PACIFIC LAMPREY RESTORATION IN THE ELWHA RIVER DRAINAGE FOLLOWING DAM REMOVALS

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Dams and other man-made obstacles to fish passage fragment riverine habitats and re-structure fish communities. Many of these structures provide no means of fish passage or only partial passage for a few species. This is particularly problematic for diadromous and potamodromous species that must move between rearing, feeding, and spawning habitats to complete their normal life cycle. In the United States and in Europe, many of these structures have become obsolete, and as a consequence, dam removal has become a feasible fish restoration solution in many areas (Jackson and Moser 2012, Hogg et al. 2013, Jolley et al. 2013, Lasne et al. 2015).

In the northwestern corner of Washington state, the Elwha Dam, a 32-m high hydroelectric facility, was constructed during 1910–1913 on the Elwha River at rkm 7.9 (Duda et al. 2011, Figures 1 and 2). In 1925, the 64-m high Glines Canyon Dam was built at Elwha rkm 21.6 (Figures 1 and 2). These dams were constructed with no regard for local and tribal concerns regarding fish passage (Valadez 2003) and included no provisions for passage of salmon or other fish species. Consequently, the dams completely blocked access to over 90% of the anadromous fish spawning and rearing habitat in this pristine drainage (Valadez 2003).

The Elwha River drainage historically supported a wide array of anadromous species. Salmonids affected by these dams, including Bull Trout (*Salvelinus confluentus*), sea-run Cutthroat (*Oncorhynchus clarki*), Steelhead (*O. mykiss*) and all five species of Pacific salmon: Chinook (*O. tshawytscha*), Sockeye (*O. nerka*), Chum (*O. keta*), Coho (*O. kisutch*), and Pink (*O. gorbuscha*) (Pess et al. 2008). Tribal elders described prolific salmon runs prior to dam construction and legendary king salmon of over 100 pounds each. One of the few remaining elders to have experienced the pre-dam fisheries recently passed away. The loss of tribal traditional ecological knowledge and the ability to pass down the culture of natural resource harvest and preparation is in danger of being lost.

The Elwha River drainage is uniquely beautiful and awe-inspiring. Over 80% of the watershed is within the Olympic National Park boundary and thus is essentially undeveloped (Duda et al. 2011). It is considered a World Heritage Site and International Biosphere Reserve, both testaments to the undisturbed nature of the area and the fact that it supports a rich diversity of flora and fauna. In addition to being an internationally recognized natural resource, the Elwha River

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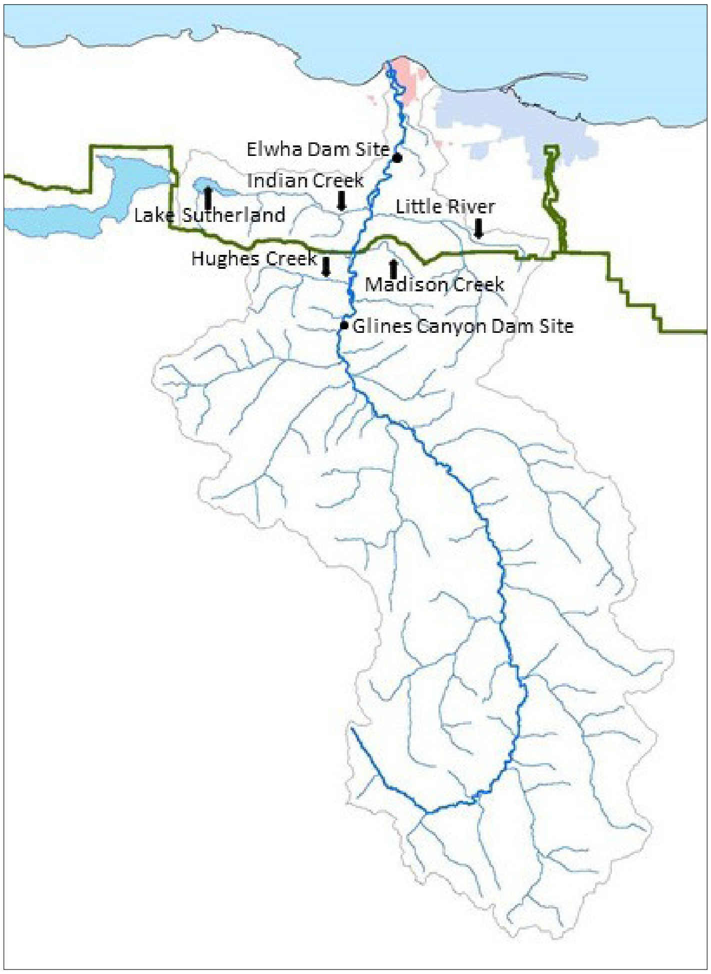

