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# CHAPTER 8. ARTIFICIAL PRODUCTION AND THE EFFECTS OF FISH CULTURE ON NATIVE SALMONIDS

*". . . fish so abundant that they can be caught without restriction, and serve as cheap food for the people at large, rather than to expend a much larger amount in preventing the people from catching the few that still remain after generations of improvidence."*

G. B. Goode, 1884, Report of the US Commission of Fish and Fisheries (p. 1157).

*"... a management strategy that has as a centerpiece artificial propagation and restocking of a species that has declined as the result of environmental degradation and over exploitation, without correcting the causes for the decline, is not facing biological reality. Salmonid management based largely on hatchery production, with no overt and large scale ecosystem-level recovery program is doomed to failure."*

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

Artificial propagation is an important tool used by salmon managers in the Columbia River for the past 120 years. It was the first management activity undertaken in the basin and it has consumed a major portion of the fisheries budget over the intervening years (General Accounting Office 1992). In the early years of its development, artificial propagation of salmon was carried out at a small scale in low cost facilities and required little effort. However by as early as 1898, 26 million salmon fry were being released from hatcheries into the Columbia Basin each year. These early attempts at large-scale propagation were largely ineffective (Columbia Basin Fish and Wildlife Authority 1990) thus early hatcheries may not have had a significant effect on the number of adult salmon returning to the river. Nevertheless, the program did have a lasting and major influence on fisheries management philosophy and approach. Consequently, understanding the growth and evolution of the hatchery program is an important starting point for anyone attempting to understand the current status of salmon in the Columbia River basin.

Hatcheries are still a major part of the restoration program and they make a significant contribution to the remnant runs of salmon into the river. Today, about 80 percent of the adult salmon and steelhead entering the Columbia River were hatched and reared in a hatchery (NPPC

1992a). Between 1981 and 1991, hatcheries consumed 40 percent of the $1.3 billion spent on salmon restoration in the basin. Furthermore, about 50 percent of the increase in salmon production predicted to result from the Council's program is expected to come from artificially propagated fish (RASP (Regional Assessment of Supplementation Project) 1992; NPPC 1994a) and much of this through supplementation projects. Hatcheries have had a strong influence on the past attempts to rehabilitate depleted salmon stocks in the Columbia Basin, and the salmon management institutions continue to expect major contributions from hatcheries in the future. However, the National Fish Hatchery Review Panel, solicited by the U.S. Fish and Wildlife Service to provide outside objective evaluation of the federal fish hatchery program, the National Research Council, and the Council's Scientific Review Team have recently called for significant changes in the approach, operation and expectations from artificial propagation (National Fish Hatchery Review Panel 1994; National Research Council (NRC) 1996; Scientific Review Team 1999). The National Fish Hatchery Review Panel report provides detailed recommendations that would integrate the federal hatchery system into a support role for ecosystem management, including restoration of ESA stocks.

Whether the region's management institutions are willing or able to act on those recommendations is a major uncertainty. Because of the dominant role hatcheries have, and may still play, the review of science in the current fish and wildlife program requires an understanding of the positive and negative contribution of artificial propagation to the status of Pacific salmon in the basin. The purpose of this report is to provide a part of that understanding.

In the section below, we first describe the history and development of the hatchery program and second describe the impacts of hatcheries on salmon in the Columbia Basin. It is generally recognized that the early hatcheries made little or no contribution to salmon production in the basin, so prior to 1930, we emphasize the way hatcheries influenced management policy. After 1930, with the help of a strong emphasis on science, hatcheries slowly improved and began making significant contributions to the fisheries especially after 1960. We describe hatchery evaluations carried out after 1930 and the emergence of new objectives for the use of artificially propagated fish. The final section describes the positive and negative effects of hatcheries on Pacific salmon in the Columbia River.

## Hatcheries in the Columbia Basin Before 1930

In 1877, in response to a perceived decline of the spring run of chinook salmon, and to avoid proposed restrictions in the fishery, Livingston Stone was sent to the Columbia River to help the Oregon and Washington Fish Propagating Company (OWFPC) build and operate a hatchery (Stone 1879; Hayden 1930). A site on the Clackamas River was selected and the hatchery buildings and a rack across the river were constructed. OWFPC closed the hatchery five years later in 1882. In 1888, it was reopened and taken over by the state of Oregon (Cobb 1930). After 1888, there would never be another year in which the reproduction of salmon in the Columbia Basin was entirely natural. By 1928, 15 hatcheries were operating in the basin and a total of 2 billion artificially propagated fry and fingerlings had been released into the river (Figure 8.1).

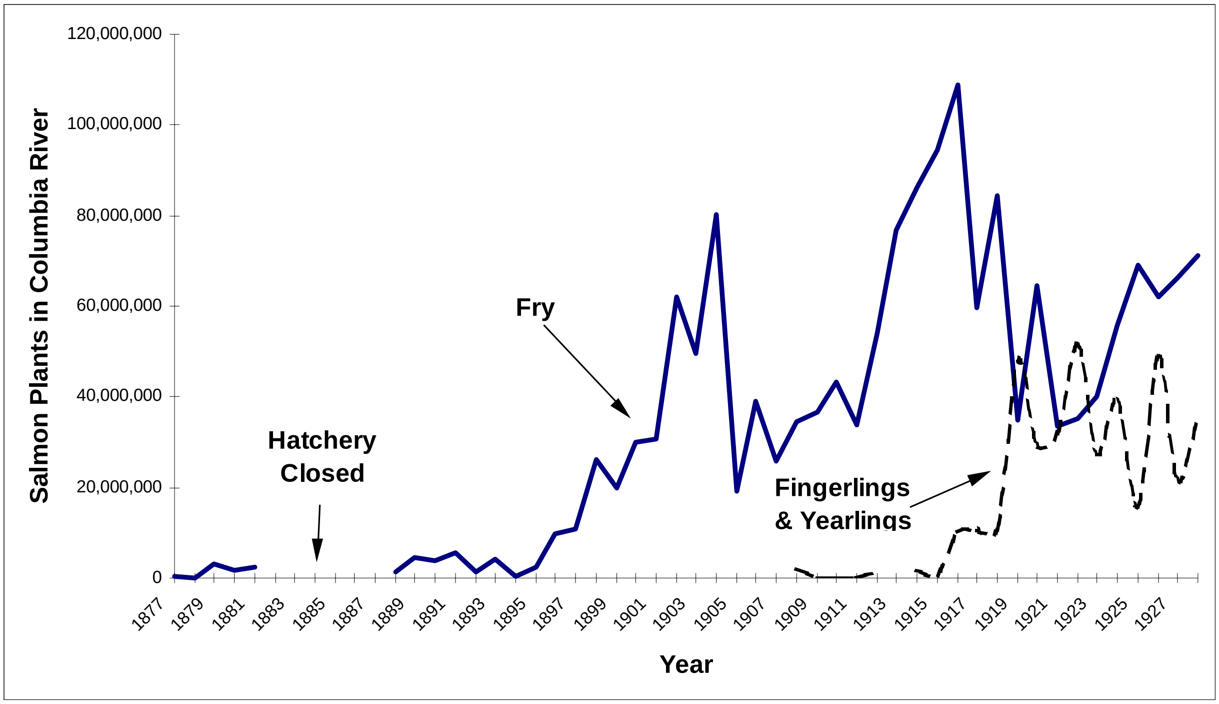


**Figure 8.1**. Hatchery production of all salmon species in the Columbia River (1877 – 1928) as the annual numbers of fry, fingerlings, and yearlings released into the river (Cobb 1930).

Because chinook salmon, especially the spring and summer races, made the highest quality canned product and brought the highest prices, fishermen targeted that species in the early fishery (Craig and Hacker 1940). The early hatchery program also focused exclusively on the chinook salmon (Figure 8.2); however, when the abundance and harvest of chinook salmon began to decline, the fishery switched to other species and the hatcheries followed. Coho salmon and steelhead were propagated in hatcheries beginning about 1900; chum and sockeye salmon were taken into the hatchery program about a decade later (Cobb 1930).

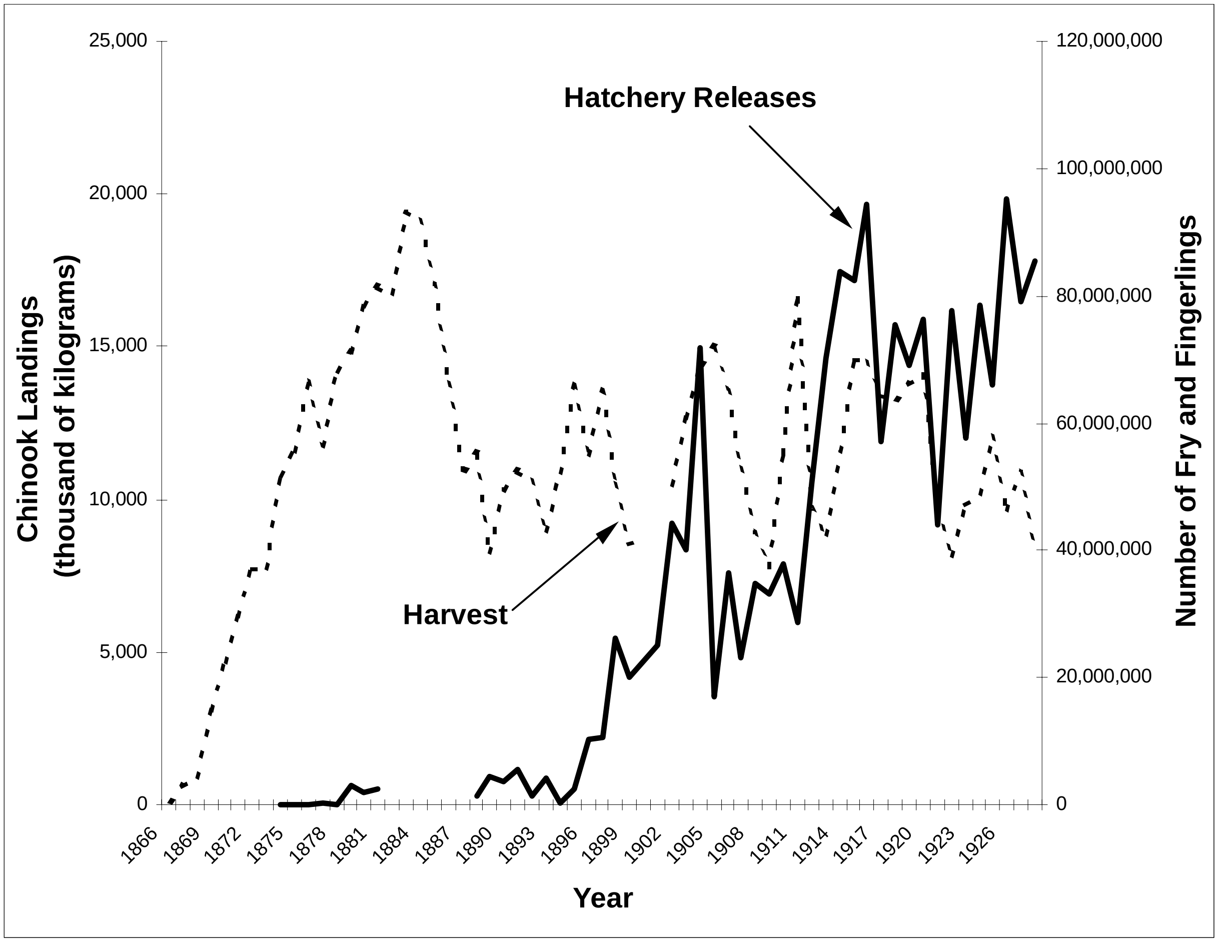


**Figure 8.2**. Harvest and hatchery production of chinook salmon in the Columbia River (1866 – 1928) as the annual numbers of fry, fingerlings, and yearlings released into the river (Cobb 1930; Beiningen 1976).

*Objectives*

The objectives of early fish culture efforts were entirely utilitarian: i.e., to gain control over the production of salmon (Goode 1884) and maintain a supply of fish for the salmon industry in the face of intensive harvest (Oregon Board of Fish Commissioners 1888). The salmon industry supported hatcheries as an alternative to other forms of conservation such as a restriction in the harvest (DeLoach 1939). Additionally, the policies governing the early hatchery program reflect overly optimistic expectations of mangers and their belief that artificial propagation was more efficient than natural production.

