American Fisheries Society Symposium 70:1005–1019, 2009

Failures to Incorporate Science into Fishery Management and Recovery Programs: Lessons from the Columbia River

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Abstract.—The Pacific Northwest states of Oregon, Washington, California, and Idaho are engaged in a massive effort to restore depleted populations of Pacific salmon *Oncorhynchus* spp. The region's largest watershed, the Columbia Basin, is the focus of what has been called the world's largest attempt at ecosystem restoration. After 26 years of implementation, the failure of the program to achieve its modest recovery goal was the result, in part, of a failure to incorporate the latest science into the program. The fundamental assumptions and principles that guide the selection of recovery tasks and their implementation were not based on the latest scientific understanding of the salmon production system. Three impediments to the incorporation of science into management and recovery programs are identified: an inadequate conceptual foundation, fragmented institutional structures, and political interference. Each impediment is illustrated and discussed using case histories from the Columbia River.

Introduction

In 1980, the U.S. Congress enacted the Northwest Power Planning and Conservation Act (Power Act). One purpose of the act was to create greater parity between fish and electric power production in the management of the Columbia River. To implement the Power Act, Congress created the Northwest Power and Conservation Council (Council) made up of two representatives from the states of Oregon, Washington, Idaho, and Montana. Congress directed the Council to develop a fish and wildlife restoration program funded by the Bonneville Power Administration using power revenues (McConnaha et al. 2006). The first Fish and Wildlife Program (FWP) was adopted in 1982, and it has been amended periodically since then. The scope of the FWP and its cost constitutes what may be the largest attempt at ecosystem restoration in the world (Lee 1993).

Historical analysis conducted at the Council's direction estimated the annual predevelopment salmon *Oncorhynchus* spp. runs at 10–16 million adult fish (Figure 1). By the early 1980s, the annual run (catch plus es-

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capement) had declined to an average of 2.5 million fish (NPPC 1986). After estimating the losses attributable to the operation of the federal power system, the Council adopted a modest recovery goal of five million adults in the annual run, a doubling of the average run at the time the Power Act was enacted (Williams et al. 2006).

During the first twenty years of implementation (1982–2003), the Council spent 1.16 billion dollars in direct funding for fish recovery projects under the FWP. Adding in indirect costs, such as forgone power revenues when water is spilled at dams to facilitate downstream migration of juvenile salmon, brings the total cost of the FWP to $6.45 billion dollars (NPCC 2003). Since implementation of the Council's FWP, the estimated total number of salmon entering the Columbia River has fluctuated from 750 thousand to 3 million fish. During the late 1980s and the first few years of 2000, salmon escapement to the river increased reaching a peak of about three million fish (Figure 1). This most recent increase was due, in part, to favorable ocean conditions. In 1999, several indicators suggested a return to a cool ocean regime favorable to salmon survival; however, this favorable change in ocean regime appears to have been short lived. Since 2002, the indicators suggest a return to less favorable ocean conditions (Bottom et al. 2006) and in the past few years, salmon escapement has declined.

Monitoring at the ecosystem level is inadequate to determine how the causes of higher salmon escapement in 2000–2003 might be separated into the effects of ocean conditions or the results of recovery actions taken by the FWP. In addition, the monitoring data (Figure 1) used for evaluation are escapement of salmon to the river, which includes harvest in the river but not ocean harvest. Total catch

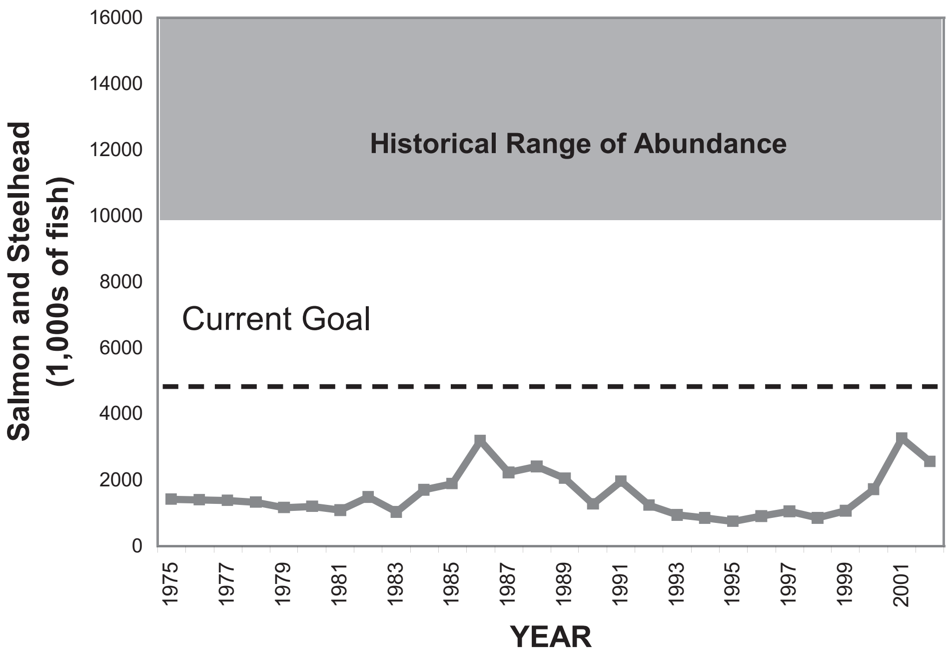

FIGURE 1. Estimated total number of salmon and steelhead entering the Columbia River prior to development (shaded area) from NPPC (1986). The estimated total number of salmon entering the Columbia River (1975–2002) from ODFW and WDFW (2006). The restoration goal for Pacific salmon in the Columbia River from Williams et al. (2006).

