding Ives and Pierce Islands immediately below Bonneville Dam, fall spawning season 1999. Map courtesy of the Fish Passage Center.

analysis of fall Chinook in this area by WDFW suggests they are derived from remnant lower Columbia River fall Chinook through natural colonization and growth, rather than being derived from mid-Columbia or upper-river fall Chinook salmon.

Low flows from Bonneville Dam in October 1997 (117 kcfs) threatened to dewater the spawning area. Further research and monitoring indicate that dewatering of redds could occur at flows below approximately 150 kcfs. Presently, Bonneville Dam operations are coordinated with spawning area water level sensors through the Fish Passage Center's monitoring program to avoid dewatering redds of both chum and fall Chinook salmon in the Hamilton Slough area.

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 traditional solution involves a combination of hatchery technology (to maximize the number of smolts produced), flow augmentation, and juvenile transportation

via barges to move them as rapidly and efficiently as possible past the dams. This strategy is reflected in restoration expenditures (General Accounting Office 1992, 2002; Bernhardt et al. 2005) and in the measures supported by management agencies and tribes for implementation (ISRP 1997, 1998, 1999; CBFWA 2004).

The region, through its policy representatives and the evaluative processes described above, 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 is unwilling to improve the ecological conditions needed to achieve the Council's current salmon recovery goals, then those goals must be changed. The challenge before the region is to reach agreement on the extent to which the 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 bring about salmon recovery and to achieve the Fish and Wildlife Program's salmon restoration goals.

Unfortunately, the restoration program based on the current set of assumptions has failed to curtail the decline of wild salmonid fishes. Moreover, it may be actively interfering with conservation efforts for resident fishes or other management goals in headwater areas not accessible to salmon; for example, 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).

Need for an Explicit Conceptual Foundation

The lack of progress towards salmon recovery goals in the Columbia Basin has been linked to restoration programs derived from a conceptual foundation that sought to circumvent *important ecological processes*. Recovery of anadromous salmonids in the basin needs to be centered around an explicitly defined conceptual foundation based on ecological principles. We have consistently recommended that the region adopt an explicitly defined conceptual foundation that is based on ecological principles (see Chapter 3). Without a fundamental change in our approach to salmon restoration, more extinctions of salmon populations are likely and progress toward the rebuilding goal is unlikely. Temporary increases in some populations may occur in response to fluctuations in ocean conditions, and small increases may result from large-scale use of technology such as hatcheries, but the overall downward trend in returns of wild fish that has occurred throughout this century will likely continue without a fundamental change in approach.

The most recent (2000, 2004) Fish and Wildlife Program drafted by the Northwest Power and Conservation Council is a major move toward the conceptual foundation and the programmatic approach we have been recommending; however, more needs to be done.

Need for an Integrated Approach

The potential social, economic, and biological trade-offs that are needed to improve the ecological conditions in the Columbia River are not fully known; nor have they been subject to open discussion and debate. Identifying and quantifying those trade-offs where possible is a high priority. 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 regional fisheries management and recovery plans (IEAB 1999).

A rigorous program of evaluation, monitoring, research, and adaptive management derived from the appropriate conceptual foundation 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. This approach might be tested at the subbasin level as a first step (Hill and Platts 1998). Recent versions of the Council's program (NPPC 2000, 2004) have stressed ecological principles, multi-species actions, and increased coordination and integration.

Manage for Biological Diversity

Biological diversity is the cornerstone for long-term population viability among species inhabiting stochastic environments (Frankham *et al.* 2002). The Pacific Northwest region needs to explicitly recognize that salmonid fishes in the Columbia River exist naturally as aggregates of populations (Brannon *et al.* 2004), likely organized as metapopulations (described in Chapter 4). Thus, managing for life history and genetic diversity among salmonid populations is essential for the long-term persistence of these species. The results of such actions will likewise manifest themselves in increased survival and total production within these areas. This, in turn, further reduces the cumulative impacts from deterministic effects which pose hazards to the populations' longevity and reduces the effect of unforeseen catastrophes; that is, strong, healthy, interconnected populations are better able to weather demographic and environmental stochasticity (Gilpin 1996; Frankham *et al.* 2002). Although much of the natural diversity of salmonid fishes has been lost (Nehlsen *et al.* 1991; Huntington *et al.* 1996), we must assume that salmonids retain the capacity to re-express life history and population diversity if opportunities for access to suitable habitat are provided (Healey 1994). As habitats improve in the Columbia Basin, metapopulation structure will likely develop from the natural expansion of remaining wild core populations (e.g., fall Chinook in the Hanford Reach) by processes variously described as metapopulation "rescue effects" (Stacey and Taper 1997).

Protect and Restore Habitat

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 (Figure 13.20), restoring degraded habitat, and providing access for salmonids to diverse habitats should be management priorities (Chapter 5). This approach will permit 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:

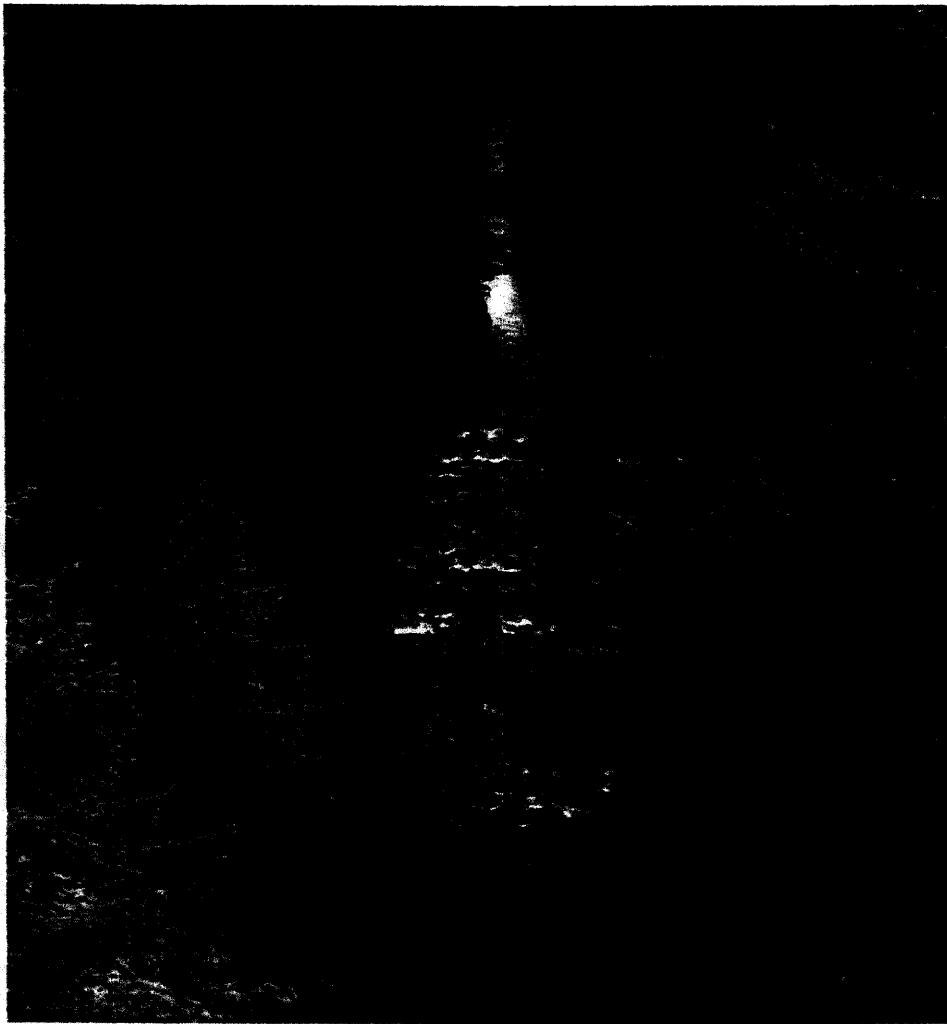


Figure 13.20 The Wind River Canyon in southwestern Washington. This section of the Wind River is home to a remnant but depressed wild steelhead population. Photo by R. N. Williams.

1. Re-regulate flows to restore the spring high-water peak, including occasional, especially high flood peaks, that will revitalize the mosaic of habitats in alluvial riverine reaches.
2. Re-regulate flows to stabilize daily fluctuations in flow (caused by the practice of "power peaking") to allow food web development in shallow water habitats and reduce juvenile mortalities via stranding.
3. Provide incentives for watershed planning that emphasize riparian and upland land use activities that support natural interactions between land and water, and insist on empirical evaluation of effectiveness of management practices (Figure 13.21).

Reduce Sources of Mortality

Reduce sources of mortality in the mainstem of the Columbia and Snake Rivers and improve effectiveness of mitigation activities within the hydroelectric system (Chapters 6 and 7). These goals include managing stocks with a more complete understanding of their migratory behavior and how this behavior is affected by various modes of river regulation. Mitigation meas-



Figure 13.21 The lower Lemhi River is a highly productive tributary of the upper Snake River in central Idaho, where water and land incentives have encouraged local ranchers to protect important spawning and rearing habitat for Chinook salmon and resident rainbow trout. Photo by R. N. Williams.

ures for dams should be directed toward increasing natural riverine processes and functions needed by salmon for spawning and rearing.

We identified four specific areas or activities that would improve the survival of salmon in the mainstems of the Columbia and Snake Rivers:

1. Couple seasonality of flow with spill rates over the dams that efficiently bypasses juveniles and adults around mainstem dams and behaviorally cue (rather than physically flush) the juveniles through the mainstem.
2. Reduce mortality from gas bubble trauma with field research on causes of the problem and installation of devices that reduce nitrogen gas supersaturation.
3. 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 it is clear that natural habitats in the mainstems cannot be restored.
4. Restore mainstem, floodplain, and estuary habitats to more natural conditions where possible, which will reduce predation rates on migrating juvenile salmon and provide more rearing and resting habitat.

Improve Effectiveness of Mitigation Actions

The Pacific Northwest region needs a better strategy to reduce inadvertent negative impacts and improve the effectiveness of mitigation actions associated with habitat restoration, artificial propagation, and harvest management. Planning and implementation of mitigation measures will be more effective if they 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 the mainstem and tributaries must receive high priority (Chapter 5). Restoration efforts should be directed at providing the habitat opportunities that historically supported salmonids in their natural state and the connectivity to those habitats (Healey 1994).

Artificial propagation (Chapter 8) must be viewed as an experiment to be implemented within an adaptive management framework (NRC 1996), rather than a proven technique to increase the number of fish for harvest or accelerate the recovery of wild stocks. It will be difficult to determine if it is possible to integrate hatchery operations with natural production in the basin (Scientific Review Group 1999; Myers et al. 2005); monitoring and evaluation should be designed to make that determination. Resolving that issue has been avoided for too long. The role and scale of artificial production at the subbasin level should be consistent with the rebuilding goals for natural production. Supplementation goals emphasizing harvest should be secondary to population restoration and self-sufficiency. Monitoring, and especially

evaluation, remains inadequate to address the many outstanding uncertainties associated with the use of artificial propagation (ISAB 2003).

Appropriate harvest control is necessary for successful salmon conservation (Chapter 9), with full accounting for harvest (both direct and indirect) to ensure the persistence of salmon populations. With degraded habitats, reduced life history diversity, and reduced abundance, it is essential to account for all sources of mortality in all localities and to control harvest to levels consistent with those other sources of mortality and with salmon recovery. Harvest regulation should take into consideration the keystone role that salmon carcasses play in riverine food webs.

Manage Considering Ocean and Estuary Conditions

Estuary and ocean dynamics are now recognized as major controlling factors of salmon productivity (Chapter 10). This will require adjustments in management actions for all other aspects of the life cycle under human control, such as harvest, hatchery operations, river and tributary habitats, and hydrosystem operations. Prudent management actions should increase or maintain biodiversity in salmon populations to help them cope with the effects of a fluctuating marine environment. A better understanding of estuarine and oceanic food webs is needed. Much recent work has been conducted in this area (Bottom *et al.* in press), yet our understanding and ability to maintain salmon productivity in the estuary is limited.

