Juvenile salmon assemblages at the Mirror Lake Complex in the lower Columbia River before and after a culvert modification

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Abstract

This study examined salmonid assemblages upstream of a culvert connecting the Mirror Lake Complex (MLC) with the lower Columbia River before and after the culvert was modified to improve habitat connectivity and fish passage. Initially the culvert limited water flow between the Columbia River and the MLC. The outlet and interior of the culvert was reconfigured to create a more ‘natural’ and suitable passageway for salmonids, through the removal of rip rap, and strategic placement of boulders, cobbles, gravels, baffles, and weirs. Prior to the culvert modification, three sites were sampled monthly between April and August of 2008, 5.0 km and 0.5 km upstream of the culvert, and immediately downstream of the culvert. After the culvert modification, the same sites were sampled from 2009–2012 with two additional sites added in 2010. Sites near the culvert supported Chinook Salmon Oncorhynchus tshawytscha, Coho Salmon O. kisutch, and Chum Salmon O. keta; while sites further from the culvert supported unmarked Coho Salmon and Rainbow/Steelhead Trout O. mykiss, and Cutthroat Trout O. clarkii. Clear trends in salmonid occurrence were not observed, although densities of Chinook Salmon tended to be higher in years post-modification than before modification. Culvert modifications should focus on alleviating site specific fish passage conditions to result in substantial changes to habitat connectivity.

Introduction

The Columbia River historically provided feeding, rearing, and migration habitat for some of the largest Pacific salmonid Oncorhynchus spp. runs in the world (NRC 2004; Weitkamp et al. 2012). Salmon runs have declined to 10% of the historic levels (Williams et al. 1999) to the point that most extant populations are protected under the U.S. Endangered Species Act as threatened or endangered (Ford 2011). Population losses are partially a result of human activities over the last century, including the loss of more than half the Columbia River estuarine wetlands, which juvenile salmon often depend on for rearing (NRC 1996; Marcoe and Pilson 2017). Lower Columbia River estuary (LCRE) is typically defined as the tidally influenced area extending from the mouth of the Columbia River to Bonneville Dam (rkm 234) (Simenstad et al. 2011; Jay et al. 2016). As part of the effort to restore Columbia River salmon, attention has been increasingly focused on improving and increasing available estuarine rearing habitat for juvenile salmonids in the LCRE (Fresh et al. 2005; Bottom et al. 2005, 2006; Weitkamp et al. 2012; Bennett et al. 2016).

Fish passage barriers can reduce the amount of available salmonid habitat anywhere from less than 1% to over 90% of historic capacity (Beechie et al. 1994; Pess et al. 2008). According to Sheer and Steel (2006), approximately 40% of the total stream fish habitat (~15,000 km) in the Willamette and Lower Columbia River basins are inaccessible to salmonids. Other studies show that many existing barriers (including culverts) are impassible for fish (Poplar-Jeffers et al. 2009; Price et al. 2010; Makrakis et al. 2012). Specific design for fish passage or modifications needed are recommended to improve fish population (Poplar-Jeffers et al. 2009; Price et al. 2010; Franklin and Bartels 2012; Erkinaro et al. 2017). Restoration efforts in the Pacific Northwest often involve removal or modification of fish passage barriers such as dams, levees, culverts, and tide gates (Bond and Lake 2003; Roni et al. 2002, 2008; Kiffney et al. 2009; Pess et al. 2012; 2014; Bennett et al. 2016; Krueger et al. 2017; Seifert and Moore 2018), and in some cases these efforts have been quite successful. For example, restoration efforts focused on floodplain connection in the upper Chilliwack River watershed of British Columbia, identified that between 27–34% of the overall Coho Salmon O. kisutch smolt migration could be attributed to those restored habitat types (Ogston et al. 2014). Large-scale connectivity restoration actions such as dam removal have also shown population level responses. Dam removal on the Elwha River in Washington has resulted in Coho Salmon population level responses, where relocated hatchery Coho Salmon adults moved into the newly available habitat (Liermann et al. 2017). Specifically, Liermann et al. (2017) documented immediate freshwater production that was comparable to other systems throughout the Pacific Northwest. Thus, allowing fish passage through culverts and other artificial barriers in streams is important for maintaining connectivity among habitats (Roni et al. 2002; Fullerton et al. 2010; Crook et al. 2015; Diebel et al. 2015).

This study examined the salmonid assemblages in conjunction with fish passage improvement at the Mirror Lake Complex (MLC), a 390-acre flood plain area along the tidal freshwater portion of the LCRE, located in Oregon at rkm 208 in the Columbia River Gorge, 26 rkm downstream of Bonneville Dam. Salmonid assemblages were monitored before and after a culvert modification. The MLC includes two lakes, two streams, an expansive riparian zone, tidally influenced freshwater wetlands, and remnants of its bottomland hardwood forests (Parametrix 2008). Both Young Creek and Latourell Creek, which flow east to west through the site and connect upstream of Mirror Lake, support spawning populations of lower Columbia River Coho Salmon (Parametrix 2006, 2008). The outlet of Mirror Lake connects to the Columbia River through a 72 m twin concrete box culvert (consisting of two 3 m × 3 m barrels), passing under Interstate-84 (I-84). Following construction of the interstate and culvert in the 1950's, this outlet provided the only connection between the MLC and the Columbia River. The MLC was further degraded over the past century due to land clearing, agriculture, grazing, and the introduction of invasive plants. In the spring, the MLC becomes inundated with water, mostly influenced by Columbia River backflow through the culvert and by flows from two creeks (Parametrix 2006).

