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Abstract

The decision to remove the Elwha and Glines Canyon dams on the Elwha River, Washington was preceded by the collection of substantial amounts of biological and physical data. Studies were conducted to identify existing water quality within the reservoirs and river, fish populations and habitat availability, fish passage mortality through the dams and reservoirs, effects of the hydropower projects on wildlife habitat, and economics. Although this information was generally specific to the federal hydropower licensing process, it provides valuable information on baseline, or with-project, conditions that may allow for comparisons to the post-project river.

Introduction

The September 2007 award for construction of the water treatment system for the City of Port Angeles marked the first on-the-ground step towards removal of the two Elwha River dams and recovery of the Elwha River ecosystem. This is a significant step in a process that was the first in the nation requiring the Federal Energy Regulatory Commission (FERC) to consider dam removal rather than licensing over the objections of the owner and the operator of the dams. During the run up to the actual removal of the dams, managers and researchers interested in understanding the environmental response to a restoration project of this magnitude have begun to implement baseline studies for their selected field of interest, and plan for long-term monitoring following dam removal. It is our observation that the science of monitoring the effects of this project is much different than the science that was needed to make the decision that dam removal was a good idea in the first place.

The decision to remove the Elwha River dams required that policy makers and regulators understood the effect the existence of the two facilities had on the ecosystem, were confident that removal would lead to recovery of the ecosystem on a scale that justified the expense, and were convinced that the impacts of dam removal were balanced against the benefit of the action. The need for this information drove the scientific investigations with efforts tending to focus on evaluating the effectiveness of various fish passage facilities, estimating potential fish production if passage were provided, and estimating the environmental consequences of various approaches to restoring the ecosystem (including dam removal). Additionally, historic records were gathered to document the efforts that had already gone into preserving fish and wildlife in the basin as a result of the effects of the dams.

It is our observation that much less information is needed in the dam removal decision process than that needed to test scientific hypotheses. In general, the policy maker must make a decision whether or not to remove a dam within the framework of the National Environmental Policy Act (NEPA; Public Law 91-190, 42 U.S.C. 4321-4347, January 1, 1970, as amended) or related state environmental review processes. Commonly, such a decision within NEPA is based on "common sense" as supported by "credible scientific evidence" and "within the rule of reason" (NPS 2001). In general, the information used to support the decision often involves single point estimates or at best a couple of years worth of data that may not accurately reflect annual and seasonal trends. In contrast, testing of scientific hypotheses require enough data to test statistical accuracy.

Although the science needed to decide to remove the Elwha River dams was often not as

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complex as the baseline monitoring work currently underway, that is not to say that it was any less valid or important. In fact, critical information was collected in the years leading up to the decision to remove the two dams upon which subsequent efforts may build upon. Further, we believe that it is important that today's researchers are aware of the work that went before and the context under which the work was completed. In this paper, we review selected information collected before and during the Federal Energy Regulatory Commission (FERC) licensing proceeding and during the National Park Service (NPS) EIS processes. This includes sections on fish, wildlife, invertebrates, water quality, sediment, and socioeconomic factors. No specific studies were directed at vegetative communities as a part of the decision process, but plant communities were described in DOI (1996) and DOI (2005) and a draft revegetation plan provided in DOI (1996).

Historical Background

Hydropower Licensing and the Elwha Act

Most non-federal hydroelectric projects must be licensed by the federal government under authority of the Federal Power Act (FPA; 16 U.S.C. 791-828c as amended; Chapter 285, June 10, 1920; 41 Stat. 1063). Federal licensing authority first resided with the Federal Power Commission which later became the FERC. Because the Elwha Dam, built from 1910 to 1913, preceded the Federal Power Act, the owners were not required to seek a license. Indeed, the only regulation any agency sought to enforce was the provision in Washington State law that required, "fishways wherever food fish are wont to ascend" although even this requirement was circumvented (Brown 1982). At that time fishways generally referred to fish ladders, although the broader definition today would include trap-and-haul and juvenile fish screens. Curiously, "food fish" in Washington were defined as salmon whereas "game fish" were steelhead (*Oncorhynchus mykiss*) and other trout. The Glines Canyon Hydroelectric Project was constructed from 1925 to 1927 and received a 50 year operating license in 1926.

In the 1960s, the FERC began exerting its authority over unlicensed non-federal hydroelectric projects across the country, including the Elwha Hydroelectric Project. The owner of the Elwha Hydroelectric Project at the time, the Crown Zellerbach Corporation, filed a license application for the project (FERC No. 2683) in 1968 and an application to relicense the Glines Canyon Hydroelectric Project (FERC No. 588) in 1973. In 1979, after issuing an order finding that the two hydroelectric projects were hydraulically, electrically, and operationally interconnected the FERC combined the two license proceedings into a single process where the combined impacts could be assessed.

When evaluating whether to issue a new license as in the case of the Elwha or a relicense as in the case of Glines Canyon, the FERC must balance competing benefits and costs, and in so doing give "equal consideration" to power production, impacts to fish, wildlife, and their habitat, and recreational opportunities affected by the project (16 U.S.C. 797(f)). In addition, the Electric Consumers Protection Act requires FERC to include license conditions to protect, mitigate, and enhance fish and wildlife (see 16 U.S.C. 803(a)). Key to this requirement is that FERC must consider recommendations from state and federal fish and wildlife agencies (16 U.S.C. 803(j)(1)) and affected Indian Tribes (16 U.S.C. 803(a)(2)(B)). Further, Section 18 of the FPA confers upon the Secretaries of Commerce and Interior the authority to prescribe fishways, although the FERC has sought to considerably weaken this authority by claiming it must ultimately "balance" all impacts to projects, including the rejection of fishway prescriptions it deems inappropriate or too costly.