Figure 1. Map of the Elwha River drainage with locations of dams indicated by black dots.

drainage represents a crucial link to the cultural heritage of the Lower Elwha-Klallam Tribe (LEKT 2012). The vision of the 2012–2016 Strategic Plan for the LEKT is "To ensure the Lower ElwhaKlallam people can pass on their way of life to their children." This includes retention of historical access to fisheries and aquatic habitats. The Strategic Plan further provides the following mission statement: "To build a strong and healthy sovereign nation where Tribal members live their values and culture. This means enhancing the lives of our people both physically and spiritually through the social well-being and economic independence while preserving and enhancing our natural resources and cultural heritage."

In 1992, the US Congress passed the Elwha River Ecosystem and Restoration Act, which authorized dam removal. On 29 February 2000, the tribe realized a crucial step towards recovery of their cultural heritage when the US purchased the dams for $29.5 million (Valadez 2003). At that time, the Northwest Indian Fisheries Commission (NWIFC) stated that "With the transfer of these dams, we have crossed the divide which will lead to the restoration of these salmon and steelhead runs" and the return of the "biological heart" of Olympic National Park" (Valadez 2003). After two decades of planning, the staged removal started in September 2011. By March 2012 the lower Elwha Dam was completely gone, and in September 2014 the upper Glines Canyon Dam was removed (Figure 2). The Elwha River is now free from man-made barriers.

Much attention has been directed towards restoration of iconic salmonids to the Elwha Basin. However, the less glamorous Eulachon (*Thaleichthys pacificus*) and anadromous lamprey species (River Lamprey, *Lampetra ayresii* and Pacific Lamprey *Entosphenus tridentatus*) were also potentially blocked by the dams (Scott and Crossman 1973, Duda et al. 2011). Native lampreys are frequently stigmatized by association with the Sea Lamprey (*Petromyzon marinus*), a non-native species that invaded the Laurentian Great Lakes and caused damage to commercial and recreational fish resources there. Ironically, native lampreys worldwide have experienced declines as a consequence of habitat degradation, passage obstacles, and programs to eliminate them outright, due to the perception that they are a nuisance parasite (Maitland et al. 2015, Crandall and Wittenbach 2015).

Recently the ecosystem services that lamprey provide have been recognized by conservation groups, and the importance of these services to native cultures has been brought to the fore by Columbia Basin Native Americans (Close et al. 2002). The important ecological role of lamprey is recognized and honored by many tribal cultures throughout the Pacific Northwest (Crandall and Wittenbach 2015). Lamprey contribute vital marine-derived nutrients to areas where they spawn, filter water, and provide food for native fish and wildlife and potentially buffer predation during critical salmonid migration periods (Jolley et al. 2013, Dawson et al. 2015). The ability of native lampreys to recolonize lost habitats, like those in the upper Elwha drainage, is largely undocumented. However, Sea Lamprey (*Petromyzon marinus*) were able to quickly colonize a Maine stream in their native range (Hogg et al. 2013).