*Assumptions*

Salmon managers believed natural reproduction was inherently inefficient and wasteful. It was subject to major, uncontrolled sources of mortality, which could be reduced or eliminated through artificial spawning and incubation in a protected environment (Foerster 1936; Hedgepeth 1941). These assumptions are reflected in the hatchery policy of the U. S. Fish Commission, which was to make:

> *". . . fish so abundant that they can be caught without restriction, and serve as cheap food for the people at large, rather than to expend a much larger amount in preventing the people from catching the few that still remain after generations of improvidence."* (Goode 1884, p. 1157)

The belief that protection of incubating eggs in hatcheries would make salmon so abundant that regulations would be unnecessary suggests that carrying capacity or density dependent limits to production were not considered. However, by 1894, after 22 years experience with artificial propagation and few tangible results, the U. S. Fish Commission reduced its expectations for artificial propagation. Marshall McDonald, who succeeded Spencer Baird stated,

> *". . . we have relied too exclusively upon artificial propagation as a sole and adequate means for maintenance of our fisheries. The artificial impregnation and hatching of fish ova and the planting of fry have been conducted on a stupendous scale. We have been disposed to measure results by quantity rather than quality, to estimate our triumphs by volume rather than potentiality. We have paid too little attention to the necessary conditions to be fulfilled in order to give the largest return for a given expenditure of effort and money."* (McDonald 1894, p. 15).

McDonald raised several questions regarding the use of hatcheries including three important points that are still valid today:

1) a <u>warning</u> regarding an over dependence on hatchery production as a substitute for stewardship;
2) a <u>criticism</u> of evaluations based on the quantity of juveniles released rather than the quality of the adult populations; and
3) a <u>recommendation</u> for the need to evaluate the quality of the receiving waters in watersheds to be stocked with hatchery fish.

However, McDonald's reservations did not diminish the enthusiasm for artificial propagation.

The first hatcheries in the Columbia Basin were built less than 20 years after Darwin (1859) published his evolutionary theories. Concepts such as reproductive isolation, natural selection, and local adaptation had not yet become a part of science. Salmon from different rivers were believed to be genetically similar (Ricker 1972) and therefore interchangeable, consequently mass transfers of fish among streams were common. For example, when Bonneville Hatchery was constructed in 1909, one of its chief purposes was to serve as a central clearinghouse for the distribution of salmon eggs throughout the region (Figure 8.3). Eggs were brought into Bonneville Hatchery from distant rivers and hatcheries, held to the eyed-stage, then either the fry were released from Bonneville Hatchery into the Columbia River or the eyed eggs were shipped to hatcheries on other rivers. The source stream and the ultimate destination of a group of eggs were rarely the same.

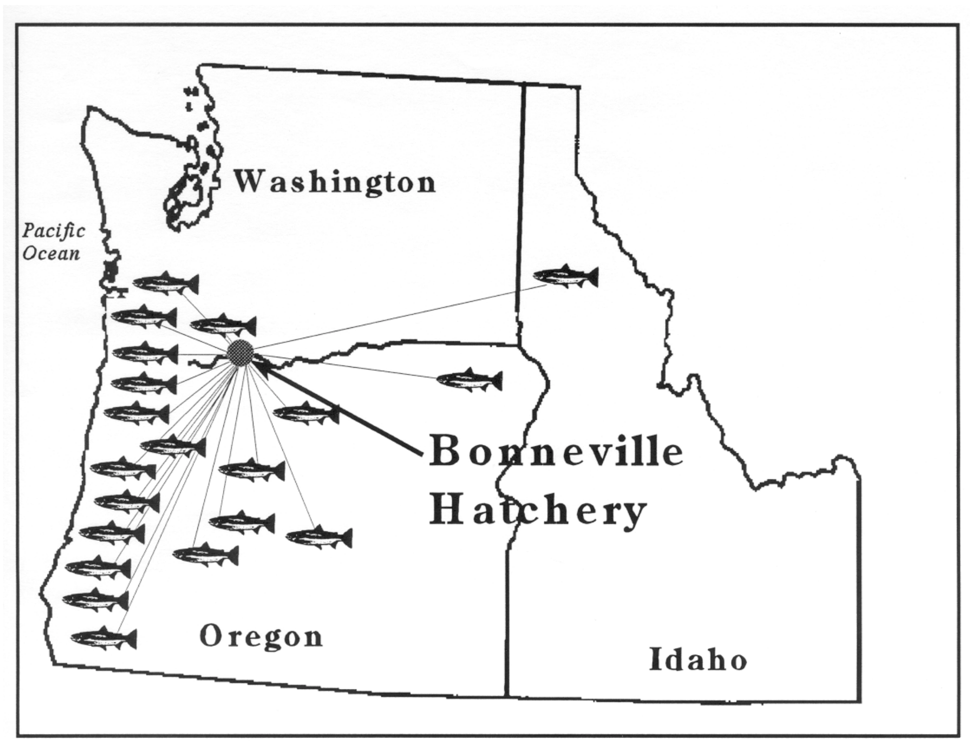


**Figure 8.3**. Transfers of salmon from Bonneville Hatchery in Washington, Oregon, and Idaho from 1909 to 1950. Each line can represent multiple plants (Wallis 1964).

*Evaluations*

During the first 80 years that hatcheries were operated in the Columbia River, scientifically-based evaluations of them did not occur. Claims of success for the hatchery program were based on short-term correlations; evidence that was weak at best, or on no evidence at all. The early history of the hatchery program is marked by extravagant and undocumented claims of hatchery effectiveness. For example, in 1883, George Brown Goode of the U.S. Fish Commission told the International Fisheries Exhibition in London, England that the Pacific salmon fisheries in the Sacramento and Columbia rivers were under the complete control of fish culture (Maitland 1884). When Goode made that claim, the only hatchery on the Columbia River had been closed for two years (Cobb 1930).

Early experiments, based on returns of fin-clipped hatchery fish, were poorly designed and executed and did little more than confirm that some of the fish reared at hatcheries returned as adults (Washington Department of Fisheries and Game 1904). Declining or fluctuating catches in spite of an increasing number of fry released from hatcheries (Figure 8.3), discouraged fishery managers (Oregon Department of Fisheries 1908) and led in 1911, to an experimental change in the hatchery program. The common practice at the time was to release the salmon shortly after hatching and before they started to feed. In the experiment, hatcheries reared small lots of juvenile salmon for several months and released them at larger sizes. The catch increased in 1914, the year managers expected the first returns from their experiment. After five successive years of improved catches in the Columbia River, the Oregon Fish and Game Commission announced the success of their experiments:

> *"...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 but that the annual pack can in time be built up to greater numbers than ever before known in the history of the industry..."* (Oregon Fish and Game Commission 1919).

At the same time, the State of Washington claimed that the increase in harvest in 1914 was due to an increase in production from their hatcheries (Washington Department of Fish and Game 1917). Subsequent review indicated that the claims of hatchery success were premature and the increased catch was not caused by the new methodology (Johnson 1984) and probably had little to do with artificial propagation in Oregon or Washington. Instead, the increase in harvest from 1914 to 1920 was consistent with the pattern of variation in harvest for the previous 20 years (Figure 8.4) and probably resulted from favorable environmental conditions. For example, the 1914 chinook salmon run into the Umatilla River, which had no hatchery, also increased dramatically (Van Cleve and Ting 1960), supporting the suggestion that the increase in harvest was a response to natural climatic fluctuations.

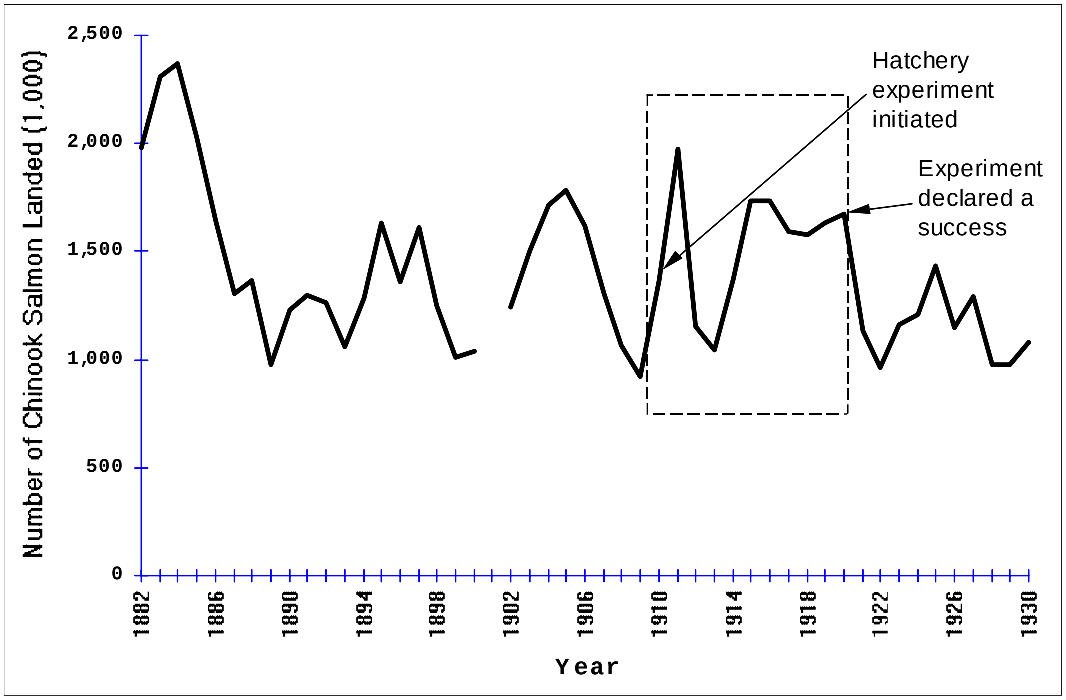


**Figure 8.4**. The number of chinook salmon landed in the Columbia River (1882 – 1930). The data inside the box are discussed in the text.

In 1914, Willis Rich initiated studies of the life history of chinook salmon which had two practical purposes: 1) to determine the value of hatchery work; and 2) to understand the differences in early life history between spring and fall chinook (Rich 1920). The latter was important because the spring chinook were more valuable commercially and their increase through artificial propagation was an important objective of the industry. Rich (1920) initiated several marking experiments at hatcheries in the basin to test the efficiency of hatchery practices and to test the homing ability of chinook salmon. He also examined scale patterns from collections of juvenile wild salmon captured throughout the lower Columbia River. The marking experiments also allowed him to verify his interpretation of scale patterns on unmarked salmon (Rich and Holmes 1929). Rich's marking experiments were a major improvement over earlier "evaluations," but they did not come close to the standards of experimental design used in later evaluations, e.g. (Wahle et al. 1974; 1978). At the time of Rich's experiments, the institutional infrastructure needed to coordinate coastwide recovery of marked salmon did not exist.

Based on his observations on the timing of the migration of juvenile chinook salmon, Rich (1920) concluded that the release of sack fry should be terminated. He recommended that fry be held in the hatchery and released during the natural migration. He also recommended that juveniles be allowed to migrate out of the hatchery ponds on their own volition. One of the more important contributions from Rich's studies was the acquisition of data, which later contributed to his synthesis paper on the importance of stocks or local breeding groups to the maintenance of productive salmon fisheries (Rich 1939).

None of the early studies attempted to evaluate the relative contribution of artificially and naturally propagated salmon; i.e., to answer the question: Are hatcheries making a significant contribution to the adult returns to the river?

Nationally, by the 1920s, biologists were beginning to question the efficacy of fish culture during its first 50 years and as a result hatchery programs came under increasing criticism (Wood 1953). The first scientific evaluations of hatchery programs reinforced the growing skepticism. Studies involving yellow-pike perch in lakes Huron and Michigan (Hile 1936), whitefish in Lake Erie (Van Oosten 1942), and Atlantic salmon in the Penobscot River, Maine from 1872 to 1939 (Rounsefell 1947) concluded that artificial propagation was not significantly more efficient than natural production and in the case of the Atlantic Salmon, that hatcheries were not able to prevent a decline in abundance. The lack of rigorous, scientific evaluation of the hatchery programs for Pacific salmon led Cobb (1930) to conclude that artificial propagation was a threat to the continued existence of the Pacific salmon fishery. Cobb was not opposed to artificial propagation, but he believed that managers had to put aside their optimism and stop relying on hatcheries alone to increase or maintain the fishery.