(all sources) and escapement to spawning data are not available and are needed to determine if the Council has achieved its goal of five million fish. However, after twenty years the program has not appeared to achieve its goal; the progress towards the recovery goal is muddled due to incomplete data.

In 1995, when total salmon escapement to the river reached a low of 750 thousand fish, the Council asked the Independent Science Group (ISG), a panel composed of eleven senior scientists and managers, to undertake a review of the scientific foundation of the FWP. A published summary of the ISG's subsequent report included the statement that follows:

"After reviewing the science behind salmon restoration and the persistent trends of declining abundance of Columbia River salmon, we concluded that the FWP's implied conceptual foundation did not reflect the latest scientific understanding of ecosystem science and salmonid restoration" (ISG 1999).

How could the Council's salmon recovery program, with its massive financial backing, fail to incorporate the latest science? The purpose of this paper is to address that question. In our approach, we draw a distinction between fishery science and fishery management, including restoration programs. Fisheries science includes the body of research conducted by academic and fish and wildlife management institutions, and others. Fisheries management includes the programs and policies intended to conserve and/or recover fish resources and their habitats. The separation between fishery science and fishery management means that the incorporation of the latest science into management and recovery programs is not automatic, but must be a consciously implemented process that should not be impeded. A brief historical sketch of the FWP and the findings of the ISG suggest that impediments exist to the incorporation of fishery science into the Columbia Basin's principal salmon recovery program. Three of those impediments are described here.

The paper is divided into three parts. First, three case histories are provided to illustrate delays or failures to incorporate science into management and recovery programs. Second, a description is provided of three impediments to the incorporation of science into fishery management and recovery programs. In the final section, the conclusions are presented.

Case Histories

Ecosystem Management

Fishery scientists have called for an ecosystem approach to salmon management (e.g., several papers in Stouder et al. 1997), which is consistent with the broader call for an ecosystem approach to the management of natural resources (Mangel et al. 1996). Recognizing this advance in resource management science, the Council emphasized an ecosystem approach to the recovery of Pacific salmon in its 1994 version of the FWP (NPPC 1994). The ecosystem approach was reflected in many of the measures in the FWP, especially in Section 7 (Salmon Production and Habitat). For example, under a subsection titled Ensure Biodiversity, the plan included nine measures, which encouraged work on the following topics:

1. Develop a Policy to protect wild spawning populations

2. Evaluate salmon survival in the rivers and estuary to understand the ecology and capacity of the basin.

3. Adjust hatchery releases to river carrying capacity.

4. Collect baseline data on population status and life history of wild populations.

5. Conserve genetic diversity.

6. Review procedures for conducting population vulnerability analyses.

7. Evaluate systemwide and cumulative impacts of existing and proposed artificial production projects.

8. Establish a biodiversity institute.

These project areas are basic elements in an ecosystem approach to salmon recovery in the basin. In revising the salmon recovery plan to emphasize an ecosystem approach, the Council recognized that biodiversity was an important aspect of that approach; however, the Council has limited control over which parts of the FWP are actually implemented. The salmon management agencies in the basin select the measures they will implement, prepare funding proposals, and then submit them to the Council.

Fish managers generally disregarded implementation of Section 7 of the FWP, and did not submit any proposals to implement the measures in the biodiversity subsection. The subsections under which the fish managers submitted the largest number of project proposals were those related to hatchery supplementation and new artificial propagation projects. In its review of the suite of projects submitted by the fishery managers, the Independent Scientific Review Panel (ISRP; for a description of the ISRP see Williams and Lichatowich 2009, this volume) noted that, "A noticeable discrepancy exists between the mix of projects actually funded and the ISRP's interpretation of the intent and priorities of the FWP. A somewhat greater discrepancy occurs between the mix of projects actually funded and the Fish and Wildlife Program, if the recommendations from recent scientific panels (report of the Snake River Recovery Team, Upstream, Return to the River, and National Fish Hatchery Review Panel) are considered" (ISRP 1997).

The Council's attempt to incorporate an ecosystem approach to salmon recovery consistent with the latest science was thwarted by the implementation proposals submitted by salmon managers. However, this problem could have been overcome if the Council had released requests for proposals (RFP) targeted to the specific measures ignored by the managers. The RFPs released on an open competitive basis would have attracted interest from universities and consulting firms whose opportunities to participate in the Council's program were normally very limited. The Council did release a few targeted RFPs, but not enough to realign the program's implementation (Williams and Lichatowich 2009). Both the Council and the fish managers bear responsibility for the failure to implement the 1994 FWP consistent with the latest science.

The Stock Concept

Evidence that fish species were composed of reproductively isolated populations or stocks entered fishery science through studies conducted in Europe in the late 19th Century (Sinclair and Solemdal 1988). In the Pacific Northwest, as early as 1893, fish culturist and cannery owner, R. D. Hume, recognized differences in salmon populations from different streams and incorporated those observations into management recommendations (Hume 1893). However, it was not until 1939 that Willis Rich, after reviewing the results of salmon tagging experiments, described the importance of the stock concept for Pacific salmon (Rich 1939). At that time, some fish culturists recognized the implications of the stock concept to salmon management, i.e., the transfer of salmon between rivers (between stocks) was not a desirable management activity (Oregon Fish Commission 1933). Biologists constructed salmon management units to facilitate harvest regulation and these artificial constructs were sometimes referred to as stocks. The importance of biological stocks received little attention for the next several decades.

Interest in biological stocks surfaced again in the 1970s (Calaprice 1969), and in the 1980s and 1990s management agencies began inventorying biological salmon stocks (e.g., Howell et al. 1985; Nehlsen et al. 1991; Washington Department of Fisheries et al. 1993). Fifty-seven years after Rich identified stocks as the basic unit of management, Flagg et al. (1995) reported that one of the factors contributing to the decline of the lower Columbia River stocks of coho salmon *O. kisutch* was the continued stocking of universal donor coho stocks in the lower river tributaries, essentially ignoring the stock concept.

