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One Hundred Years of Pacific Northwest Salmon Management: Goals, Results, and Lessons Learned

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Pacific salmon are, perhaps above all other animals, identified with the environment of the Pacific Northwest coast. As a regional icon of environmental quality, salmon have enjoyed unprecedented management attention for well over a century. They are an important commercial species and have been so since the mid-1800s. The first Euroamerican commercial fisheries began around 1830, and by the turn of the century there were economically important and lucrative salmon fisheries in major coastal rivers from San Francisco to southern Alaska (National Research Council 1996). Salmon are also much sought after by recreational fishers in salt and fresh water and form the basis of a regionally important sport fishing industry (Smith and Steel 1997). To indigenous peoples of western North America, especially those inhabiting coastal watersheds, salmon were an important seasonal food source and often the center of culturally rich religious traditions (Netboy 1980). Pacific salmon are the focus of environmental awareness and educational activities; most schoolchildren participate in a salmon project at one time or another during their primary education. Finally, salmon are "keystone species" that link marine, freshwater, and terrestrial ecosystems along the Pacific coast by returning marine-derived nutrients to streams, riparian zones, and scavengers (Kline et al. 1993; Bilby, Fransen, and Bisson 1996). For all these reasons, salmon conservation has become a high priority among the region's policy makers.

Most Pacific salmon are anadromous; they spawn in fresh water and migrate to sea, where they grow and mature. In the late 1980s, salmon underwent a taxonomic revision (McPhail 1997) in which the two species that may spawn more than once (steelhead and sea-run cutthroat trout) were added into the genus *Oncorhynchus* with the five species that spawn once and then die (chinook or king salmon, coho or silver salmon, chum or dog salmon, pink or humpy salmon, and sockeye or red salmon). Thus the term "salmon" is here used to denote all seven anadromous species. Although the current status of each of these seven species differs somewhat, there is universal agreement that salmon are in general decline along the Pacific coast from parts of British Columbia south to the geographical limit of their distribution in central California. So serious have these declines become (Nehlsen, Williams, and Lichatowich 1991) that a number of salmon runs have been listed as threatened or endangered species under the U.S. Endangered Species Act. The recent National Research Council report (NRC 1996:2-3) has summarized the overall status of Pacific salmon as follows:

- Pacific salmon have disappeared from about 40 percent of their historical breeding ranges in Washington, Oregon, Idaho, and California over the last century, and many remaining populations are severely depressed in areas where they were formerly abundant. If the areas in which salmon are threatened or endangered are added to the areas where they are now extinct, the total area with losses is two-thirds of their previous range in the four states. Although the situation is not as serious in southwestern British Columbia, some populations there are also in a state of decline, and all populations have been completely cut off from access to the upper Columbia River in eastern British Columbia.
- Coastal salmon populations tend to be somewhat better off than populations inhabiting interior drainages. Species with populations that occurred in inland subbasins of large river systems such as the Sacramento, Klamath, and Columbia rivers—spring/summer chinook, summer steelhead, and sockeye—are extinct over a greater percentage of their range than species limited primarily to coastal rivers.
- Salmon populations near the southern boundary of species' ranges tend to be at greater risk than northern populations. Proportionately fewer healthy populations exist in California and Oregon than in Washington and British Columbia.
- Species with extended freshwater rearing (up to a year), such as spring/summer chinook, coho, sockeye, sea-run cutthroat, and steelhead, are generally extinct, endangered, or threatened over a greater percentage of their ranges than species with abbreviated freshwater residence, such as fall chinook, chum, and pink salmon.
- In many cases, populations that are not smaller than they used to be are now composed largely or entirely of hatchery fish. An overall estimate of the proportion of hatchery fish is not available, but several regional estimates make clear that many runs depend mainly or entirely on hatcheries.

The salmon crisis has sparked considerable debate (Botkin et al. 1995), and the public is asking how species that have received so much management attention could have become so scarce. The fact that runs are declining has been known for a long time (Stone 1892; Netboy 1980). Indeed, at the turn of the century many runs had already been rendered extinct or nearly so through habitat destruction or overfishing (Chapman 1986). The first laws protecting salmon habitat in the Pacific Northwest were enacted in 1848 and the first fishing regulations date back to 1859, although the latter were more concerned with allocation than with conservation (Wendler 1966). Over the past one hundred years, inhabitants of the Pacific Northwest have invested heavily in technological solutions to conserve, restore, and enhance declining salmon runs. Many of these efforts, however well-intentioned, have not lived up to hopes and expectations (Meffe 1992; Lichatowich 1997). Because previous management attempts to protect salmon have often not worked as intended, scientists and policy makers alike have called for new and innovative solutions (Botkin et al. 1995; Regier 1997; Lee 1997).

The objective of this article is to examine salmon management within the context of active and passive approaches. Threats to Pacific salmon are often categorized as the "4-Hs": harvest (fishing), hydroelectric development (dams), hatchery propagation (competition between hatchery and wild fish), and habitat loss. Although these four categories do not encompass all the important factors controlling salmon abundance, in the aggregate they form the basis for much of the human intervention in salmon life histories and likely include the majority of anthropogenic impacts to most stocks. Using an analysis of management practices over the past century, the following discussion will show how salmon policies have become increasingly dependent on active management, usually based on technological innovation. This is certainly understandable given the management strategies that have accompanied the development of other natural resources. This article does not advocate turning away from active management, but argues that the lessons of history suggest that policies for salmon tend to work best when they explicitly acknowledge uncertainty, include a "margin for error," and incorporate adaptive learning into management frameworks. A few examples of how such an approach might be applied to forest policy are presented.

The 4-Hs and Active Management

Hatcheries

For more than a century, hatcheries were believed to be the technological solution that could save salmon from excessive mortality caused by fishing, natural predators, and habitat loss (Meffe 1992; Bottom 1997). So optimistic were fishery managers that artificial propagation would ensure an abundance of salmon in perpetuity that hatcheries were vigorously promoted by fishery agencies and private landowners. In the words of the Oregon State Game and Fish Protector in 1896 (quoted by Lichatowich and Nicholas, in press):

> There can be no doubt in the mind of anyone who has studied the question, that the future prosperity of our salmon fisheries depends largely upon artificial propagation. . . . I am convinced that not more than 10 percent of the ova spawned in the open streams are hatched, owing principally to spawn-eating fish that prey on them . . . while from artificial propagation 90 percent are successfully hatched. What more need be said in favor of fish culture?

