Restoration of the Elwha River Ecosystem

By Robert C. Wunderlich, Brian D. Winter, and John H. Meyer

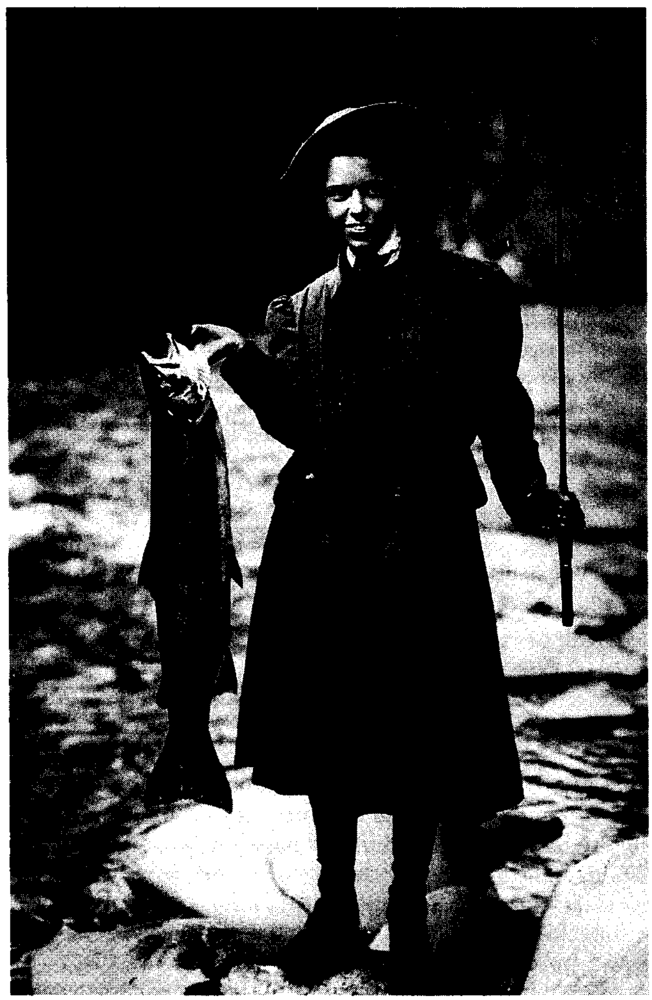
ABSTRACT

Historically, the Elwha River in western Washington was renowned for an abundance and diversity of anadromous salmonids. Most of the river system lies within Olympic National Park and remains in pristine condition, but two dams in the lower river have blocked all anadromous fish for more than 80 years. To restore the Elwha's historic fishery resources and resolve an impasse about federal licensing of the dams, the U.S. Congress passed the Elwha River Ecosystem and Fisheries Restoration Act in 1992. The act required an analysis of alternatives (dam retention with fish passage facilities v dam removal) to achieve full ecosystem and fishery restoration. Analysis indicates that removal of both dams is the only option that will achieve full restoration, but dam removal and fish restoration efforts could span 20 years and cost from US$147 million to US$203 million. Although fish restoration poses problems because of limited native runs, sediment management presents the most significant environmental challenge and cost. Nevertheless, a unique opportunity to fully restore the ecosystem of a major anadromous-salmonid-producing river is at hand.

In 1992, the U.S. Congress passed the Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495), the express purpose of which was the "full restoration" of the ecosystem and anadromous fish runs that historically inhabited the Elwha River in northwestern Washington state. The act provides a unique opportunity for ecosystem and fishery restoration because it allows for removal of two hydroelectric dams on the Elwha River to accomplish this objective.

The unusual nature of this action resulted from several factors. The Elwha River lies largely within Olympic National Park, a United Nations-designated World Heritage Site and Biosphere Reserve. The river historically supported a rich and diverse anadromous salmonid fauna, but now more than 115 river kilometers (rkm) of pristine anadromous salmonid habitat are totally blocked by the dams. During the 1980s, licensing by the Federal Energy Regulatory Commission (FERC) became extremely contentious and drawn out, primarily because of national policy implications of licensing a project within a national park; the inability to design fish and wildlife mitigation measures capable of meeting federal, state, and tribal resource goals; and legal challenges by conservation groups to fully mitigate all dam-related impacts to the Elwha's fish and wildlife resources.

Removal of both dams emerged as an alternative to meet the goals of ecosystem and fisheries restoration. However, it appeared likely that any decision FERC



Asahei Curtis

Removal of one or both dams on the Elwha River, Washington, may be the best approach to restoring anadromous fish runs, historically large chinook salmon.