Although the importance of the biological stocks has been recognized for several decades, management practices such as harvest regulation are still, in some cases, based on management units that are aggregates of biological stocks. These artificial management units are constructed for bureaucratic efficiency often to the detriment of conservation objectives. For example, today, sixty-four years after Rich's paper, the harvest of salmon in the Columbia River is not based on escapement targets for biological stocks, but on mixed stock aggregates defined as fish passing convenient counting sites such as mainstem dams. This approach does not take into account the different productivities of the individual stocks or the variation in habitat quality of the different tributaries (Mundy 2006). The lack of stock and habitat specific escapement targets is not limited to the Columbia Basin (Knudsen 2000). Fisheries science has recognized the importance of the biological stock as the basis of sustainable management; however, that realization has not yet been incorporated into all appropriate management activities in the Columbia River basin.

Artificial Propagation

In 1903, thirty-one years after artificial propagation of Pacific salmon was initiated, some biologists recognized that they had little scientific basis for their hatchery programs. Recognizing the lack of a scientific basis for salmon propagation, Chamberlain (1903) declared:

"Until the salmon industry or the people choose to pay for several years {of} careful, expensive investigation, propagation must be taken on faith. Without this, even if our fisheries should increase, we could not be sure it was from the hatchery work…"

The success of hatcheries was taken on faith for another 20 years when two evaluations of artificial propagation were undertaken—a field study of artificial propagation carried out in British Columbia at the Cultus Lake Hatchery (Foerster 1936), and a statistical analysis of hatchery releases and adult returns in the Columbia Basin (Rich 1922). The Cultus Lake Hatchery study was a test of a key assumption in the use of artificial propagation, specifically that hatcheries produce adult salmon more effectively than natural propagation. The study showed that artificial propagation was no more effective than natural propagation. Following the publication of those results, hatcheries in British Columbia were closed. The statistical analysis of Columbia River hatchery releases and adult harvest did not find evidence that artificial propagation influenced the supply of salmon to the fishery; however, those findings had no effect on the operation of hatcheries in the Columbia Basin (Lichatowich 1999).

The 1930–1939 period was a critical decade for Pacific salmon in the Columbia Basin. The construction of the first three mainstem dams (Wells, Grand Coulee, and Bonneville dams) and development of the basin's hydroelectric system marked a new phase in the development of the river. Faced with the loss of habitat behind the impassable

Grand Coulee Dam and in the reservoirs behind Wells and Bonneville dams, managers used artificial propagation to mitigate for the expected loss of salmon production. Hatcheries were relied on to make up for lost habitat, even though fish culturists had not yet demonstrated the efficacy of artificial propagation (Lichatowich 1999). Biologists still took the success of hatcheries as a matter of faith, or "idolatrous faith" as one biologist described (Cobb 1930).

In the 1930s, the federal Secretary of the Interior recognized that mainstem dams in the Columbia Basin posed a serious threat to the sustained production of Pacific salmon. To ensure the mitigation plan had a high probability of success, the Secretary appointed a Board of Consultants to review the physical and biological feasibility of using hatcheries to mitigate the losses of natural production. The Board of Consultants recognized the uncertainty inherent in the decision to use artificial propagation as a mitigation tool, so they recommended an approach that in recent times would be called adaptive management. They recommended treating the plan to use artificial propagation as an experiment and cautioned the salmon mangers to accept the possibility of failure and, "…that the adoption of the plan for trial should not be understood as implying an indefinite commitment to its support, but only for so long as the results may reasonably appear to justify its continuance" (Board of Consultants 1939).

Sixty years after the Board of Consultants submitted its report, the Council undertook a review of artificial propagation in the Columbia Basin, which resulted in the adoption of ten policies to guide the use of hatcheries. Among those policies was this one: "Artificial propagation remains experimental. Adaptive management practices that evaluate benefits and address scientific uncertainties are critical" (NPPC 1999). When the Council rediscovered the need to treat the use of artificial propagation as an experiment, it overlooked the fact that at a broad, basin level the experiment had already been carried out. Given the status of salmon in the Columbia Basin, it's clear that artificial propagation failed to achieve its early objectives of maintaining the supply of fish to the fishery and its later objectives of mitigating for lost habitat (Lichatowich et al. 2006).

Supplementation is the latest modification of the use of artificial propagation, and it is intended to rebuild depleted natural populations in marginal habitats. In its review of supplementation, the Independent Scientific Advisory Board (ISAB), which replaced the ISG in 1996, concluded that even though it was considered experimental, supplementation was being carried out in a way that will make comprehensive evaluation unlikely (ISAB 2003). Implementation of "experimental" uses of hatcheries without actually carrying out the experiment is a persistent problem. Without adequate monitoring and evaluation, learning by management agencies is impeded (Hilborn 1992), and institutional learning is an important part of the process of incorporating science into management programs.

The history of hatchery operations is a clear example of what Hilborn (1992) called "goal displacement," which occurs when a program's original objective and performance measure are replaced by another objective and performance measure. The original objective of artificial propagation was to increase or maintain the harvest of salmon, and the release of juveniles from hatcheries was one step in the process of achieving that goal. However, the original goal of artificial propagation has been displaced from adult returns to the release of juveniles. The new performance measure is the number of juveniles a hatchery releases rather than the contribution of the hatchery releases to the fishery or to escapement (Hilborn 1992).

Goal displacement was evident in a 1999 audit of the performance of 51 Oregon coastal and Willamette River hatchery programs. After a review of the audit, Oregon's Independent Multidisciplinary Science Team concluded that 41 of the 51 programs used smolt releases as a measure of performance and only 9 of the 51 programs used adult returns as the measure of performance (IMST 2000).