The first artificial propagation facility, an egg-taking station on Oregon's Clackamas River, was built in 1877, and during the next fifty years hundreds of

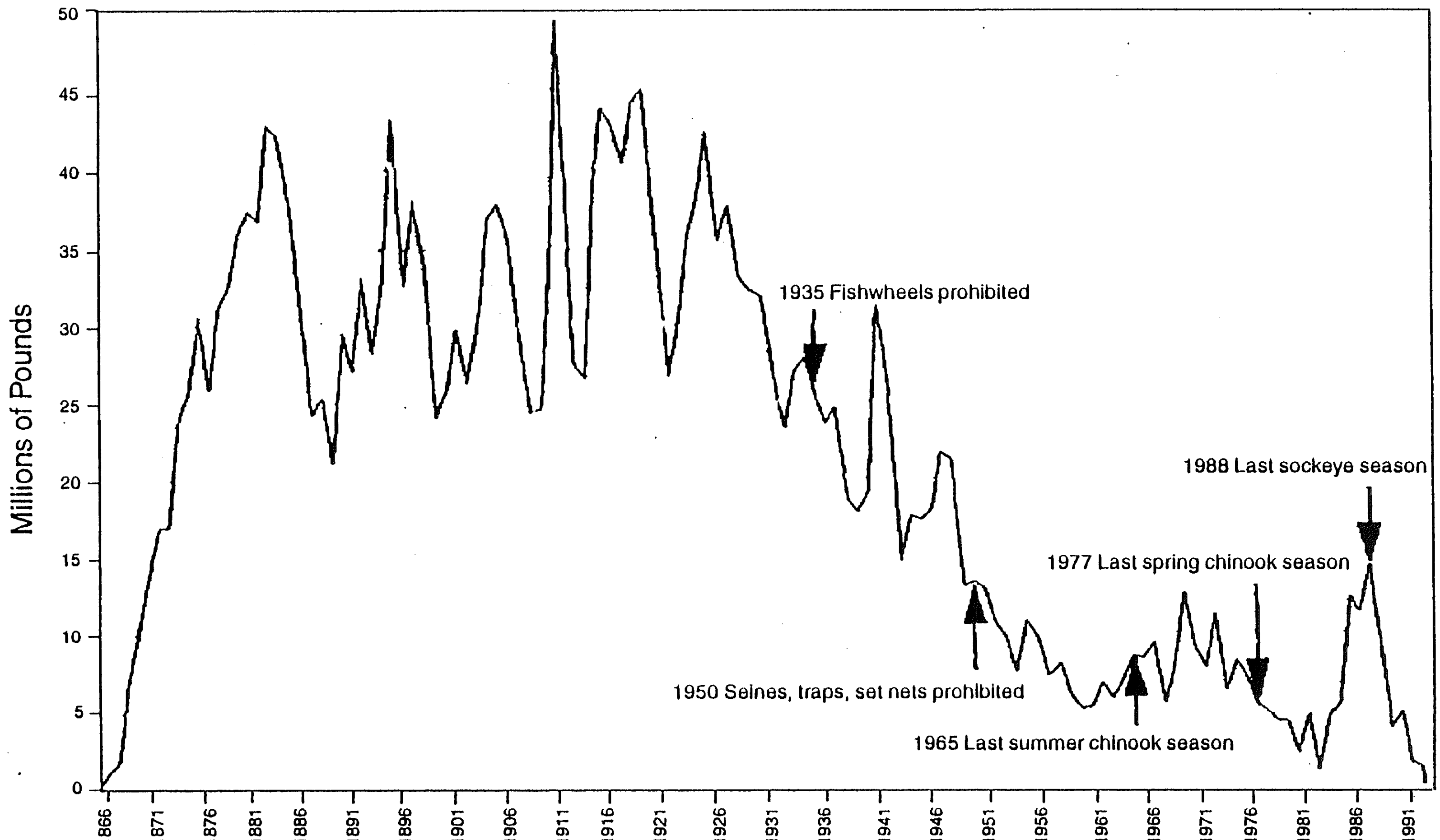

Figure 1. Total commercial harvest (pounds) of salmon and steelhead in the Columbia River from 1866 to 1993. From NRC (1996) based on data from the Oregon Department of Fish and Wildlife and the Washington Department of Fish and Wildlife.

federal and state-operated hatcheries were built in the Pacific Northwest. Harvest of salmon generally increased along the coast of Washington and Oregon throughout the late 1800s, culminating in enormous catches at the turn of the century. By 1907, Oregon possessed twelve hatcheries releasing 27 million salmon fry (NRC 1996), and the large catches of salmon were generally attributed to this hatchery production. When runs began to decline, hatchery operators reasoned that survival would be even greater if fish were reared to a larger size in the hatchery instead of being released as fry (Bottom 1997). Technological improvements in fish holding and feeding enabled year-round hatchery operation, and even greater numbers of fish returned from 1910 to 1915, leading fish managers to conclude that the new salmon-rearing technology had solved the problem of declining runs. Apparently overlooking the fact that in 1914 record salmon runs also returned to rivers that did not possess hatcheries, and thus that other factors might have caused the huge runs that year, the Oregon Game and Fish Commission in 1919 proclaimed (quoted by Lichatowich and Nicholas, in press):

> This new method has now passed the experimental stage, and . . . the Columbia River as a salmon producer has "come back." By following the present system, and adding to the capacity of our hatcheries, thereby increasing the output of young fish, there is no reason to doubt . . . that the annual pack in time can be built up to greater numbers than ever before known in the history of the industry.

Despite this optimism, salmon runs in the Columbia River and elsewhere did not respond as planned (Figure 1). Many rivers with hatcheries experienced declining catches from the 1920s to the 1950s, for a number of reasons including overharvest, habitat loss, water pollution, dams, and ocean conditions.

There was a strong resurgence in hatchery construction during the 1950s and 1960s. The hatcheries relied on even more sophisticated technology that included extended rearing, state-of-the-art water systems and disease treatment, and newly developed semi-moist high protein foods. Some of the new hatcheries were built to mitigate for habitat lost through dam construction, but many others were built simply to create more fish for harvest (Bottom 1997). Survival of young salmon in the hatchery environment was exceptionally high, often greater than 90 percent. For about a decade, it appeared that hatcheries in some river systems were having a substantial, positive effect on numbers of salmon; harvests were up and hatchery fish were prominent in the catch, a conclusion based on a new technique of marking which used microscopic wire tags implanted in the snout of salmon before they were released to migrate to sea. The apparent success of hatchery-produced salmon and the need to provide eggs for new hatcheries led to widespread transplants of fish between hatcheries in different river basins.