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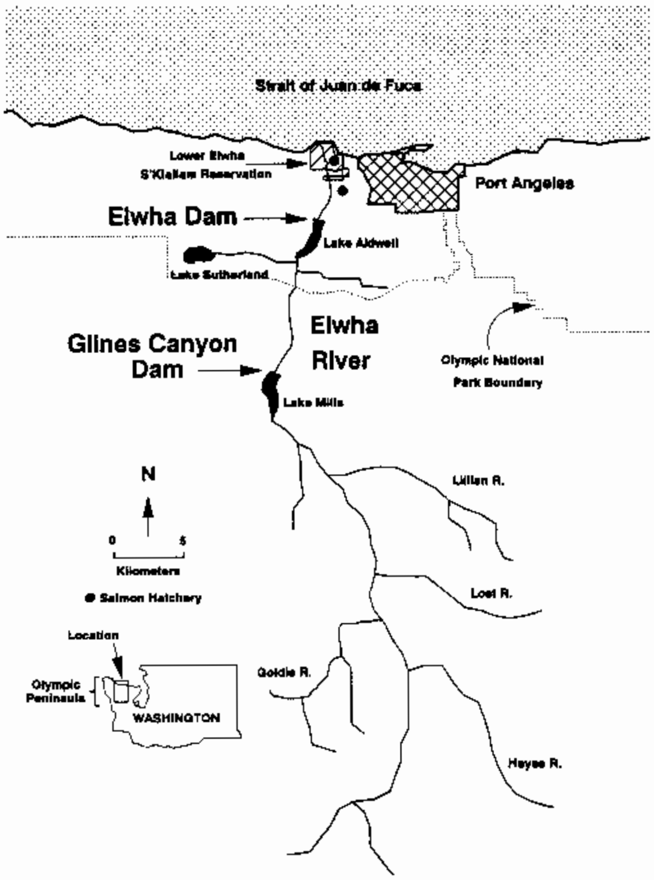


Figure 1. The Elwha River and the historical extent of anadronous salmonoids prior to the Elwhad dams.

might render, dam removal or licensure, would be challenged in court by one party or another. The U.S. Department of Justice, at the request of the U.S. departments of commerce and interior, appealed a determination by FERC that FERC had authority to relicense Glines Canyon Dam within the confines of Olympic National Park. Prior to passage of the act, the North Pacific International Chapter of the American Fisheries Society (AFS) unanimously passed a resolution calling for removal of the Elwha dams, while the Northwest Public Power Association unanimously passed a resolution to retain the dams in 1991.

Since costly legal challenges could delay the federal licensing or removal by a decade, Congress offered legislation to resolve the problem. On 26 October 1992, President Bush signed the Elwha River Ecosystem and Fisheries Restoration Act into law. The act authorized the secretary of the interior to develop a report to identify the alternative (dam retention with fish passage measures or dam removal) that would result in "full restoration" of the Elwha River ecosystem and native anadromous fisheries. If the secretary determines that dam removal is necessary for full restoration, acquisition of the projects is authorized for $29.5 million, and the mill's electrical power production is assured through the Bonneville Power Administration. However, if the secretary does not determine that dam removal is warranted or cannot secure the necessary funds to remove the dams, the projects will revert back to FERC jurisdiction.

Here, we contrast the past and current status of the Elwha River's ecosystem and anadromous salmonids and the restoration alternatives assessed in reaching the dam removal option. We also outline the proposed restoration process that would occur through dam removal.

The Elwha River Ecosystem and Anadromous Salmonids

Basin Description

The headwaters of the Elwha River and much of its drainage basin (692 km^2) are located in the heart of Olympic National Park. The river flows north 71 km through old-growth forests before entering the Strait of Juan de Fuca near the city of Port Angeles (Figure 1). Except for the two Elwha dams and the absence of anadromous fish, much of the Elwha River basin is in pristine condition. A greater proportion of the river basin, approximately 83%, lies within the park than any other river basin on the Olympic Peninsula. Natural ecological processes in many other north Olympic Peninsula rivers have been harmed by extensive land use, particularly timber harvest, but the Elwha basin remains largely in a natural condition above the dams. The river's water quality is rated by the Washington State Department of Ecology as class AA—extraordinary quality. Only limited development has occurred below the park boundary. Water is withdrawn for municipal and industrial uses at rkm 5.3 upstream from the mouth. Other lower river impacts include extensive shoreline development in Lake Sutherland, the basin's principal lowland lake (Figure 1), and some timber harvest.

Dam-related impacts are much more severe. Elwha Dam has stopped downstream movement of gravel for more than 80 years, leaving very coarse substrate in the lower 8 rkm; only limited amounts of substrate below both dams remain suitable for spawning by anadromous or resident salmonids. The lack of gravel recruitment has affected the river's estuary. Although the Elwha estuary was never large, Lower Elwha S'klallam Tribal members who have lived near the mouth report a significant decrease in the estuary's size since the dams were constructed.

The dams also increase water temperatures in the middle and lower reaches of the river in late summer and early fall because of heat storage in Lake Mills and Lake Aldwell. During years of low snow pack and rainfall, summer water temperatures exceed 18° C, which aggravate parasite and disease infestations, resulting in large losses of pre-spawning adult chinook in the lower river; approximately two-thirds of the 1992 return died prior to spawning. A number of mitigation scenarios involving reservoir drawdown have been attempted but have not succeeded in resolving the water temperature problems.