Goal displacement reduced hatchery evaluations to the number of juveniles released, and as a result, it focused research on those hatchery operations that lead directly to the release of juveniles. Consequently, the incorporation of science has been largely limited to the improvement of activities within the hatchery, such as animal husbandry, the formulation of nutritious feeds, disease identification and treatment, the genetics of breeding procedures, improvements in hatchery operation, and the design of better facilities (Williams et al. 2003). Did hatcheries meet their goal of maintaining the abundance of adult salmon? Science related to that question has been slow to develop. Goal displacement and the lack of adequate monitoring and evaluation have contributed to the failure of artificial propagation to achieve its goals. After more than a century of use, salmon management institutions have missed the opportunity to learn adaptively, and as a consequence, artificial propagation not only failed to meet its goals, but it has contributed to the depleted state of the salmon (NRC 1996).

The listing of Pacific salmon under the federal Endangered Species Act created a new reason to focus attention on artificially propagated fish outside the hatchery facility. The concern boils down to this question: Are artificially propagated fish equivalent to naturally propagated fish for the purposes of listing or delisting Pacific salmon? NOAA Fisheries recently released a draft hatchery policy which proscribes the conditions under which artificially propagated fish could be used to assess the status of an ESU (NOAA 2004). The policy was reviewed by the Salmon Recovery Scientific Review Panel (SRSRP), a panel of independent scientists convened by NOAA Fisheries. The SRSRP found that the policy did not reflect the latest science (Myers et al. 2004). Even for this crucial problem, the development and incorporation of science regarding the consequences of artificial propagation beyond the hatchery fence has been impeded.

Impediments to the Incorporation of Science into Fishery Programs

In this section the discussion of the case histories is extended to examine three impediments to the incorporation of science into salmon management and recovery programs in the Columbia Basin. Those impediments are: inadequate conceptual foundation, fragmented institutional structure, and political interference.

Inadequate Conceptual Foundation

Several papers have called attention to the importance of the conceptual foundation used as an underlying presupposition in fisheries management and recovery programs (Rigler 1982; Bottom 1997; Frissell et al. 1997; Acheson and Steneck 1997; Williams et al. 1999; and Bottom et al. 2005). A conceptual foundation is the set of principles, assumptions, and beliefs about how an ecosystem and its fish production systems function. The conceptual foundation influences the development of management policies and programs, including fishery restoration programs. It determines what problems (e.g., limitations on fish production) are identified, what information is collected, and how it is interpreted, and as a result, establishes the range of appropriate solutions (Lichatowich et al. 1996). As a consequence, the conceptual foundation can determine the success or failure of management and recovery programs.

Conceptual foundations are buried so deep in the culture of management institutions that they can exert strong influence on policy and programs while rarely being subjected to critical review and evaluation (Botkin 1990; Evernden 1993).

In its review of the scientific basis of the Council's Fish and Wildlife Restoration Program in the Columbia River, the ISG concluded that the failure to achieve the program's modest goal was in part due to a conceptual foundation that was based on outdated or inadequate science (ISG 1999; Williams 2006). The ISG identified three global statements that characterized the conceptual foundation that has been used to guide the program:

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

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

• Salmon species can effectively be managed independently of one another. Management actions designed to protect or restore one species or population will not compromise environmental attributes that form the basis for production by another species or population (Williams et al. 1999)

This conceptual foundation, or a variation of it, has been in widespread use for most of the history of fishery management (Bottom 1997); however, that these assumptions would play such an important role in Columbia River salmon management was not inevitable. The pioneering work of some early fisheries biologists might have lead to a different conceptualization of fish production systems. For example, the holistic and ecological approach of biologists such as S. A. Forbes influenced fishery management in its early years (McIntosh 1985). In the Pacific Northwest, the work of Charles Gilbert, Willis Rich, and others stressed the importance of life history—habitat relationships and an ecological conceptualization of salmon production systems (Lichatowich 1999). At the same time, another approach to fisheries management, which led to a greatly simplified view of fish production systems, was gaining in importance. Managers shifted focus to the production of single species and management programs based on an agricultural view of watersheds and fisheries production systems (McIntosh 1985; Bottom 1997). Implicit in this approach was the belief that a simplified production system dependent on technology could maintain the abundance of salmon and other fisheries. Salmon management guided by that conceptual foundation led to a reliance on halfway technologies, i.e., management and restoration measures that treat symptoms without addressing their underlying cause (Meffe 1991). Halfway technologies are consistent with a "command and control" approach to management, which results in natural ecosystems becoming more brittle, less resilient, and less capable of long-term sustainability (Holling and Meffe 1995).

The reliance on halfway technology is clearly shown in the way funds have been allocated for salmon recovery in the Columbia Basin. Prior to 1980 and prior to the implementation of the Council's FWP, habitat restoration (a major cause of declining salmon abundance) received less than one percent of the funding for salmon recovery whereas hatcheries (treating the symptom of too few fish by making more) received forty-three percent of the funding. During the first ten years of the FWP, expenditures on habitat restoration improved slightly to about six percent of the salmon recovery budget; however, artificial propagation still received forty percent of the funds (Lichatowich et al. 2006). It is argued that an inadequate conceptual foundation impeded the use of new science and created several problems. Among those problems were the failure to implement any of the biodiversity measures in the 1994 version of the FWP; the lack of stock specific escapement targets; the reluctance to deal with the impacts of artificial propagation to the ecosystem beyond the hatchery; and the reliance on an approach to salmon recovery based on halfway technology and command and control management.