Estuarine habitats and the near-shore Columbia River plume can be improved by pollution abatement and continuing enhancement of the spring freshet associated with the restoration of more normal flow regimes (Cury and Roy 1989; Bottom and Jones 1990; Lawson 1993). Numbers of smolts released from hatcheries should take ocean productivity into account; it may be prudent to limit releases during periods of low ocean survival and growth (Francis 1997) or to time hatchery releases to avoid attracting large numbers of predators during smolt migration periods. Management actions affecting freshwater parts of the salmon's life cycle should emphasize the linkages between habitat and biological diversity, as a biologically diverse suite of salmon and steelhead populations are likely to be buffered against fluctuating ocean conditions (Francis 1993; Bisbal and McConnaha 1998; Hilborn *et al.* 2003).

Establish Salmonid Reserves

It is critical to protect remaining viable, naturally spawning salmon and steelhead populations and to restore habitats with the potential to re-establish core populations at strategic locations within the basin. One way to accomplish this would be to reconsider the concept of salmonid reserves. Reserves protect habitats that currently support remaining viable core populations (Figure 13.22), and they could serve as foci for rebuilding salmonid abundance and metapopu-

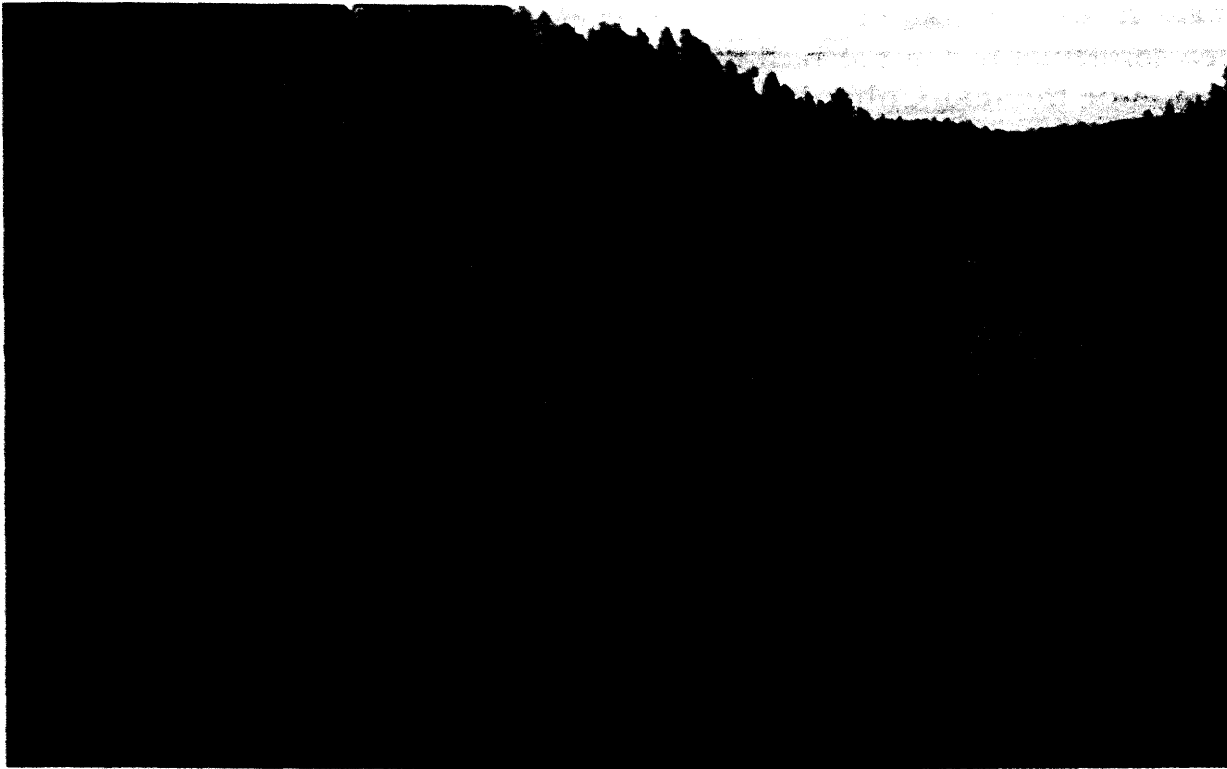


Figure 13.22 Granite Creek is an important tributary in the John Day River system for spring Chinook spawning and rearing. The John Day system is significant, as it is the only major sub-basin in the Columbia and Snake River systems where artificial production of salmon and steelhead has not occurred. Of the seven healthy salmon and steelhead populations identified by Huntington et al. (1996) in the Columbia River Basin, five of them occurred in the John Day subbasin. Photo by R. N. Williams.

lation structure throughout the Columbia Basin. We believe priority should be given to considering the confluence of the Snake and Columbia Rivers, including the Hanford Reach, as a potential reserve area (Williams 2001).

The concept of salmon reserves has been discussed by salmon managers for over 100 years, including at least four recommendations for the inclusion of reserves in the Columbia Basin (Rahr et al. 1998). Moreover, promulgations by the Clinton administration regarding their "Roadless Area Conservation Rule" states that 237,000 sq. km of inventoried roadless areas (IRAs) would remain roadless and be protected from timber extraction and other activities under the rule (USDA Forest Service 2000). Loucks et al. (2003) concluded 77% of these IRAs have outstanding potential to conserve threatened, endangered, or imperiled species and that the conservation of such areas would have far-reaching effects. The U.S. Forest Service Roadless Area Final Environmental Impact Statement identified IRAs as having a direct or indirect influence on critical habitat for more than 30 threatened or endangered species, including most trout and salmon (USDA Forest Service

2000). In spite of its long history of discussion, no salmon reserves have ever been implemented in the basin. The Hanford Reach, a roughly 75 km long portion of the mid-Columbia River, is the only remaining large, undammed mainstem river segment, and it contains the largest natural spawning population of fall Chinook in the Columbia Basin above Bonneville Dam. Over the last two decades, naturally spawning Hanford Reach fall Chinook have continued to be productive while other stocks have declined. These fish exhibit characteristics of a core population both in their resiliency, being the only remaining mainstem Chinook salmon population of significance, and their contribution to spawning populations elsewhere in the basin. (Marked individuals have been recovered at other mid-Columbia and Snake river sites; see Figure 3.16.) The Hanford Chinook stock likely has remained productive because of the lack of dams in this river section and the maintenance of necessary ecological processes and functions through the re-regulation of flows during the Chinook spawning season.