Because the issuance of a license for either or both projects constituted a major federal action as defined by NEPA, the FERC initiated development of an environmental impact statement (EIS) in 1989. Unique to the FERC EIS at that time was the evaluation, limited though it was, of dam removal over the objections of the projects' owner. In doing its analysis, the FERC considered information already submitted but also directed the applicant to develop significant new environmental data and requested much information from the federal and state agencies and the Lower Elwha Klallam Tribe (LEKT). This wealth of data resides in a number of locations, including reports by the applicant to the FERC, filings by the Joint Fish and Wildlife Agencies (JFWA; consisting of the National Marine Fisheries Service, U.S. Fish and Wildlife Service, National Park Service, Washington Department of Game, and the Lower

Elwha Klallam Tribe), reports by the Washington Department of Fisheries, U.S. Fish and Wildlife Service, National Marine Fisheries Service, and LEKT, and summarized in a FERC report (FERC 1993) following passage of the Elwha River Ecosystem and Fisheries Restoration Act (Elwha Act, Public Law 102-495) of 1992.

The Elwha Act is a negotiated settlement among the parties to the FERC licensing proceedings that removed FERC's authority "to issue a permanent license or similar order with respect to either project" (Section 5(a)). The Elwha Act also conferred upon the Secretary of the Interior the authority to remove both dams for the "full restoration of the Elwha River ecosystem and the native anadromous fisheries" (Section 3(c)). Because this standard is much different than the FERC requirement to balance all of the potential benefits and impacts associated with licensing the hydroelectric projects, much new information needed to be developed. This information was developed by the fisheries agencies, LEKT, U.S. Bureau of Reclamation, and the U.S. Army Corps of Engineers and contained in technical reports and three EISs (DOI 1995, 1996, 2005).

Hatchery Operations

On October 30, 1912 during a storm, the foundation of the Elwha Dam failed and the gathering waters within Lake Aldwell rushed downstream unhindered. This catastrophe occurred because Elwha Dam was laid upon river gravel rather than connected to bedrock (DOI 1996). The Olympic-Leader reported on November 1, 1912 the events of the resulting flood, noting that the 9 m high torrent had left *"great numbers of salmon and trout strewn over the fields and through the woods, and everyone going down that way got all the fish they could carry home."* This event highlighted the devastating impacts to Elwha River fisheries that had been largely ignored by the dam's proponents.

Beginning in 1915 and continuing through the present, a significant effort was focused on preserving remnant fish populations with hatchery supplementation below Elwha Dam instead of restoring anadromous fish to the watershed. Concern over the fate of Elwha River fish populations prompted the Washington Department of Fish and Game to use the existing state fish passage law to negotiate a settlement with the dam owners to operate a fish hatchery in lieu of fish passage facilities (WDFG 1915). The hatchery operated from 1915 to 1923 before being discontinued because of poor success (WDFG 1924). In that time, over 22,000,000 eggs were collected from fish captured at the base of Elwha Dam (Hosey and Associates 1988). In Table 1, egg take has been used to estimate a minimum adult return, using a point estimate for eggs/female from the ranges provided in Groot and Margolis (1998) and an assumed 1:1 male to female ratio.

Interest in the use of hatcheries to preserve Elwha River salmon, in particular Chinook salmon (*O. tshawytscha*), was reinvigorated in 1930 when Ernie Brannon, superintendent of Washington State's Dungeness Hatchery, turned his eye to the Elwha River (Lane and Lane Associates 1990).

TABLE 1. Hatchery egg takes (**E**, eggs x 10^3) and corresponding estimates of adult broodstock (**A**) from 1914 -1923 in the Elwha River.

	Coho		Chinook		Steelhead		Chum		Pink		Total	
Year	E	A	E	A	E	A	E	A	E	A	E	A
1914	600.5	400	0	0	0	0	0	0	0	0	600.5	400
1915	1050	700	160.3	70	433	290	0	0	0	0	1643.3	1060
1916	5263	3500	304.6	135	139	90	0	0	0	0	5706.6	3725
1917	4148	2750	0	0	0	0	0	0	0	0	4148	2750
1918	60	40	944.5	420	440.5	290	0	0	0	239.5	1684.5	1070
1919	40	30	376	170	361	240	0	0	0	0	777	440
1920	0	0	0	0	0	0	2120	1400	0	0	2120	1400
1921	143	100	137	60	178	120	3997	2650	0	0	4455	2930
1922	60	40	185	80	139	90	0	0	0	1278	1662	1910
Total	11365	7560	2107.4	935	1757.5	1165	6117	4050	1517.5	2020	22864	15685

Brannon reported an extensive population of Chinook salmon in the lower river, many of a very large size. He began gaffing Chinook from the Elwha to raise juvenile Chinook at the Dungeness Hatchery for release back into the Elwha. For this paper, records were not located that document the number of Chinook released into the river for all years from 1930 to 1958 (but see Brenkman et al. 2008a for a summary of existing hatchery records). However, in a November 3, 1930 letter to the State Superintendent of Fisheries, Brannon reported that he had gaffed 181 female and 215 male Chinook in a 10 day period (approximately 900,000 eggs). In a subsequent letter to the superintendent dated November 25, 1946, Brannon reported collecting another 578,000 Chinook eggs from the Elwha.

The practice of rearing Elwha Chinook at the Dungeness Hatchery for release back into the Elwha River continued through he mid-1970s, when the State's Elwha Rearing Channel was constructed. This facility was designed to serve as a spawning channel for adult Chinook salmon, without egg incubation or early rearing facilities. Funding for the channel was provided by the Crown Zellerbach Corporation, the owner of Elwha Dam, as part of a settlement with the Washington Department of Fisheries. Expected mortality through the two dams (see Fish Passage section, below), combined with costs associated with fish passage devices made restoring fish to the upper watershed more costly than rearing fish in a hatchery (WDF 1971). Once again, the State opted for artificial production instead of natural production via fishways. The Elwha Channel became operational in 1975.

In 1978, the LEKT also began hatchery operations on the Elwha River. Unlike the State's facility, the Tribal hatchery was not directly associated with the existence of the two dams on the river, but was rather an outgrowth of the 1974 "Boldt" decision which affirmed the treaty rights of Washington Tribes to harvest fish within their, "Usual and Accustomed Areas." The facility was intended to provide an adequate supply of fish for the Tribe's members to harvest and was not initially used to preserve Elwha stocks.