In the mid-1970s there was an unexpected change in the ocean environment. Sea surface temperatures increased and coastal upwelling adjacent to Oregon and Washington declined, leading to reduced plankton production in

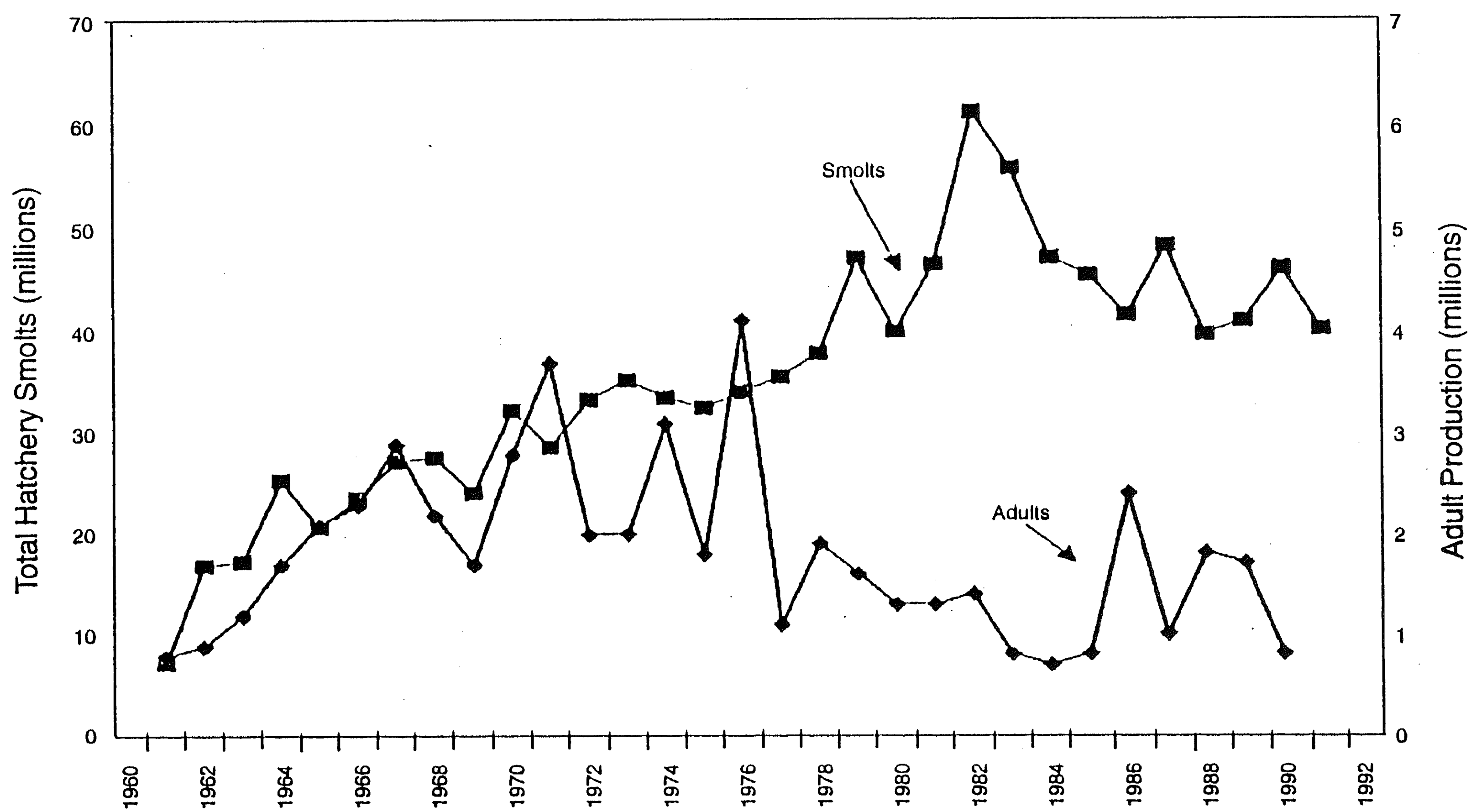

Figure 2. Production of hatchery coho salmon smolts (filled squares) and the estimated number of adult salmon (filled diamonds) produced the following year in the Oregon Production Index area (mouth of the Columbia River to Cape Blanco, Oregon). Data from the Oregon Department of Fish and Wildlife.

offshore waters. While the release of smolts (young salmon ready for the saltwater transition) from hatcheries remained at very high levels, the numbers of returning adults declined dramatically (Figure 2). Most scientists now believe this decline was related to reduced productivity in the ocean along the Pacific Northwest coast, and it turned out that the reduced oceanic productivity off Washington, Oregon, and northern California was mirrored by a sharp increase in salmon productivity in populations along the Gulf of Alaska and Bristol Bay (Beamish and Bouillon 1993). The surge in productivity of the ocean adjacent to Alaska was caused by an intensification of the Aleutian low pressure system, which diverted nutrient-rich water from the Pacific Northwest to the Gulf of Alaska (Pearcy 1992). What was earlier credited to a successful hatchery program—increased harvests during the 1960s—was found to have resulted in large part from favorable ocean conditions off the Pacific Northwest coast. These conditions have since become relatively unfavorable and the duration of this unfavorable ocean period is unpredictable, leading some scientists to suggest that massive releases of hatchery smolts into an unproductive ocean environment may be ill-advised (Francis 1997).

And there was new evidence that the widespread transfer of salmon eggs among hatcheries—along with breeding and rearing practices—was leading to unwanted genetic changes that had lowered the genetic "fitness" (the ability of fish to produce reproductively successful offspring) of wild salmon populations with which stray adults from hatcheries had interbred. Although studies specifically examining genetic fitness of salmon are relatively rare, at least one study (Reisenbichler 1997) has shown that fitness may be significantly lowered after as little as one or two generations of artificial propagation. Because some populations of salmon have been cultured for more than thirty generations, the potential for genetic harm to wild fish from decades of hatchery culture and straying may have been great.

The foregoing discussion is not intended to suggest that all hatchery operations are detrimental and should cease. There is general agreement that hatchery practices should be reformed, that the major emphasis of hatcheries in some river basins should be the conservation of rare stocks instead of production for harvest, and that hatcheries should continue to play a role in salmon management in the Pacific Northwest, albeit somewhat limited (NRC 1996; Kapuscinski 1997). The point to be made here is that our use of artificial propagation technology without adequate monitoring and without research designed to yield a better understanding of the ecological consequences of hatchery operation (Hilborn 1992; Hilborn and Winton 1993) has led to a massive regional investment in capital structures whose effectiveness too often remains unproved.

Harvest

Salmon harvest has also been influenced by technological advances. Early aboriginal and Euroamerican fisheries in the nineteenth century were generally located in rivers along salmon migration routes and used fixed traps, dipnets, and spears (Stewart 1977). In low flow conditions these traps could be very effective, but during periods of high flow the traps often washed out and salmon could travel to spawning grounds unimpeded. For the most part, such fisheries were sustainable and stocks were not overexploited. As net technology improved prior to the turn of the century, large gillnet fisheries developed at river mouths. These fisheries were much more efficient, and the sheer numbers of fishers often harvested great quantities of salmon. In the 1860s, storage technology enabled large catches to be canned and shipped to eastern markets. The Columbia River gillnet fleet grew from two boats in 1866 to more than 1,500 by the 1880s and peaked at about 2,800 boats by the mid-1910s (Smith 1979). At the same time, new trapping methods, including fyke nets and fishwheels, were installed at important salmon-holding locations and migration routes in rivers, and these techniques also harvested large numbers of fish.