The Hanford Reach also provides an excellent case study of how using normative river principles (in this case, flow management and protection of riparian areas) can maintain a healthy salmon population in spite of other human development. Success to date has been achieved as a result of restricting operations of the hydropower system to stabilize flows in the Reach during spawning, incubation, and emergence of fall Chinook. Additionally, land surrounding the Reach is isolated from human activities, as it lies within the Federal Hanford Nuclear Reservation where management actions, other than those associated with development of atomic resources, have not been permitted to date. The Hanford Reach is now part of the Hanford Reach National Monument, which has a series of management units based on their "ecological values," which includes spawning areas for salmon. The U.S. Fish and Wildlife Service is currently going through a Draft Comprehensive Conservation Plan/Environmental Impact Statement (<http://hanfordreach.fws.gov/fac.html>) for the Monument which will, in theory, result in a management plan.

The viability of naturally spawning Chinook in the Hanford Reach provides a template that may be replicated elsewhere in the Columbia Basin. Therefore, adequate protection of both the habitat function of the Reach and the fall Chinook that spawn there are of the highest priority (Geist 1995; Whidden 1996; Williams 2001). While continuing to protect the natural features of the Hanford Reach area, the region should search for other candidate areas in the Columbia and Snake Rivers where spawning and rearing habitat can be protected or restored, and natural population and metapopulation structure re-established. A likely candidate is the approximately 50-mile stretch of undammed Snake River between Hells Canyon Dam and the upper reaches of the reservoir behind Lower Granite Dam, where rapid daily fluctuations in flow are still permitted. The John Day River, which

currently supports healthy Chinook and steelhead populations, is another candidate area for special management attention (Figure 13.22).

Return to the River: The Challenge Ahead

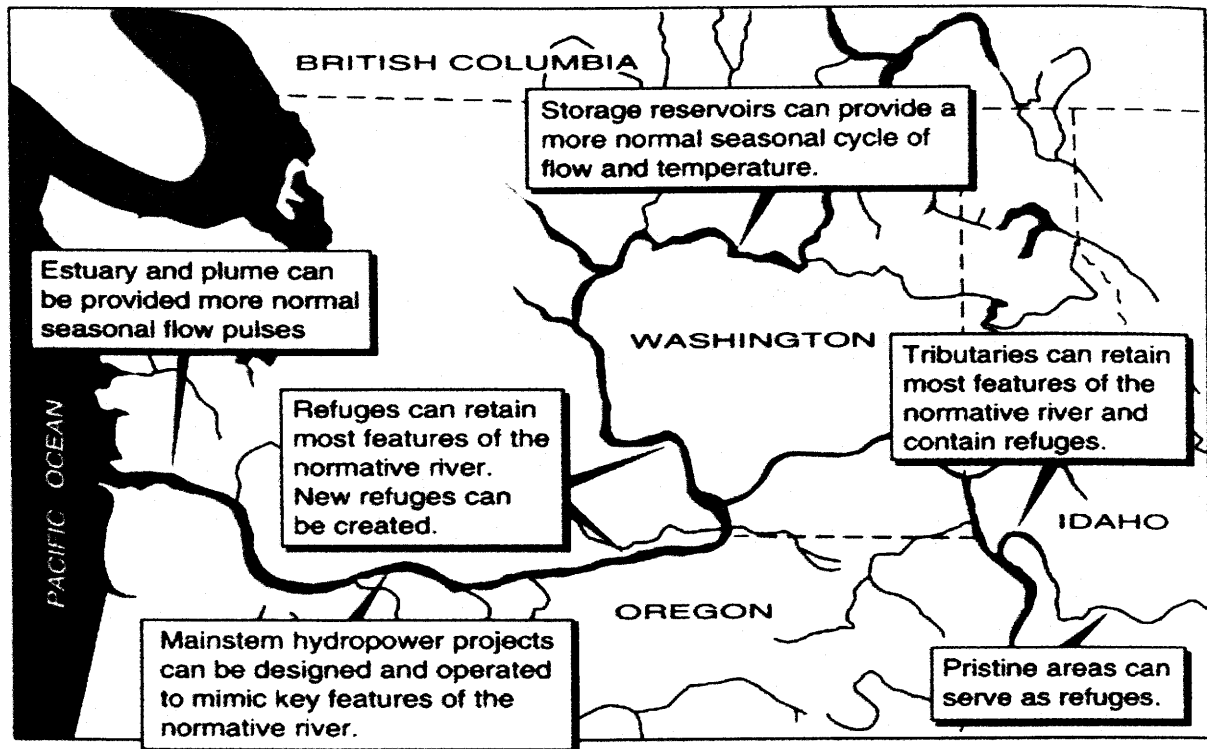
"There is no course of action for society to select that will reverse the apparent decline of wild salmon that is not socially disruptive and economically expensive."

—Robert T. Lackey. 1999. *Salmon policy: Science, society, restoration, and reality*. *Renewable Resources Journal* 17(2):6–16.