The State never seriously pursued hatchery production of any species other than Chinook and steelhead (*O. mykiss*), whereas the Tribe focused primarily on coho (*O. kisutch*) and steelhead (FERC 1993). Only limited efforts were made to implement a chum (*O. keta*) hatchery program and efforts on pink (*O. gorbuscha*) salmon were only in the area of spawning surveys. A few sockeye (*O. nerka*) salmon were released in the reservoirs to evaluate the utility of a larger scale enhancement program (Moore 1959) nd nonnative kokanee (landlocked sockeye) were released in Lake Sutherland for thirty years (Hiss and Wunderlich 1994b) in order to support the recreational fishery, but no concerted effort was ever made to create an anadromous sockeye hatchery run in the Elwha basin.

Historical Scientific Investigations

Fish Populations

Although prior to passage of the Elwha Act hundreds of dams had been removed in the United States (Hart et al. 2002) for safety, economic, or other reasons, it was unthinkable at that time that two high head hydroelectric projects might be removed primarily for fisheries benefits. The concept that dam removal of this magnitude might be a viable option in the FERC licensing/relicensing process only gained momentum when a growing body of evidence showed that significant gains in salmon abundance would only be possible by removing the dams. This concept was strengthened with the acknowledgement by all parties that certain species, like pink and chum salmon, were unlikely to benefit from provisions for fish passage because much of the upstream spawning habitat for these fish is inundated by the reservoirs (Hosey and Associates 1987) and too many of the juvenile migrants would not survive reservoir passage to sustain upstream runs (JFWA 1988). This and other information that helped define the decision is summarized below.

Fish Passage

In the early 1950s, Milo Bell, with the Washington Department of Fisheries, outlined a research program to investigate fish passage options on the Elwha and other rivers throughout the state (Johnson 1997). Under Bell's program, Schoeneman and Jung (1954) evaluated mortality of juvenile coho and Chinook salmon at the two Elwha River dams between 1952 and 1954, finding an overall survival rate of 62–94% depending upon whether the fish exited the reservoirs through the turbines or over the spillways. Mortality also varied between the two facilities and between fish species.

Even though mortality could be quite high, WDF deemed fish passage to be economically feasible (Johnson 1997). They continued passage studies through 1957 and went so far as to contract with an engineering firm to design a fish ladder and trap-and-haul facilities. At a cost of over $300,000 in 1956 dollars, the dam owners were not enthusiastic about constructing the facilities. Further, the ocean survival of fish that passed the dams appeared to be extremely low. Despite the planting of 950,000 coho, over 1,000,000 chinook and approximately 4,000 sockeye smolts above the dams between 1952 and 1957, there was no obvious increase in the number of fish returning to the river as a result of the efforts (Moore 1959).

Official interest in providing fish passage at the two dams did not begin again until the FERC proceedings for licensing of the Elwha Dam began in 1968. WDF revisited the work done in the 1950s and developed a suite of options for increasing downstream survival of juvenile salmon (WDF 1971). Although WDF officially settled with the dam owners by agreeing that providing fish passage was not necessary, the LEKT, Olympic National Park (ONP), USFWS, National Marine Fisheries Service, Washington Department of Wildlife, and a number of environmental advocacy groups continued to push for restoring salmon runs to the upper watershed.

In 1983, ONP and the USFWS began a series of studies to continue evaluation of downstream passage survival at Glines Canyon Dam and Elwha Dam across a variety of species and exit locations. Mortality was assessed in a number of locations, including the reservoir/forebay, turbines, spillway, and tailraces (Wunderlich 1983, 1988; Wampler et al. 1985; Wunderlich and Dilley 1985, 1986, 1990; Dilley and Wunderlich 1987, 1990; Wunderlich et al. 1988,1989)

Survival was found to be heavily dependent upon mode of exit as well as dam operation (Table 2). For example, survival was nearly 100% for yearling steelhead at the Glines Canyon spillway, if the spillway was passing >12.75 cms of flow. However, if the gate opening was reduced to pass <7.10 cms, then survival dropped to 32%. Similarly, if the Glines Canyon turbine was operated at full capacity, survival of Chinook fry was as low as 28%. This contrasts with the finding of Schoeneman and Junge (1954) of 67% survival through the turbine, though they failed to report the generation level at the time of their test. This is an important oversight because generation was found to a have a major affect on survival through the Elwha Dam turbines.

It is clear from the above information that the sensitivity of passage survival to dam operation had the potential to significantly affect the economic viability of the two dams. With survival directly related to decreased power generation at the turbines and increased flow passage through the spillways, any successful efforts to restore salmon to the upper watershed would require a major reduction in power production and modifications to the facilities to increase survival.

One obvious potential alteration to the facilities was screening the penstocks to prevent entry by juvenile fish. The dam owners knew that conventional screens were very expensive to install and maintain. Therefore, in the early 1990s they joined with the Electric Power Research Institute (EPRI) to investigate a lower cost alternative, an inclined plane screen (or Eicher screen). Initial tests of the Eicher screen were very promising, with nearly 100% survival seen under ideal conditions. However, in order to clean the screens of debris, they would be rotated to a position parallel with the flow through the penstock and then reseated. The initial tests after each cleaning were showing significant increases in mortality due to impingement along the seal of the screen. To correct the problem, the penstock would be dewatered and the screen manually reseated. Although this particular problem could conceivably have been corrected

TABLE 2. Juvenile fish passage survival (%) estimates by exit strategy (summarized from U.S. Fish and Wildlife reports, see text) for the Elwha River dams.