The simplified, techno-production system described in the conceptual foundation that formed the basis of salmon recovery in the Columbia River is not unique to that watershed or fishery. In an examination of the assessments of the northern cod stock prior to its collapse, Finlayson (1994) identified six assumptions (conceptual foundation) that described a "techno–utopian" approach to cod management. Three of those assumptions are:

• The universe is mechanistic and deterministic, and its workings are governed by a few fundamental and unvarying laws.

• These variables are knowable and their effects on the stocks are simple, continuous, and can be realistically modeled by an equation with a small number of parameters. Therefore, they are predictable.

• Science-based management can manipulate some of these variables (primarily fishing mortality). It can monitor the others to effectively control the system and produce (within certain broad limits) equilibrium states in general harmony with human needs and desires.

Strong parallels exist between this set of assumptions about the northern cod production system and the conceptual foundation that underlies salmon management and recovery programs in the Columbia Basin. A comparable conceptual management likely underlies some aspects of the fishery management of the Laurentian Great Lakes, especially Lake Michigan (e.g., Jones and Bence 2009, this volume).

To rectify the situation in the Columbia River, the ISG proposed an alternative conceptual foundation consisting of three assumptions.

• Restoration of Columbia River salmonids must address the entire ecosystem, which encompasses the continuum of freshwater, estuarine, and ocean habitats where salmonid fishes complete their life histories. This consideration includes human developments, as well as natural habitats.

• Sustained salmonid productivity requires a network of complex and interconnected habitats, which are created, altered, and maintained by natural physical processes in freshwater, the estuary, and ocean. These diverse and high-quality habitats, which have been extensively degraded by human activities, are crucial for salmonid spawning, rearing, migration, maintenance of food webs and predator avoidance, and for maintenance of biodiversity. Ocean conditions, which are variable, are important in determining the overall patterns of productivity of salmon populations.

• Genetic diversity, life history, and population diversity are ways that salmonids respond to their complex and connected habitats. These factors are the basis of salmonid productivity and contribute to the ability of salmonids to cope with environmental variation that is typical of freshwater and marine environments (Liss et al. 2006).

Fisheries science has largely adopted this conceptual foundation or some variation of it. Fisheries management has begun to slowly shift from a techno-agricultural to an ecological approach; however, progress has been slow and impeded by political agendas (Liss et al. 2006).

In 2000, the Council revised the FWP and, following the advice of the ISG, incorporated an explicit conceptual foundation into the plan. The revised plan called on the ISAB to review the scientific soundness and basin-wide applicability of the 2000 FWP. The ISAB concluded that the scientific principles making up the conceptual foundation were consistent with ecological theory. However, the ISAB also found that the linkage between the conceptual foundation and the plan's objectives was weak and the objectives were not especially consistent with the principles making up the conceptual foundation (ISAB 2001). The Council made an attempt to incorporate a scientifically sound conceptual foundation into its FWP, but fell short of translating the conceptual foundation's principles into the actual implementation mechanisms of the plan. It left the door open for a continuation of the status quo.

Fragmented Institutional Structure

The salmon's ecosystem extends from the headwaters down to the estuary and several hundred miles into the North Pacific Ocean. It is so large that humans have been unable to either conceive of or implement a coherent institutional structure capable of managing the salmon at the ecosystem level. In addition, the salmon's ecosystem is fragmented among several institutions, each making decisions that can affect the salmon directly or indirectly by altering the quality of the habitat. Some of those institutions have primary missions that can conflict with salmon conservation. For example, the mission of public and private power utilities that operate hydroelectric dams can conflict with salmon conservation. In the Columbia Basin, a salmon smolt leaving the Lochsa River in Idaho will, in its migration to sea and back, pass through seventeen salmon management jurisdictions (Wilkinson and Conner 1983) and several other land and water management agencies whose decisions can affect salmon habitat.

The problems that fragmented institutional structures create for effective salmon management and restoration have been recognized for a long time. President Theodore Roosevelt mentioned one in his State of the Union Address for 1908. He was worried about the lack of effective harvest management in the lower Columbia River—the inability of the states of Oregon and Washington to agree on a unified set of regulations. Again in the late 1930s and early 1940s, the states of Oregon and Washington recognized the obstacles to effective salmon management that a fragmented institutional structure created (Lichatowich 1999). A special subcommittee of the Washington State Senate issued a report, which concluded that effective salmon management will be "… hopelessly defeated in obtaining any solution to the Columbia River fisheries unless we simplify our administration over the resource" (WSS 1943). The Oregon State Planning Board reached a similar conclusion (Lichatowich 1999). Following its review of the Pacific salmon crisis in 1996, the National Research Council concluded, "The current set of institutional arrangements is not appropriate to the bioregional requirements of salmon and their ecosystems," and that, "the current set of institutional arrangements contributes to the decline of salmon and cannot halt the decline" (NRC 1996).

The Snake River Salmon Recovery Team (SRSRT 1994) linked the fragmented institutional structure to the failure to incorporate the best science into salmon recovery programs in the Columbia Basin. In its final recommendations on recovery of salmon populations in the Snake River, the SRSRT characterized the situation as "… jurisdictional chaos, no one in charge, important decisions not based on science, and stifled science."

The current institutional structure stifles the incorporation of science into salmon management and recovery in two ways: 1) continued reliance on a flawed conceptual foundation, and 2) distribution of funds based on existing relationships rather than in accordance with science-based priorities. As discussed earlier, fisheries science has been advocating an ecosystem approach to management programs. Management of an ecosystem such as the Columbia Basin that is fragmented among several institutions, many of which have conflicting purposes, tends to favor activities constrained by narrowly defined agency missions. For fisheries, this favors a conceptual foundation based on simplifying assumptions about production processes and an emphasis on harvest management and artificial propagation. Those activities cause little conflict with the activities and jurisdictions of other institutions. In fact, mitigation hatcheries can help further economic development that conflicts with salmon conservation. Hatchery mitigation for the construction of hydroelectric dams is an example. The vision of a simplified salmon production system highly dependent on technology to circumvent ecological processes as embodied in the existing conceptual foundation has co-evolved with the fragmented institutional structure. Each reinforces the other, which means that any attempt to change the conceptual foundation will have to include institutional reform.