Returning the river to a more natural state runs counter to the management philosophy that has guided salmon restoration in the Columbia River Basin for much of the 20th century. For this reason, restoration or improvement of ecological conditions will require an examination of the values that underlie Columbia River management (Miller 1997; Wood 1998). However, the conceptual foundation outlined above (and in Chapters 3–6) provides a scientific basis for that debate. In the recent past, failure of the scientific community to resolve key restoration issues was often used to justify maintaining the status quo and avoid the necessary public debate over the social and economic costs of salmon recovery. However, expecting scientists to agree on each of the key questions is an unrealistic assumption. The healthy exercise of scientific debate should not be used as an excuse to hold progress hostage to the unattainable goal of perfect scientific consensus.

Maintaining the historical fisheries management approach is unlikely to result in significant improvement in the status of Pacific salmon in the Columbia River. It is more likely to result in further declines, extirpations, and extinctions. If the region is genuine in its desire to restore Pacific salmon in the Columbia Basin, continuing the status quo is not an option (ISG 1998, 1999). 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. The 2004 Biological Opinion (BiOp) for the Federal Columbia River Power System Operations did not require the U.S. Army Corps of Engineers or the Bureau of Reclamation to significantly change the current hydroelectric operations. It called on river operators to make relatively minor, albeit expensive, modifications that left the currently altered flow regime in place (see Chapter 12). In May 2005, Judge Redden of the US District Court in Portland, Oregon invalidated the 2004 BiOp on the grounds that it was legally flawed. The opinion was the latest in a series of decisions issued by judges from the Portland District Court since 1994, addressing the 1993, 1995, 2000, and 2004 Biological Opinions issued by the National Marine Fisheries Service (now NOAA Fisheries). The Biological Opinions have attempted to balance the economic, commercial, and recreational interests in the Pacific Northwest, served by the ongoing operations

Return to the Normative¹ River Depends on Location and Prior Development



¹ the norm of Standard for Measure

Figure 13.23 Opportunities to preserve, restore, or enhance ecological conditions favorable to salmon and steelhead exist in the Columbia River Basin, although individual opportunities may be constrained by the impacts of prior development or by the social and cultural value derived from the development.

of the Columbia and Snake River hydroelectric system, with the conservation of salmon species listed under the Endangered Species Act.

In invalidating the 2004 Biological Opinion, Judge Redden described the BiOp as having a jeopardy analysis that ignored the reality of past, present, and future effects of federal actions on listed species. Consequently, he judged that NOAA Fisheries' interpretation of jeopardy and their proposed mitigation measures conflicted with the structure, purpose, and policy behind the Endangered Species Act. In June 2005, Judge Redden further offered injunctive relief against NOAA Fisheries and the 2004 BiOp by requiring summer spill from some of the Columbia and Snake River hydrosystem projects to aid outmigrating juvenile salmonids. The fact that (for now) salmon recovery efforts are being directed by the Portland Oregon US District Court, rather than by state, federal, and Tribal fisheries managers, underscores the long-term failure of the fisheries management community, as well as our appointed and elected policy-makers, in the Pacific Northwest to deal

adequately with the decline and endangerment of Pacific Northwest salmon and steelhead stocks.

The first step in developing a Scientifically-sound restoration program for salmon is to clearly articulate the conditions needed for salmon relative to the region's salmon recovery goals. The next step is to determine what changes in the federal hydropower system and other uses of the river are needed to achieve these conditions (Figure 13.23). The difficult job of debating cost and benefits of salmon restoration is the next step. Significant changes will, in many cases, require painful decisions, perhaps even congressionally mandated alteration of federal hydrosystem project operations. Other lesser changes might limit, but not eliminate, the region's ability to use the Columbia River as a navigation corridor and to supply some irrigation needs.

This volume and other recent reviews of the salmon problem (NRC 1996; Stouder et al. 1997) provide an improved 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 policy makers are willing to face the difficult task of significantly changing the status quo. Restoration of fish and wildlife in the Columbia River Basin will require difficult decisions and will continue to test whether the region's policy makers and elected officials can find the political will necessary to endorse and implement a scientifically sound salmon recovery program (Figure 13.24).