*Results*

With all the clarity of hindsight, it is now generally recognized that the early hatchery programs had little positive impact on the abundance of salmon in the Columbia River (Columbia Basin Fish and Wildlife Authority 1990). Nevertheless, it is impossible to estimate the impacts of massive stock transfers, stream racking, and the overall mining of eggs from productive, wild populations of salmon, although they may have been considerable.

Perhaps the greatest impact of the early hatchery program was its influence on fisheries management philosophy and direction. As suggested in the U. S. Fish Commission's hatchery policy, fish culture was viewed as an alternative to other forms of management, such as harvest regulation or habitat conservation. In addition, hatcheries were also viewed as a means of compensating for production lost through habitat degradation (Lichatowich and Nicholas In press). If hatcheries could compensate for lost and degraded habitat, managers could afford to give habitat protection and restoration a lower priority, which they did. By 1932, 50 percent of the best spawning and rearing habitat in the Columbia Basin had been lost or severely degraded

(Oregon Fish Commission 1933). This loss and the loss of habitat that continued after 1930 is in part, the legacy of over optimism regarding the effectiveness of artificial propagation.

That this philosophy has continued to the present is clearly shown in the distribution of expenditures for salmon protection in the Columbia River prior to 1980. Less the 1 percent of the funds were spent on habitat, whereas 43 percent of the expenditures went to the hatchery program (General Accounting Office 1992). In recent years, the situation has improved, but expenditures on habitat are still only 6 percent of the total; hatchery expenditures are 40 percent of total (General Accounting Office 1993).

Artificial propagation not only influenced attitudes towards habitat protection, but the overly optimistic expectations and a tradition of inadequate evaluation has extended to the present. Recently, several key studies and reviews have addressed critical aspects of artificial production (Integrated Hatchery Operations Team 1994; Watson 1996; Northwest Power Planning Council 1998; Scientific Review Team 1999). However, these analyses were unable to reach a bottom-line evaluation (i.e., egg to adult survival rates, as well as costs) due to inadequacies in the available databases. Thus, in spite of these new and more sharply focused review efforts, after 120 years in which hatcheries have been a primary management tool in the basin, there has never been a comprehensive evaluation of the program.

## Hatcheries in the Columbia Basin After 1930

Declining harvests and the failure of the hatchery programs to prevent depletion eventually convinced salmon managers that artificial propagation needed a scientific approach. However, such an approach required the assistance of biologists, basic research, and stream survey information. But in the early decades of this century, state fish commissions, which had been dominated by fish culturists, often did not trust or hire biologists (Moore 1925). The growing criticism of the hatchery programs and the call for the development of a scientific approach to propagation, e.g., (Culler 1932; Huntsman 1937; Needham 1939) eventually led the Fish Culture Division of the American Fisheries Society (AFS), to question the ability of hatcheries to perform the tasks that had been assigned to them (Gottschalk 1942). It was becoming clear that artificial propagation had to be based on science, rather than blind optimism.

### *Objectives*

Nevertheless, the objectives of the hatchery program after 1930 remained utilitarian: i.e., to augment declining natural production of salmon and steelhead and maintain a supply of salmon for the fishing industry in the face of intensive harvest. Managers remained overly optimistic about their expectations and predictions for the success of hatcheries and those in the

United States did little to rigorously evaluate the efficacy of hatcheries themselves or of the overall hatchery program.

*Assumptions*

Scientific management emphasized the principle of supply and demand, which is best exemplified in the catchable trout program (Bottom 1997). Catchable sized trout are delivered to the stream in the right quantity to meet the demand. The catchable trout program counted on little or no long-term survival of the planted fish. Therefore, the stream, its habitat, carrying capacity and food gradients were not important considerations (Wood 1953). The shift to smolt releases in anadromous salmonids can be considered the equivalent to the catchable trout program. As hatchery programs shifted to smolt releases, it diminished the importance of the stream as an integrated ecosystem. The rivers became merely channels to transport smolts to sea (Ortmann et al. 1976).

Salmon managers generally remained convinced that artificial propagation could compensate for the basinwide destruction of habitat in the Columbia River watershed (Schwiebert 1977). Managers predicted that genetic selection in the hatchery program would produce strains of steelhead suited to the changing environment of the Columbia River (Ayerst 1977). Through a combination of hatcheries and other technology such as transportation and spillway deflectors salmon and steelhead populations would be restored in a few years and ultimately; in the Snake River, would return in numbers greater than existed before (Ebel 1977).

Eighteen years later, chinook salmon, sockeye salmon, and steelhead trout from the Snake River are on the Endangered Species List. The National Fish Hatchery Review Panel and the National Research Council (NRC) concluded a major revision in the role and objectives of artificial propagation is necessary (National Fish Hatchery Review Panel 1994; National Research Council (NRC) 1996). In general, the reviews recommended that hatchery programs become integrated into comprehensive ecosystem restoration plans and work toward conservation objectives, rather than focusing on the production of fish for harvest (Flagg et al. 1995b).

*Evaluation*

In 1922, the British Columbia Fisheries Commission was concerned about the lack of any positive results from its hatchery program for sockeye salmon, so it recommended an evaluation be carried out. The Commission stipulated that the study be carried out under competent scientific supervision and R. E. Forester was assigned the task. The question to be addressed by the study was also a departure from the norm. The study was designed to not only evaluate the number of juveniles released from the hatchery and the number of adults returned; it would evaluate the benefits of artificial propagation by comparing the difference in contribution from natural and artificial propagation in a controlled system where both could be monitored (Foerster 1936). The study was carried out at the Cultus Lake sockeye salmon hatchery in the Fraser River.

The study monitored the contribution of natural and artificial propagation for 10 years. No significant difference in the efficiency of natural and artificial propagation was found. Because the hatchery could incubate only a small fraction of the eggs in the spawning population, the small incremental increase in adult returns produced by artificial propagation was not worth the expense of the hatchery. Based on this study, British Columbia closed all its sockeye salmon hatcheries (Foerster 1936). Foerster not only conducted one of the earliest scientific evaluations of a hatchery program for Pacific salmon, but he tested the fundamental assumption underlying all salmon hatcheries (artificial propagation was more efficient than natural reproduction) and found it to be false at least as far as sockeye salmon was concerned. However, Foerster's study only evaluated the difference in survival between natural and artificial propagation of sockeye salmon when the hatchery fish were planted into Cultus Lake or its tributaries as fry or eyed eggs (Foerster 1936).

In 1934, shortly before Foerster completed his study, Salo and Bayliff (1958) started an evaluation of natural and artificial propagation in Minter Creek, a small stream in Puget Sound. They compared the relative survival and contribution of wild and artificially propagated coho salmon, which were reared for extended periods before release, rather than the fry that Foerster used in the Cultus Lake study. At the time Salo and Bayliff's study was initiated, most hatcheries released fry with little or no feeding, conditions that were similar to those evaluated in Foerster's study. However, hatcheries were gradually shifting from fry releases to extended rearing on the assumption that larger, older fish would survive better after release from the hatchery. Like Foerster's study, the Minter Creek evaluation was carried out for several years. The findings, however, differed from Foerster's.

Salo and Bayliff (1958) reported that coho salmon reared in the hatchery for extended periods of 6 to 12 months produced greater adult returns than coho juveniles from an equivalent number of wild spawners. The Minter Creek study showed that under the right hatchery practices, artificial propagation could be more efficient than natural production and artificially propagated salmon could significantly increase adult production in small populations. However, in the 1940s and 1950s, extended rearing presented hatchery managers with a new set of problems for which they had no clear solutions. Extended rearing required improved disease prevention and treatment and the development of nutritious feeds.

By the 1940s, individual hatcheries were fin-clipping juvenile salmon in order to evaluate returns to the hatchery from routine production or to evaluate experimental hatchery practices.

Often the experiments had too few recoveries to be conclusive. The results of many of those studies are summarized by Wallis (1964).

Extended rearing in the hatcheries prompted research into the nutritional requirements of juvenile salmon and the prevention and treatment of diseases. By the mid-1960s, the development of new feeds, better prevention and treatment of diseases, and improved hatchery practices such as the optimal size and time of release started to produce tangible results (Lichatowich and Nicholas In press). Artificially propagated salmon began making significant contributions to the fishery, however, that success created another set of ecological, genetic, and management problems which are discussed later in this report.

Beginning in the 1960s, the National Marine Fisheries Service (NMFS) conducted a series of large-scale evaluations of the contribution of chinook and coho salmon from Columbia River hatcheries to various fisheries in the Northeast Pacific. The 1961 through 1964 broods of juvenile fall chinook from 13 hatcheries in the Columbia Basin were given special marks (fin clips) before release so their contribution to the sport and commercial fisheries could be estimated. The evaluation was stimulated by a moratorium on new hatchery production until it could be demonstrated that such construction was economically justified (Wahle and Vreeland 1978). Results of the evaluation were positive. The benefit cost ratio for all hatcheries combined for each of the brood years was 1961, 3.7:1; 1962, 2.0:1; 1963 7.2:1; and 1964, 3.8:1. The potential catch per 1,000 fish released was 1961, 6.7; 1962, 3.1; 1963, 10.0; and 1964, 6.5. Average survival for all hatcheries combined was 0.7 percent. Overall, an estimated 14 percent of the fall chinook salmon caught in the sport and commercial fisheries from southeast Alaska to northern California originated from the Columbia River hatcheries (Wahle and Vreeland 1978).

The NMFS repeated the fall chinook evaluation with the 1978 to the 1982 broods. Total survival for all four brood years and all facilities was 0.33 percent or about half the survival of the earlier study, however the benefit-cost ratio was still positive at 5.7:1. The overall contribution to the fishery was 1.9 adults for each 1,000 juveniles released (Vreeland 1989). The NMFS used a similar approach to evaluate the contribution made to the west coast fisheries by the 1965 and 1966 broods of coho salmon. Juvenile coho salmon from 20 hatcheries in the Columbia Basin were marked for the study. Recoveries were monitored from British Columbia to California. Coho salmon from Columbia River Hatcheries made up about 16 percent of the total catch in the sampling area. The catch from both brood years combined was 55 adults for each 1,000 smolts released for a benefit cost ratio of 7.0:1 (Wahle et al. 1974). These results prompted additional investment in artificial production programs.

*Results*

A complete evaluation of a hatchery or group of salmon hatcheries should address three basic questions:

1) Do the salmon and steelhead of hatchery origin contribute to the fisheries and/or escapement and is the economic value of that contribution greater than the cost to produce it?
2) Is the level of contribution consistent with its purpose or objective of the hatchery? For example, if a hatchery is intended to replace natural production lost due to habitat degradation, this question asks did the hatchery, in fact, replace the lost production?
3) Do artificially propagated fish add to existing natural production or do they replace it, i.e., Does the hatchery operation generate a cost to natural production through mixed stock fisheries, domestication and genetic introgression?

The NMFS evaluations were well designed and executed, but they only addressed the first question. That was a serious omission. From a historical perspective, it is clear that artificial propagation has failed to replace natural production lost due to habitat degradation. In addition, hatcheries have caused direct and indirect costs to the existing natural production (Flagg et al. 1995a; Utter et al. 1995).

Coho smolts released from Columbia River hatcheries achieved high levels of survival in the late 1960s and early 1970s. Although some biologists recognized that favorable ocean conditions contributed to improved production, managers largely credited hatcheries for the improved harvests which "*...while most encouraging, was not unplanned, nor unexpected*" (Oregon Fish Commission (OFC) 1964).