In the discussion of case histories, it is shown that in spite of the Council's adoption of an ecosystem approach to salmon recovery in the Columbia Basin, the management agencies largely "cherry picked" the measures out of the FWP that were consistent with the existing conceptual foundation, i.e., they emphasized artificial propagation and the passage of juvenile salmonids at the mainstem hydroelectric projects. An ecosystem approach to salmon management requires cooperation among several agencies, institutions, and jurisdictions, which is difficult to obtain in a watershed the size of the Columbia River.

The second way that institutional fragmentation impedes the incorporation of science into management and recovery programs is more troubling. When huge sums of money were pumped into the Columbia Basin's highly fragmented institutional structure, it shifted some of the focus from the common goals of restoring salmon using the latest science to the division of funds among competing institutions. In his book, *Fishy Business*, Rik Scarce (2000) discusses this problem and the way it results in projects selected for funding based on a relationship network, rather than the scientific merits of individual proposals.

Political Interference

The authors recognize that salmon management and recovery policy must take into account not only science, but also economic, social, and political factors. In a basin the size of the Columbia, where the hydro-power system is a major driver in the region's economy, conflict and tradeoffs in the river's management is a fact of life. Such conflict, if properly managed, can be a source of learning (Lee 1993) and a means of ensuring the appropriate use of science in policy making. It can also have the opposite effect. We define political interference as the attempt to present a policy decision made for political or economic reasons as the outcome of scientific analysis when the science does not support the decision.

NOAA Fisheries' draft hatchery policy mentioned in the case histories above is an example of political interference. The SRSRP concluded that the policy did not reflect the published scientific research on the difference between hatchery and wild salmon and the implication of those differences for management and recovery programs. According to panel members interviewed by the Union for Concerned Scientists, they were told to take their recommendations out of the report or "see their report end up in a drawer." Some time later, the flawed policy was traced to a non-scientist political appointee (http://www.ucsusa.org/scientific_integrity/interference/deleting-scientific-advice-on-endangered-salmon.html).

Important economic, social, or political reasons may exist that administrators at NOAA Fisheries took into account in drafting the hatchery policy. We do not dispute that they can and should take into account more than biological factors; however, when the scientists are asked to strip out their scientific findings to give cover to a salmon hatchery policy that runs counter to science, then the process has slipped into political interference. While many who have worked in salmon management and recovery during the last few decades know of examples of political interference, few have had the courage shown by the SRSRP to bring the problem to public attention and publish an account of it.

Conclusion

The depleted status of Pacific salmon in the Columbia Basin and the massive remedial efforts that are underway should have been a strong incentive to incorporate the latest scientific understanding of the salmon's biology and ecology into the management and recovery program. We described three impediments to the incorporation of science into management and recovery programs and, in spite of the massive funding for salmon recovery, those impediments receive little attention. We want to emphasize these are impediments and not total blocks.

Incorporating science into management and recovery programs requires successful institutional learning. Undoubtedly, salmon management institutions will continue to learn. What is not certain is whether the mode of learning will be adequate to overcome the crucial challenges to the salmon's persistence (Volkman and McConnaha 1993). Will learning be intentional and directed, or will the future be tied to outdated assumptions and beliefs? Will learning be encumbered by inadequate institutional structures, and subjected to political interference? All of these variables constrain the learning possibilities and impede the incorporation of science into management and recovery programs.

The Independent Scientific Advisory Board for the Columbia River salmon recovery program suggests that management is still tied to the past assumptions and beliefs to the detriment of salmon recovery (Williams 2006). The State of Washington's Independent Science Panel bluntly described this dependence on past assumptions and beliefs in its review of the state's salmon recovery program: "The proposed set of minor changes to existing programs and reliance on historically ineffective voluntary measures leaves the impression that tinkering with the failures of the past will restore the glories of the past" (ISP 2000). We believe this reliance on past approaches to salmon restoration indicates a program that is still tied to the old conceptual framework and its reliance on halfway technology. Yet a careful examination of those obstacles is always very difficult (Cronon 1995).

In his book on the integration of science and politics in the Columbia Basin, Lee (1993) offered an explanation for the reluctance of management agencies to critically examine the status quo. He discussed this problem in the context of single and double loop learning. Single loop learning takes place within the constraints of underlying theory or, to use our terminology, the conceptual foundation upon which the organization is based. Double loop learning breaks out of the constraints of single loop learning and includes a self examination of the conceptual foundation and its inadequacies in identifying and dealing with the problems facing the institution. Double loop learning—essential to adaptive management—is seldom undertaken (Botkin 1990; Evernden 1993; Lee 1993).

Overcoming the obstacles to institutional learning and the incorporation of science into management and recovery programs require one initial and fundamental step. The management agencies must put learning and incorporation of science on the agenda (Hilborn 1992), something which in our experience management agencies have been reluctant to do.

References

Acheson, J., and R. Steneck. 1997. Bust and then boom in the Maine lobster fishery: perspective of fishers and biologists. North American Journal of Fisheries Management 17:826–847.

Board of Consultants. 1939. Report of the Board of Consultants on the fish problems of the upper Columbia River: Section 1. Stanford University, Palo Alto, California.

Botkin, D. 1990. Discordant harmonies: a new ecology for the twenty-first century. Oxford University Press. New York.