Fish and Fisheries

Prior to hydropower development, the Elwha River was considered the most prolific fish producer on the Olympic Peninsula of Washington State. Residents acquainted with the early conditions of the river report that migratory fish had unlimited access to the entire river's length, and large runs of anadromous salmonids flourished (Schoeneman and Junge 1954). The Elwha was one of the few rivers in the contiguous United States that supported all the anadromous salmonids native to the

Pacific Northwest: spring- and summer-fall-run chinook *(Oncorhynchus tshawytscha)*, coho *(O. kisutch)*, chum *(O. keta)*, pink *(O. gorbuscha)* and sockeye salmon *(O. nerka)*, summer- and winter-run steelhead *(O. mykiss)*, sea-run cutthroat trout *(O. clarki)*, sea-run native char (Dolly Varden *(Salvelinus malma)*, and bull trout *(S. confluentus)*).

The Elwha River was particularly renowned for its run of large chinook salmon. Brown (1982:61) stated that these salmon were "easily the largest on the Olympic Peninsula." He recounts how Manuel Quimper, a Spanish explorer, purchased a number of salmon of 45 kg (100 lbs) from Native Americans near the Elwha on 25 July 1790. These chinook salmon were apparently uniquely adapted to the temperature regimen, flow patterns, and other environmental variables found within the Elwha drainage, its estuary, and ocean migration route; some unknown factor or combination of factors selected for large size (Brannon and Hershberger 1984).

Before Olympic National Park was established, the Elwha River was dammed for hydropower generation. Elwha Dam was constructed from 1910 to 1912 at rkm 8 and consists of a concrete-and-earth structure that is 32 m high and 137 m long at its crest (Figure 2). The impoundment created by the dam, Lake Aldwell, is 4 km long. Glines Canyon Dam began operating in 1927 at rkm 22 and consists of a concrete-arch structure 64 m high (Figure 3). The dam impounds 4.5-km-long Lake Mills. Power from both projects (average annual generation of 18.7 megawatts) meets almost 38% of the electrical need of a nearby paper mill.

Neither Elwha nor Glines Canyon dams has provision for fish passage. When Elwha Dam was constructed, Washington law required fish passage wherever food fish (salmon) migrated upstream. Nevertheless, then-State Fish Commissioner Leslie Darwin allowed the dam builders (Olympic Power Company) to build a hatchery in lieu of a fishway by allowing the dam to "be considered a state obstruction for the taking of eggs to supply the hatchery" (Brown 1982). The hatchery began operation in 1915 and collected more than 23 million eggs from Elwha River salmon and steelhead before closing in 1922 because "very few salmon ascended as far up the river as the dam" (Maib undated). Because Elwha Dam had no fish passage facilities, no provision for fish passage was considered necessary at Glines Canyon Dam.

Anadromous fish have been restricted to the 8 rkm below Elwha Dam for close to 80 years, and their numbers are acutely reduced due to loss of upriver habitat. Nehlsen et al. (1991) list native Elwha River sockeye salmon as extinct, spring chinook and chum salmon as possibly extinct, pink salmon at high risk of extinction, and sea-run cutthroat as a species of special concern. Summer steelhead are considered depressed (WDF et al. 1993).

Unfortunately, no large (45 kg) chinook salmon has been observed in the Elwha River for many years. The size of Elwha chinook salmon now appears to be typical of most other Puget Sound and Washington coastal rivers. However, Brannon and Hershberger (1984) believe the genetic potential for large fish has been preserved in the remnant stock, but current hatchery practices are suppressing its expression.

While anadromous fish in the Elwha River suffer from many problems common to other Washington salmon, the loss of access to the upper river and continuing impacts of the dams remain the most serious threats. Overharvest in mixed ocean fisheries remains a significant concern for Elwha chinook and coho salmon, although harvest restrictions being considered for weak stocks of Washington and Oregon salmon under the Pacific Salmon Treaty should benefit Elwha stocks.

Recreational and treaty Native American fishing occurs in the river for hatchery-produced coho salmon and steelhead. Harvest of other species has been curtailed to protect remnant stocks, including chinook salmon. The Lower Elwha S'Klallam Tribe, which has treaty rights to these fish, has shared the burden of protecting these fish through the years and is a strong advocate and partner in the restoration effort.

Current Hatchery Production

Hatcheries have been constructed in the lower river by the Lower Elwha S'Klallam Tribe and the Washington Department of Fish and Wildlife (WDFW). The tribal facility has had variable success in producing coho salmon and winter-run steelhead. Despite large releases of these species, catches fluctuate widely and have been relatively low in recent years. The state facility releases chinook salmon caught in substantial numbers in marine fisheries, but no recreational fishing in the river and only very limited tribal fishing occurs for this species. The state facility continues to encounter problems in acquiring adequate eggs to meet its needs. In those years when there have been relatively large returns of chinook, disease and parasites have taken a heavy toll on the adults prior to spawning.