By 1900 the most important commercial run of salmon, spring-run chinook, was overfished and seriously declining in rivers such as the Sacramento and Columbia. Consequently, salmon fishers switched to other stocks (summer and fall chinook, coho, chum, sockeye, and steelhead) to provide a year-round supply for canning (NRC 1996). By the end of World War I, many of these stocks were also overfished and fishing closures began to take effect in an attempt to rebuild depleted runs. To get around closed seasons, fishers took advantage of two important technological developments, the gasoline engine and refrigeration, to move many fisheries offshore into the open ocean where they could employ troll, trawl, or purse seine techniques. A surplus of salmon caught in Alaskan waters combined with the Great Depression to reduce harvests in the Pacific Northwest until the end of World War II. But after the mid-1940s, ocean fisheries expanded greatly and harvest by recreational anglers also increased.

Salmon harvest remained relatively high in the Pacific Northwest throughout the 1950s and 1960s, although many of the commercially valuable species (chinook, coho, and sockeye) had experienced significant declines relative to catches in the early twentieth century. The most lucrative fisheries remained offshore, where stocks from multiple river basins occurred together. Harvest of salmon in these "mixed stock" ocean fisheries created a problem that did not exist in river ("terminal") fisheries: salmon from depressed populations were caught along with fish from strong populations in mixed stock fisheries. Thus many small stocks declined even though most fish in the harvest originated from a relatively few large stocks. The problem of declining weak stocks forced fishery management agencies to implement a highly complex system of regulations prescribing where, when, and how salmon could be caught as a means of protecting weak runs. Regulations have been further complicated by fishing treaties between nations, including a 1974 U.S. court decision that Puget Sound treaty tribes were entitled to 50 percent of the harvestable runs, and a U.S.-Canada salmon treaty that specified how many salmon produced in each country could be harvested by fishers in another.

Highly technological fisheries and an increasingly arcane set of regulations have placed great pressure on management agencies to actively manage the harvest so that all fishing constituencies receive their fair share. Traditionally, the process for determining how many salmon can be caught is based on models proposed by Ricker (1954) and Beverton and Holt (1957), in which the number of fish available for harvest includes only fish above and beyond the number needed to replace the existing population. The models require that fishery managers know the relationship between the number of spawners (the "stock") and the number of adults produced in the subsequent generation (the "recruits"). Typically, the models are in the form of dome- or asymptotically-shaped curves defining the rate at which the population can grow at each generation until it becomes so abundant that survival rates decline. From stock/recruitment curves it is possible to predict the harvest rate that gives the maximum sustained yield (MSY). Maximum sustained yield has for years been the basis of salmon fishery regulation (the harvest rate is often set somewhere between 50 and 70 percent of the adult population). For predominantly hatchery-supported salmon populations, in which survival of juveniles in the hatchery environment is quite high, harvest rates of 70 to 90 percent of the adult population are not unknown.

Application of MSY to managing salmon harvest has not been very successful. There are significant limitations to the accuracy of the model (NRC 1996), including:

- Estimation of the biological production function (number of recruits per spawner) in a highly variable natural environment.
- Differences between populations and change over time within populations.
- The necessity for accurate data on total fishing mortality by age and population over all fisheries, on number of spawners by age, and on future production.

Furthermore, climate change can affect not only abundance but the ability to predict future run sizes. Walters (1995) gives an excellent example of how this type of uncertainty results in harmful management decisions. Some fishery management decisions are based on in-season harvest adjustments, in which catch quotas can be raised or lowered in response to how the runs depart from predictions. Such adjustments are usually made early in the run and assume that what is happening early will also happen during the middle and latter parts of the run. Walters points out that variation in the timing and location of runs can send false signals to managers, the worst of which is a "little run coming early"—a situation that can lead to serious overfishing. Currently, the ability to predict future run sizes remains crude; estimates are often in error by a factor of plus or minus 50 percent. Given this level of variability, determining the maximum rate of harvest that is sustainable over multiple salmon generations becomes quite difficult.

There is no easy solution to problems related to harvest levels and catch allocation among different groups of fishers. NRC (1996) recommended replacing the concept of maximum sustained yield with the notion of minimum sustainable escapement (MSE) as the guiding paradigm of salmon harvest management. Under a strategy of MSE, the goal would be to allow more than enough adults to escape the fishery and spawn to ensure that the population persists over time in a variable environment. For populations that are highly endangered, this will mean a complete cessation of fishing; for others, it may mean harvesting at a lower rate until the population is rebuilt (even so, a low fishing rate and high abundance can yield the same or larger catches than a high exploitation rate and low abundance). Because the minimum number of adults needed to enable the population to persist is not known with certainty, an MSE strategy would give the benefit of the doubt to increasing spawning escapement, not maximizing harvest. If spawning escapements proved to be insufficient to allow naturally reproducing populations to grow, harvest would be reduced even more until sustained population growth has been demonstrated. Such an approach would allow for a greater margin of error than exists in current management decisions and would have a greater likelihood of avoiding overfishing.

Hydroelectric Development (Dams)

Actually, the majority of dams in the Pacific Northwest do not generate electricity. Many were built for other purposes, such as flood control, water storage for municipal drinking water and agriculture, log transport, and mining. The total number of dams on fish-bearing streams and rivers in the Pacific Northwest is not known, but is probably on the order of several thousand (NRC 1996). However, the largest dams on mainstem rivers have usually been associated with hydroelectric development. In some river basins (e.g., Sacramento River and Columbia River), hydroelectric dams have probably had a greater impact on salmon than have all other types of anthropogenic effects. But the importance of hydroelectric dams to the region's economy should not be underestimated. Over 90 percent of the electricity in the Pacific Northwest is generated by hydroelectric sources, and power costs to consumers are among the lowest in the nation (Jackson and Kimerling 1993).

The earliest hydroelectric and flood control dams were built in the late 1800s and a few were added in the early 1900s, but it was not until the 1920s through 1950s that dam construction intensified (Figure 3), just as in other major river basins of the United States (e.g., the Tennessee and Colorado Rivers). In river basins where hydroelectric development occurred rapidly, available salmon habitat was lost at a dramatic rate. For example, prior to water impoundment, over 163,000 square miles of the Columbia Basin's 260,000 square miles were available to salmon, but only 73,000 remain available today. This reduction amounts to a 55 percent loss of total watershed area and a 31 percent loss of stream length historically occupied by salmon (NRC 1996). By 1975, when dam construction in the Columbia Basin was essentially complete, 58 dams had been built for hydropower development and an additional 78 had been built for multiple uses (hydropower, flood control, water storage, recreation), including 14