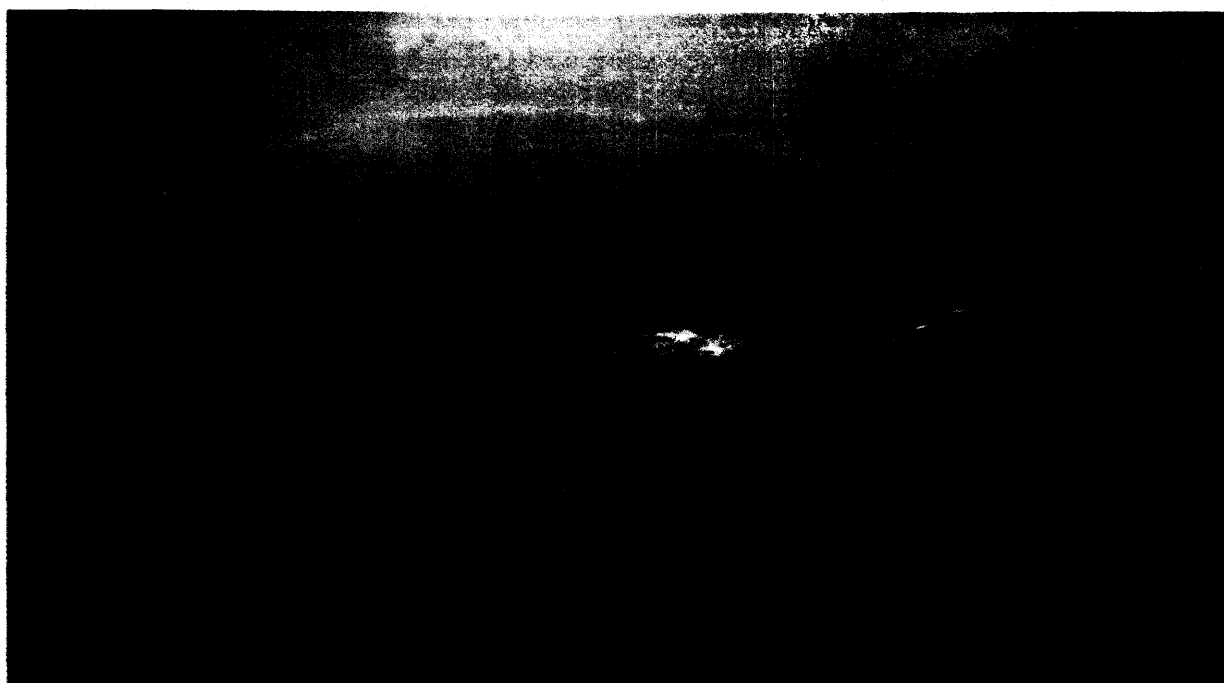


Figure 13.24 Rainbow over the lower Columbia River Gorge, symbolizing the hope that all in the region have that salmon and steelhead populations can be maintained in the Columbia and Snake Rivers while the cultural, societal, and economic benefits derived from the river and its salmon can also be maintained. Photo by Mike Pinney, www.photobymike.com.

Literature Cited

- Battelle's Pacific Northwest Division and US Geological Survey. 2000. Assessment of the impacts of development and operation of the Columbia River hydroelectric system on main-stem riverine processes and salmon habitats (Draft Final Report). Bonneville Power Administration. Portland, Oregon.
- Beechie, T. and S. Bolton. 1999. An approach to restoring salmonid habitat-forming processes in Pacific Northwest watersheds. *Fisheries* 4:6–15.
- Bisbal, G. A., and W. E. McConnaha. 1998. Consideration of ocean conditions in the management of salmon. *Canadian Journal of Fisheries and Aquatic Sciences* 55:2178–2186.
- Blumm, M. C., L. J. Lucas, D. B. Miller, D. J. Rohlf, and G. H. Spain. 1998. Saving Snake River water and salmon simultaneously: The biological, economic, and legal case for breaching the Lower Snake River dams, lowering John Day Reservoir, and restoring natural river flows. *Environmental Law* 28:101–153.
- Bottom, D. L., and K. K. Jones. 1990. Species composition, distribution, and invertebrate prey of fish assemblages in the Columbia River estuary. *Progressive Oceanography* 25:243–270.
- Bottom, D. L., C. A. Simenstad, J. Burke, A. M. Baptista, D. A. Jay, K. K. Jones, E. Casillas, and M. H. Schiewe. In press. Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon. NOAA Technical Memorandum.
- Brannon E. L., M. S. Powell, T. P. Quinn, and A. Talbot. 2004. Population structure of Columbia Basin Chinook salmon and steelhead trout. *Reviews in Fisheries Science* 12:99–232.
- Busby P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon and California. NOAA Technical Memorandum NMFS-NWFSC-27.
- Columbia Fish and Wildlife Authority (CBFWA). 2004. FY 2001-2003 Provincial Review Implementation Report. Columbia Fish and Wildlife Authority. Portland, Oregon. 299 p.
- Chapman, D. W. 1986. Salmon and steelhead abundance in the Columbia River in the nineteenth century. *Transactions of the American Fisheries Society* 115:662–670.
- Columbia-Blue Mountain Resource Conservation and Development Area. 2004, May 28. John Day Draft Subbasin Plan. Prepared for the Northwest Power and Conservation Council.
- Cury, P., and C. Roy. 1989. Optimal environmental window and pelagic fish recruitment success in upwelling areas. *Canadian Journal of Fisheries and Aquatic Sciences* 46:670–680.
- Drawdown Regional Economic Workgroup. 1999. Lower Snake River juvenile salmon migration feasibility study, draft economic analysis project study plan (PSP). US Army Corps of Engineers. Walla Walla, Washington.
- Dauble, D. D., T. P. Hanrahan, D. R. Geist, and M. J. Parsley. 2003. Impacts of the Columbia River hydroelectric system on main-stem habitats of fall Chinook salmon. *North American Journal of Fisheries Management* 23:641–659.
- Ebersole, J. L. W. J. Liss, and C. F. Frissell. 1997. Restoration of stream habitats in the western United States: Restoration as reexpression of habitat capacity. *Environmental Management* 21:1–14.
- Francis, R. C. 1993. Climate change and salmon production in the North Pacific Ocean. Pages 33–43 in K. T. Redmond and V. J. Tharp, eds. *Ninth Annual Pacific Climate (PACLIM) Workshop, April 21-24, 1992*. California Department of Water Resources.
- Francis, R. C. 1997. Managing resources with incomplete information: Making the best of a bad situation. Pages 513–524 in D. J. Stouder, P. A. Bisson, and R. J. Naiman, eds. *Pacific salmon and their ecosystems*. Chapman and Hall, New York.
- Frankham, R., J. D. Ballou, and D. A. Briscoe. 2002. *Introduction to conservation genetics*. Cambridge University Press, Cambridge, United Kingdom. 617 p.
- Garcia, A. P., W. P. Connor, and R. H. Taylor. 1994. Fall Chinook salmon spawning ground surveys in the Snake River. Annual Report for 1993. Pages 1–21 in D. W. Rondorf and K. F.