Lamprey exhibit a great degree of life history diversity, from non-parasitic freshwater brook lampreys to fully anadromous parasitic forms. Pacific Lamprey are anadromous and occurs along the Pacific Coast of North America from the Bering Sea to Mexico. This species apparently does not home to natal streams, but may use pheromones produced by larvae to locate suitable spawning and rearing habitats (Yun et al. 2011). This reliance on larval pheromones may limit the ability of adults to find and colonize areas where conspecifics have been extirpated for many years. Adult lamprey build nests in substrates similar to those used by Steelhead and are often seen during Steelhead spawning (redd) surveys (Figure 3). Larval lamprey (ammocoetes, Figure 4) hatch after about two weeks and drift downstream to silty rearing habitats, where they burrow into the sediment. Lamprey ammocoetes filter feed on organic detritus, diatoms, algae, and bacteria (Dawson et al. 2015). Pacific Lamprey juveniles are thought to remain in fresh water for up

Figure 2. The Elwha dam before (top left) and after (center left) dam removal. Glines Canyon dam before (bottom left) and after (above) dam removal. (Photos by John McMillan [Elwha before] and Tiffany Royal [Elwha and Glines after], and courtesy of National Park Service [Glines before])

to seven years before metamorphosing and migrating downstream to marine waters. This metamorphosis is a dramatic morphological re-structuring wherein ammocoetes transition from eye-less, worm-like filter-feeders to active, eyed, predators (i.e., macrophthalmia). The seaward migration of macrophthalmia occurs primarily at night and during freshets when water velocity and turbidity are high. After entering the ocean, Pacific Lamprey assume a parasitic existence for several years before embarking on a free-swimming pre-spawning migration that may require more than two years and cover hundreds of kilometers (Moser et al. 2015).

Pacific Lamprey, like Pacific salmon, were negatively impacted by dam construction on the Elwha River. The historical population was never documented; however, anecdotal observations suggest the Elwha lamprey population was large (Dick Goin, personal communication). By the late twentieth century, observations of Pacific Lamprey were rare in the Elwha drainage. An adult Pacific Lamprey was reported from a screw trap in the lower Elwha River as late as 28 April 2008 (unpublished data, LEKT Natural Resources). In the same year, larval lamprey (n = 20) were electrofished from the mainstem Elwha River (rkm 0.7) on 2 October during 82 minutes of sampling (unpublished data, LEKT Natural Resources). The fact that lamprey continued to exhibit migratory movements in the Elwha River was also documented during a pilot study in 2006 (unpublished data, H. Gowton, REU Water Resources Program, University of Idaho). Eighteen adult Pacific Lamprey were collected from adjacent streams, implanted with radio transmitters, and released in the lower Elwha River at kilometer 2.7. Of these fish, the majority either stayed near the release site (n = 2) or moved upstream (n = 10). Four fish were detected at the base

Figure 3. Adult Pacific Lamprey observed upstream from the Elwha River dam during Steelhead redd surveys. (Photo by Heidi Hugunin)

Figure 4. Ammocoetes collected in spring 2016 from the Indian Creek salmonid smolt trap. (Photo by Rebecca Paradis)

of the Elwha Dam (Figure 1) for several months (B. Burke, unpublished data, National Marine Fisheries Service).

Pacific Lamprey have rapidly colonized tributaries upstream from Elwha Dam since its removal in March 2012. From spring to early fall each year, a rotary screw trap is operated in Indian Creek, several kilometers upstream from the Elwha Dam site (Figure 1), to document juvenile salmonid migration (LEKT Natural Resources Department, Figure 5). Prior to dam removal, no lamprey occurred there, but in 2013 nine adult Pacific Lamprey were captured in the trap (Figure 6). By 2014, 6 adults were captured along with 132 larvae (Figure 4). In 2015, there were 7 adults and 407 larvae, and by summer 2016, 13 adults, 1,805 larvae, and 71 metamorphosing Pacific Lamprey were collected at the trap (unpublished data, LEKT Natural Resources). These captures indicate that Pacific Lamprey spawned in Indian Creek in spring 2013 and grew very rapidly. Indian Creek flows from Lake Sutherland (Figure 1) and is a low gradient, warm, productive stream that supports rapid salmonid growth and earlier spawn times than in other parts of the drainage (McHenry et al. 2014). Electrofishing surveys conducted in Indian Creek indicated that by 2016, lamprey had ascended the system to Lake Sutherland (unpublished data, G. Pess, National Marine Fisheries Service).

Other monitoring in the upper Elwha drainage provided evidence for rapid lamprey colonization. On 12 September 2012, an adult lamprey was electrofished from the Little River (unpublished data, G. Pess, National Marine Fisheries Service, Figure 1). In 2016, evidence of Pacific Lamprey spawning at the mouth of Little River (the next tributary upstream from Indian Creek) was reported (unpublished data, LEKT Natural Resources). However, thus far no lamprey have been captured in the screw trap located in Little River less than 1 km upstream.