A major component of the multi-phase restoration effort at the MLC was to modify the culvert under the I-84 to improve fish passage. Prior to the culvert modification, passage condition at the culvert was adequate (preferred depth for juvenile or adult passage) only during the spring runoff (when the Columbia River backwaters into the site), while during other portions of the year substrate and hydrology within the culvert limited passage (Parametrix 2008). Modification to the I-84 culvert was necessary because 1) during low flow periods (late summer and early fall), riprap below the culvert did not allow adequate passage for fish because water levels were too low, and 2) during elevated flows periods (winter–early spring when precipitation and stream flow in the MLC creeks increase) when the Columbia River flow is not high enough to backwater into the site, the flow in the culvert still did not provide adequate passage conditions for fish (Parametrix 2008).

Migration patterns vary across different species of juvenile salmonids, and each species is known to use different parts of an estuary during their migration to the ocean (Groot and Margolis 1991). For example, Coho Salmon fry emerge in late winter and remain in their natal streams through the summer and winter before migrating (as smolts) to the ocean the following spring (Groot and Margolis 1991; Wigington et al. 2006). However, juvenile fall Chinook Salmon O. tshawytscha (i.e., subyearlings) are known to migrate as fry and extensively use off-channel habitats (Groot and Margolis 1991; Friesen et al. 2007; Bottom et al. 2008; Johnson et al. 2015). Some juvenile fall Chinook Salmon may even migrate tens of kilometers upstream from the mainstem Columbia River (Teel et al. 2009). The motivation for juvenile fall Chinook Salmon to move upstream is not well understood; however, Kahler and Quinn (1998) suggest that some salmonids move through culverts in response to unstable environmental conditions, such as changing water temperature (Clapp et al. 1990; Meyers et al.1992), food (Flick and Webster 1975; Wilzbach 1985), and preference for low velocity habitats (Cederholm and Scarlett 1982; Peterson 1982).

In this study we examined whether the modification of the I-84 culvert resulted in a change in salmonid assemblages at the MLC. This study describes juvenile salmonid use of the MLC by salmonids by 1) characterizing juvenile salmonid density before culvert modification in 2008; and 2) comparing these data with post-modification (2009–2012) data to assess whether salmonid density above the culvert changed with time.

Methods

<A> Study sites—In the late summer of 2008, restoration work was completed on the culvert connecting Mirror Lake to the Columbia River. The outlet and interior of the culvert were reconfigured by removing rip rap, and strategically placing boulders, cobbles, gravels, baffles, and weirs (Parametrix 2008). Prior to the culvert modification in 2008, three sites were monitored at MLC for salmonid abundance: lagoon, Mirror Lake, and Young Creek (Figure 1). Following the culvert modification, these sites were sampled 2009-2012, with two additional sites (Confluence and Latourell Creek) added in 2010-2012.

Sampling sites were as follows:

Lagoon: Located at the north entrance to the I-84 culvert, the Lagoon is connected to the mainstem Columbia River with no barrier (0.8 km downstream through a small channel/embayment, Figure 1). The monitoring site was located just downstream of the culvert. The water level varies seasonally (depth ranging from 1–6 m), and is primarily influenced by the Columbia River stage.

Lake: The monitoring site was located on the north shore of Mirror Lake, approximately 0.5 km upstream of the south entrance of the I-84 outlet culvert. The water level varies seasonally (depth ranging from 1–6 m), and is influenced by both backwater effects during higher Columbia River stages as well as discharge from Young and Latourell creeks.

Young Creek: The Young Creek monitoring site was located approximately 4.5 km upstream of the Mirror Lake site, and 3 km upstream from the Young Creek/Latourell Creek confluence. At this location, the creek varies from approximately 1.5 m in width and 1.0 m in depth at low water, to 5.0 m in width and 3.0 m in depth at high water.

Latourell Creek: The Latourell Creek monitoring site was located approximately 2.5 km upstream of the Mirror Lake monitoring site, and 1.0 km upstream from the Young Creek/Latourell Creek confluence. It is approximately 100 m below Latourell Lake, a slower flowing backwater section of Latourell Creek. The site varies from approximately 1–2 m in width and 0.5–1.0 m in depth over the typical range of water levels seen.

Confluence: The Confluence site was located at the confluence of Young Creek and Latourell Creek, approximately 1.5 km upstream of the Mirror Lake monitoring site, and 1.0 km above the upstream end of Mirror Lake. The water level varies seasonally, influenced by discharge from Young and Latourell creeks, and backwater effects of the Lake. The site varies from approximately 3–4 m in width and 0.25–1.0 m in depth at low water, to 10.0 m in width and 3.0 m in depth at high water.

<B>Environmental Variables—The Water level at the MLC is strongly influenced by the Columbia River stage below the Bonneville Dam. The stages recorded at the I-84 culvert (staff gage reading of 4 m, NAVD88, which corresponds to the point at which the Columbia River begins to backwater into the site) were approximately 1.5 m lower than those recorded at the Bonneville gage; a 0.3 m fluctuation in stage for a given discharge was observed due to tidal influence (Parametrix 2006). High water at the culvert occurs from late February through mid-July, influenced by the Columbia River backflow through the culvert and streams above; and low water occurs from mid-July through October (Parametrix 2008).

<C>Fish monitoring—Sampling in 2008 occurred at three of the five sites: Lagoon, Lake, and Young Creek. Starting in 2010, Confluence and Latourell Creek were added, but these sites were sampled intermittently due to difficulty gaining access during high water periods. Fish sampling was generally initiated in April and continued monthly through August. The number of sets conducted per month for each site is shown in Table 1.