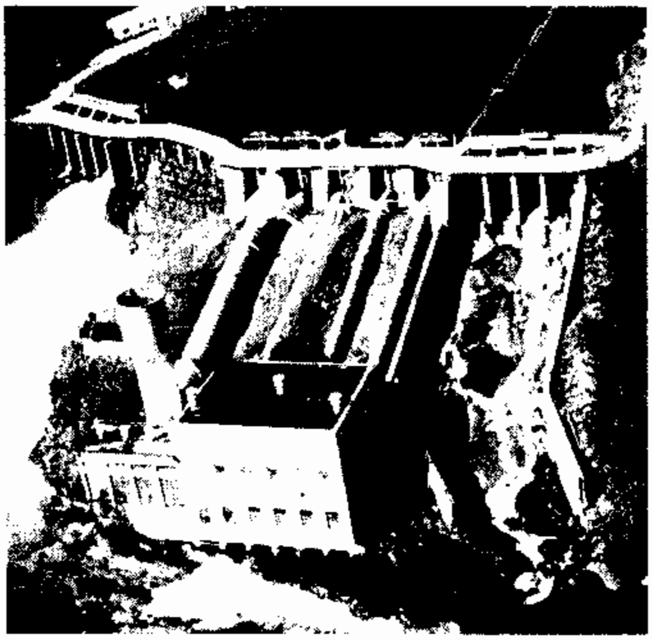


Figure 2. Elwha Dam

Alternatives for Ecosystem Restoration

Assessment Approach

In assessing fish passage, we and several other researchers assumed that measures to restore anadromous fish would include upstream and downstream passage facilities and operation of Glines Canyon Dam in a run-of-the-river mode with continuous spill for passing downstream migrants (USDI et al. 1994). To pass fish at Elwha Dam, an adult fish ladder, juvenile fish screen system, and spillway improvements would be installed. To pass fish at Glines Canyon Dam, a trap-and-haul operation would be necessary for adult fish, as well as continuous spill and a facility for screening juvenile fish away from the turbine intake.

Alternately, removal of both dams would involve elimination of both structures and appurtenant facilities as well as management of accumulated reservoir sediments. Dam removal would result in unobstructed juvenile and adult fish passage, restoration of inundated habitat, and recovery of natural physical processes (i.e., sediment and nutrient transport, hydrology, and temperature regimens) in the lower river.

The prospect for restoring each fish stock was qualitatively assessed under the alternatives of dam retention (with state-of-the-art fish passage facilities) or dam removal (either or both dams). Site-specific information on expected fish passage success at each dam and reservoir (Hosey and Associates 1988; Wunderlich and Dilley 1990) and expected recovery of habitat within the historic range of each stock (Figure 1) was evaluated. Availability of brood sources was also considered since six of the 10 native Elwha anadromous fish stocks are either extinct or acutely reduced, and replacement stock is limited within the region (WDF et al. 1993).

The prospect for recovering the river's native biological populations and communities and its natural physical processes (collectively considered "ecosystem restoration" here), was qualitatively assessed for each alternative. As an indicator of ecosystem recovery, the magnitude and timing of potential salmon biomass (carcass) contributions in the Elwha River basin were compared for each alternative (USDI et al. 1994). This comparison assumed full use of available habitat (i.e., spawner escapement based on optimal seeding for stocks with at least a fair prospect for restoration under each alternative) and reflected differences in *recovered habitat* rather than differences in recovered run sizes. Additional salmon biomass contributions (i.e., potential egg and juvenile mortalities) would also occur, but they would not approach the contribution of adult carcasses.

Salmon biomass contribution and ecosystem response were assumed to be directly related, since one of the principal benefits of fish in the ecosystem is their contribution to the prey base. Increased nutrient levels, and in some cases primary and secondary production, have been observed in streams following spawning by pink salmon (Brickell and Goering 1970; Walter 1982), sockeye salmon (Donaldson 1967; Mathisen 1971), coho salmon (R. Bilby and P. Bisson, Weyerhauser Company, personal communication), and kokanee *(O. nerka)* (Richey et al. 1975). Moreover, Cederholm et al. (1989) found that at least 22 species of birds and mammals use salmon carcasses as a seasonal food source in Olympic Peninsula streams. Of 286 species of birds found in Olympic National Park, one-third consume fish (mostly juveniles) as a primary or incidental source of prey. In northern Puget Sound, Stalmaster and Gessaman (1984) found that bald eagle *(Haliaeetus leucocephalus)* populations were often food-limited by low returns of salmon, and nesting activity and juvenile survival increased when salmon carcasses were abundant.