	Turbines		Spillway	
Species	Elwha	Glines Canyon	Elwha	Glines Canyon
Chinook		28.1 - 35.4		42.2
Coho	70.5 - 87.8		65.9 - 88.7	
Steelhead yearlings		< 50	32	32 - 100

through increased vigilance by the operator, the fisheries agencies had called for testing of smaller fish and testing under cold water conditions when fish were more lethargic and thus potentially vulnerable to greater impingement rates. Further, any screening did not solve the problem of fish passage through the reservoirs. Rather than continue with the testing requested by the fisheries agencies, the Eicher screen technology was set aside.

Residualism and mortality in the reservoirs and forebay were considered during the licensing proceedings. Dilley and Wunderlich (1990) evaluated the migration patterns of 430,000 Chinook pre-smolts (60 mm total length) that were planted throughout the upper Elwha watershed in April and found a predominately late-summer passage time at the Glines Canyon Dam. They noted that predation and residualism had greatly increased (up to 54%) for other late-migrating stocks and cautioned that the Elwha reservoirs could adversely affect success of restoration efforts.

Hosey and Associates (1990) evaluated this same information and arrived at a different conclusion. First, they found that overall survival from planting to emigration was about 30%. This value was consistent with observations of a number of other investigators in Washington and Oregon. Second, stomach content analysis of bull trout (then identified as Dolly Varden) taken in June and July from Lake Mills found that just 16% of the fish sampled had eaten Chinook smolt. In each case (5 of 30) only a single Chinook was found. Therefore, they concluded that predation could be a concern but the magnitude of the problem was unclear as the abundance of bull trout and other predators was unknown. Finally, the authors noted that although the migration of planted Elwha Chinook appeared to be delayed, the fish emigrated at a larger size than the hatchery fish, increasing early survivorship and adult return rates.

In summary, cumulative passage mortality through both dams without specific actions to improve survival could be as high as 45% for fall Chinook and 29% for coho (FERC 1993). Costs to screen the penstocks at the Elwha Dam would be quite high (Wampler et al. 1985, FERC 1993) while FERC rejected screening of the penstock at the Glines Canyon Dam even though the JFWA had called for it. Similarly, there would be high costs in terms of reduced power production to pass adequate flow through the spillways to ensure fish survival (FERC 1993). Despite these potentially high costs and the cursory investigation of dam removal ordered by FERC, it appeared unlikely that FERC would have ordered the project owner to remove the dams and much more likely that FERC would "balance" competing issues by ensuring profitability for continued hydropower production at both dams.

Species Abundance and Distribution

At the time Elwha Dam was constructed, limited documentation existed on salmonid utilization of the Elwha River, with no technical information on salmonid abundance or distribution. Certainly, members of the Tribe were intimately familiar with the river's salmon as were other locals, but they were not consulted until years or decades later (Lane and Lane Associates 1990). Records from the original Elwha Hatchery provided some information on fish abundance and species diversity in the years immediately following dam construction, but they are limited in scope. Specifically, during its operation over 22,000,000 eggs were collected by the hatchery staff from fish captured at the base of the dam (Hosey and Associates 1988) (Table 1). Fish collected were likely only those that were ripe on the day of capture and therefore do not represent the total population that likely reached the dam in any given year. By 1923, the numbers of fish ascending to the dam had declined to a point that the operation was deemed to be no longer feasible (Johnson 1997).

Several attempts have been made to describe fish distribution above Elwha Dam following dam construction (summarized by Brenkman et al. 2008b). Adams et al. (1999) conducted an extensive systematic survey effort of mainstem and tributary habitat from the headwaters to Lake Aldwell, utilizing snorkeling, electrofishing, and angling methods. Rainbow trout were observed to be the most abundant species in the watershed, followed by bull trout. Localized populations of native cutthroat (*O. clarki*), non-native brook trout (*S. fontinalis*), and potentially introduced cutthroat (*O. clarki lewisi*) were also observed. The investigators also attempted to estimate the abundance of each species, although variance of the estimates was quite high. Morrill and McHenry (1995) also investigated distribution of fish in tributaries, primarily in the middle reaches of the river. Finally, Washington Trout (Glasgow 2000) evaluated the upper limits of fish distribution in the mainstem

TABLE 3. Estimates of historic Elwha River salmonid and trout production based upon available habitat in the Elwha River and production estimates from other watersheds.

Method	Chinook	Coho	Steelhead	Pink	Chum	Sockeye	Bull trout	Cutthroat
WDF (1971)	8500	0	0	91000	15000	0	0	0
WDG (1973)	0	0	5100	0	0	0	0	9900
BIA (1983)	1284	3520	483	3147	9042	0	0	0
Hosey (1988)	6720	6860	3616	12000	0	85	1000	0
JWFA (1988)	17493	19143	0	137600	25600	0	3709	1000
FERC (1993)	6900	12100	5757	96000	18000	0	0	0
DOI (1994)	6900	12100	5757	96000	18000	6000	0	0

Elwha River and tributaries, finding fish habitat up to the base of a 9.1-meter falls near the snow finger forming the headwaters of the Elwha River (approximately rkm 69.7), with the last fish seen several hundred meters downstream.

The impetus to estimate historic production of the Elwha watershed was partially driven by a desire to restore the watershed. Of equal importance was a desire by the State to estimate legal damages caused by the dams. Without direct information available to describe historic production, it was necessary to make estimates based upon available habitat in the Elwha River and production estimates from other watersheds (Table 3). The first detailed analysis of potential production was completed by WDF in 1971 (WDF 1971), with subsequent efforts made by WDG (Katz et al. 1983), the Bureau of Indian Affairs (Chapman 1983), Hosey and Associates (1988), the Joint Fish and Wildlife Agencies (JFWA 1988), the Federal Energy Regulatory Commission (FERC 1993), and the DOI et al. (1994). In some cases, estimates of available habitat were made directly, by on-the-ground surveys (WDF 1971, Hosey and Associates 1988) of lineal accessible distance. In other cases, estimates of available habitat were made by mapping exercises, estimates of watershed area, flow based habitat modeling, or simple comparisons to "similar" basins.