Columbia River coho salmon are a major contributor to the Oregon Production Index (OPI), which is a measure of the abundance of coho salmon south of Illwaco, Washington (Oregon Department of Fish and Wildlife 1982). The hatchery and wild stocks of coho salmon from the Columbia River are managed as part of the (OPI). The history of ocean harvest of coho salmon in the OPI illustrates the need for more comprehensive evaluations of hatchery programs. It's now understood that the pattern of production with lows from the 1930s to the 1950s, followed by a period of high production in the 1960s and 1970s and another trough in the 1980s and 1990s (Figure 8.5 and 8.6), largely reflects the response to changing ocean conditions and climate patterns, rather than only to the release of hatchery reared coho (Nickelson 1986; Lichatowich 1996).

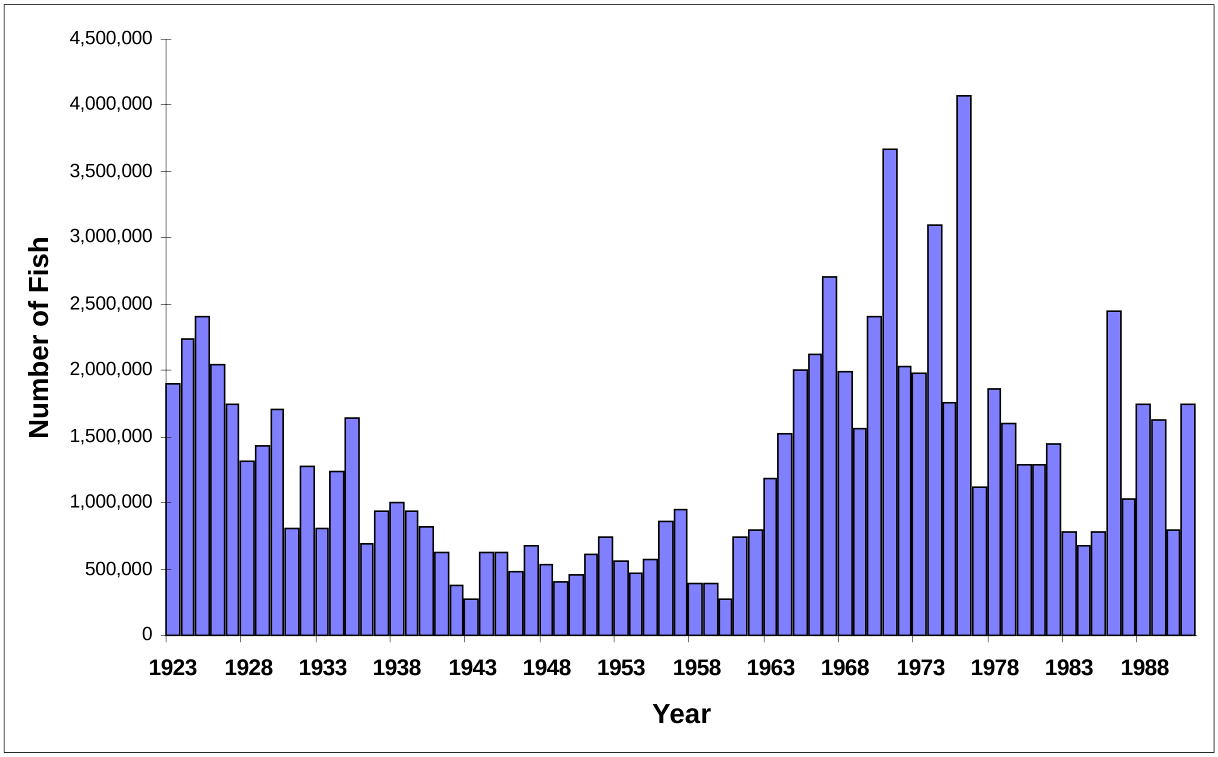


**Figure 8.5**. Harvest of coho salmon in the Oregon Production Index (OPI). (Sources: 1923-1970 from unpublished ODFW data; 1971 – 1991, Pacific Fisheries Management Council 1992).

Prior to 1960, most of the coho salmon harvested in the OPI were naturally produced (Oregon Department of Fish and Wildlife 1982). After 1960, artificially propagated salmon made up an increasing proportion of the catch. Unfortunately, the contribution of hatchery and wild coho salmon to the OPI ocean harvest was monitored in only eleven of the years between 1960 and 1992 (Figure 8.6). What appears to be a recovery in the 1960s and 1970s was dominated by artificially propagated coho salmon. Wild fish showed little sign of recovery. Harvest targeted on the dominant hatchery component of the OPI had significant impact on the natural production of Oregon's coastal and lower Columbia River coho stocks. The mixed stock (hatchery plus wild) fishery in the OPI has consistently over-harvested the wild coastal stocks of coho salmon. Of 55 coastal stocks of coho identified by ODFW, 41 were classified as depressed (Nickelson et al. 1992) and between 1981 and 1991, escapement goals were met in only 3 of the 11 years (Pacific Fishery Management Council 1992).

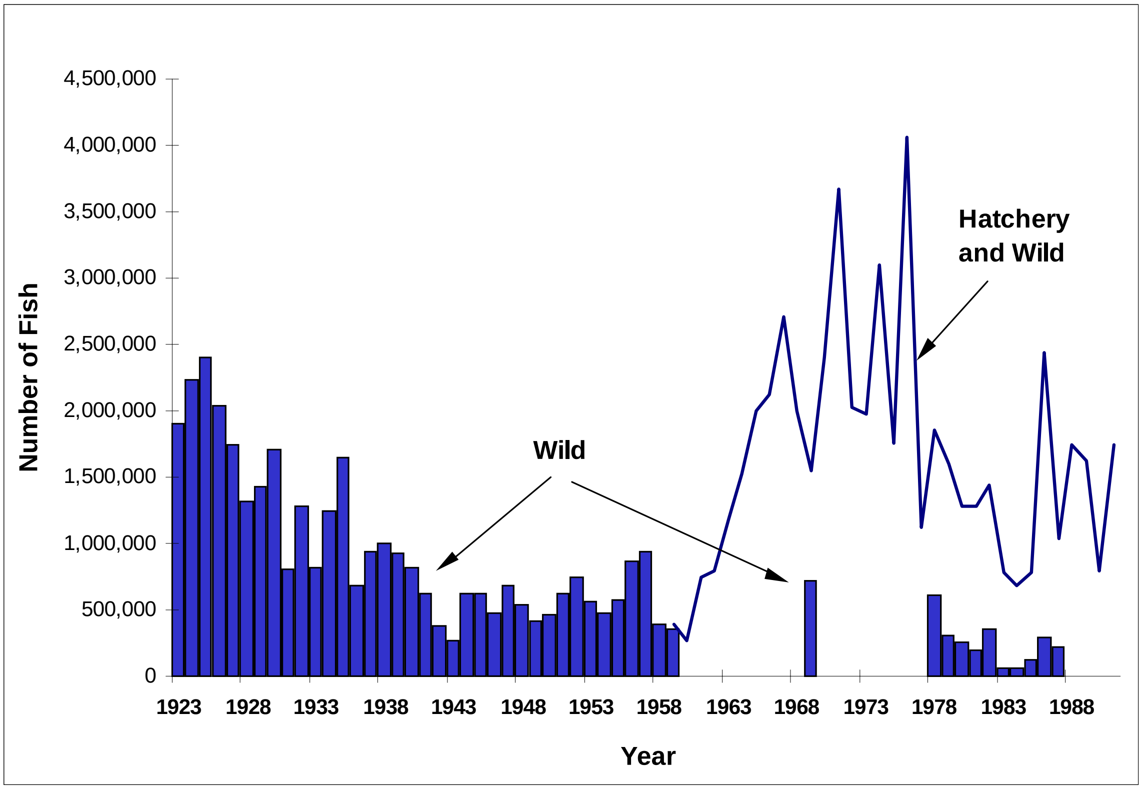


**Figure 8.6**. Harvest of coho salmon in the Oregon Production Index partitioned into wild and hatchery fish. Solid bars are catch of wild coho salmon. All coho salmon are assumed to be wild before 1960. (Source: 1923-1970 unpublished data from ODFW ; 1971-1991 Pacific Fishery Management Council (1992); Wild harvest 1959, 1969, ODFW 1982; 1978-87, Borgerson, ODFW (December 1992)--figure taken from Lichatowich ***in press***).

Wild coho salmon from the lower Columbia River, which were also part of the OPI, are largely extinct, although remnant populations may still exist in the Clackamas, Hood, and Klickitat rivers. High harvest rates on the mixed hatchery and wild stocks, which often exceeded 90 percent, were exacerbated by hatchery practices. Flagg et al. (1995b) identified the following hatchery practices that contributed to the decline and extirpation of coho salmon in the lower Columbia River:

1) Selection for early spawners.
2) Fry stocking that exceeded carrying capacity.
3) Planting fry that were larger than their wild counterparts.
4) Inter-hatchery stock transfers.

## Influence on management of Columbia River salmonids

In 1930, John Cobb, Dean of the College of Fisheries at the University of Washington, listed artificial propagation as one of the threats to the fishing industry for Pacific salmon.

> "*In some sections an almost idolatrous faith in the efficacy of artificial culture of fish for replenishing the ravages of man and animals is manifested, and nothing has done more harm than the prevalence of such an idea. While it is an exceedingly difficult thing to prove, the consensus of opinion is that artificial culture does considerable good, yet the very fact that this can not be conclusively proved ought to be a warning to all concerned not to put blind faith in it alone*." (Cobb 1930, p 493).

Artificial propagation of salmon was established in the Columbia Basin before state management institutions were created or before the U. S. Fish Commission established a permanent presence in the Pacific Northwest. In the decades after the management institutions were created, their mission was primarily to build and operate hatcheries. The way in which institutional budgets were expended confirms the priority and emphasis that was given to artificial propagation. In 1922, 76 percent of the Oregon Fish Commission's budget was expended on artificial propagation (Shoemaker and Clanton 1923). In the Columbia River, since the development of the hydroelectric system, artificial propagation has consumed the largest share of the budget (Figure 8.7). Prior to 1980, habitat received less than one percent of the funding; after 1981 habitat received about 6 percent. These figures reflect a national trend. From 1989 to 1993, the average expenditures of Federal Aid in Sportfish Restoration Program funds in 36 states included 42 percent to hatchery-related projects while only one percent of the funds went to habitat-related projects (McGurrin et al. 1995).

Perhaps the most important legacy of the hatchery program throughout its 120 history has been its influence on management, rather than any direct contribution to the various fisheries. Belief in the success of artificial propagation, which was largely unsubstantiated prior to 1960, made compromise leading to habitat destruction and over-harvest easier to accept (Hilborn 1992; Lichatowich 1999; Lichatowich and Nicholas In press).

Salmon populations throughout the northwest, similar to the one that persists in the Hanford Reach, were destroyed in part by faith that hatchery technology would maintain production. Hatcheries have influenced management in two important ways: First, in the late 1800's and through to the 1970's, management institutions were willing to trade habitat for hatchery programs. The result was a massive shrinkage in the natural production base and a dependence on a large, expensive hatchery program which could only maintain salmon and steelhead at a fraction of their historical abundance. Second, management agencies are now forced to provide major emphasis and allocate resources to the restoration of those degraded habitats in an attempt to enhance the depleted base of natural production.