Due to varying characteristics of the site and water level, several types of gear were used to sample the MLC sites, depending on site conditions. During moderate to high water conditions (> 1 m depth) at the Lagoon, Lake, and Confluence, fish were collected with a Puget Sound beach seine (37.0 × 2.4 m, 10 mm mesh size) deployed using a boat. At low water conditions (< 1 m depth) a modified Puget Sound beach seine (7.5 × 2.4 m, 10 mm mesh size) was deployed on foot. At Young Creek and Latourell Creek, fish were collected with a block net [where the middle portion of the Puget Sound beach seine was used as a block net and a second net (2 × 1.5 m, 10 mm mesh size) was used as a chase net to herd the fish into the block net].

All fish collected were identified to the species level when possible and counted. On salmonids, the presence/absence of the adipose fin was noted (a clipped adipose fin is indicative of a marked hatchery fish).

<D>Calculations and statistical analyses—We followed the recommended guideline for beach seining in Puget Sound (PSEP 1990). A variety of factors including gear type, fishing techniques, habitats (e.g., substrate, vegetation, clarity, currents) can affect fishing efficiency (Hahn et al. 2007). Also, water level can allow escapement, and species and size-specific factors may affect catchability (Bayley and Herendeen 2000). Even though multiple gear or fishing techniques were used based on characteristics of the site and water level, we assumed similar catch efficiency when corrected for the area covered by the gear used. At each sampling event, the area covered by the gear was noted for calculation of fish density. For this study, density is defined as the number of fish captured in the surface area sampled by the fishing technique used. Density was standardized to the number of fish captured per 1,000 m^2 (Roegner et al. 2009), similar to fish densities reported in other studies in the LCRE (Bottom et al. 2008; Johnson et al. 2011; Sather et al. 2016). Rainbow/Steelhead Trout O. mykiss and Cutthroat Trout O. clarkii were caught in low numbers, so they were pooled for calculations.

We plotted salmonid density data from the sampling sites and found the distribution to be non-normal and non-continuous. Due to this asymmetry, we chose non-parametric test (paired data, Wilcoxon pair rank test) to compare density differences among the years (2008-2012) and among sites. All statistical analyses were completed using the JMP statistical software package (Version 13).

Results

<A>Water level and temperature—Visual observation of the culvert after the modification showed that during low flow periods in the Columbia River, water at the culvert was no longer restricted and the water velocity behind the boulders was lower than in the unobstructed flow area (Lower Columbia Estuary Partnership 2010). The river stages recorded at Bonneville and I-

84 culvert for 2003-2005 were correlated ($y = 0.059\times + 7.71$, $r^2 = 0.89$); stages recorded at I-84 were approximately 1.7 m lower than Bonneville stages (Parametrix 2006). Water depth at the culvert was not measured during the course of this study; however, peak stage at Bonneville was variable from year to year (Figure 2). The highest stage occurred during 2011 when a maximum water level at Bonneville Dam of approximately 10.0 m was recorded. In 2012, a more extended period of high water level was observed compared to other years.

Water temperature at the MLC varied throughout the year (Figure 3). At the Lagoon and the Lake, water temperature increased steadily throughout the sampling season from 9–17ºC in April and May to over 20ºC in July and August. At the Confluence, Latourell Creek, and Young Creek, summer temperatures were much lower than at either the Lake or Lagoon, remaining below 20ºC in all months and sampling years (Figure 3). At Young Creek, temperature increased steadily from April-May (7.8–13.7ºC) to June-September (13.0–14.5ºC). The highest temperatures were observed in 2009, with maximum summer temperatures of 31.5ºC at the Lagoon and Lake. Temperature at the Confluence and at Latourell Creek were similar to Young Creek, with maximum summer temperatures between 14.7–16.8ºC.

<B>Species composition—We collected a total of 28 species of fish at the MLC. Species composition varied among sites (Figure 4, Supplemental Table 1). The highest number of species was observed at the Lagoon and the number of species observed at each site decreased with distance from the culvert. Total number of species observed at each site varied but were generally similar from year to year (Figure 4). At Young Creek, salmonids were the dominant species, while at other sites, other non-salmonid species were the dominant species.

Salmonid species present at MLC varied by site (Figure 4). Chinook Salmon (marked and unmarked), Coho Salmon (marked and unmarked), and unmarked Chum Salmon O. keta were present at the Lagoon; whereas Chinook Salmon (marked and unmarked) and unmarked Coho Salmon were present at the Lake; and unmarked Coho Salmon and unmarked trout were present at Young Creek. At the Confluence, Chinook Salmon (marked and unmarked) and unmarked Coho Salmon were present, and at Latourell Creek only unmarked Coho Salmon were present. Other fish species caught at MLC from 2008-2012 are shown in Supplemental Table 1.

The percentage of salmonids present at the MLC were highly variable (Figure 4). At the Lagoon, the percentage of salmonids in the catch in 2008 was lower than in 2009-2012 (27% compared to a mean of 12%, ranging from 2–21%). At the Lake, the percentage of salmonids in the catch in 2008 was higher than in 2009-2012 (7% compared to a mean of 4%, ranging from 2–7%). At Young Creek, the percentage of salmonids in the catch in 2008 was similar to percentage in 2009-2012 (82% compared to a mean of 83%, ranging from 51–96%). The percentage of salmonids in the catch at the Confluence decreased from 25% in 2010 to < 1% in 2012. Similarly, at Latourell Creek, the percentage of salmonids in the catch decreased from 91% in 2010 to 27% in 2012.