As might be expected, each method provided a different estimate of production, with substantial variability between methods. For example, the BIA (1983) estimate of 1,284 Chinook spawners above Elwha Dam was at the low end of the range, while the JFWA (1988) calculated a spawning potential of over 17,000. Estimates of chum spawners provided by WDF (1971), the JFWA (1988), and FERC (1993) ranged from 15,000 to 25,600. On the other hand, Hosey and Associates (1988) believed that chum salmon recovery simply wasn't possible. Similar variability was seen for the other species.

Observations by Tribal elders and early settlers provide qualitative information to compare with contemporary estimates of production and distribution of salmon in the Elwha. Ed Sampson, a Klallam native who grew up on the Elwha River, noted when interviewed in 1976 (Lane & Lane Associates 1990) that "*the fish were so plentiful that there was no need to select 'good' areas*." He also said "*When I went out fishing with my grandmother, I would catch 50 fish. She would catch 100. We'd carry them back in a wheel-barrow*." Other early homesteaders to the area reported that pink salmon were so abundant in Little River, a tributary near the head of Lake Aldwell, that horses shied and refused to cross the channel (Brown 1982). Martin Humes, whose homestead was located upstream of Rica Canyon near the mouth of Idaho Creek, wrote to his sister on November 9, 1897, "*The salmon lay there with their backs out of water. All I had to do was to reach over them, hook the hook in their back and pull them out. They are the hook bill* [coho] *salmon and have just come from salt water. We look for lots of them to run now as this run has just commenced.*" Joe Sampson, a Klallam native, reportedly made expeditions to Chicago Camp and found large salmon there (Adamire and Fish 1991).

Despite historic reports, questions continued to exist about the ability of salmon to access the upper reaches of the Elwha (Pess et al. 2008). WDF (1971), based upon their physical surveys of the river, believed that salmon could ascend upstream to rkm 66.0. However, the owners of the dams questioned whether or not salmon could pass beyond Grand Canyon (rkm 34.6) (Katz et al. 1975) or even Rica Canyon. In order to assess the ability of fish to colonize the watershed, and pass through these potential barriers, the USFWS radio-tagged adult summer steelhead (Wampler 1984) obtained from the WDG, and released them at various locations in the upper watershed. Releases were timed during the summer months (July to September) with flows ranging from 16.7 cms to 51.0 cms. In all cases, fish released in Lake Mills were observed to readily pass through both Rica Canyon and Grand Canyon, ascending to at least the Goldie River, located above rkm 46.7. A fish released near Camp Wilder ascended upstream to rkm 59.5. This work, combined with the snorkel surveys conducted by Hosey and Associates (1987) confirmed that fish could pass through Rica and Grand Canyon, upstream to near the headwaters. The only limitation identified was for pink and chum salmon which may not be able to ascend through Rica Canyon. Munn et al. (1999) confirmed the amount of accessible habitat and concluded that although many Elwha River tributaries within Olympic National Park are inaccessible because of physical migration barriers, they are nonetheless important as sources of sediment, woody debris, and nutrients.

Stock Integrity

In order for successful recolonization of the upper Elwha watershed to occur, fish must have access to the habitat, appropriate founder stocks must be present, and productivity of the watershed must be sufficient to offset sources of mortality, including natural mortality and harvest mortality. Assuming that providing access is relatively straightforward (either through dam removal or fish passage provisions), and further assuming that productivity is not limiting (given that the upper watershed is in relatively pristine condition) then the question of appropriate founder stocks becomes key. Prior to the decision to remove both dams, a significant amount of effort went into determining whether or not the remnant populations of fish in the river were suitable for large scale restoration efforts (Wunderlich and Pantaleo 1995).

The river's Chinook salmon population, which was renowned for its large body size, was the subject of considerable interest. Ernie Brannon had argued successfully that this stock should not be lost as early as 1930 (Lane and Lane Associates 1990). However, with over 70 years of hatchery influence, it was not clear that this population could be used to restore the Elwha. Large fish were rarely seen and the early returning component (i.e., spring run with peak entry in early July) was no longer evident (Dick Goin, Port Angeles fisheries historian, personal communication).

Ernest L. Brannon (son of the Dungeness Hatchery manager Ernie Brannon) and Bill Hershberger (1984) studied the migration behavior of Elwha Chinook compared with other Puget Sound populations and an Elwha/Lake Washington hybrid population. They found that these fish maintained a distinct pattern passed on between generations. Genetic analysis of tissue collected from Elwha Chinook showed a distinct separation from all other Puget Sound stocks (WDFW and WWTIT 1994, Meyers et al. 1998), although not of a scale to constitute a unique evolutionary significant unit, supporting the theory that the remnant Elwha Chinook population retained its unique heritage (see also Winans et al. 2008). Finally, investigations by the USFWS on fish passage through the two Elwha River dams showed that young Chinook could successfully rear in the upper Elwha watershed and return successfully to the river as adults at rates similar to, or better than the Elwha hatchery populations (Wunderlich 1983, 1988; Wampler et al. 1985; Dilley and Wunderlich 1987, 1990; Wunderlich and Dilley 1985, 1986, 1990; Wunderlich et al. 1988, 1989)

Questions remain, though, regarding the large body size of the historic Elwha Chinook population and the status of the early component of the run. Roni (1992) did not find evidence of unique growth, age, or fecundity for Elwha Chinook and hypothesized that rearing of fish in the hatchery may have altered the expression of certain phenotypic characteristics. Wunderlich et al. (1992) found that a few Chinook (<50) were migrating into the river in June, but could not confirm a distinct racial separation from the main summer/fall run. Even if these fish do represent a distinct race, the numbers may be at levels where inbreeding effects become a concern.

The Elwha River has been heavily planted with the Chambers Creek population of hatchery steelhead, as well as a locally adapted hatchery population established through collection of Elwha native brood and reared at the tribal hatchery (WDFW and WWTIT 1994), and a variety of resident rainbow trout stocks. Differential run timing between the hatchery populations and the native Elwha stock (Winter 1989) appears to have allowed for the maintenance of at least the spring spawning component of the native run. Wunderlich et al. (1992) found wild steelhead to be ten times more abundant than Chinook during spring test fisheries. Catch data and scale analysis of fish captured in tribal net fisheries indicated an average annual abundance of approximately 400 wild spawning adults between 1982 and 1997 (WDFW et al. 1997).