Table 1. Restoration prospects for stocks of anadromous salmonids native to the Elwha River (source: USDI et al. 1994). State-of-the-art fish passage is assumed for all dam-retention alternatives.

	Restoration prospects			
Stock	**Retention of both dams**	**Elwha Dam removal**	**Glines Canyon Dam removal**	**Removal of both dams**
Spring chinook salmon	**Poor**	**Fair/poor[a]**	**Fair/poor[a]**	**Good**
Summer-fall chinook salmon	**Poor[a]**	**Fair/poor[a]**	**Fair/poor[a]**	**Excellent**
Coho salmon	**Fair**	**Fair**	**Fair/poor[a]**	**Good/excellent**
Chun salmon	**Poor/none[b]**	**Poor**	**Poor/none[b]**	**Good**
Pink salmon	**Poor/none[b]**	**Poor**	**Poor/none[b]**	**Good**
Sockeye salmon	**Poor/none[c]**	**Fair/poorf**	**Poor/none[c]**	**Fair/poor[f]**
Winter steelhead	**Fair[a]**	**Fair[a]**	**Good[a]**	**Excellent**
Summer steelhead	**Fair**	**Fair[a]**	**Good**	**Good**
Searun cutthroat trout	**Unknown[d]**	**Unknown[d]**	**Unknown[d]**	**Good**
Searun native char	**Unknown[d]**	**Unknown[d]**	**Unknown[d]**	**Good**

[a] Significant uncertainities are associated with reservoir, spillway, and turbine passage mortality as well as degraded habitat and water quality.

[b] Inability of juveniles to survive reservoir passage coupled with degraded habitat indicates there is little chance of successful restoration of these stocks.

[c] Lack of a broodstock and expected low probability of successful passage through turbine screens make restoration of sockeye salmon unlikely.

[d] The ability of cutthroat and Dolly Varden to successfully navigate the proposed passage facilities is unknown.

[e] Habitat inundation and degradation limit restoration prospects.

[f] Habitat within Lake Sutherland is rated marginal.

Table 2. Potential carcass biomass (kg) contributed to the Elwha River ecosystem from salmon stocks with at least fair propects for restoration (source: USDI et al. 1994). State-of-the-art-fish passage is assumed for all dam-retention alternatives.

	Comparative biomass contribution (kg)			
	Retention of both dams	Elwha Dam removal	Glines Canyon Dam removal	Removal of both dams
Spring chinook salmon	0	15,900	15,900	15,900
Summer-fall chinook salmon	0	61,600	61,600	63,700
Coho salmon	49,800	51,600	51,600	53,400
Chum salmon	0	0	0	107,100
Pink salmon	0	0	0	118,600
Sockeye salmon	0	12,500	0	12,500
Total:	49,800	141,600	129,100	371,200

Consequences of Alternatives

Comparing the alternatives of fish passage and dam removal indicates that retention of either or both dams, even with the provision of fish passage facilities, would not allow for full restoration of native anadromous fisheries such as chinook, chum, and pink salmon (USDI et al. 1994). Assessments by the U.S. General Accounting Office (1991) and FERC (1994) have closely agreed.

Cumulative losses of juveniles and adults in the reservoirs, spillways, turbines, passage facilities, and degraded habitat greatly reduce the chances of restoring viable populations for all species except coho salmon and steelhead (Table 1). The reservoirs constitute virtually insurmountable barriers to outmigrating chum and pink salmon, the most abundant species historically, and inundate much of their historical spawning habitat (Figure 1). Chinook salmon would experience losses during upstream passage in ladders and trap-and-haul facilities, in addition to juvenile losses during downstream passage in reservoirs. Continued pre-spawning mortality of chinook would occur in the lower river in years of low summer streamflow.

With retention of either or both dams, ecosystem restoration would be significantly compromised, as indicated by reduced inputs of biomass (Table 2), especially from fall to spring when large inputs of chum and pink salmon biomass would otherwise be available. Moreover, retention of either or both dams would prevent downstream nutrient and organic transport, since reservoirs are known to block movement of these materials (Webster et al. 1979; Newbold 1987). Important riverine habitat would remain flooded by the reservoirs. Historically, these reaches were mostly broad alluvial valleys of moderate gradient (averaging less than 1%) that were used by all anadromous fish species for spawning, rearing, and migration. Trapping of bedload with the consequent loss of spawning substrate below the dams would also continue.

In contrast, dam removal and restoration of anadromous fish would result in returns of fish to the river throughout the year, optimize use of all accessible portions of the watershed, produce much greater numbers of fish, and restore ecosystem processes. Wildlife prey would be provided by fish carcasses, juveniles, and eggs. Removal of the two reservoirs would allow nutrients and bedload (sand, gravel, and cobble) to pass naturally downstream.