<C>Density of Chinook Salmon—The density of Chinook Salmon at the MLC varied from year to year (Figure 5), but showed no clear pattern relative to the culvert modification. No inter-year differences were observed at the Lagoon or at the Lake (Wilcoxon non-parametric test for each pair, $P > 0.05$). Chinook Salmon were not collected at Latourell Creek or at Young Creek. At the Confluence, however, Chinook Salmon were caught in 2011 for the first time, but no inter-year differences were found ($P > 0.05$).

The mean ± SD density of Chinook Salmon at the Lagoon in 2008 was higher than the density of Chinook Salmon at the Lake, but no difference was observed (Wilcoxon non-parametric test for each pair, $P > 0.05$, Figure 5). Similarly, for the years 2009-2012, the Chinook Salmon density at the Lagoon (76.7 ± 171.8 fish per 1,000 m^2) was higher than at the Lake (20.7 ± 67.5 fish per 1,000 m^2), but no difference was observed ($P > 0.05$). Chinook Salmon were not collected at Young Creek in any sampling year. Overall, for all the years sampled (2008-2012), the mean density at the Lagoon (64.1 ± 154.9 fish per 1,000 m^2) was higher than the density of Chinook Salmon at the Lake (17.6 ± 61.0 fish per 1,000 m^2) ($P < 0.05$).

In 2008, Chinook Salmon at MLC were collected from May through August. Marked Chinook Salmon were collected in May and August, while unmarked Chinook Salmon were collected in May and June. In 2009–2012, marked Chinook Salmon were collected April through July and unmarked from April through August. Peak density of Chinook Salmon was observed in May (Table 2).

<D>Density of Coho Salmon—The density of Coho Salmon at the MLC varied from year to year (Figure 6), but showed no clear pattern relative to the culvert modification. At the Lagoon, no inter-year differences were observed (Wilcoxon non-parametric test for each pair, $P > 0.05$). At the Lake, density in 2010 was higher than in 2012 ($P < 0.05$). At Young Creek, some inter-year

differences were observed (2008 vs 2009 and 2008 vs 2011, $P < 0.05$). At the Confluence and Latourell Creek, no inter-year differences were observed ($P > 0.05$).

In 2008, the mean ± SD density of Coho Salmon at Young Creek was higher than Lagoon and Lake (Wilcoxon non-parametric test for each pair, $P < 0.05$, Figure 6). For the years 2009-2012, the Coho Salmon density at Young Creek (1,700.7 ± 2,370.0 fish per 1,000 m^2) was higher than at the Lagoon (15.1 ± 37.8 fish per 1,000 m^2) and the Lake (3.1 ± 11.7 fish per 1,000 m^2) ($P < 0.05$). For both 2008 and 2009-2012, the densities of Coho Salmon at the Lagoon were higher than the Lake, but no differences were observed ($P > 0.05$).

The amount of time that Coho Salmon were present at the MLC varied from year to year (Table 2). In 2008, marked Coho Salmon were collected in May and unmarked Coho Salmon were collected May through August. For years from 2009–2012, marked Coho Salmon were collected in April, May, and July, while unmarked Coho salmon were collected April through August (Table 2). The density of unmarked Coho Salmon was higher in the summer than in the spring, but the density of marked Coho Salmon was lower than the density of unmarked Coho Salmon for most sampling periods (Table 2).

E>Density of Chum Salmon—Chum Salmon were not collected at MLC sites in 2008; however, a small number of Chum Salmon were collected only at the Lagoon in April 2009 and 2010 (Table 2). Chum Salmon were not collected at sites above the culvert (Figure 7).

<F>Density of trout—No consistent trend was observed in trout density (Figure 7). Trout were collected at the Lagoon in 2010, and at the Lake in 2008 and 2010. No trout were collected at the Confluence or at Latourell Creek. At Young Creek, trout were collected in 2008, 2010, and 2012. In 2008, trout were collected in July and August, whereas 2009-2012 trout were collected June through August (Table 2).

Discussion

In this study, we did not see clear changes in salmonid assemblages at the MLC that could be linked to the modification of the culvert. Chinook Salmon were collected at the Lake and the Lagoon, indicating that Chinook Salmon pass through the culvert. Additionally, densities of Chinook Salmon tended to be higher in years post-2008, suggesting increase in passage associated with the culvert modification. However, the density of Chinook Salmon at the Lagoon was consistently higher than at the Lake, suggesting that conditions at the modified culvert could still be limiting movement of salmonids upstream. We also found that Chinook Salmon used the lower MLC sites before and after culvert improvement, but were generally absent in the upstream MLC sites. The presence of Chinook Salmon at the lower MLC sites is consistent with other studies, as subyearlings of this species are known to make extensive use of shallow, nearshore habitats before entering the ocean (Bottom et al. 2005, 2008; Fresh et al. 2005; Roegner et al. 2008; Johnson et al. 2011; Sagar et al. 2015; McNatt et al. 2016).