Interestingly, it appears that there may also be a remnant population of the native Elwha River steelhead population in the South Fork Little River above Elwha Dam. Genetic analysis by Reisenbichler and Phelps (1989) and Phelps et al. (2001) found that these resident rainbow trout were more closely related to coastal wild steelhead than to hatchery rainbow or other resident rainbow populations. Further, Hiss and Wunderlich (1994) captured a number of rainbow trout below Glines Canyon Dam that expressed the characteristics of outmigrating smolts. Similarly, progeny of resident Elwha River rainbow reared at the tribal hatchery were observed to smolt at the appropriate age (Larry Ward, Lower Elwha Klallam Tribe, personal communication). It is not known whether these resident fish are more closely related to summer or winter run steelhead, although known spawn timing of resident rainbow in the Elwha would seem to coincide with the winter race.

Elwha River coho salmon have been reared in the tribal hatchery since the 1970s, while the river has continued to support a naturally spawning component as well. Given that there has been little stocking of non-native coho populations into the Elwha (WDFW and WWTIT 1994), it is assumed that both the hatchery and wild spawning populations represent the original Elwha stock. The Elwha Tribe and NOAA Fisheries are currently conducting genetic analyses to answer this question (Winans et al. 2008). Like Chinook, coho fry planted above Glines Canyon Dam were observed to thrive, emigrate to the ocean, and return to the river as adults (Wunderlich 1993). Based upon coded wire tag data, the ocean distribution of the fish that reared naturally above the dam mirrored the distribution of hatchery fish of the same brood year (Wunderlich 1993).

Of all Elwha River salmon populations, pink and chum salmon experienced the most precipitous decline in abundance following dam construction (DOI et al. 1994). In fact, it was believed that Elwha pink salmon had been extirpated from the system until spawning fish were observed in the late 1990's (DOI et al. 1994). These low abundance levels led to considerable concern regarding the availability of sufficient numbers of fish to effectively recolonize the watershed. The USFWS, in cooperation with the LEKT, conducted a series of spawner surveys to estimate the abundance of Elwha chum salmon (Wunderlich et al. 1994, Hiss 1995). They concluded that the annual spawning abundance was much less than 500 fish and perhaps as low as 250 fish. However, they did conclude through genetic analysis that the population was distinctly separate from other chum salmon populations in Puget Sound, although a component of the run appeared to be influenced by hatchery plants of Walcott Slough chum. In order to protect this population as well as any remaining pink salmon, it was recommended that any hatchery releases of coho be delayed until June 1, to avoid the observed emigration timing of the native chum (Peters 1996).

Although a few sockeye are observed below Elwha Dam each year, the construction of Elwha Dam blocked access to Lake Sutherland which was believed to support the historic population, essentially extirpating anadromous sockeye from the basin (DOI et al. 1994). However, Lake Sutherland continues to support a viable kokanee population which may be related to the historic Elwha population (Hiss and Wunderlich 1994). WDFW hatchery records indicate the release of nonnative kokanee in Lake Sutherland from 1934 until 1964 (Hiss and Wunderlich 1994b). The influence of nonnative kokanee releases on the native kokanee and sockeye population was unknown until recently, but tissue samples collected for genetic analysis in 1994 and 2005/2006 seem to indicate that Lake Sutherland kokanee are distinguishable from Lake Whatcom kokanee populations which were periodically planted in Lake Sutherland (Faler and Powell 2003, Winans et al. 2008).

Cutthroat trout (*O. clarki*) and native char (*Salvilinus sp.*) were long known to be self-sustaining in the Elwha watershed above Elwha Dam (Mausolf 1975, Hosey and Associates 1988b). Abundance levels remain uncertain as does the origin of cutthroat trout populations. Until recently it was assumed that all native char in the river were Dolly Varden (*S. malma*), but Hiss and Wunderlich

(1994) confirmed that Elwha native char were bull trout (*S. confluentus*). Non-native brook trout (*S. fontinalus*) also inhabit the river (Morrill and McHenry 1995, Brenkman et al. 2008b).

Wildlife Populations

Potential impacts to wildlife were evaluated both because of standard FERC requirements but also to consider the ramifications of dam removal. A number of methods were used but were limited because little was known about pre-project wildlife populations in the Elwha River drainage other than potential species presence, similar to that known for fish populations. Because of this dearth of information, Stendal and Engman (1973) relied on historical accounts of species presence and a general understanding of habitat inundated by the two reservoirs. They concluded that 490 acres of this flooded habitat was important elk and deer wintering area.

Hosey & Associates (1990b) also used a habitat based approach, the Habitat Evaluation Procedure (HEP), to compare and contrast pre-project and with-project wildlife habitat conditions for lands owned by the applicant around Lake Aldwell, at the McDonald Bridge USGS river gauge, and associated with the Glines Canyon Hydroelectric Project. Wildlife species included in the analysis included Cooper's hawk, Douglas squirrel, pileated woodpecker, yellow warbler, lesser scaup, Roosevelt elk, black-tailed deer, beaver, and mink. Results of the HEP analysis indicated that construction of the two hydroelectric projects led to a decrease of habitat for all species except lesser scaup (Table 4).

Hosey & Associates (1990a) also conducted standardized sampling, field reconnaissance, and interviews with subject experts to determine locations and abundances of bald eagles within the Elwha River watershed. Counts were conducted between November 25, 1989 and April 14, 1990 during daylight. Eagles were most common around the river delta and decreased in numbers with increasing distance upstream, with very low numbers found upstream of Lake Mills. This disparity was assumed to be related to the absence of salmon above Elwha Dam.