With dam removal, the river's historic fisheries, except possibly for sockeye salmon, could resume (Table 1). However, most of the river's stocks would take advantage of the large amounts of pristine habitat within the park and could be expected to provide harvestable surpluses. Lower-river spawners, such as chum and pink salmon, could require a longer recovery period as the lower river stabilizes after dam removal. Anadromous fishing opportunities would expand from the 8 rkm currently available to the entire river. Catches would also shift away from fisheries of short duration targeted on hatchery stocks to year-round fisheries on wild stocks.

Proposed Restoration Process

Dam Removal and Sediment Management

The principal steps involved in removing the projects would include diverting the river around the dams to allow structure removal, and managing sediments that have accumulated in each reservoir. Four feasible plans for diverting the river and demolishing the dam structures have been identified (USDI et al. 1994), including diverting the river (1) in tunnels, (2) around dams in a surface channel, (3) through dam structures, or (4) over dams by creating a notch through the structures. The notch approach appears to be the most feasible and economical at this time.

For nearly 80 years the projects have acted as large settling basins, slowing the velocity of the river and trapping sediments. From 2 million to 3 million m^3 of sediment have accumulated in Lake Aldwell and nearly 9 million m^3 in Lake Mills, most of which is deposited in deltas at the head of each reservoir. The management of these sediments to minimize short-term environmental degradation downstream provides the greatest challenge and economic cost of the dam removal effort.

Three feasible plans for managing the sediments have been identified (USDI et al. 1994): (1) The material could

Figure 3. Glines Canyon Dam

be removed from the inundated regions and relocated to a terrestrial or saltwater site; (2) The river could be allowed to erode a new channel through the accumulated material with subsequent sediment deposition in saltwater; and (3) Only the material in the path of the river would be relocated and stabilized adjacent to the new river channel, leaving the remaining material in place for re-vegetation and habitat restoration.

The ultimate choice of a sediment management strategy rests on costs, protection of downstream water users and fish habitat, and the need to restore the original stream channel configuration in Lake Mills and Lake Aldwell. From an ecosystem and fishery restoration standpoint, complete removal of all sediments to another site would be most desirable, but this option is exponentially greater in cost than other approaches (up to US$194 million). Partial erosion of sediments to saltwater, coupled with relocation of material in place, could allow the passage of fish, support revegetation, safely accommodate flood flows, and remain relatively maintenance-free at a substantially reduced cost (US$63 million). Thus, the latter strategy may be most desirable from both an environmental and economic standpoint.

Ecosystem and Fishery Restoration

The cornerstone of ecosystem and fishery restoration for the Elwha River is the expected recovery of native anadromous fish runs following dam removal and restoration of inundated terrestrial and riverine habitat. Natural recovery of wildlife populations is expected to occur after habitat recovery and restoration of the full complement of anadromous fish runs.

Precise replication of past habitat conditions within the lake basins would be impossible, but written records, historic photographs, and rich oral history provide a guide for habitat restoration. Prior to inundation, these broad alluvial valleys were bordered by steep forested slopes. During dam removal, habitat restoration actions would consist of immediate, short-term measures to provide erosion control and form a suitable substrate and organic layer for native species regeneration. After dam removal, a sequential, recurring revegetation program would be initiated to permanently reestablish native mixed-conifer/hardwood forests and riparian vegetation (USDI et al. 1994).

Anadromous fish restoration activities are necessarily intertwined with the expected timing of complete dam removal (no sooner than 1998) and reestablishment of a relatively stable river channel in the lower river. Rebuilding Elwha River anadromous fisheries may span 20 years to complete stock assessment, brood development, juvenile outplanting, and evaluation of adult returns and ecosystem response (USDI et al. 1994), although we acknowledge that restoration is an ongoing process and not easily fixed in a specific time period.

Management of impacting fisheries is an integral part of fisheries restoration. During the rebuilding period, harvest rates would be phased down on stocks currently supported by hatchery production (chinook and coho salmon and steelhead) to a level conducive with wild production.

Key assumptions in rebuilding the Elwha's anadromous fisheries are (1) fish passage through the dam sites would be hazardous until dam removal is completed; (2) the viability of lower Elwha River fish habitat and hatcheries during dam removal depends on sediment management scenario employed; and (3) juvenile outplanting would significantly speed fish restoration and allow reintroduction of fish stocks best adapted to the Elwha River's unique environment.