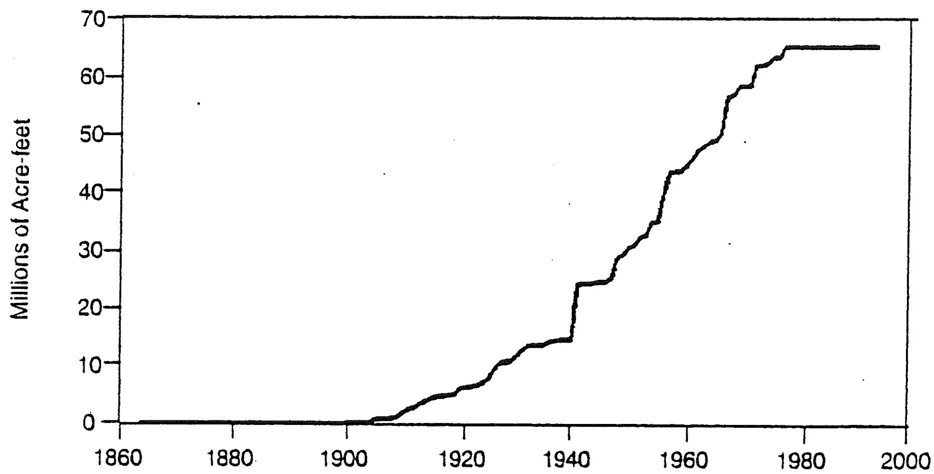

Figure 3. Cumulative volume of water impounded by federal and nonfederal dams in the Pacific Northwest from 1860 to 1990. From NRC (1996) based on data from federal and state water resource agencies in Idaho, Washington, and northern California.

mainstem Columbia River and 13 mainstem Snake River dams. Only a single 50 mile reach of the mainstem Columbia River near the Hanford Nuclear Reservation between McNary Reservoir and Priest Rapids Dam remains unimpounded. Currently, this last free-flowing reach contains one of the most productive chinook salmon populations in the entire river basin.

Not all of the mainstem dams completely block fish passage. Many are low enough to be fitted with fish ladders and juvenile bypass systems. Nevertheless, dam-related mortality is observed in both adult salmon migrating upstream and smolts migrating to sea. The mortality rate at each dam is highly variable and ranges from less than 5 percent to greater than 10 percent per project, depending on flow conditions and bypass facilities; however, cumulative mortality over all dams in the migration corridor can be quite high. Fish passage engineers utilize a variety of technological solutions to reduce mortality of salmon at or near the dams. Early fish ladders often contained excessive flows and turbulence and did not pass fish well. Other ladders built of wood were destroyed by floods and debris. Spillways close to the exits of ladders sometimes pull adult salmon back over the dam, and fish are killed when they are sucked into turbine intakes. Downstream migrating juvenile salmon also experience mortality or stress when they pass through turbines or over spillways. Mortality also occurs between dams. Migrating smolts are eaten by predators such as northern squawfish and a variety of introduced game fishes. During years of high runoff, the large amount of water passing over dams (rather than running through turbines) creates dissolved gas supersaturation causing gas-bubble disease, which can be lethal to migrating smolts. But even when runoff is high, the total amount of time required by smolts to migrate from natal streams to sea is much greater than when the Columbia River was free flowing.

One of the most controversial measures to increase survival rate and hasten downstream travel time has involved trapping smolts at dams in the Snake River and transporting them in barges around the dams. This is a highly technological solution whose efficacy has been questioned, yet it appears to produce survival rates equal to or greater than other measures being used at this time (NRC 1996). Opponents of smolt barging argue that research in the 1970s demonstrated a significant positive correlation between river flow velocity and smolt survival, and in fact there was higher survival of juvenile chinook and steelhead in high flow years between 1973 and 1979 (Sims and Ossiander 1981). By drawing down the reservoirs behind mainstem dams during the spring-summer smolt migration period, some scientists claim, passage time can be significantly shortened and there will be no need for barging. The tradeoff is that reducing the water in the reservoirs will negatively impact hydropower production and water available for agricultural use, river transportation of crops, and recreation. Additionally, lowering reservoirs high in the Columbia Basin (those in British Columbia, Montana, and Idaho) may have damaging effects on the nonanadromous fishes in these areas.

What to do about managing river flows in the Columbia Basin and elsewhere is a difficult problem to which there will be no easy solutions. The problem has been exacerbated by a lack of research upon which to base management decisions. For example, the study of the effect of river flows on smolt survival cited above (Sims and Ossiander 1981) included only two species over a period of seven years about two decades ago, yet since that time no additional studies to confirm or disprove this relationship have been done. So serious is this lack of scientific information that Naiman et al. (1995) have stated:

> . . . more than $150 million is spent annually on the recovery of the degraded salmon and steelhead runs in the Columbia River, yet a monitoring program that would enable the measurement of the major sources of mortality at key points in the river and ocean ecosystem does not exist. With little or no formal peer review, this spending constitutes twice the annual budget of the Environmental Biology Program at the National Science Foundation, which is the primary source of competitive funding for basic research in freshwater ecology in the United States.

Continued declines in salmon populations suggest that technology-based mitigation for dams has often been applied without the requisite science to ensure that the projects have a reasonable chance of succeeding. Like attitudes concerning hatcheries and harvest technology, optimism in the ability of active management to solve fish passage problems has led to the implementation of very expensive measures without an adequate understanding of the ecology of systems being manipulated.

Habitat

For the 214 salmon stocks identified by Nehlsen et al. (1991) as being at risk of extinction in Washington, Oregon, Idaho, and California, the factor most commonly associated with stock declines was habitat loss. This was the case for virtually every species, even pink and chum salmon whose juveniles spend only a few days in fresh water before migrating to sea. Habitat loss began early in the ninetheenth century, and by the 1850s significant losses were resulting from mining and grazing. By the early twentieth century, habitat was also being degraded by forestry, agricultural, and floodplain reclamation practices; and after the two world wars there were surges of urban and industrial development (Gregory and Bisson 1997) that resulted in further losses.

To offset habitat losses, habitat managers have used a wide variety of mitigation and restoration techniques (Table 1) to improve spawning areas, create summer and winter rearing habitat, add cover, prevent streambank erosion, and revegetate riparian zones. Many of these techniques originated in eastern North America or in the Great Lakes region (Hunt 1993), where the hydrologic regime tends to be dominated by snowmelt runoff. The same methods applied to hydrologically flashy, rainfall-dominated streams of the coastal Pacific Northwest have met with only limited success. As has been the case with the management approaches used in hatcheries, harvest, and hydroelectric development, habitat improvement projects have rarely been adequately monitored (Hilborn and Winton 1993).

In the few instances where project success has been followed for more than several years, the frequency of failure (i.e., damage to structures or failure of projects to function as anticipated) has been surprisingly high. Frissell and Nawa (1992) found that fewer than half of the engineered habitat structures (logs and boulders) continued to function as planned in southern Oregon streams over a five-year period, although structures placed along streambanks tended to fare better than those placed in the center of the channel. Sedell and Beschta (1991)

Table 1. Some categories of habitat loss and restoration used in the Pacific Northwest.