Interestingly, no Chinook Salmon were collected at the Confluence in 2010. However, coinciding with higher water levels in 2011 and 2012, Chinook Salmon were collected at the Confluence. This suggests that the upstream sites may not be suitable or preferred habitat for Chinook Salmon during normal water levels. Higher water levels may be an important factor facilitating the movement of Chinook Salmon to the Confluence. Annual inundation in a river-floodplain system can provide higher biotic diversity (Junk et al. 1989), which may partially explain observation of Chinook Salmon at the Confluence during high water periods. In combination with the high water conditions, modifications made at the culvert may have also facilitated the use of these habitats by Chinook Salmon by making the upstream sites more accessible. Access to wetland habitats such as the MLC could be an important contributor to the fitness of the Columbia River fall Chinook Salmon in the area. For example, Sommer et al. (2001) showed through bioenergetics modeling that feeding success was greater for Chinook Salmon in the floodplain of the lower Sacramento River despite an increased metabolic cost of rearing in a warmer floodplain. The upstream sites at MLC, which have lower temperatures than the downstream MLC sites, may also serve as cool water refugia for juvenile Chinook Salmon.

In addition to Chinook Salmon, juvenile Coho Salmon were collected at the Lake, Lagoon, and the upstream sites. Both marked and unmarked Coho Salmon were collected at the Lagoon. As several hatcheries on the Columbia River upstream of the study area release Coho Salmon and the occurrence of marked Coho Salmon in our catches corresponds with the April and May timing of hatchery releases for this species (Columbia River DART, http://www.cbr.washington.edu/dart/hatch.html), these are a likely source for marked Coho Salmon collected at the Lagoon. The lack of marked Coho Salmon at the Lake and upstream sites suggest that marked Coho Salmon may only use more accessible habitat associated with the mainstem Columbia River.

Only unmarked Coho Salmon were collected at the Lake and the upstream sites. While interannual variation was apparent at these sites, culvert modification did not appear to have an effect on the density of these fish. The upstream MLC sites are a likely source of unmarked Coho Salmon at the Lake and the Lagoon (Parametrix 2008). After Coho Salmon fry emerge from the gravel, they take up residency in their natal stream for a year or more before migrating to sea (Groot and Margolis 1991). The areas near the falls that feed Young Creek and Latourell Creek contain gravel substrate that is suitable for Coho Salmon spawning (Parametrix 2008). Coho Salmon fry were captured in large numbers at Young Creek, Latourell Creek, and to a lesser degree at the Confluence from April through August; these areas seem to be favorable rearing habitat for juvenile Coho Salmon. The timing of unmarked Coho Salmon occurrence at the Lagoon and the Lake (April-July) coincides with the juvenile Coho Salmon migration timing in the Columbia River (Weitkamp et al. 1995), so some of the yearling Coho Salmon observed at the Lagoon at the MLC could be migrants from sites further upstream in the Columbia River basin.

Chum Salmon were not collected at the MLC sites prior to the culvert modification in 2008, though small numbers were captured at the Lagoon in 2009 and 2010 during April and May. Due to having no abundance data from before the culvert modification, we are unable to determine if the culvert modification affected Chum Salmon utilization of the MLC or if their presence was due to outside factors. Two Chum Salmon spawning populations occur in the Columbia River Gorge and it is plausible that the Chum Salmon observed at the Lagoon originated at nearby Hamilton Creek and Hardy Creek (Good et al. 2005). The timing of Chum Salmon in our catch is consistent with the typical migration season of these populations (Myers and Holton, 1982; Johnson 2007), and with other recent reports of Chum Salmon occurrence in the LCRE (Roegner et al. 2008; Johnson et al. 2011). Chum Salmon may have migrated from the mainstem Columbia River to use the Lagoon at the MLC, but were not collected above the culvert in the Lake or upper sites.

Salmonids in many nearshore sites in the Columbia River may encounter high water temperatures that are potentially stressful (Richter and Kolmes 2005; Bottom et al. 2008). This problem could be remedied in some cases by modification of the culvert or other barriers that could reduce water temperature by creating a free-flowing environment with less standing water. For Chinook Salmon, temperatures above 16ºC have been associated with reduced growth rates

(Bisson and Davis 1976; Marine and Cech 2004), and temperatures exceeding 20ºC are associated with increased mortality (McCullough 1999). Similarly, juvenile Coho Salmon avoid streams with temperatures above 18ºC (Welsh et al. 2001). At the lower MLC sites, few salmonids were observed in the summer when the water temperatures were consistently above 20ºC, with temperatures above 30°C in some years, suggesting the culvert modification did not appear to alleviate high temperature problem for salmonids. However, temperatures at the upstream sites rarely exceeded 15ºC, potentially explaining the suitability of these habitats for a large population of Coho Salmon. Culvert modifications that allow salmonid populations access to the cool water in the upstream MLC sites may be important to providing thermal refugia for these species during summer months. In light of predicted impacts of global climate change, alterations such as increased winter rainfall, earlier spring runoff, and drier summers in the Pacific Northwest (Payne et al. 2004; Mantua et al. 2010; Hamlet et al. 2013), increasing fish passage to cooler refugia may be important to maintaining salmonid populations.

A variety of factors contributed to the difficulty in detecting clear changes in salmonid occurrence before and after culvert modification at the MLC: 1) the fish passage at the MLC was not completely restricted prior to the culvert modification, therefore, expected results may not be as dramatic as restoration projects that involve culvert/barrier removal (Roni et al. 2008; Kiffney et al. 2009; Pess et al. 2012; 2014; Birnie-Gauvin et al. 2018); 2) data gaps due to inconsistent site sampling, the timing of our sampling permit, high water levels, or difficulty in accessing sites increased variability in the population measurements; and 3) different gear types or techniques used to sample the MLC sites may have increased uncertainty in comparison among the sites. Additional tests may be needed to examine catch efficiency of gear used both among sites and across conditions within a site.