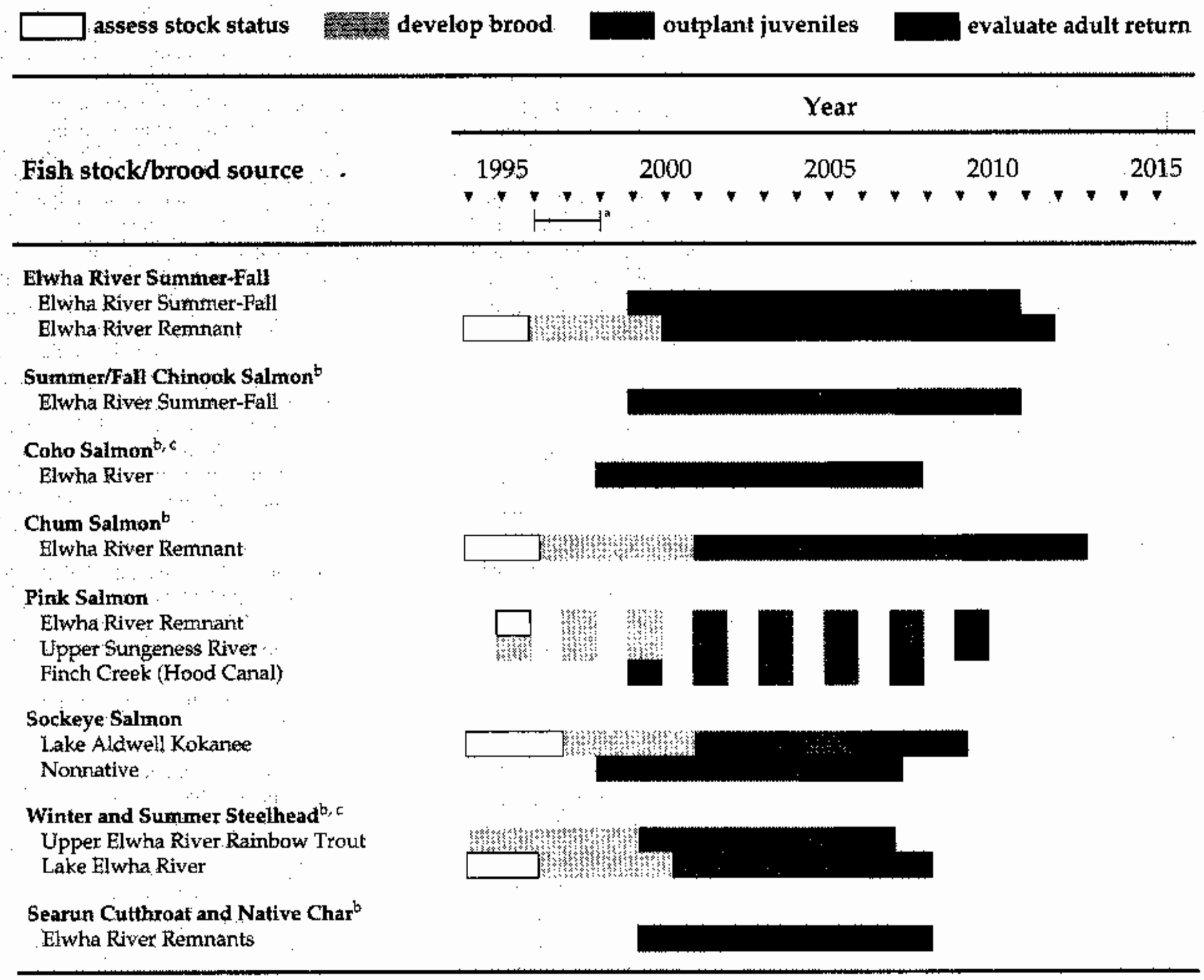
Reintroduction of existing Elwha fish stocks should yield the greatest adult return (Nickelson et al. 1986; Reisenbichler 1988), and use of native Elwha stock is a first priority in rebuilding fish runs. However, past hatchery introductions and lack of access to upriver habitat have depleted native Elwha stocks so nonnative introductions may be necessary for some stocks.

More than one restoration option is identified to restore most Elwha fish stocks; primary options and a timeline for reintroduction are shown in Table 3. For planning purposes, two cycles of each major activity (identification and development of brood stock, as necessary, followed by outplanting and evaluation of adult return) are depicted to give perspective on the time scale involved. Restoration planning efforts would initially be directed toward all options, but those that demonstrate most promise would eventually be pursued.

Natural recolonization is fully anticipated for some fish stocks because adult anadromous salmonids would gradually penetrate the upper drainage and reestablish themselves once access is regained. In Puget Sound, for example, when access to 145 rkm in the upper Skykomish River above Sunset Falls (a natural barrier) was provided, chinook and pink salmon penetrated the upper reaches of the basin, and their populations peaked in 15 and 25 years, respectively (Seiler 1991).

Restoration of spring chinook salmon would primarily rely on outplanting juvenile summer-fall Elwha stocks in their historic range (the uppermost reaches of the basin) and then allowing natural processes to establish an early run (Table 3). Chinook salmon are known to adapt rapidly to new situations (Healey 1991), and significant shifts in spawn timing have been reported in response to new environmental conditions (Kwain and Thomas 1984).

Table 3. Principal options for restoring Elwha River anadromous fish stocks. Major activities involved in restoration options are:



[a]Assumed dam removal and fish passage restoration (1996-1998).