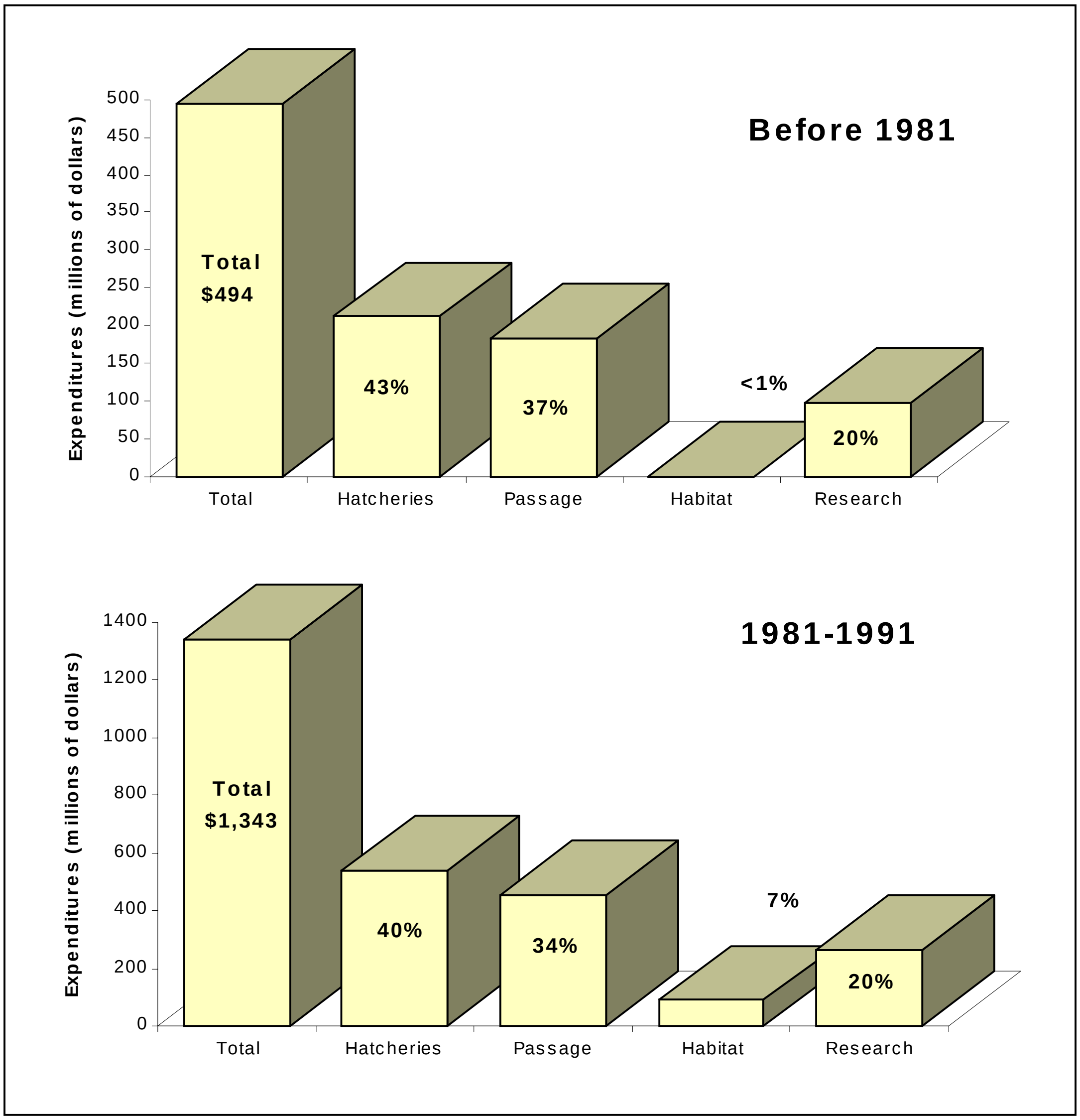


**Figure 8.7**. Distribution of expenditures for salmon restoration in the Columbia River prior to 1981 and from 1981-1991 (Source: General Accounting Office 1992).

For the past two decades, salmon management has been changing. From a program almost entirely devoted to hatchery production and harvest regulation, management is shifting toward a greater concern for natural production. In recent years, the states of Oregon and Washington have conducted extensive surveys of the status of naturally reproducing stocks of salmon and steelhead (Washington Department of Fisheries et al. 1993; Kostow 1995). Hatchery programs are being designed to minimize their impact on natural production and new programs are subject to extensive monitoring (Bowles and Leitzinger 1991; Messmer et al. 1992). Harvests are severely restricted to protect weak natural stocks and biologists are recommending that hatchery programs be revised to include conservation objectives, instead of merely supplying fish for harvest (Flagg et al. 1995a; Flagg et al. 1995b). Which direction an emerging new role for artificial propagation will take is hard to predict, however biologist Gary Meffe has outlined one approach that has merit:

> *"... a management strategy that has as a centerpiece artificial propagation and restocking of a species that has declined as the result of environmental degradation and over exploitation, without correcting the causes for the decline, is not facing biological reality. Salmonid management based largely on hatchery production, with no overt and large scale ecosystem-level recovery program is doomed to failure. Not only does it fail to address the real causes of salmonid decline, but it may actually exacerbate the problem and accelerate the extinction process."* (Meffe 1992, p 351).

## Biological Effects of Hatcheries

In spite of over a century of reliance on hatchery production to bolster or mitigate natural production, and unheeded cautions about the effects and efficacy of hatchery mitigation (Rich 1939; Schuck 1943; Reisenbichler and McIntyre 1977; Reisenbichler and McIntyre 1986), only recently have fisheries managers begun to seriously investigate the effects that cultured fish can have on natural populations of salmonids (Hindar et al. 1991; Krueger and May 1991; Washington and Koziol 1993; Busack and Currens 1995; Campton 1995; Leary et al. 1995). In part, this effort is fueled by a growing recognition that local salmonid populations (or aggregates of populations; i.e., a metapopulation) are frequently distinct from other conspecific populations (or aggregates) (Allendorf and Utter 1979; Ryman and Utter 1987; Gharrett and Smoker 1993). Past stocking efforts, particularly where non-indigenous stocks were used, have resulted in unanticipated detrimental effects on natural fish populations, rather than bolstering natural production as hoped (Washington and Koziol 1993; Schramm and Mudrak 1994; Utter et al. 1995).

Interactions between hatchery and wild fish can occur directly through interbreeding or indirectly through ecological and behavioral interactions (Waples et al. 1991c) and can alter the genetic architecture of a species (and natural populations) by changing the distribution of genetic variation within and among populations (Allendorf and Leary 1988; Allendorf 1991; Utter et al. 1995). Genetic changes also can occur in hatchery stocks themselves, increasing the likelihood that detrimental consequences will occur when natural stocks experience contact with hatchery stocks (Reisenbichler 1995; Reisenbichler 1997; Reisenbichler and Rubin 1999). Hindar et al. (1991) reviewed and summarized the genetic effects (both direct and indirect) of cultured salmonids on natural salmonid populations and concluded that where genetic effects have been documented, they always appear to be negative in comparison with the unaffected native populations. Hindar et al argued that the one-sidedness of the empirical observations in favor of the greater fitness of local populations resulted from a lack of observations in the opposite direction, rather than from a bias in selecting references.

Campton (1995) presented another perspective on the genetic effects of hatchery fish on wild Pacific salmon populations, in which he notes the genetic effects on wild fish can be attributed to either the direct biological effects of hatcheries and hatchery fish or the indirect – and biologically independent – effects of stock transfers, mixed-stock fisheries on hatchery and wild fish, and other human factors related to management. The latter set of factors relate to hatchery management philosophy and practices; whereas the direct biological effects describes the genetic effects of hatcheries and artificial propagation on hatchery fish, as well as the genetic consequences of hatchery fish interbreeding with wild fish.

### *Direct Genetic Effects*

Direct genetic effects are those that result from hybridization of cultured fish with wild fish. The effects of such interactions are generally negative and usually result in reduced fitness in the wild population, due to the breakup of various coadapted gene complexes that are linked to local adaptation, performance, and fitness in the local population. Progeny of such matings usually suffer increased mortality and lowered reproductive success as compared to progeny of native wild fish (Leary et al. 1995). Numerous studies exist that document losses of within- or among-population genetic variability as a result of genetic interactions between hatchery and wild fish (Allendorf and Ryman 1987; Currens et al. 1990; Hindar et al. 1991; Leary et al. 1995; Williams et al. 1996).

#### Within-Population Variability

Loss of within-population variation is usually linked to small effective population size ($N_e$), where allelic diversity can be lost through drift or sampling error. Generally, wild populations are not effected by this process, unless their numbers reach very low levels (like many of the current Idaho salmon stocks); however, considerable data exist documenting the debilitating effect of small $N_e$ on hatchery populations.

In those few instances where hatchery and wild fish populations are similar genetically and slightly inbred, heterosis, or $F_1$ hybrid vigor may occur. However, as genetic differences between the hatchery and wild stocks increase (usually measured by genetic distance), the more likely it is that outbreeding depression will occur and lead to reduced fitness in the $F_1$ hybrids (Figure 8.8). Recombination in the $F_2$, and subsequent generations, is likely to reduce fitness even further (Emlen 1991; Waples 1991b).

<u>Among-Population Variability.</u>

Reductions in among-population genetic variances can occur where a single broodstock is used over a wide geographic area (Reisenbichler and Phelps 1989), such as occurred with the Carson spring chinook stock and the Skamania steelhead stock, or where substantial numbers of cultured fish have strayed into natural populations, as has occurred for steelhead in the Deschutes River (Chilcote 1998) and for Atlantic salmon in Norwegian rivers due to net pen escapees (Hindar et al. 1991; Gausen 1993; Heggberget et al. 1993). Reductions in reproductive fitness are the most likely result of genetic interactions between hatchery and wild fish (Hindar et al. 1991; Waples 1991b). Such reductions in fitness are due to outbreeding depression (Figure 8.8), where two genetically dissimilar individuals (or stocks) interbreed.

*Indirect Genetic Effects*

Indirect genetic effects result from the ecological and behavioral interactions between wild and hatchery fish that occur without direct genetic exchange. However, the interactions have genetic, and therefore fitness, consequences (Waples 1991b). Any factor that causes a reduction in population size can have an indirect effect on the genetic structure of wild fish populations, as well as increasing the risk of local extinction of that population through stochastic environmental perturbations (Soule 1987; Lande 1988). Factors that can adversely effect population size include: competition; hatchery stocking densities that exceed carrying capacity; increased physiological stress associated with agonistic encounters; predation; disease; harvest of hatchery target (underharvest – increases opportunities for hatchery fish to stray or to breed with wild fish; overharvest – also harvests wild stock and reduces its population size); and altered selection regimes. There is a substantial body of literature, which is not reviewed here, that documents interactions between wild and hatchery fish for these factors, for example, (Fausch 1988), presents a review of competitive interactions between introduced and native fishes in stream systems. Some of these factors can have profound effects on genetic variability and population viability. An extreme example that illustrates the some of the negative consequences that can result from large-scale interactions of hatchery raised fish and wild fish occurred in Norwegian Atlantic salmon populations. Heggberget et al. (1993) note that disease transfer from farmed fish into native fish, after a catastrophic release of net pen fish, led to the complete extirpation of more than 30 native populations. Many of these factors alter the selection regimes faced by populations, which can shift the population's genetic and phenotypic attributes, as well as numerical abundance.

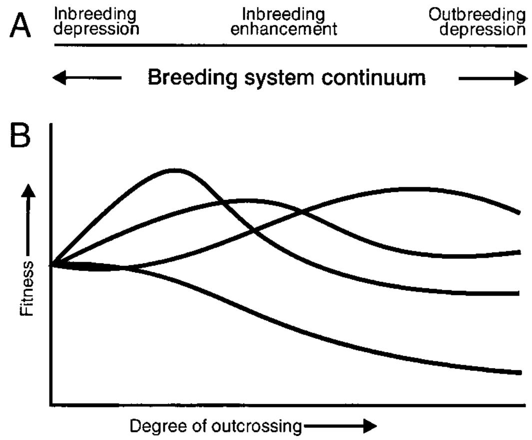


**Figure 8.8**. Breeding systems and genetic effects. (A) A continuum of breeding systems that, at opposite extremes, can lead to inbreeding or outbreeding depressions. (B) Several possible forms of the relationships between fitness and the degree of outcrossing. (Source: Allendorf and Waples 1996).

Directional Selection

Character values, such as run-timing, size at maturity, etc., are typically distributed in normal frequency distributions that are bell-shaped. Directional selection happens when selection occurs for a character value other than the mean (Figure 8.9). A typical example of this type of selection is the effect that fishing pressure (and various types of nets and gear) have in selectively harvesting larger fish, causing the mean or average size of fish in the run to decrease.

Stabilizing Selection

Stabilizing or truncating selection happens when selection occurs specifically for the mean character, which will act to reduce overall variation, i.e., diversity (Figure 8.10). Management actions that focus on mean values may promote selection of this type. An example of this is the reduction observed in the number of wild smolts emigrating during the late summer and fall as management actions have focused on the mean emigration time for all smolts combined (mid-April to mid-June). Smolts emigrating during this time period are favored by circumstances related to human development, while those outmigrating in the early spring or the late summer and fall months appear to have been disadvantaged and in some cases eliminated.