Bottom, D., B. Riddell, and J. Lichatowich. 2006. The estuary, plume and marine environments. Pages 507–569 *in* R. Williams editor. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press, Burlington, Massachusetts.

Bottom. D. 1997. To till the water: a history of ideas in fisheries conservation. Pages 569–597 *in* D. Stouder, P. Bisson and R. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York.

Bottom. D., C. Simenstad, J. Burke, A. Baptista, D. Jay, K. Jones, E. Casillas, and M. Schiewe. 2005. Salmon at river's end: the role of the estuary in the decline and recovery of Columbia River salmon. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-69.

Calaprice, J. R. 1969. Production and genetic factors in managed salmonid populations. Pages 377–388 *in* T. G. Northcote, editor. Symposium on Salmon and Trout in Stream. H. R. MacMillan Lectures in Fisheries, Institute of Fisheries, The University of British Columbia, Vancouver, British Columbia.

Chamberlain, F. M. 1903. Artificial propagation. Pacific Fisherman 1:(11)10.

Cobb, J. N. 1930. Pacific salmon fisheries. U.S. Bureau of Fisheries Document No. 1092, Washington, D.C.

Cronon, W. 1995. Forward: With the best intentions. Pages vii–ix *in* N. Langston, author. Forest dreams, forest nightmares: the paradox of old growth in the inland west. University of Washington Press, Seattle.

Evernden, N. 1993. The natural alien: humankind and environment. University of Toronto Press, Toronto, Ontario.

Finlayson, A. 1994. Fishing for truth: a sociological analysis of northern cod stock assessments from 1977–1990. Social and Economic Studies No. 52. Institute of Social and Economic Research. Memorial University of Newfoundland, St. Johns, Newfoundland and Labrador.

Flagg, T., F. Waknitz, D. Maynard, G. Milner, and C. Mahkhen. 1995. The effect of hatcheries on native coho salmon populations in the lower Columbia River. Pages 366–375 *in* H. L. Schramm, Jr. and R. G. Piper, editors. Uses and effects of cultured fishes in aquatic ecosystems. American Fisheries Society Symposium 15, Bethesda, Maryland.

Foerster, R. E. 1936. Sockeye salmon propagation in British Columbia. Biological Board of Canada, Bulletin No. 53, Ottawa.

Frissell, C., W. Liss, R. Gresswell, R. Nawa, and J. Ebersole. 1997. A resource crisis: changing the measure of salmon management. Pages 411–444 *in* Stouder, D., P. Bisson and R. Naiman, editors. Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York.

Hilborn, R. 1992. Can fisheries agencies learn from experience? Fisheries 17:4 6–14.

Holling, C., and G. Meffe. 1995. Command and control and the pathology of natural resource management. Conservation Biology 10:328–337.

Howell, P., K. Jones, D. Scarnecchia, L. Lavoy, W. Kendra, and D. Ortmann. 1985. Stock assessment of Columbia River anadromous salmonids. Volume I: Chinook, coho, chum and sockeye salmon stock summaries. Bonneville Power Administration, Portland, Oregon.

Hume, R. 1893. Salmon of the Pacific Coast. Schmidt Label & Lithographic Company, San Francisco.

Independent Multidisciplinary Science Team (IMST). 2000. Letter to Kay Brown, Oregon Department of Fish and Wildlife, Salem, Oregon. October 25, 2000.

Independent Science Group (ISG). 1999. Scientific issues in the restoration of salmonid fishes in the Columbia River. Fisheries 24:10–19.

Independent Science Panel (ISP). 2000. Review of statewide strategy to recover salmon: Extinction is not an option. ISP 2000–1. Governor's Salmon Recovery Office, Olympia, Washington.

Independent Scientific Advisory Board (ISAB). 2003. Review of salmon and steelhead supplementation. ISAB 2003–03. Northwest Power Planning Council, Portland, Oregon.

Independent Scientific Advisory Board (ISAB). 2001. Review of the biological objectives in the 2000 Fish and Wildlife Program. ISAB, 2001–6. Northwest Power and Conservation Council, Portland, Oregon.

Independent Scientific Review Panel (ISRP). 1997. Review of the Columbia Basin Fish and Wildlife Program as directed by the 1996 amendment to the Power Act. Annual Report, ISRP 97–1. Northwest Power Planning Council, Portland, Oregon.

Jones, M. L., and J. R. Bence. 2009. Uncertainty and fishery management in the North American Great Lakes: lessons from applications of decision analysis. Pages 1059–1081 *in* C. C. Krueger and C. E. Zimmerman, editors. Pacific salmon: ecology and management of western Alaska's populations. American Fisheries Society, Symposium 70, Bethesda, Maryland.

Knudsen, E. 2000. Managing Pacific Salmon escapements: the gap between theory and reality. Pages 237–272 *in* E. Knudsen, C. Steward, D. MacDonald, J. Williams, and D. Reiser, editors. Sustainable fisheries management: Pacific salmon. Lewis Publishers, Boca Raton, Florida.

Lee, K. 1993. Compass and gyroscope: integrating science and politics for the environment. Island Press, Washington, D.C.

Lichatowich, J. 1999. Salmon without rivers: a history of the Pacific salmon crisis. Island Press, Washington, D.C.

Lichatowich, J. A., L. E. Mobrand, R. J. Costello, and T. S. Vogel. 1996. A history of frameworks used in the management of Columbia River Chinook salmon. A report prepared for Bonneville Power Administration included in Report DOE/BP 33243–1, Portland, Oregon.

Lichatowich, J., M. Powell, and R. Williams. 2006. Artificial production and the effects of fish culture on native salmonids. Pages 417–463 *in* R. Williams, editor. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press, Burlington, Massachusetts.