Management Implications

There have been many efforts in recent years to restore physical habitats in freshwater ecosystems to aid in the recovery of threatened and endangered salmonids (Bond and Lake, 2003; Roni et al. 2002, 2008). The success of restoration efforts to restore ecosystem structure and function have varied (Larson et al. 2001; Roni et al. 2002, 2008), and studies of the impacts of techniques such as culvert modification are required to determine the utility of these actions. As there was only one year of the pre-modification data in this study, we cannot be certain that these measures are truly representative of the MLC sites prior to the culvert modification. In turn, this confounds our ability to conclude whether the variability we observed is representative of normal inter-annual variation, patchiness of salmonids utilizing the MLC habitats, or reflective of culvert modification having a lasting impact on the system. Additional long term monitoring will be needed to evaluate success of these actions, especially since colonization of the newly accessible habitat takes several years due to low fish numbers or intermittent passability through the culvert during certain seasons (Roni et al 2008). Future research considerations would include long term baseline data, additional sampling throughout varying conditions at each site, and studies of gear efficiency. Ultimately, long term monitoring is required to better evaluate the effectiveness of restoration actions both from economical and biological standpoints.

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Table 1. Monthly seine sets made at Mirror Lake Complex (MLC) sites, 2008–2012.

	month					
sites	Year	April	May	June	July	August
Lagoon	2008	NA	3	1	3	2
	2009	1	1	4	3	3
	2010	2	1	2	2	2
	2011	PI	1	HW	2	2
	2012	1	1	1	2	3
Lake	2008	3	2	2	1	3
	2009	3	2	4	3	2
	2010	3	3	2	3	3
	2011	PI	2	1	2	3
	2012	2	2	1	1	3
Confluence	2010	3	3	1	3	NA
	2011	PI	1	HW	1	NA
	2012	1	NA	HW	HW	2
Latourell Creek	2010	NA	NA	NA	2	NA
	2011	PI	DA	NA	DA	NA
	2012	NA	NA	HW	DA	2
Young Creek	2008	1	3	HW	3	3
	2009	2	3	2	2	2
	2010	3	3	HW	3	3

2011	PI	HW	HW	2	2
2012	HW	HW	HW	HW	3

DA = difficult access; HW = high water; PI = permit issue; NA = not attempted

Table 2. Mean ± SD monthly density (number of fish per 1,000 m^2) of salmonids from Mirror Lake Complex (MLC) sites sampled in the years 2008 and 2009–2012. n indicates number of seine sets in a given month and year(s).

			Month		
	April	May	June	July	Aug
	(n = 25)	(n = 31)	(n =21)	(n = 38)	(n = 43)
Chinook Salmon (marked)					
2008 (n = 30)		0.9 ± 2.5			1.4 ± 14.0
2009–2012 (n = 128)	11.7 ± 53.6	21.3 ± 39.2	0.7 ± 2.2	3.3 ± 12.7	
Chinook Salmon (unmarked)					
2008 (n = 30)		20.5 ± 34.9	5.6 ± 5.0		
2009–2012 (n = 128)	27.2 ± 77.3	80.1 ± 184.1	13.0 ± 26.0	12.7 ± 9.6	0.2 ± 0.9
Coho Salmon (marked)					
2008 (n = 30)		59.1 ± 133.5			
2009–2012 (n = 128)	0.2 ± 0.9	2.3 ± 7.8		0.1 ± 0.8	
Coho Salmon (unmarked)					

2008 (n = 30)		133.5 ± 143.6	5.9 ± 5.3	2484.4 ± 3136.6	2442.0 ± 3428.0
2009–2012 (n = 128)	25.2 ± 47.0	76.2 ± 120.1	51.0 ± 124.6	1113.4 ± 2109.6	816.6 ± 1649.1
Chum Salmon					
2008 (n = 30)					
2009–2012 (n = 128)	1.4 ± 6.0				
Trout					
2008 (n = 30)				9.4 ± 25.0	8.3 ± 23.3
2009–2012 (n = 128)			0.8 ± 2.4	1.3 ± 7.1	1.3 ± 4.2