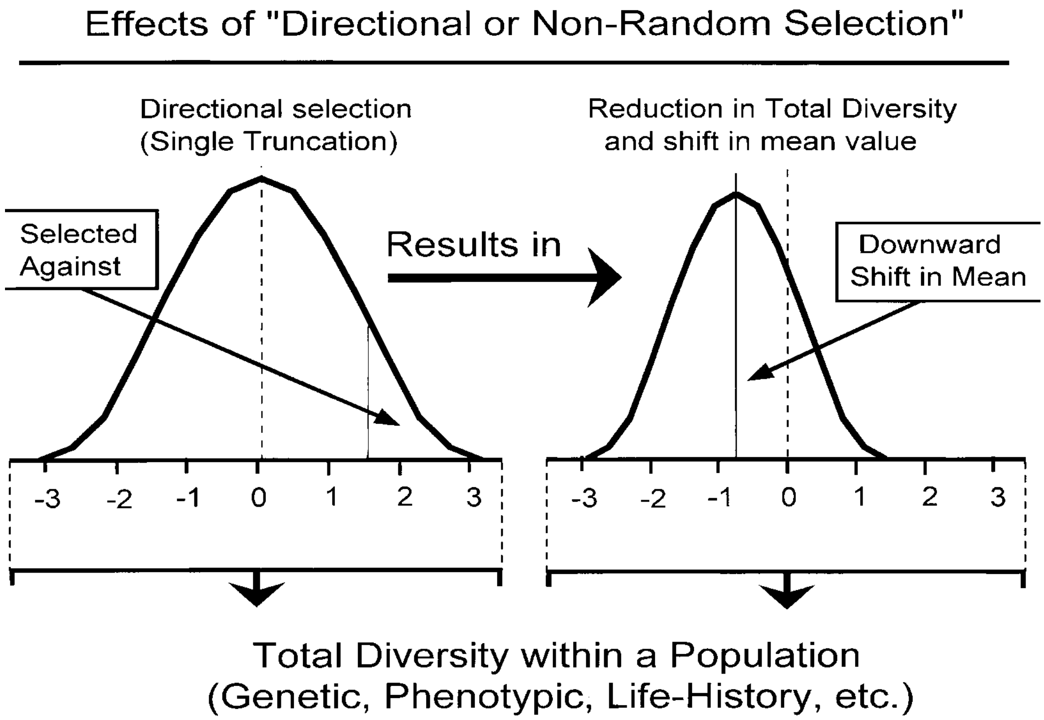


**Figure 8.9**. Directional selection happens when selection occurs for a character value other than the mean. A typical example of this type of selection is the effect that fishing pressure using size selective nets have in selectively harvesting larger fish, causing the mean size of fish in the run to decrease.

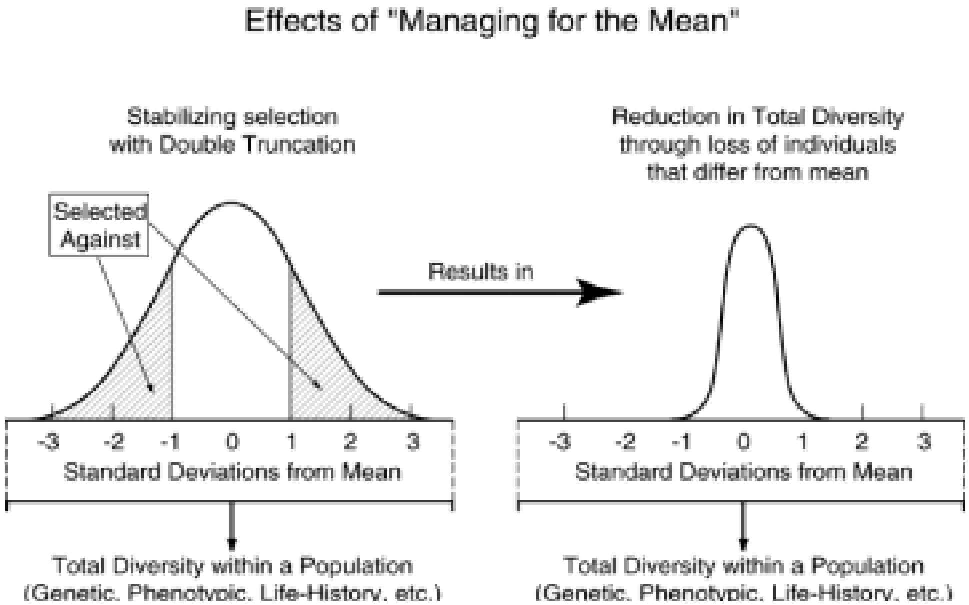


**Figure 8.10**. Stabilizing or truncating selection happens when selection occurs specifically for the mean character, which will act to reduce overall variation.

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*Genetic Changes to Hatchery Stocks*

Genetic changes, and the potential for such changes, have been well documented for hatchery stocks. Reductions in overall levels of genetic variability, usually due to small effective breeding population size associated with hatchery practices, and concomitant reduced fitness attributed to inbreeding depression have been reported in some hatchery stocks (Allendorf and Phelps 1980; Leary et al. 1985; Allendorf and Ryman 1987; Waples and Smouse 1990), but not all hatchery stocks (Utter et al., 1989). Genetic changes in hatchery stocks can also be attributed to artificial selection or domestication selection.

<u>Artificial Selection</u>

Artificial selection is directed or inadvertent selection that can occur in the hatchery environment (Waples 1991b; Reisenbichler 1995). A well-known example of this is the common advancement of time of spawning in hatchery strains of rainbow trout and timing of spawning migrations of Pacific salmon and steelhead trout that occurs from a greater than representative contribution to spawning populations from early maturing fish.

<u>Domestication Selection</u>

Domestication selection is natural selection occurring within the hatchery environment, whereby fish that perform better in the hatchery environment have a selective advantage (Reisenbichler and McIntyre 1977). In general, domestication selection results in increased fitness in the hatchery environment, but decreased fitness under wild conditions (Campton 1995).

*Genetic Changes to Wild Stocks*

Numerous studies have documented direct genetic interactions between wild and hatchery fish (Campton and Johnston 1985; Campton and Utter 1985b; Bartley et al. 1990; Currens et al. 1990; Forbes and Allendorf 1991; Eriksson and Eriksson 1993; Leary et al. 1995; Utter et al. 1995; Williams et al. 1996). Despite a large body of evidence documenting genetic interactions between hatchery and wild salmonids, and correlative observations of declines in abundance of natural salmonids, little empirical evidence exists documenting reductions in fitness in wild populations as a result of genetic interactions with hatchery reared fish, but see Gharrett and Smoker (1991) and Philipp and Clausen (1995). Data on fitness have proven notoriously difficult to collect, nevertheless, there is a substantial body of established theory that is supported widely by emperical observation from other vertebrate species and supported to some extent by observation on salmonids indicating that interbreeding between strains of hatchery fish and wild fish can result in offspring with reduced fitness.

## Recent Uses of Hatcheries

*Mitigation for Hydropower Development*

<u>Grand Coulee Fish Maintenance Project</u>

The first major program designed to compensate for hydroelectric development in the Columbia basin was the Grand Coulee Fish Maintenance Project. With a height of 500 ft, Grand Coulee Dam was too high to successfully pass salmon via a ladder or elevator. Salmon managers considered the construction of a hatchery immediately below the dam, but engineering problems caused the biologists to look for an alternative. The plan eventually implemented had three key elements: 1) adult salmon and steelhead were trapped in the ladders of Rock Island Dam from 1939 to 1943 and the fish taken to holding areas; 2) some adults were released into rivers selected for the transplanted runs and allowed to spawn naturally; and 3) the remaining fish were held for artificial propagation at Leavenworth hatchery. The streams which received the transplanted fish were Wenatchee, Entiat, Methow and Okanogan rivers and Lake Osoyoos (Fish and Hanavan 1948) .

The results of the fish maintenance program were evaluated by comparing the contribution of relocated stocks to the Columbia River escapement above Bonneville Dam before the Grand Coulee cut off salmon migration (1938-1942). Counts at Rock Island Dam were used as estimates of the escapement of relocated stocks. Based on this analysis, Fish and Hanavan (1948) regarded the Grand Coulee Salmon Salvage Program a success. However twenty four years later, Ricker (1972) gave a more pessimistic appraisal of the program and concluded that it salvaged nothing. Mullan et al. (1992a) concluded that the fish maintenance program conserved the genetic diversity of the salmon stocks in the area, however, the large-scale capture, mixing, and relocation of chinook salmon stocks above Rock Island Dam permanently altered the population structure and was the genesis of the present stock structure of salmon in the mid-Columbia (Utter et al. 1995).

Lower Columbia River Fishery Development Program

The current restoration program for Columbia River salmon and steelhead has its roots in the Lower Columbia River Fishery Development Program (LCRFDP), which was strongly influenced by the concepts and design of the Grand Coulee Fish Maintenance Project. Originally, LCRFDP had an implementation life of 10 years, however, the program, with some modifications has continued to the present. As the title suggests, the program's initial objective was to concentrate salmon production in the lower Columbia River below McNary Dam. At the time it was believed that the construction of McNary Dam and the other proposed dams in the upper Columbia and Snake rivers would eventually eliminate salmon in the upper basin. In 1956, congress changed the purpose of the LCRFDP by adding fishery restoration above McNary Dam and the word “Lower” was dropped from the program title (Delarm et al. 1989) .

The LCRFDP had six principal parts (Laythe 1948):

1) Remove migratory obstructions in the tributaries to the lower Columbia River. This part of the program included the stream clearance work that removed large woody debris and reduced habitat quality in some streams.
2) Clean up pollution in major tributaries like the Willamette River.
3) Screen water diversions to prevent the loss of juveniles in irrigation ditches, and construct fishways over impassable barriers in the tributaries of the lower Columbia River.
4) Transplant salmon stocks from above McNary Dam to the lower river.
5) Expand the hatchery program by rebuilding existing hatcheries or new facilities.
6) Create salmon refuges by setting aside the lower river tributaries exclusively for the maintenance of salmon and steelhead runs.

Stream clearance was consistent with management understandings and attitudes at the time (Sedell and Luchessa 1981; Lichatowich 1999), but it is no longer practiced unless the obstruction presents a complete unnatural block to migration. The transfer of stocks to the lower river ignored the stock concept and the adaptive relationship between the stock and its habitat. The hatchery program was one of six parts of the program, but within a few years it was the dominant part. By 1951, hatcheries consumed 49 percent and habitat work 5 percent of the budget (unpublished budget information obtained from the National Archives PNW Center, record group 22). Screening of diversions continues to the present (Independent Scientific Review Panel 1999). No salmon refuges were created.

Mid-Columbia Mitigation

Mitigation programs in the mid-Columbia evolved in three phases. The first phase was the Grand Coulee Fish Maintenance Project described above. From 1961 to 1967, four hatcheries and a satellite facility were constructed to mitigate for mainstem habitat inundated by five PUD projects. This second phase, originally consisted of three spawning channels (Priest Rapids, Turtle Rock and Wells) and two conventional hatcheries (Rocky Reach and Chelan). The spawning channels were later converted to conventional hatcheries. The third phase has been implemented since 1989 and is composed of the Methow hatchery and two satellite ponds, the Eastbank Hatchery with five satellites, and Cassimer Bar Hatchery. This phase is intended to mitigate for juveniles produced in the tributaries which are lost in passage past Wells and Rock Island Dams. Monitoring and evaluation of the mid-Columbia mitigation is underway.

Lower Snake Compensation Plan

The Lower Snake River Compensation Plan (LSRCP) was developed to mitigate for the loss of fish and wildlife resources resulting from the construction of Ice Harbor, Lower Monumental, Little Goose and Lower Granite dams. The dams were completed between 1969 and 1975 (Lavier 1976). Planning for the compensation program started in 1966 and was approved by the U. S. Congress in 1976. The McCall Hatchery was the first facility constructed (completed in 1979), followed over the next eight years by several other hatcheries and satellite facilities. Presently, there are twelve hatcheries and eleven satellites employed in the LSRCP (Mighetto and Ebel 1995).