Habitat Loss	Habitat Restoration
Sedimentation	Fish ladders
Streambank erosion	Spawning channels
Channelization	Rearing ponds
Instream mining	Artificial wetlands
Diking, draining, and filling	Log and boulder structures
Estuary loss	Gravel retention devices
Altered streamflow	Gravel cleaning
Altered groundwater	Streambank stabilization
Riparian vegetation loss	Riparian revegetation
Altered temperature	
Loss of large woody debris	
Migration barriers	
Water pollution	
Loss of marine-derived nutrients	
Loss of seasonal refuges	

and Bisson et al. (1992) argued that many habitat enhancement projects for salmon in the Pacific Northwest were inappropriately matched to the prevailing geology and climate, but instead appeared to be designed to enhance habitat for certain species of fish regardless of whether the habitat being created would have occurred at the site naturally.

Matching habitat restoration approaches to the condition of the stream or lake requires a knowledge of the ability of the aquatic ecosystem to recover naturally. If habitat is altered to the extent that natural recovery is not possible, then the type of intervention should be compatible with both natural and anthropogenic disturbances the target body of water is likely to undergo (Figure 4). Habitat management options based on priorities established by analysis of the entire watershed range from leaving an area completely alone to recover naturally, to creating entirely new habitat as mitigation for habitat unavoidably lost to development (NRC 1996). The *protection* option involves preserving areas that are ecologically intact and fully functional. In this option, human activities that significantly impact aquatic and riparian ecological functions are restricted. The strategy is intended to protect aquatic and riparian ecosystems that are currently in good condition so that naturally regenerative processes can continue to operate.

The *restoration* option involves both passive and active components. *Passive restoration* includes the removal of anthropogenic disturbances from altered aquatic and riparian ecosystems in order to allow natural processes to be the primary agents of recovery. This strategy allows the natural disturbance regime to dictate the speed of recovery in areas that have a high probability of returning to a fully functional state (Naiman et al. 1992) without human intervention.

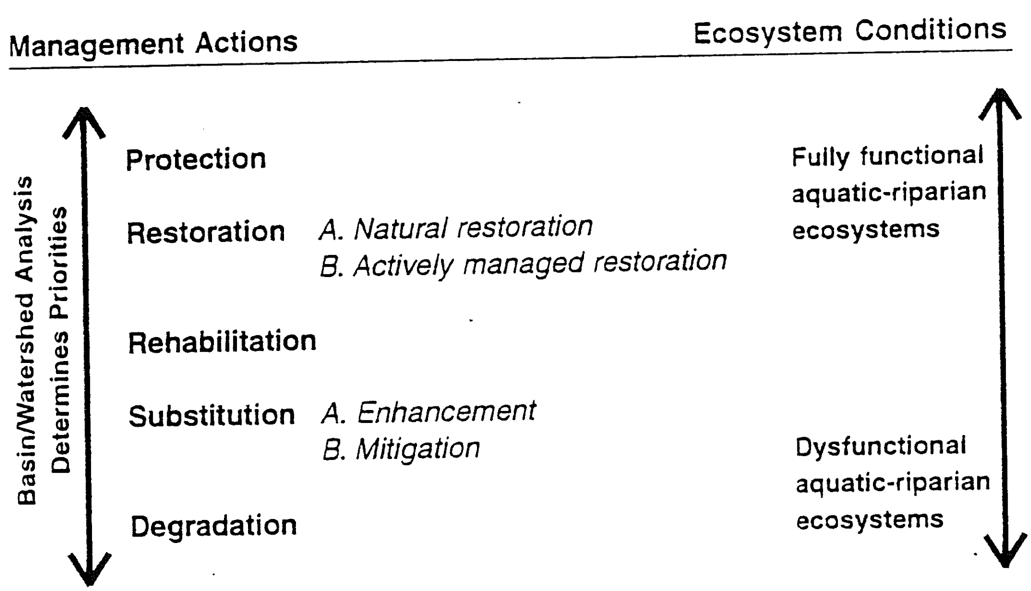

Figure 4. Habitat management options based on watershed analysis and relative ecological health of aquatic and riparian ecosystems. Redrawn from NRC (1996).

Using *active restoration*, dysfunctional aquatic-riparian ecosystems are returned to a state that would occur naturally at the site by actively managing certain aspects of habitat recovery. The strategy is to combine elements of natural recovery with management activities directed at accelerating development of self-sustaining, ecologically healthy streams. Many riparian restoration projects fall into this category.

The *rehabilitation* option involves reestablishing naturally self-sustaining aquatic-riparian ecosystems to the extent possible, while acknowledging that irreversible changes such as dams, permanent channel changes due to urbanization and roads, stream channel incision, and floodplain and estuary losses, permit only partial restoration of ecological functions. The strategy is to combine natural and active management approaches where ecological self-sufficiency cannot occur.

Finally, the *substitution* option includes two components, the appropriateness of which depends on the degree of habitat alteration and the potential for partial recovery. *Enhancement* is used to deliberately increase the abundance or functional importance of selected habitat characteristics as desired. Such modifications may be outside the range of conditions that would occur naturally at a site. The strategy involves technological intervention and substitution of artificial for natural habitat elements. In using this strategy, there is some risk that enhancement may shift aquatic and riparian ecosystems to another state in which neither restoration nor rehabilitation can be achieved (NRC 1996). *Mitigation* is an attempt to offset habitat losses by improving or creating habitat somewhere else or by replacing lost habitat on site. The strategy involves extensive use of technological intervention and replacement of natural habitats with artificially created habitats, and is often employed in highly altered urban/industrial settings.

Failure of habitat improvement projects to achieve defined objectives may be caused by unrealistic goals or inappropriate approaches. The use of habitat substitution has been widespread in the Pacific Northwest (Sedell and Beschta 1991), despite the unpredictable nature of the region's climate. Like hatcheries, habitat enhancement projects have sometimes been designed to increase salmon production for harvest, not to conserve threatened stocks. Such projects have rarely been monitored, and of those where salmon populations have been studied before and after project implementation, only a very few have resulted in a statistically significant increase in the number of returning adults (Hilborn and Winton 1993). Although typical habitat project costs are less than the cost of building a hatchery, they can still be expensive. The cost of a single habitat structure using a combination of cabled logs and boulders, including labor, raw materials, and engineering, can be $5,000 or more. Because many projects require treating an entire reach of stream, the number of structures per project can easily be in two or three figures. In one stream in Oregon (Fish Creek, a tributary of the Clackamas River), an entire fourth-order stream channel was enhanced with approximately 1,400 instream structures, off-channel rearing ponds, and fish passage improvement projects in the 1980s at a total cost of several hundred thousand dollars (Everest et al. 1984). Even with this massive habitat improvement effort, salmon and steelhead populations in Fish Creek have not exhibited a sustained increase over the last ten years (G. H. Reeves and B. Hansen, USDA Forest Service, Corvallis, Oregon, pers. commun.). The inability of many existing habitat enhancement efforts to produce consistently greater salmon runs should not be taken to indicate that habitat loss is not an important limiting factor; rather, the results suggest that creating more elements of the physical environment does not always improve production. Clearly, the problem is more complex.