- Tiffan, eds. *Identification of the spawning, rearing, and migratory requirements of fall Chinook salmon in the Columbia River Basin*. Bonneville Power Administration. Portland, Oregon.
- Geist, D. R. 1995. The Hanford Reach: What do we stand to lose? *Illiahee* 11:130–141.
- Geist, D. R., and D. D. Dauble. 1998. Redd site selection and spawning habitat use by fall Chinook salmon: The importance of geomorphic features in large rivers. *Environmental Management* 22:655–669.
- General Accounting Office. 1992. Endangered Species: Past actions taken to assist Columbia River salmon. General Accounting Office. Briefing Report to Congressional Requesters, GAO/RCED-92-173BR. Washington, DC.
- General Accounting Office. 2002. Columbia River Basin salmon and steelhead: Federal agencies' recovery responsibilities, expenditures and actions. General Accounting Office. Report to US Senate, GAO 02-612. Washington, DC.
- Gilpin, M. E. 1996. Spatial structure and population vulnerability. Pages 124–158 in M. E. Soule, ed. *Viable populations for conservation*. Cambridge University Press, Cambridge, United Kingdom.
- Gregory, S. V., L. R. Ashkenas, and P. Minear. 2001. Application of analysis of historical channel change in the restoration of large rivers. *Verh. Internat. Verein. Limnol* 27:4077–4086.
- Gustafson, R. G., T. C. Wainwright, G. A. Winans, F. W. Waknitz, L. T. Parker, and R. S. Waples. 1997. Status Review of sockeye salmon from Washington and Oregon. NOAA Technical Memorandum NMFS-NWFSC-33.
- Hauer, F. R., C. N. Dahm, G. A. Lamberti, and J. A. Stanford. 2003. Landscapes and ecological variability of rivers in North America: Factors affecting restoration strategies. Pages 81–105 in P. A. Bisson, ed. *Strategies for restoring river ecosystems: Sources of variability and uncertainty in natural and managed systems*. American Fisheries Society, Bethesda, Maryland.
- Healey, M. C. 1994. Variation in the life history characteristics of Chinook salmon and its relevance to conservation of the Sacramento winter run of Chinook salmon. *Conservation Biology* 8:876–877.
- Healey, M. C., and A. Prince. 1995. Scales of variation in life history tactics of Pacific salmon and the conservation of phenotype and genotype. *Evolution and the aquatic ecosystem: Defining unique units in population conservation* 17:176–184.
- Hilborn, R., T. P. Quinn, D. E. Schindler, and D. E. Rogers. 2003. Biocomplexity and fisheries sustainability. *Proceedings of the National Academy of Sciences* 100(11):6564–6568.
- Hill, M. T., and W. S. Platts. 1998. Ecosystem restoration: A case study in the Owens River Gorge, California. *Fisheries* 23:18–27.
- Huntington, C., W. Nehlsen, and J. Bowers. 1996. A survey of healthy native stocks of anadromous salmonids in the Pacific Northwest and California. *Fisheries* 21:6–14.
- Independent Economic Advisory Board (IEAB). 1999. River Economics: Evaluating Trade-offs in Columbia River Basin Fish and Wildlife Programs and Policies. Northwest Power Planning Council. IEAB 99-1. Portland, Oregon.
- Independent Scientific Advisory Board (ISAB). 1998. Recommendation for stable flows in the Hanford Reach during the time when juvenile fall Chinook are present each spring. Northwest Power Planning Council and the National Marine Fisheries Service. ISAB Report, 98-5. Portland, Oregon.
- ISAB. 2003. Review of salmon and steelhead supplementation. Northwest Power Planning Council. Report ISAB 2003-03. Portland, Oregon. 229 p.
- Independent Scientific Group (ISG). 1993. Critical uncertainties in the Columbia River Basin Fish and Wildlife Program. Bonneville Power Administration. Report to Policy Review Group, SRG 93-3. Portland, Oregon. 17 p.
- ISG. 1998. Return to the river: An ecological vision for the recovery of the Columbia River salmon. *Environmental Law* 28:503–518.

- ISG. 1999. Scientific issues in the restoration of salmonid fishes in the Columbia River. *Fisheries* 24:10–19.
- Independent Scientific Review Panel (ISRP). 1997. Review of the Columbia River Basin Fish and Wildlife Program as directed by the 1996 amendment to the Power Act. Northwest Power Planning Council. Annual Report, ISRP 97-1. Portland, Oregon.
- ISRP. 1998. Review of the Columbia River Basin Fish and Wildlife Program as directed by the 1996 amendment to the Power Act. Northwest Power Planning Council. Annual Report, ISRP 98-1. Portland, Oregon.
- ISRP. 1999. Review of the Columbia River Basin Fish and Wildlife Program as directed by the 1996 amendment to the Power Act. Northwest Power Planning Council. Annual Report, ISRP 98-2. Portland, Oregon.
- Johnson, O. W., W. S. Grant, R. G. Kope, K. Neely, F. W. Waknitz, and R. S. Waples. 1997. Status review of chum salmon from Washington, Oregon, and California. NOAA Technical Memorandum, NMFS-NWFCS-32.
- Lackey, R. T. 1999. Salmon policy: Science, society, restoration, and reality. *Renewable Resources Journal* 17:6–16.
- Lawson, P. W. 1993. Cycles in ocean productivity, trends in habitat quality, and restoration of salmon runs in Oregon. *Fisheries* 18:6–10.
- Lichatowich, J. 1999. *Salmon without rivers: A history of the Pacific salmon crisis*. Island Press, Washington, D.C.
- Loucks, C., N. Brown, A. Loucks, and K. Cesareo. 2003. USDA Forest Service roadless areas: Potential biodiversity conservation reserves. *Conservation Ecology* 7(2):5. Available at <http://www.consecol.org/vol7/iss2/art5>
- McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. US Department of Commerce. NOAA Tech. Memo. NMFS-NWFSC-42. 156 p.
- Meffe, G. K. 1992. Techno-arrogance and halfway technologies: Salmon hatcheries on the Pacific coast of North America. *Conservation Biology* 6:350–354.
- Miller, D. B. 1997. Of dams and salmon in the Columbia/Snake Basin: Did you ever have to make up your mind? *Rivers: Studies in the Science, Environmental Policy, and Law of Instream Flow* 6:69–79.
- Mullan, J. W., A. Rockhold, and C. R. Chrisman. 1992. Life histories and precocity of Chinook salmon in the Mid-Columbia River. *Progressive Fish-Culturist* 54:25–28.
- Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Walknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of Chinook salmon from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum, NMFS-NWFSC-35.
- Myers, R. A., S. A. Levin, R. Lande, F. C. James, W. W. Murdoch, and R. T. Paine. 2005. Hatcheries and endangered salmon. *Science* 303:1980.
- Naiman, R. J., and R. E. Bilby, eds. 1998. *River ecology and management: Lessons from the Pacific Coastal Ecoregion*. Springer-Verlag, New York.
- National Marine Fisheries Service (NMFS). 1995. Draft Biological Opinion on reinitiation of consultation on 1994-1998 operation of the federal Columbia River Power System and juvenile transportation program in 1994-1998. US Army Corps of Engineers, Bonneville Power Administration, Bureau of Reclamation, and National Marine Fisheries Service. Portland, Oregon. 146 p.
- NMFS. 2000. Final FCRPS (Federal Columbia River Power System) Biological Opinion. Northwest Fisheries Science Center, NOAA. Endangered Species Act–Section 7 Consultation. Seattle, Washington.
- National Oceanic and Atmospheric Administration (NOAA) Fisheries, Northwest Fisheries Science Center. 2004. Final FCRPS (Federal Columbia River Power System) Biological