Figures

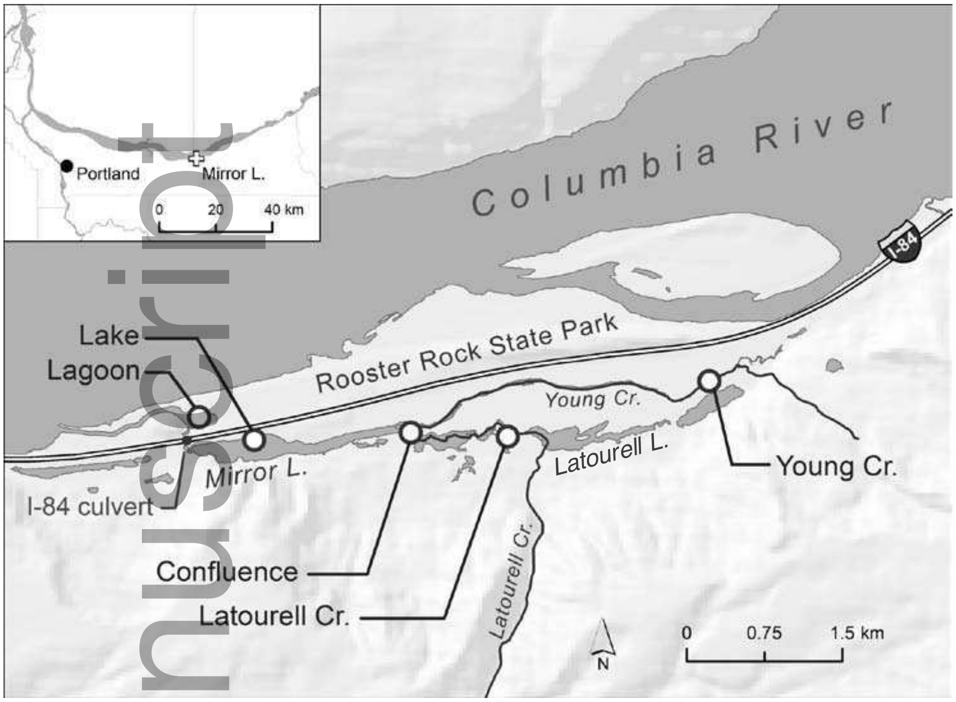

Figure 1. Areas of fish collection at Mirror Lake Complex (MLC) sites.

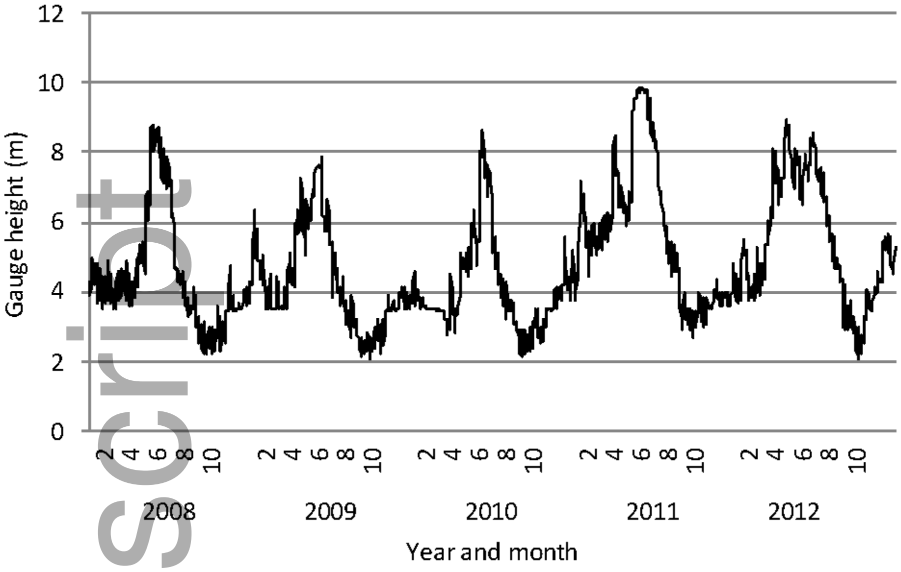

Figure 2. Average daily water level at Bonneville Dam (rkm 234) on the Columbia River from 2008-2012 (data source: https://waterdata.usgs.gov/nwis/uv?site_no=14128870).

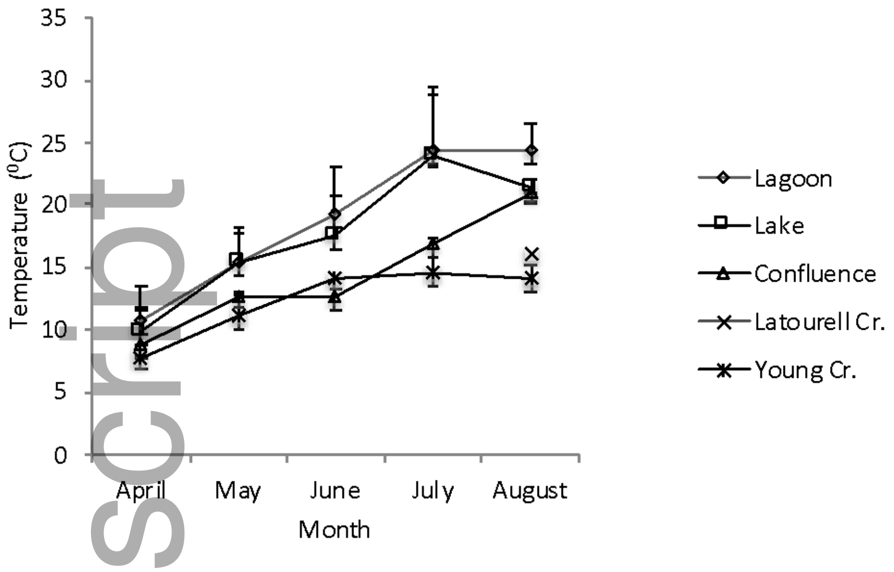

Figure 3. Average monthly temperature at the Mirror Lake Complex (MLC) sites.