Implications for Forest Policy

Over the last century probably more money has been spent managing Pacific salmon than any other type of freshwater fish, yet the recent and impending listing of a number of salmon stocks under the Endangered Species Act should remind us that current policies count more failures than successes among their ranks. There is no single (or even most important) cause of the plight of salmon, but one pattern that has been repeated with regularity throughout the management of each of the 4-Hs has been an inability to treat policies as large experiments, learn from past mistakes, and plan for the unforeseen—in other words, to manage adaptively (Lee 1993). As expressed by the National Research Council (NRC 1996):

> The pattern of technological attempts to offset human impacts is not limited to the Columbia River; it is widespread throughout the Northwest, from California to British Columbia and Alaska. A consistent theme of this technological optimism has been neglect of scientific rigor. Hatcheries and other means intended to benefit fish and wildlife were rarely monitored or evaluated. Management objectives or other ways of stating hypotheses about effectiveness were not formulated. Undocumented judgments of agency personnel, often made without supporting evidence, were accepted as expert opinion. Historical experience that would have prevented the re-enactment of errors was not taken into account. All that seemed unimportant at first: adult fish appeared to be abundant in the oceans and the river reaches below the dams. . . . As salmon abundances have declined and American Indian treaty rights have gained legal standing, however, the inadequacy of the scientific record has become glaring and finally crippling.

Reasons why salmon management has not yielded satisfactory results usually fall into three categories: (1) science, specifically monitoring, has been insufficient; (2) management decisions have failed to account for uncertainty; and (3) managers have failed to address the problem as a whole instead of a series of unrelated parts. In combination, these three types of failures often lead to management actions based on decision thresholds or criteria that do not take into

Table 2. Some examples of "managing to the edge."

Factor	Example
Hatcheries	Adult spawning quotas Smolt production goals
Harvest	Maximum sustained yield Minimum "surplus" escapement to streams
Hydroelectric development	Minimum instream flow standards Maximum gas saturation
Habitat	Maximum/minimum water quality standards Minimum streamside buffer width Minimum riparian trees or basal area Minimum large woody debris counts

account the incompleteness of scientific understanding, the uncertainty of future events, and the possibility that activities in one management arena may affect other management arenas. Our tendency to "manage to the edge" (Table 2) has resulted in decisions which favor the exploitation of salmon and their ecosystems and often cause further population declines by leaving little margin for error.

To avoid repeating past mistakes it would be helpful if forest policies included provisions for protecting currently healthy streams and associated riparian zones, and a rationale for restoration of altered habitat based on reestablishing natural energy and material exchanges between land and water (Table 3). Such policies *may not* be favorable to salmon in every instance, but would explicitly acknowledge the role of natural disturbances in creating diverse physical conditions to which aquatic communities in the Pacific Northwest are locally adapted (Bisson et al. 1997). They would also be likely to maintain a more complete range of native species than if the goals of management were directed solely at salmon. Similar approaches have been proposed by authors of the aquatic conservation strategy of FEMAT (Sedell et al. 1994) and by Moyle and Yoshiyama (1994).

In summary, forest management in the Pacific Northwest is undergoing a significant and precedent-setting shift in the emphasis and implementation of policy decisions (Kohm and Franklin 1997). Forest policies have a very large impact on salmon, but other management actions do too, and all must be considered together. Over the last century, what was once a plentiful and valuable natural resource in the region has dwindled to the point of federal Endangered Species Act intervention. Many factors have mediated these declines, and there is little point in trying to elevate one factor above the other by placing blame; poor policy decisions have occurred in virtually all arenas. Management of publicly owned and privately owned forests can play an important role in salmon recovery. There is a need for *both* active and passive management of aquatic and riparian ecosystems in forested watersheds (Berg 1995), but the extent to which

Table 3. Examples of policy, outcome, and goal statements providing for a wide range of aquatic and riparian habitats across forested landscapes.

Policy	Protect aquatic and riparian ecosystems that have not been significantly altered by anthropogenic disturbance, and restore altered habitats using approaches that will lead to restoration of ecological functions without continued human intervention.
Desired outcome	Achieve a forested landscape in which aquatic and riparian ecosystems contain all elements and processes necessary to sustain naturally diverse assemblages of plants and animals, and in which the long-term productivity of valuable species is not impaired.
Goal	Manage aquatic ecosystems, riparian zones, and uplands in a manner that will lead to the full range of conditions in streams and lakes, similar to what would be produced by natural disturbance regimes.

these systems can be actively managed will depend on the extent of anthropogenic alteration and the long-term potential for self-recovery. Recovery of some habitats will be slow; but given the legacy of past management actions, patience is a virtue (Bisson et al. 1992).

A few management cautions are suggested by the lessons learned to date:

- Habitat improvement projects that do not take into account natural disturbance processes such as floods, fires, and windstorms are probably doomed to failure in the long term.
- The potential for successful application of protection and passive restoration approaches may be greater in forest lands than in lands with other uses, because forested watersheds are usually in better condition. Active management may be appropriate in some instances and inappropriate in others, especially if habitat substitution is involved.
- Habitat projects directed at enhancing individual salmon species rather than restoring ecological integrity are likely to have unexpected outcomes and to compromise biological diversity.

More information is needed on landscape patterns created by natural disturbances, especially in riparian zones. Current knowledge is such that the establishment of specific landscape-scale goals with regard to riparian and aquatic habitat is difficult at best (Bisson et al. 1997). One-size-fits-all habitat prescriptions (Table 2) are as inappropriate in riparian zones as they are in stream channels or in riparian protection requirements. If we are to avoid repeating the mistakes of the last century, a much greater effort to monitor a wide variety of management approaches should be undertaken so that successes and failures can be clearly identified. This will require unusual political commitment and a cooperative spirit among affected organizations, but it appears necessary to stem salmon declines.

References

Beamish, R. J., and D. R. Bouillon. 1993. Pacific salmon production trends in relation to climate. *Canadian Journal of Fisheries and Aquatic Sciences* 50:1002-1016.

Berg, D. R. 1995. Riparian silvicultural system design and assessment in the Pacific Northwest Cascade Mountains, USA. *Ecological Applications* 5:87-96.

Beverton, R. J. H., and S. J. Holt. 1957. *On the Dynamics of Exploited Fish Populations.* Fish Investigations Series II, XIX. Her Majesty's Stationery Office, London, England.

Bilby, R. E., B. R. Fransen, and P. A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: Evidence from stable isotopes. *Canadian Journal of Fisheries and Aquatic Sciences* 53:164-173.

Bisson, P. A., T. P. Quinn, G. H. Reeves, and S. V. Gregory. 1992. Best management practices, cumulative effects, and long-term trends in fish abundance in Pacific Northwest river systems. In *Watershed Management: Balancing Sustainability and Environmental Change*, ed. Robert J. Naiman, pp. 189-232. Springer-Verlag, New York.