Invertebrates

Munn et al. (1996) collected samples to determine baseline conditions of benthic invertebrates in the Elwha River (see also Morley et al. 2008). They found that the taxa were diverse with many species sensitive to the environmental quality present, indicating good water quality and habitat conditions. The divergence from these samples were those collected below Elwha Dam where midges (*Diptera: Chironmidae*) were numerically dominant and mayflies (*Ephemeroptera*) were depauperate.

TABLE 4. Habitat evaluation procedure (HEP) results showing net change in wildlife habitat units caused by Elwha and Glines Canyon dams (adapted from Hosey & Associates 1990b). Results apply to the areas around Lake Aldwell, Lake Mills, and the river between the dams.

Species (Habitat)	Pre-Project Annualized	With Project Annualized	Net Change
Pileated woodpecker	941.41	634.71	-306.70
Yellow warbler	16.20	12.00	-4.21
Cooper's hawk	838.58	746.83	-91.75
Douglas squirrel	1689.68	1345.34	-344.33
Mink (paulstrine)	47.18	48.70	1.52
Mink (Lacustrine)	0	340.64	340.61
Mink (Riverine)	262.96	95.00	-167.96
Beaver	127.38	98.72	-28.66
Roosevelt elk	593.14	512.81	-80.33
Black-tailed deer	773.09	647.90	-125.18
Lesser scaup (winter)	0.00	39.69	39.69

Water Quality

Since large reservoirs commonly alter water quality parameters such as water temperature and dissolved oxygen (Binger et. al. 1978) and have been used as a basis for mitigation (warm water fisheries in the reservoir and coldwater fisheries in the tailrace) FERC commonly orders studies to document reservoir water quality by season. For Lake Mills and Lake Aldwell water quality, Hosey & Associates (1988a) conducted field sampling during July through October 1987. For Lake Aldwell, Secchi disc readings varied from 4.39 m in early August to 7.22 m in late August and September. Dissolved oxygen (DO) concentrations ranged from 7.8 to 10.6 ppm at depths < 18.3 m with measurements as low as 3.3 ppm below 18.3 m. Temperature stratification of the reservoir water was strongest in early August followed by turnover and mixing by mid-October. For Lake Mills, Secchi disc readings varied from 7.32 m in late August to 4.88 m in late September, DO concentrations ranged from 5.4 to 10.5 ppm at depths less than 33.53 m with measurements as low as 1.3 ppm below 33.53 m, and temperature stratification of the reservoir water was strongest in late July and early August followed by a break down of stratification by early October (Hosey & Associates 1988a). Calculated flushing times at 14.2 cms for the two reservoirs varied from 8 days for the volumetrically smaller Lake Aldwell to 32 days for Lake Mills.

Groundwater resources of the Elwha River basin below Elwha Dam were extensively studied to determine if sufficient water quantities existed to eliminate the need for surface diversion and treatment to protect water users during dam removal. It was determined that there are insufficient quantities to meet water needs during dam removal (URS 2001). The appendices in this report provide a lot of information, including well logs.

In unrelated actions, Walters et al. (1979) evaluated the water resources of the Lower Elwha Indian Reservation and reported on surface water quality from Bosco Slough, West Slough, East Slough and the river mouth, as well as temperature data from the McDonald Bridge gauge and below Lake Aldwell. Surface water quality was reported to be of "excellent chemical quality" with mainstem temperatures ranging from 2.2° to 17.8° C. Water data from 22 wells was also reported. Groundwater was also considered to be of "excellent chemical quality" with temperatures ranging from 6.7° C to 8.9° C, but over-pumping could result in saltwater intrusion from the Strait of Juan de Fuca. McCormick (1996) sampled water quality parameters monthly from May 16, 1995 to September 4, 1995 to document baseline water chemistry and the influence of Glines Canyon Dam on downstream water quality. Sampling sites were located on the mainstem Elwha River at rkm 13.5, rkm 25.6, and rkm 42.0 and on Cat Creek, Stony Creek, and Lost River, all near the stream mouths. In general, mean nutrient levels were low and differences between the sites were mostly negligible.

Sediment

The primary environmental consideration with removal of the Elwha and Glines Canyon dams is not how to remove the actual structures or draining of the reservoirs but rather management of the sediments that have accumulated within the reservoirs. A key element is estimating the amount of each size class of sediment accumulated in each river delta since they respond to erosional processes differently. Hosey and Associates (1990d) drilled six auger holes, 13 piston core samples, and 32 thickness probe measurements on the Lake Mills delta in 1989. For Lake Aldwell, they accomplished 10 vibrocore holes, 17 piston-core holes, a seismic refraction survey, ground penetrating radar, and 24 thickness probe tests. The Bureau of Reclamation (BOR) used these data to estimate post-dam sediment distribution, grain-size gradations, and sediment volumes in each reservoir (BOR 1995). However, BOR also conducted geologic mapping, surface sampling, and drill hole sampling on Lake Aldwell in 1994 and geologic mapping and sampling programs for each reservoir area in 1994-1995 to further refine the estimates.

Sediment transport by the Elwha River since Glines Canyon Dam was constructed has resulted in a 914 m long, 21.3-24.4 m thick delta at the head of Lake Mills composed primarily of sand but also of gravel, cobbles, and boulders (BOR 1995). The reservoir floor is covered by a long, gently sloping accumulation of fine sand, silt and clay that extends to the dam. The total amount of sediments within Lake Mills was estimated to be 10.58 million cubic meters with the following percentages: 48% silt and clay, 37% sand, and 15% gravel, cobbles, and boulders (BOR 1995).

Because construction of Glines Canyon Dam interferes with the downstream transport of sediments to Lake Aldwell, the amount of accumulated sediments in this reservoir are comparatively small. There is a narrow, 762 m long, 5.5-7.3 m thick delta at the head of Lake Aldwell with a similar gently sloping deposit of fine sand, silt, and clay that extends to Elwha Dam (BOR 1995). There was roughly 2.97 million cubic meters of sediment in Lake Aldwell with 67% being silt and clay, 28% sand, and 5% gravel, cobbles, and boulders.