During Steelhead spawning surveys in 2016, adult Pacific Lamprey were also observed spawning (Figure 7) in Madison Creek, which crosses into the National Park Boundary (Figure 1), and in Hughes Creek, which is entirely within the National Park Service boundary (unpublished data, H. Hugunin, National Park Service). Observations of lamprey and salmon in the upper Elwha coincided with the appearance of marine-derived nutrient signatures in the feathers and blood of the American Dipper (*Cinclus mexicanus*), a songbird that feeds on aquatic prey (Tonra et al. 2015). Moreover, monthly sampling detected Pacific Lamprey environmental DNA (eDNA) immediately downstream from the Glines Canyon dam site in March–June 2016 (unpublished data, J. Duda, USGS).

Records of Pacific Lamprey adults caught in a screw trap near the mouth of the Elwha River have also increased with removal of the dams. During 2005–2012, pre-dam removal captures of lamprey ranged from 0–32 larvae each year (an-

Figure 5. Screw trap used to monitor salmonid smolt outmigration in Indian Creek. (Photo by Mary Moser)

Figure 6. Adult Pacific Lamprey captured in Indian Creek (above Elwha Dam site) in spring 2014. (Photo by John McMillan)

Figure 7. Pair of spawning lamprey observed in Madison Creek during spring 2016, upstream from the Elwha Dam site and just outside the Olympic National Park boundary. (Photo by Amanda Anderson)

Figure 8. Dwarf form of Pacific Lamprey captured June 29, 2016 from the mainstem Elwha River near the mouth. (Photo by Rebecca Paradis)

nual mean of 16), and captures of adults were rare. In 2016, 7 adults were captured along with 13 larvae and 2 metamorphosed juveniles. Among the adults was a dwarf form of the Pacific Lamprey (collected 29 June 2016, Figure 8). This gravid female was 20.75 cm and weighed only 19.7 g. The typical size range of Pacific Lamprey in tributaries to the Straits of Juan de Fuca is quite a bit larger (mean length 55.9 cm, range 37.5–65 cm; mean weight 252.1 g, range 124.3–371.4 g; unpublished data, H. Gowton, University of Idaho). Very little is known about the life history of the dwarf Pacific Lamprey, but genetic analysis suggests that they are distinct from the typical Pacific Lamprey (Hess et al. 2014).

To further document migration behavior and re-colonization of both the typical and dwarf Pacific Lamprey into regions upstream from Glines Canyon, the US Fish and Wildlife Service has funded us to conduct a survey of larval lamprey distribution throughout the drainage using a specialized electrofisher (Figure 9), map lamprey nest construction, and track migration of adult lamprey tagged with radio transmitters. We hope to tag 40 adult Pacific Lamprey with both a passive integrated transponder (PIT) and a miniature radio transmitter so that we can follow their movements with an existing array of PIT antennas and radio receivers (Figure 10). In addition, we plan to surgically implant larval Pacific Lamprey collected from Indian Creek with 8.4-mm PIT tags to monitor outmigration activity of juveniles (Figure 11). This work will be coupled with genetic sampling for both species identification and parentage analysis (Hess et al. 2014). These research activities will provide data needed to help with management and restoration of Pacific Lamprey in the Elwha River and at other dam removal projects in the historical range of this species. Armed with the results of this research, the Lower Elwha-Klallam Tribe will be able to make adaptive management decisions that will increase the overall success of ecosystem restoration. An added benefit from the research is that training and equipment gained in the course of this work will position the tribe to achieve the goal of reclaiming management and stewardship of its cultural and natural resources.

Figure 9. Electrofishing for lamprey larvae in Indian Creek. (Photo by Mary Moser)

Figure 10. Surgical implantation of a radio transmitter into adult Pacific Lamprey. (Photo by Ellen Bishop)

Figure 11. Tagging larval lamprey with an 8.4-mm passive integrated transponder (PIT) tag (tag is just above lamprey's head). (Photo by Mary Moser)

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