Bisson, P. A., G. H. Reeves, R. E. Bilby, and R. J. Naiman. 1997. Watershed management and Pacific salmon: Desired future conditions. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 447-474.

Botkin, D. B., K. Cummins, T. Dunne, H. Regier, M. Sobel, L. Talbot, and L. Simpson. 1995. Status and future of salmon in western Oregon: Findings and options. Report 8. Center for the Study of the Environment, Santa Barbara, California.

Bottom, D. L. 1997. To till the water: A history of ideas in fisheries conservation. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 569-598.

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.

Everest, F. H., J. R. Sedell, G. H. Reeves, and J. Wolfe. 1984. Fisheries enhancement in the Fish Creek basin—an evaluation of in-channel and off-channel projects, 1984. Report RWU-1705. Pacific Northwest Forest and Range Experiment Station, Portland.

Francis, R. C. 1997. Managing resources with incomplete information: Making the best of a bad situation. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 513-524.

Frissell, C. A., and R. K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. *North American Journal of Fisheries Management* 12:182-197.

Gregory, S. V., and P. A. Bisson. 1997. Degradation and loss of anadromous salmonid habitat in the Pacific Northwest. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 277-314.

Hilborn, Ray. 1992. Hatcheries and the future of salmon in the Northwest. *Fisheries* 17:5-8.

Hilborn, R., and J. Winton. 1993. Learning to enhance salmon production: Lessons from the Salmonid Enhancement Program. *Canadian Journal of Fisheries and Aquatic Sciences* 50:2043-2056.

Hunt, Robert L. 1993. *Trout Stream Therapy*. University of Wisconsin Press, Madison.

Jackson, P. L., and A. J. Kimerling, eds. 1993. *Atlas of the Pacific Northwest*. Oregon State University Press, Corvallis.

Kapuscinski, A. R. 1997. Rehabilitation of Pacific salmon in their ecosystems: What can artificial propagation contribute? In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 493-512.

Kline, T. C., Jr., J. J. Goering, O. A. Mathisen, P. H. Poe, P. L. Parker, and R. S. Scalan. 1993. Recycling of elements transported upstream by runs of Pacific salmon: II. $\delta^{15}N$ and $\delta^{13}C$ evidence in the Kvichak River watershed, Bristol Bay, southwestern Alaska. *Canadian Journal of Fisheries and Aquatic Sciences* 50:2350-2365.

Kohm, Kathryn A., and Jerry F. Franklin, eds. 1997. *Creating a Forestry for the 21st Century: The Science of Ecosystem Management*. Island Press, Washington, D.C.

Lee, Kai N. 1993. *Compass and Gyroscope: Integrating Science and Politics for the Environment*. Island Press, Washington, D.C.

——. 1997. Sustaining salmon: Three principles. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 665-675.

Lichatowich, J. A. 1997. Evaluating salmon management institutions: The importance of performance measures, temporal scales, and production cycles. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 69-87.

Lichatowich, J. A., and J. W. Nicholas. In press. Oregon's first century of hatchery intervention in salmon production: Evolution of the hatchery program, legacy of a utilitarian philosophy and management recommendations. International Symposium on Biological Interactions of Enhanced and Wild Salmonids, Nanaimo, British Columbia, Canada, June 17-20, 1991. *Canadian Journal of Fisheries and Aquatic Sciences*.

McPhail, J. D. 1997. The origin and speciation of *Oncorhynchus* revisited. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 29-38.

Meffe, G. K. 1992. Techno-arrogance and halfway technologies: Salmon hatcheries on the Pacific coast of North America. *Conservation Biology* 6:350-354.

Moyle, P. B., and R. M. Yoshiyama. 1994. Protection of aquatic biodiversity in California: A five-tiered approach. *Fisheries* 19:6-18.

Naiman, R. J., T. J. Beechie, L. E. Benda, D. R. Berg, P. A. Bisson, L. H. MacDonald, M. D. O'Connor, P. L. Olson, and E. A. Steel. 1992. Fundamental elements of ecologically healthy watersheds in the Pacific Northwest Coastal Ecoregion. In *Watershed Management: Balancing Sustainability and Environmental Change*, ed. Robert J. Naiman, pp. 127-188. Springer-Verlag, New York.

Naiman, R. J., J. J. Magnuson, D. M. McKnight, J. A. Stanford, and J. R. Karr. 1995. Freshwater ecosystems and their management: A national initiative. *Science* 270:584-585.

National Research Council (NRC). 1996. *Upstream: Salmon and Society in the Pacific Northwest*. National Academy Press, Washington, D.C.

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.

Netboy, Anthony. 1980. *The Columbia River Salmon and Steelhead Trout: Their Fight for Survival*. University of Washington Press, Seattle.

Pearcy, W. G. 1992. *Ocean Ecology of North Pacific Salmonids*. Washington Sea Grant Program, University of Washington Press, Seattle.

Regier, H. A. 1997. Old traditions that led to abuses of salmon and their ecosystems. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 17-28.

Reisenbichler, R. R. 1997. Genetic factors contributing to declines of anadromous salmonids in the Pacific Northwest. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 223-244.

Ricker, W. E. 1954. Stock and recruitment. *Journal of the Fisheries Research Board of Canada* 11:559-623.

Sedell. J. R., and R. L. Beschta. 1991. Bringing back the "bio" in bioengineering. *American Fisheries Society Symposium* 10:160-175.

Sedell, J. R., G. H. Reeves, and K. M. Burnett. 1994. Development and evaluation of aquatic conservation strategies. *Journal of Forestry* 92(4):28-31.

Sims, Carl W., and Frank J. Ossiander. 1981. Migrations of juvenile chinook salmon and steelhead trout in the Snake River from 1973 to 1979. National Marine Fisheries Service Final Report of Research to the U.S. Army Corps of Engineers, contract no. DACW68-78-C-0038, Portland, Oregon.

Smith, Courtland L. 1979. *Salmon Fishers of the Columbia*. Oregon State University Press, Corvallis.

Smith C. L., and B. S. Steel. 1997. Values in the valuing of salmon. In *Pacific Salmon and Their Ecosystems*, ed. Stouder, Bisson, and Naiman, pp. 599-616.

Stewart, Hilary. 1977. *Indian Fishing: Early Methods on the Northwest Coast*. University of Washington Press, Seattle.

Stone, L. 1892. A salmon national park. In *Transactions of the American Fisheries Society: Proceedings of the 21st Annual Meeting*, pp. 149-162.

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.

Walters, C. J. 1995. Fish on the line: The future of Pacific fisheries. Report to the David Suzuki Foundation, Fisheries Project, Phase 1, Vancouver, B.C., Canada.

Wendler, H. O. 1966. Regulation of commercial fishing gear and seasons on the Columbia River from 1859 to 1963. *Fisheries Research Papers* (Washington Department of Fisheries) 2(4):19-31.