Initially, steelhead increased in abundance as a result of the releases from LSRCP hatcheries and the program was considered successful in terms of its original objectives (Herrig 1990; Mighetto and Ebel 1995). In 1994, the summer steelhead run was the lowest since 1982 (U.S. Fish and Wildlife Service 1995) and recently with steelhead numbers following the earlier declines of chinook salmon, LSRCP hatcheries are having difficulty meeting production and smolt release targets due to inadequate numbers of returning adult steelhead (U.S. Fish and Wildlife Service (USFW) 1998). Chinook salmon returns have been well below target levels for some time. The LSRCP hatcheries were originally designed as conventional hatcheries, however in some cases, conventional hatchery operations have evolved into supplementation programs (Messmer et al. 1992). The programs and the supplementation technology are too new to determine if they will be successful (RASP (Regional Assessment of Supplementation Project) 1992; Bowles 1995).

The objective of the Lower Snake River Compensation Program did not include Snake River coho salmon or Snake River sockeye salmon, which were relatively abundant at the time LSRCP was being planned. Relatively few resources were devoted to Snake River fall chinook, with only one of twelve hatcheries being devoted to this life history type. It is worth noting that coho salmon are presently extirpated from the Snake River Basin, sockeye salmon are nearly extinct, and fall chinook are listed as endangered under the Endangered Species Act.

### Summary results on uses of hatcheries

After 120 years of salmon management based largely on the assumption that artificial propagation could replace natural production in the Columbia Basin and the development of a massive system of hatcheries, its instructive to note that the most productive stock in the basin is the fall chinook population that spawns naturally in the free flowing Hanford Reach of the mainstem Columbia. In the context of the entire history of the hatchery program, and the history of salmon management in the basin, the hatchery program has failed to meet its objectives. In 1994, the smallest number of salmon and steelhead entered the Columbia River since counts began in 1938, and by 1939, salmon production was already far below historical levels. Artificial propagation of salmon did not maintain salmon production. The early optimism that predicted hatcheries would make up for overharvest and habitat degradation has given way to the reality of depletion, closed fisheries, and a fragmented ecosystem in which natural production is severely restricted. Today the dominance of hatcheries in management programs is being questioned (Hilborn and Walters 1992; Washington and Koziol 1993; National Research Council (NRC) 1996). New roles for hatcheries and guidelines for their operation are being developed or proposed (National Fish Hatchery Review Panel 1994; White et al. 1995; Scientific Review Team 1999), however, in the past, the hatchery program has been slow to adopt change. For example, by 1939, fish culturists recognized that the stock concept in Pacific salmon meant interhatchery transfers were detrimental (OFC 1939), however, 56 years later, Flagg et al. (1995) were still recommending that hatcheries restrict that practice.

Since 1960, the total release of hatchery reared salmonids has grown from 79 million to about 200 million (Figure 8.11) – in recent years (1987 to 1992), the range was 179 to 221 million fish. Since 1960, the number of adult salmon and steelhead entering the Columbia River has not shown an increasing trend (Figure 8.11, although those data do not include the number of salmon harvested in interception fisheries outside the basin, which can be substantial (Lestelle and Gilbertson 1993). Prior to 1960, most of the adult salmon and steelhead entering the Columbia Basin were naturally produced (Columbia Basin Fish and Wildlife Authority 1990), however, over the past three decades the proportion of hatchery reared fish in the adult population has grown to about 80 percent (NPPC 1992a). From a cursory examination of the overall numbers, it could be argued that in recent decades the hatchery program has accomplished its objective – hatchery production has replaced natural production lost through habitat degradation, i.e., the increasing proportion of hatchery fish might indicate successful mitigation for habitat loss. However, reality is more complicated. The hatchery program since 1960 contains some successes, in other cases hatcheries have failed to reach mitigation goals, and hatchery practices have been directly linked to depleted natural populations.

The hatchery program for coho salmon contributed to the depletion of wild coho populations in tributaries below Bonneville Dam. Flagg et al. (1995b) identified factors related to the hatchery program that contributed to the decline in natural production of coho salmon in the lower Columbia River: Excessive harvest in the fisheries targeting mixed hatchery and wild stocks; selection for early spawning broodstock; fry stocking in densities greater than the carrying capacity of the receiving stream; planting hatchery fry that were larger than the naturally produced fish; and interhatchery transfers.

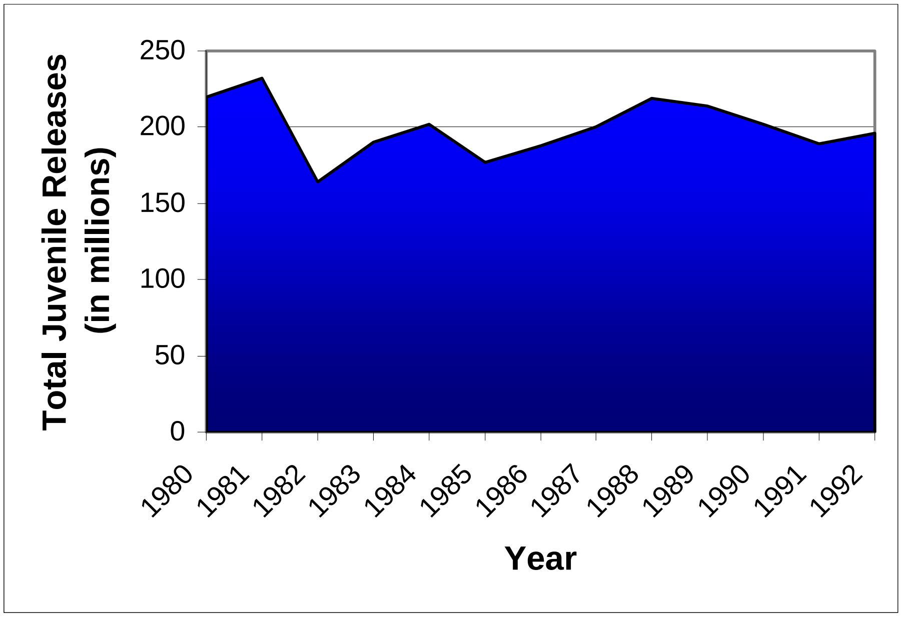


**Figure 8.11**. Total releases of anadromous salmonids into the Columbia River Basin, 1980 – 1992. (Source: Pacific States Marine Fisheries Commission).

In the upper Salmon River, hatchery mitigation has not replaced or maintained natural production lost due to smolt mortality, especially at the lower Snake River dams, however, it has slowed the decline of total production (Bowles 1993). In the South Fork of the Salmon River, hatchery mitigation has increased total production (Bowles 1993).

In the upper Snake and Columbia rivers, the present geographic distributions and genetic population structures of fall-run chinook salmon reflect stock transfers and hatchery confinements carried out between 1939-1943 under the Grand Coulee Fish Maintenance Project (GCFMP). The GCFMP intercepted upstream migratory salmonids at Rock Island Dam near Wenatchee from 1939 through 1943 for relocation in tributaries downstream of Grand Coulee Dam. In this 5-year period, almost all adult spring-run and summer-fall-run chinook, regardless of original destination, were either confined to restricted areas for natural reproduction or used in hatchery operations (Utter et al. 1995). This large-scale program, of interceptions, stock transfers, and stock mixing, permanently altered the salmon populations in the Upper Columbia River and provided the foundation for their present population structures.

Warm Springs National Fish Hatchery has successfully increased production in that river without adversely affecting wild stock production (Olson et al. 1995). This program appears to be an example of the effective use of adaptive management.

These examples suggest that the results of artificial propagation in the Columbia River since 1930 and especially after 1960 have been mixed. Unfortunately, the lack of a meaningful comprehensive evaluation doses not permit a determination and detailed description of the net effects of artificial propagation. Given the current state of the salmon and steelhead in the basin, it would be appropriate to conclude that in its 120-year history, the net effect of hatcheries has been negative.

## Future Directions for Hatcheries

Recent reviews of the efficacy of hatcheries toward fisheries management goals, and of the impact of hatchery fish and hatchery practices on wild fish populations, all appear to lead to the same general conclusion and recommendations. In the Columbia River Basin, in spite of large-scale hatchery efforts and massive outplantings of hatchery-reared fish, the hatchery program has failed to replace or mitigate for lost natural reproduction of anadromous salmonids. New directions and visions for the hatchery program are clearly needed, and several recent reviews (National Fish Hatchery Review Panel 1995; National Research Council 1995; Campton 1995; White et al. 1995; Scientific Review Team 1999) provide them, suggesting that a new role be defined for hatcheries in general, and in the Columbia River Basin in specific. The reviews are concordant in suggesting that hatcheries should have a much smaller role in salmon production and restoration than they have had in the past. Additionally, their roles and objectives (identified individually for each hatchery) need to be coordinated into an integrated recovery and management plan for each appropriately scaled management unit (watershed or subbasin). Hatcheries need to be used cautiously, as tools, that are integrated into rehabilitation or restoration strategies that focus on habitat restoration, reduction of human-induced mortality agents, and conservation of existing genetic and life history diversity in natural populations (Allendorf and Waples 1996). The National Fish Hatchery Review Panel (1995), White et al. (1995), and the Scientific Review Team (1999) provide detailed recommendations and suggestions for changes in the hatchery system.

Clearly there is a role for hatcheries in the management and restoration of Pacific Northwest anadromous salmonids. For example, in the case of dwindling upriver stocks, hatcheries may provide temporary, but key refuges, in which various populations might be sustained while downstream causes of mortality are removed or modified (Cuenco et al. 1993; Bowles 1995; Waples 1999). Similarly, hatcheries may have a temporary role in rebuilding depressed populations (e.g., through supplementation activities as described in RASP 1992). It remains to be seen, however, if there is a role for large-scale production hatcheries that is compatible with conservation and long-term management of many of our imperiled stocks (Philipp et al. 1993).

## Supplementation

One of the new and controversial roles for hatcheries and artificial production in the Columbia River Basin is supplementation, where carefully selected stocks of hatchery-produced fish are used to enhance or “reseed” streams where native populations have been depressed or extirpated. In the simplest terms supplementation is viewed as small scale and temporary to boost naturalized production in wild stocks (Steward and Bjornn 1990; Cuenco et al. 1993). Supplementation is important because it may offer a means to accelerate the process of rebuilding metapopulation structure in localities that are remote from core populations, ecological conditions permitting. Supplementation and captive brood techonology are currently in use as the major tool in the attempts to recover endangered sockeye salmon from Redfish Lake. In the upper Snake Basin, supplementation has been proposed as one important means for achieving the Council’s goal of doubling adult salmon returns. Thus, much hope is being placed in a concept that remains to be tested and proven each time it is applied (RASP (Regional Assessment of Supplementation Project) 1992; Cuenco et al. 1993).

Supplementation is a new name for an aquaculture strategy that goes back to the beginnings of artificial propagation in the Columbia Basin. Basically, supplementation envisions the use of the protected hatchery environment to obtain a survival advantage through the incubation of eggs and the early rearing stages of juvenile salmon. Those juveniles are then planted back into streams to complete their rearing under natural conditions, in the hope that they will return as adults to spawn naturally and successfully, and thereby augment overall production in the stocked watershed. In the early years of artificial propagation, the speculation that high natural egg mortality occurred was used to justify supplementation with artificially propagated salmon. Today, observations of the underseeding of tributary streams and the extremely high total mortality rates for wild salmon stocks provide the rationales for this strategy (e.g. NPPC 1994).

### *Constraints on Supplementation*

In the late 19th century, the crude technology of artificial propagation and poor understanding of the salmon's biology limited the chance of success. Today, the technology of fish culture in the hatchery has improved, although, the information needed to integrate artificial and natural production systems is still not well developed (Lichatowich and McIntyre 1987; Scientific Review Team 1999). Unfortunately, the rearing habitats in which juvenile salmon must live after planting has been considerably degraded. Our understanding of the ecology and genetics of Pacific salmon has improved and that understanding has placed new constraints on supplementation. The definition of supplementation adopted by RASP (1992) underscores those constraints:

> *Supplementation is the use of artificial propagation in the attempt to maintain or increase natural production while maintaining the long term fitness of the target population, and keeping the ecological and genetic impacts on non-target populations within specified limits* (RASP 1992, P. 6).