[b]Natural recolonization is expected to occur in conjunction with any planned outplanting.

[c]Fry outplanting may occur one year (coho) to two years (steelhead) before complete dam removal to allow for natural rearing.

In the Elwha, the existing summer-fall chinook salmon stock could eventually exhibit an earlier timed component (spring type), responding to the upper river's cooler temperature regimen, which requires an earlier return and spawn timing to complete the life cycle (E. Brannon, University of Idaho, personal communication). Alternately, a remnant spring chinook run may exist in the lower Elwha River, but further status review and enhancement are needed before seeding of the upper watershed could be undertaken with lower river stock (Table 3). Whether Elwha chinook would again exhibit their large size (up to 45 kg) is problematic; however, the environmental conditions that produced these large fish would again be available.

Summer-fall chinook and coho salmon in lower river hatcheries would serve as a ready source of brood for outplanting. Coho salmon would initially be introduced above rkm 26, the assumed limit of chum and pink salmon (Figure 1), to reduce predation on these species. Juvenile coho salmon are important predators of juvenile chum and pink salmon, and separation of these stocks in space or time is an important management consideration in Puget Sound hatchery releases (J. Ames, WDFW, personal communication).

Chum and pink salmon restoration would entail rebuilding remnant Elwha populations or importing stocks from nearby sources, such as Strait of Juan de Fuca streams (chum salmon) or the Dungeness River and Hood Canal (pink salmon). Few pink salmon have been observed in the Elwha River since 1989, compared to estimates of more than a thousand in the early 1970s (WDF et al. 1993). These pink salmon may only be strays from another river system.

Sockeye salmon restoration would follow two paths. The native lower river stock no longer exists because Elwha Dam blocks access to Lake Sutherland (Figure 1), which is needed to complete the freshwater phase of the Elwha sockeye life cycle. Sockeye restoration would involve either importing a suitable stock or enhancing the anadromous component of Lake Sutherland kokanee, assuming the stock retains a significant genetic element of the original Elwha sockeye. Kokanee, although landlocked for many generations, may produce anadromous offspring that, through captive rearing, could be used to restore depleted sockeye stocks as proposed for recovery of endangered Snake River sockeye (Bevan et al. 1992). Following this strategy, smolts would be trapped at the outlet of Lake Sutherland and reared in captivity to maturity; their offspring would be returned to the lake during one or more cycles prior to removal of Elwha Dam.

Restoration of Elwha steelhead would focus on use of native Elwha stock. Reisenbichler and Phelps (1989) suggest that the upper Elwha River rainbow trout *(O. mykiss)* may be descendants of the original Elwha steelhead, trapped in the upper river since Elwha Dam closed. Recent smolt trapping at Elwha Dam produced outmigrating steelhead (Stone and Webster Engineering Corporation 1991), which apparently originated from the upper river's rainbow trout population. Analogous rainbow/steelhead populations have been reported above man-made barriers in the Columbia River, producing anadromous offspring (Mullan et al. 1992). In the Elwha, adult trout in the river's headwaters are being captured and transferred to a lower river hatchery for brood development. If returns are adequate, progeny of these fish would be used to outplant the upper river. Alternatively, remnant runs may exist in the lower Elwha River, but further status review is needed, followed by enhancement action before seeding of the upper watershed could be undertaken (Table 3).

To rebuild native runs of searun cutthroat and native char, natural recolonization would be relied on. Remnant, landlocked forms of these species may also exist in the upper watershed in an analogous manner to rainbow/steelhead.

Restoration Costs

When the costs of project acquisition, fish and habitat restoration, water quality protection for municipal and industrial users, and dam removal and sediment management are considered, the likely total restoration costs for the Elwha River range from $147 million to $203 million and span 20 years (USDI et al. 1994). Dam removal and sediment management are the single greatest costs and will most likely range from $67 million to $80 million for 3 to 8 years. If all accumulated sediments were completely removed, the total project cost could be $313 million. Complete sediment removal is not recommended at this time but would be explored during development of an environmental impact statement, occurring now through 1995.

The estimated cost of dam retention with fish passage facilities has been estimated at $46 million for 30 years (FERC 1993). However, this alternative fails to include turbine screens at Glines Canyon Dam and gravel replenishment below both dams. It also fails to meet both ecosystem and fishery restoration goals, and thus is not a true comparison of benefits or costs.

Conclusion

Passage of the act has provided an excellent opportunity to resolve litigation associated with a contentious federal licensing proceeding and to restore the ecosystem of a major anadromous-salmonid-producing river system. Dam removal, as well as ecosystem and fishery restoration, are feasible. The short-term economic costs are high, but the long-term returns are substantial (restoration and protection of treaty Native American fishing rights, increased commercial and recreational fishing and tourism, re-establishment and protection of ecosystem diversity, and research opportunities). The act offers a once-in-a-lifetime opportunity to fully reverse an environmental mistake.

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