- Opinion. Northwest Fisheries Science Center, NOAA. Endangered Species Act—Section 7 Consultation. Seattle, Washington.
- National Research Council (NRC). 1996. Upstream: Salmon and society in the Pacific Northwest. Report on the Committee on Protection and Management of Pacific Northwest Anadromous Salmonids for the National Research Council of the National Academy of Sciences. National Academy Press, Washington DC.
- Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* 16:4–21.
- Northwest Power Planning Council (NPPC). 1986. Council Staff Compilation of Information on Salmon and Steelhead Losses in the Columbia River Basin. Northwest Power Planning Council. Portland, Oregon.
- NPPC. 1997. An integrated framework for fish and wildlife management in the Columbia River. Northwest Power Planning Council. NPPC 97-2. Portland, Oregon.
- NPPC. 1998. A proposed scientific foundation for the restoration of fish and wildlife in the Columbia River. Northwest Power Planning Council. NPPC 98-16. Portland, Oregon.
- NPPC. 2000. Columbia River Fish and Wildlife Program. Northwest Power Planning Council. Portland, Oregon.
- NPPC. 2004. Columbia River Fish and Wildlife Program. Northwest Power Planning Council. Portland, Oregon.
- Petersen, K. C. 1995. *River of life, channel of death: Fish and dams of the lower Snake*. Confluence Press, Lewiston, Idaho.
- Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestegard, B. D. Richter, R. E. Sparks, and J. C. Stromber. 1997. The natural flow regime. *Bioscience* 47:769–784.
- Rahr, G. R., J. A. Lichatowich, R. Hubley, and S. M. Whidden. 1998. Sanctuaries for native salmon: a conservation strategy for the 21st century. *Fisheries* 23:6–8.
- Reeves, G. H., L. E. Benda, K. M. Burnett, P. A. Bisson, and J. R. Sedell. 1995. A disturbance-based approach to maintaining and restoring freshwater habitats of evolutionarily significant units of anadromous salmon in the Pacific Northwest. Pages 334–339 in J. L. Nielsen, ed. *Evolution and the aquatic ecosystem*. American Fisheries Society Symposium 17, Bethesda, Maryland.
- Scientific Review Group (SRG): Brannon, E. L., K. P. Currens, D. Goodman, J. A. Lichatowich, W. E. McConaha, B. E. Riddell, and R. N. Williams. 1999. Review of salmonid artificial production in the Columbia River basin as a scientific basis for Columbia River production programs. Northwest Power Planning Council. Portland, Oregon. 77 p.
- Snake River Salmon Recovery Team. 1993. Snake River salmon recovery plan recommendations (Draft). NMFS/NOAA. Portland, Oregon. 364 p.
- Stacey, P. B., and M. L. Taper. 1997. Migration within metapopulations: The impact upon local population dynamics. Pages 267–291 in I. A. Hanski and M. E. Gilpin, eds. *Metapopulation biology: Ecology, genetics, and evolution*. Academic Press, San Diego, California.
- Stanford, J. A., and F. R. Hauer. 1992. Mitigating the impacts of stream and lake regulation in the Flathead River catchment, Montana, USA: An ecosystem perspective. *Aquatic Conservation: Marine and Freshwater Ecosystems* 2:35–63.
- Stanford, J. A., F. R. Hauer, S. V. Gregory, and E. B. Snyder. 2005a. The Columbia River, pp. 591–653. In: Benke, A. C. and C. E. Cushing, eds. *Rivers of North America*. Academic Press/Elsevier, Boston, Massachusetts. 1168 p.
- Stanford, J. A., M. S. Lorang, and F. R. Hauer. 2005b. The shifting habitat mosaic of river ecosystems. *Verh. Internat. Verein. Limnol.* 29(1):123–136.
- Stanford, J. A., J. V. Ward, W. J. Liss, C. A. Frissell, R. N. Williams, J. A. Lichatowich, and C. C. Coutant. 1996. A general protocol for restoration of regulated rivers. *Regulated Rivers* 12:391–413.

- Stouder, D. J., P. A. Bisson, and R. J. Naiman, eds. 1997. *Pacific salmon and their ecosystems: Status and future options*. Chapman and Hall, New York.
- USDA Forest Service. 2000. Forest Service, roadless area conservation, final environmental impact statement. USDA Forest Service, Washington, DC.
- Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife. 1996. Status report. Columbia River fish runs and fisheries, 1938-1998. Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife. Olympia, Washington, and Clackamas, Oregon.
- Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife. 2001. Status report. Columbia River fish runs and fisheries, 1938-2000. Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife. Olympia, Washington, and Clackamas, Oregon.
- Whidden, S. M. 1996. The Hanford Reach: Protecting the Columbia's last safe haven for salmon. *Environmental Law* 26:265-297.
- White, R. 1995. *The organic machine: The remaking of the Columbia River*. Hill and Wang, New York.
- Williams, R. N. 2001. Refugia-based conservation strategies: Providing safe havens in managed river systems. Pages 59-63 in Oregon Trout, ed. *Oregon salmon: Essays on the state of the fish at the turn of the millennium*. Oregon Trout, Portland, Oregon.
- Wood, M. C. 1998. Reclaiming the natural rivers: The Endangered Species Act as applied to endangered river ecosystems. *Arizona Law Review* 40:197-286.