The constraints contained in the RASP definition are new to artificial propagation, and because they are new, there is little experience that can be used to resolve uncertainties. RASP (1992) describes some supplementation uncertainties, which are given a thorough review by Steward and Bjornn (1990). The Council has stipulated (7.3B of the FWP) that fishery managers will use the RASP guidelines to plan new supplementation projects. This step is critical and managers must be held accountable for adequate planning of their supplementation projects, including adequate monitoring and procedures for adaptive management. Project plans must receive peer review from fisheries scientists and geneticists.

*Need for Critical Evaluation*

One of the reasons why supplementation needs critical review and evaluation is the confusion over the interpretation of what constitutes supplementation. Supplementation is generally defined as the use of artificially produced fish to augment natural production without eroding long-term fitness of target and non-target natural populations (NPPC 1987; Bowles and Leitzinger 1991; NPPC 1992a; RASP (Regional Assessment of Supplementation Project) 1992; Cuenco et al. 1993; Bowles 1995). However, outside the published definition, common usage of the term supplementation has taken on much broader meanings. Because the term supplementation has such broad meaning, there is little practical agreement on a definition. In its broadest sense, supplementation includes various fisheries management activities including restoration; introduction; rearing augmentation; and harvest augmentation (Miller et al. 1990; Steward and Bjornn 1990; Sterne 1995). Differing definitions in current use confound objectives, obscure the mechanisms for accomplishing those objectives, and circumscribe criteria used for evaluating success of supplementation programs.

Confusion over what is meant by supplementation has also hampered efforts to evaluate the effectiveness of supplementation as a tool to rebuild depressed salmon populations. This is a serious shortcoming because as much as 50 percent of the increase in salmon production projected from the systems planning model is expected to result from supplementation projects

(RASP 1992). Reviews of supplementation (Miller et al. 1990; Steward and Bjornn 1990; Hilborn and Winton 1993; Winton and Hilborn 1994; Bowles 1995; Reisenbichler 1995; Sterne 1995) indicate that supplementation projects were rarely conducted in a rigorous enough manner to permit evaluation of the outcome of the experiments. In a survey of supplementation projects in the western United States, Miller et al. (1990) found that less than ten percent of all enhancement projects examined were supplementation projects whose outcomes could be scientifically determined. Of those verifiable supplementation projects identified by Miller et al. (Miller et al. 1990), most were judged to be successful. In other investigations, supplementation for specific stocks of salmon and steelhead was rarely successful in increasing natural production, and often significant risks were incurred (Reisenbichler and McIntyre 1977; Chilcote et al. 1986; Nickelson et al. 1986; Reisenbichler and McIntyre 1986; Lichatowich and McIntyre 1987). In contrast to supplementation of salmon bearing habitats, success has most often been verified in programs that introduce fish into vacant habitat, either new areas or areas from which they had been previously extirpated (Cuenco et al. 1993). The successes reported for the salmon supplementation programs cited above have all been in areas where freshwater habitats were intact and good conditions prevailed, so caution precludes extrapolating these results into predictions of similar success for the more difficult task of rebuilding depressed populations in the extensively damaged habitats of the Columbia River Basin. Indeed, any means of salmon recovery may be expected to fail in the absence of ecological conditions capable of supporting the necessary life stages of salmonids.

The recent NRC report (1996) expressed similar concerns about the use of supplementation. The NRC panel recommended the term “supplementation” be abandoned as a goal of hatcheries. They also concluded that hatcheries were not a proven technology for achieving sustained increases in adult salmon production and their use has had adverse effects on natural salmon populations. Moreover, supplementation, which has multiple and often incompatible definitions in the literature, has generated confusion and uncertainty about appropriate roles for hatcheries. An emerging consensus (National Fish Hatchery Review Panel 1994; White et al. 1995; National Research Council (NRC) 1996; Scientific Review Team 1999) calls for new roles for hatcheries which are tied to rehabilitation or restoration goals of the specific watershed where the hatchery is located. The new roles for hatcheries should be based on and consistent with an ecologically-based conceptual foundation such as we describe in Chapter 3.

*The Experimental Nature of Supplementation*

The NRC (1996) further recommended that hatcheries should be considered an experimental treatment in an integrated regional rebuilding program and should be evaluated accordingly. This is concordant with our review as well. Supplementation will need to be monitored and evaluated on a case-by-case basis for its applicability as a means to accelerate recovery of the metapopulation structure of wild salmonid populations with respect to their abundance and life history diversities. As determined for each locality and life history type to which it is applied, supplementation may be useful over the short-term to aid in rehabilitating natural populations within the context of an integrated and comprehensive watershed-based restoration approach. The proposed chinook salmon supplementation projects in central Idaho appear to follow these guidelines (Bowles and Leitzinger 1991) and may be useful as a model for other supplementation projects.

In implementing the FWP, we advise the Council to resist attempts to implement supplementation on a large scale without adequate planning and review and without adequate monitoring and evaluation in place. Supplementation may prove to be a useful tool in the Columbia Basin for rebuilding salmon metapopulation structure by restoring depressed stocks in some localities, but this will only occur if supplementation is approached cautiously in an experimental framework that relies on careful design, rigorous evaluation, and incorporates adaptive management. Within the context of our conceptual foundation, supplementation activities are necessarily temporary, applied to allow life history types to survive over the time necessary to improve or restore ecological conditions. Once such conditions are established, the populations will be able to rebuild themselves through natural reproduction. Measurable criteria for the success of the supplementation effort need to be rigorously defined *a priori*, and we advise managers to resist the temptation to increase the scale of goals, designs, and hatchery involvement, if success occurs. Continuing the supplementation effort beyond the establishment of improved ecological conditions may pose significant genetic and demographic risks to the target stock.

Artificial propagation has a 120 year history in the Columbia Basin and an important lesson from that experience should be that the success of new technology applied to fish culture cannot be taken for granted. Each set of local biota, physical conditions and salmon life history type to which supplementation is applied represents the development of new form of aquaculture technology. Each application will be clouded by multiple uncertainties, which require careful risk assessment before implementation. Adequate monitoring and evaluation are essential if a supplementation project is implemented. The seriously depeleted condition of the resource today calls for quick action, yet the depleted salmon populations in the basin cannot afford to be subjected to new technology without adequate evaluation.

## Conclusions and Recommendations

*Conclusions (and Level of Proof)*

1. Artificial propagation has failed to achieve the objective of replacing natural production lost because of habitat degradation in the basin (1).

2. Hatcheries have been successful at preserving some of the genetic legacy, which would otherwise have been lost from salmon populations formerly occupying presently, severely degraded or occluded habitats (1).

3. Artificial propagation has not replaced, in any sense, natural production in the basin (1). See #8 below

4. Belief in the efficacy of artificial propagation led to disproportionate budgets for habitat protection and restoration (3).

5. In the 120-year history of the artificial propagation in the Columbia Basin, the program has never been subjected to a comprehensive evaluation (1).

6. The ecological, behavioral, and energetic interactions of hatchery fish with native species (including wild salmon) and fish assemblages of the Columbia River ecosystem have not been evaluated. In the operation of hatcheries, those interactions are generally assumed to be inconsequential, benign, or outside the concern or responsibility of the hatchery program managers. (3).

7. The extent to which the artificial propagation program has implemented relevant research, particularly where the interaction between natural and artificially propagated fish is concerned, has been slow (3).

8. Hatchery operations including broodstock selection, interbasin transfers, and release practices have contributed to the decline of natural production and loss of locally adapted stocks in the basin (2).

9. Management of fisheries on mixed hatchery and wild stocks have contributed to the decline of natural production in the Columbia Basin (2).

10. Because of the declining natural production in the Columbia Basin, those fisheries that still harvest Columbia River salmon are largely supported by the hatchery program (1).

11. Hatchery practices are one of the factors that have altered the genetic structure of stocks in the basin (1).

12. Hatchery programs have contributed to the protection of genetic diversity in some life history types (1).

*Critical Uncertainties*

1. A major uncertainty stems from the question, can we integrate natural and artificial production systems in the same basin to achieve sustainable long term productivity?

2. A major uncertainty associated with the use of supplementation is the condition of the habitat that will receive the juvenile salmon. Is the habitat capable of supporting salmon at levels of survival that will bring about restoration?

*Recommendations*

1. Because each application of aquaculture to conservation of a local population of a life history type represents a new technology in the recovery of endangered or depleted stocks, there are uncertainties associated with them. Any use of artificial propagation to restore depleted salmon populations should be preceded by an assessment of the risks, and applications must be accompanied with a well designed and adequately funded M&E program.

2. There are three questions that need to be answered in any evaluation of the hatchery program: Do the artificially propagated fish contribute to the fishery and/or escapement and is the economic benefit of that contribution greater than its cost? Has the program achieved its objective; i. e., has it replaced lost natural production if it is a mitigation hatchery? Has the operation of the hatchery incurred costs to natural production? The first and the third questions are related in that a meaningful cost-benefit analysis should include ecological costs. The FWP should require evaluation of all hatcheries funded which adequately answers all three questions.

3. The FWP should include a valid comprehensive evaluation of the artificial propagation program in the Columbia Basin. The evaluation should cover the entire 120-year history of the program and include direct and indirect, positive and negative effects. The comprehensive evaluation should also include an assessment of the adequacy of existing monitoring to answer ecological questions.

4. The FWP should include as a separate measure a comprehensive evaluation of the mitigation hatcheries in the basin. What were their objectives, did they achieve their objectives, and if not, why not?Are their original mitigation goals still relevant and appropriate?

5. The region needs to develop an interim policy regarding the operation and harvest management of production from each hatchery where monitoring has been inadequate to complete a comprehensive evaluation. The interim policy should be designed to minimize the ecological costs of the hatchery until the evaluation can be carried out.

6. The objectives of each hatchery need to be evaluated and redefined if necessary. The objectives should be established within the contexts of the subbasin where the hatchery operates, paying particular attention to the linkages between salmonids and their habitats, and the potential for metapopulation rebuilding. The hatchery operations should be integrated into the total production system and should assist in the recovery efforts in the subbasin. The hatchery's objectives need to be integrated and defined by the rebuilding objectives of the subbasin. The objectives should consider non-target species and the existence of metapopulation structure of the target species.

7. Artificial propagation must be treated as an experiment, with hypotheses related to uncertainties, experimental design, analysis, and integration of results with available knowledge consistent with the adaptive management provisions of the FWP.

8. The decision about when and where to deploy supplementation programs should make use of the metapopulation concept.

9. Existing hatchery populations should be protected and carefully evaluated to identify the genetic legacy, which they contain, and its potential role in rebuilding metapopulations.

## Disease Management

The Council’s 1984 Fish and Wildlife Program called upon the Bonneville Power Administration to fund development of programs to prevent the introduction of fish diseases into the Columbia Basin, prevent the spread of existing diseases, improve fish culture, minimize the impact of fish diseases on wild and cultured stocks, and improve the detection, diagnosis and control of fish diseases and parasites. These provisions were repeated in the 1987 program. The 1994 Fish and Wildlife Program included a fish health policy at Section 7.2A.6, which called for hatchery practices and operations that would preclude the introduction and/or spread of any fish disease within the Columbia Basin, and maximize the health of fish released from hatcheries.

The Scientific Review Group (SRG), a predecessor to the ISG and current ISAB, examined fish disease research and work plans in 1991 (Scientific Review Group 1991). Specifically, the SRG reviewed the Work Plan developed by the Technical Working Group on Fish Disease. The SRG was impressed with the careful professional work that had been conducted by scientists and managers in the area of fish disease. The Work Plan and the Technical Working Group did a good job of identifying problem pathogens of salmon in the Columbia Basin, and of focusing research efforts toward understanding and control of those pathogens. The Fish Disease Work Plan was notable for its sharply focused research objectives, the prioritization process used by the Fish Disease Technical Working Group to rank research priorities, and the implementation of an annual peer review process to assess program progress and modify research objectives, where appropriate. The major comment provided by the SRG in their review was the need to extend the disease work beyond the artificial production program and begin to examine disease in wild fish including the interactions between wild and hatchery fish. Neither the ISG, nor the ISAB has looked at fish disease issues since the SRG review, so we are unable to comment further.

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