Liss, W., J. Stanford, J. Lichatowich, R. Williams, C. Coutant, P. Mundy, and R. Whitney. 2006. Developing a new conceptual foundation for salmon conservation. Pages 51–98 *in* R. Williams, editor. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press, Burlington, Massachusetts.

Mangel, M. and forty-one co-authors. 1996. Principles for the conservation of wild living resources. Ecological Applications 6: 338–372.

McConnaha, W., R. Williams, and J. Lichatowich. 2006. Introduction and background of the Columbia River salmon problem. Pages 1–28 *in* R. Williams, editor. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press, Burlington, Massachusetts.

McIntosh, R. 1985. The background of ecology: concept and theory. Cambridge University Press, New York.

Meffe, G. 1991. Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific Coast of North America. Conservation Biology 6(3):350–354.

Mundy, P. 2006. Harvest management. Pages 465–505 *in* R. Williams, editor. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press, Burlington, Massachusetts.

Myers, R., S. Levin, R. Lande, F. James, W. Murdoch, and R. Paine. 2004. Hatcheries and endangered salmon. Science 303:1980.

National Oceanic and Atmospheric Administration (NOAA). 2004. Endangered and threatened species: proposed policy on the consideration of hatchery-origin fish in Endangered Species Act listing determinations for Pacific salmon and steelhead. Federal Register: 6931354–31359. Washington, D.C.

National Research Council (NRC). 1996. Upstream: salmon and society in the Pacific Northwest. Report of 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, D.C.

Nehlsen, W., J. E. William, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16:(2)4–21.

Northwest Power and Conservation Council (NPCC). 2003. Columbia River Basin Fish and Wildlife Program: twenty years of progress. Northwest Power and Conservation Council, Portland, Oregon.

Northwest Power Planning Council (NPPC). 1986. Council staff compilation of information on salmon and steelhead losses in the Columbia River basin. Columbia River Basin Fish and Wildlife Program, Portland, Oregon.

Northwest Power Planning Council (NPPC). 1994. Columbia River Basin Fish and Wildlife Program, Portland, Oregon.

Northwest Power Planning Council (NPPC). 1999. Artificial production review: report and recommendations of the Northwest Power Planning Council. NPPC 99–15 Portland, Oregon.

Oregon Department of Fish and Wildlife and Washington Department of Fish and Wildlife. 2006. Status Report: Columbia River fish runs and fisheries. Tables only. Oregon Department of Fish and Wildlife, Salem, Oregon.

Oregon Fish Commission. 1933. Biennial report of the Fish Commission of the State of Oregon to the Governor and the Thirty-seventh Legislative Assembly, 1933. State of Oregon, Salem, Oregon.

Rich, W. 1922. A statistical analysis of the results of artificial propagation of Chinook salmon. Manuscript Library, Northwest and Alaska Fisheries Science Center, NOAA Fisheries, Seattle, Washington.

Rich, W. 1939. Local populations and migration in relation to the conservation of Pacific salmon in the western states and Alaska. Department of Research, Fish Commission of the State of Oregon, Contribution No. 1. Salem, Oregon.

Rigler, E. 1982. The relationship between fisheries management and limnology. Transaction of American Fisheries Society 111:121–132.

Scarce, R. 2000. Fishy Business: Salmon, Biology and the Social Construction of Nature. Temple University Press, Philadelphia.

Sinclair, M., and P. Solemdal. 1988. The development of "population thinking" in fisheries biology between 1878 and 1930. Aquatic Living Resources 1:189–213.

Snake River Salmon Recovery Team. 1994. Final recommendations to the National Marine Fisheries Service. National Marine Fisheries Service, Seattle.

Stouder, D., P. Bisson, and R. Naiman, editors. 1997. Pacific salmon and their ecosystems: status and future options. Chapman and Hall, New York.

Volkman, J., and C. McConnaha. 1993. Through a glass darkly: Columbia River salmon, the Endangered Species Act, and adaptive management. Environmental Law 23:1249–1272.

Washington Department of Fisheries, Washington Department of Wildlife, and Western Washington Treaty Indian Tribes. 1993. Washington State salmon and steelhead stock inventory. Olympia, Washington.

Washington State Senate (WSS). 1943. Report on the problems affecting the fisheries of the Columbia River. Fisheries Interim Investigating Committee. Olympia, Washington.

Wilkinson, C., and D. Conner. 1983. The law of the Pacific salmon fishery: conservation and allocation of a transboundary common property resource. The University of Kansas Law Review 32:1.

Williams, R., P. Bisson, D. Bottom, L. Calvin, C. Coutant, M. Erho, C. Frissell, J. Lichatowich, W. Liss, W. McConnaha, P. Mundy, J. Stanford, and R. Whitney. 1999. Scientific issues in the restoration of salmonid fishers in the Columbia River. Fisheries 24:10–19.

Williams, R., and J. Lichatowich. 2009. Science and politics—an uncomfortable alliance: lessons learned from the Fish and Wildlife Program of the Northwest Power and Conservation Council. Pages 1021–1046 *in* C. C. Krueger and C. E. Zimmerman, editors. Pacific salmon: ecology and management of western Alaska's populations. American Fisheries Society, Symposium 70, Bethesda, Maryland.

Williams, R., J. Lichatowich, P. Mundy, and M. Powell. 2003. Integrating artificial production with salmonid life history, genetic and ecosystem diversity: A landscape perspective. Trout Unlimited, Portland, Oregon.

Williams, R., J. Stanford, J. Lichatowich, W. Liss, C. Coutant, P. Mundy, P. Bisson, and M. Madison. 2006. Return to the river: Strategies for salmon restoration in the Columbia River basin. Pages 629–666 *in* R. Williams editor. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press. Burlington.

Williams, R., editor. 2006. Return to the river: restoring salmon to the Columbia River. Elsevier Academic Press. Burlington.