This information above was supplemented with data derived from a 6 m drawdown experiment on Lake Mills that occurred in April 1994. The purpose of the drawdown was to determine the erodibility and size gradation of the accumulated sediments within the Lake Mills delta, impacts of the drawdown on sediment transport, and impacts to water quality (Childers et al. 2000). During the subsequent erosion of about 230,000 m^3 of delta material, stream flow data was collected at seven sites, bedload at three sites, and water quality at four sites. Fifteen cross sections were established from the mouth of Rica Canyon to about a mile downstream in Lake Mills and hundreds of particle counts accomplished. The range of daily flows during the two-week experiment was 25.2 to 49.8 cms.

Initial erosion of the delta was both vertical and horizontal but erosion was primarily lateral towards the end of the experiment when the streambed entering the reservoir attained a base level that was limited by the drawdown extent (Childers et al. 2000). Most of the delta consisted of sand-sized material but also included gravel, cobble, and large wood. Although the highest concentration of suspended sediment measured downstream of the delta but within the reservoir was 6,110 mg/L, suspended sediment concentrations below Glines Canyon Dam did not exceed 20 mg/L.

BOR combined the sediment data with the hydrologic record for the Elwha River in a mathematical model developed specifically for this project to evaluate and describe sediment-related impacts associated with removing the two dams and allowing the accumulated sediments to naturally erode downstream (BOR 1996). Model results indicated that 15-35% of the coarse sediments (sand, gravel, cobbles) would erode downstream and about 60% of the fine sediments. Sediment not eroded downstream would remain along the reservoir margins in multiple terraces. Fine sediment concentrations would typically be 200-1,000 ppm but at times be as high as 30,000-50,000 ppm, although concentrations would return to natural levels in 2-5 yrs. However, if river flows are below normal (e.g., a period of drought) the model suggests that sediment concentrations may remain high for a longer period. Alternatively, if river flows following dam removal are higher than normal and possibly as high as a 100-year flood event (which has not been documented on the Elwha River during the USGS period of record), sediment concentrations could return to normal in <3 yrs (BOR 1996). Over the long-term, coarse sediment would aggrade the river bottom increasing river stages during the 100-year flood from nothing to 0.9 m, depending on location, but average < 0.3 m.

Socioeconomic Benefits

Dam decommissioning can result in adverse economic impacts such as lost hydropower and support jobs and possibly higher power rates but it can also result in significant economic gains, such as the jobs created from removal of the projects as well as from restored fisheries. In this instance, analysis of costs and benefits followed recommendations by the Office of Management and Budget (1992) and an extended project period of 100 years was used to account for rebuilding of the fisheries (DOI 1995). Meyer et al. (1995) calculated commercial and sport fishing business benefits arising from dam removal and fish restoration in 1995 dollar values as $30.1 million and $4.5 million respectively. In addition, calculations were actually made utilizing Ricker production models originally proposed by the project applicant during the FERC licensing proceedings, which account for ocean conditions through the use of actual adult return rates. The models also accounted for reduced harvest rates during rebuilding (the first 15 to 20 years following dam removal) and with an overall rebuilding timeline of just less than 30 years (Meyer et al. 1995). These models compared favorably to observed colonization rates of many salmon populations in the South Fork Skykomish River above Sunset Falls, following construction of a fish passage facility around a natural barrier (Seiler et al. 1981).

Loomis (1996) conducted a contingent valuation survey to estimate the nonmarket value of fully restoring the Elwha River ecosystem. Based on a consultant survey of over 300 residents of Clallam County and over 1,300 citizens from throughout the United States, he estimated that the nonmarket benefits would be $3.5 billion annually for 10 years.

Meyer's economic information was updated to 2001 dollar values for the Supplemental EIS (DOI 2005) which, in part, accounted for reductions in prices to commercial fishermen. As a result, the total estimated value of the Elwha River Restoration Project decreased from $363.6 million to $355.3 million (Table 5). The nonmarket value estimate has not been updated.

TABLE 5. Value (in 2001 dollars) of dam removal and restoration over the life of the Elwha River restoration project, calculated using a 3% discount rate (adapted from DOI 2005).

Category	Benefits of Dam Removal ($)
Commercial fishing	36,700,000
Sport fishing business	10,300,000
Ediz hook	1,000,000
Recreation/Tourism	317,600,000
Total	355,300,000

Conclusion

The studies summarized above were primarily developed to investigate the FERC hydropower project licensing alternatives of dam retention with the implementation of fish and wildlife mitigation and dam removal or for the National Park Service dam removal EIS process. Specifically, studies were conducted to determine passage mortality rates of juvenile salmon and steelhead through the reservoirs, over the spillways, and through the turbines. Other studies looked at habitat quality and quantity for fish and wildlife, effects on listed species, sediment transport for both dam retention and dam removal alternatives, water quality, and economics. Most of these studies were not designed to develop baseline information to compare the pre- and post-dam removal environment. Consequently, much of the biological data are simple point estimates with no error calculations, so are only snapshots in time. They nonetheless provide useful information on current conditions.

The question is often asked, “How could the National Park Service not provide funds to study the effects of dam removal?” The answer lies in the Elwha Act, which is a negotiated settlement among the parties to the FERC licensing process to resolve associated existing and potential litigation. While the Elwha Act authorizes the Secretary of the Interior to undertake dam removal and ecosystem restoration and the Secretary has delegated this responsibility to the National Park Service, there is no requirement to study the consequences of dam removal. In addition, the drafters of the Elwha Act never contemplated that the National Park Service, with its limited budget, would have to solely fund this expensive undertaking. As a result, the National Park Service has partnered with other agencies, the Lower Elwha Klallam Tribe, universities, and others to seek alternative funding sources to study the effects on the Elwha River ecosystem from the removal of the Elwha and Glines Canyon dams. As the following papers demonstrate, there are tremendous opportunities for substantial scientific collaboration, taking advantage of this substantial river restoration project. The Elwha River is uniquely suited for scientific study with most of the basin lying within Olympic National Park and historically supporting all species of eastern Pacific salmon and trout.

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