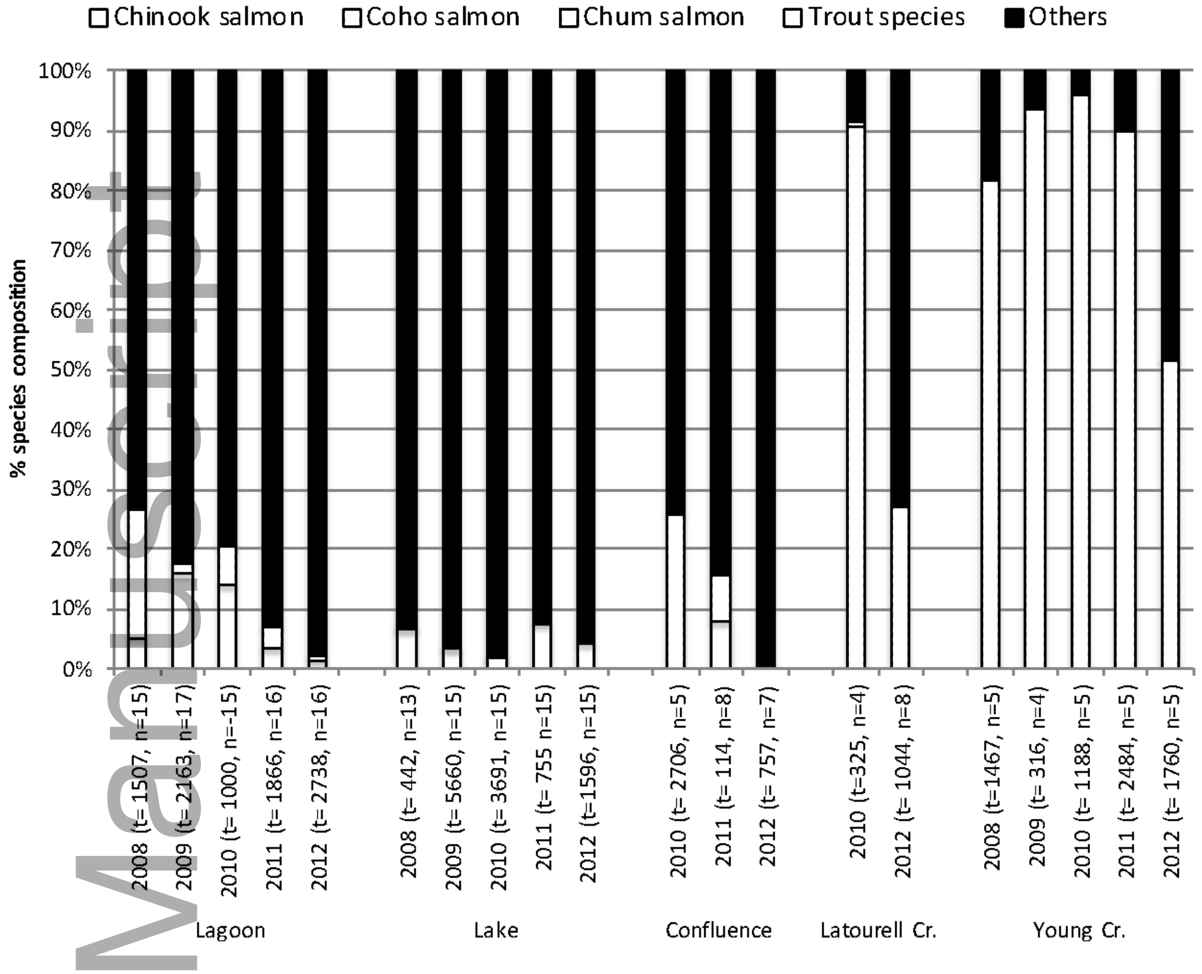

Figure 4. Percentage of salmonids in the catch at the Mirror Lake Complex (MLC) sites from 2008 to 2012. t and n indicate total number of fish and number of species caught at each site in a given year, respectively. Non-salmonid species are categorized as others.

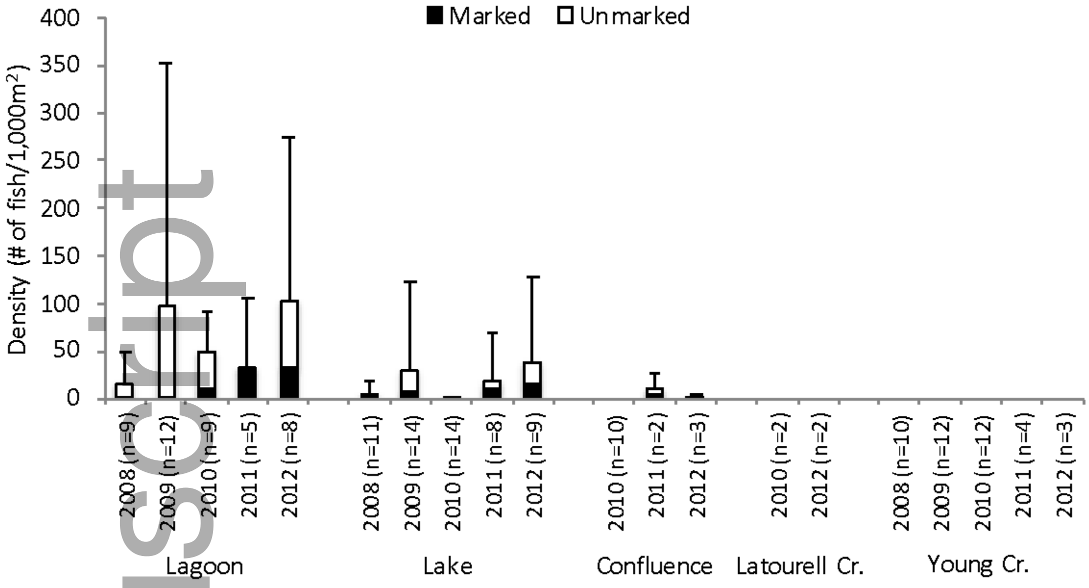

Figure 5. Mean ± SD density (number of fish per 1,000 m^2) of juvenile Chinook Salmon at the Mirror Lake Complex (MLC) sites. n indicates total number of sets conducted at each site in a given year.

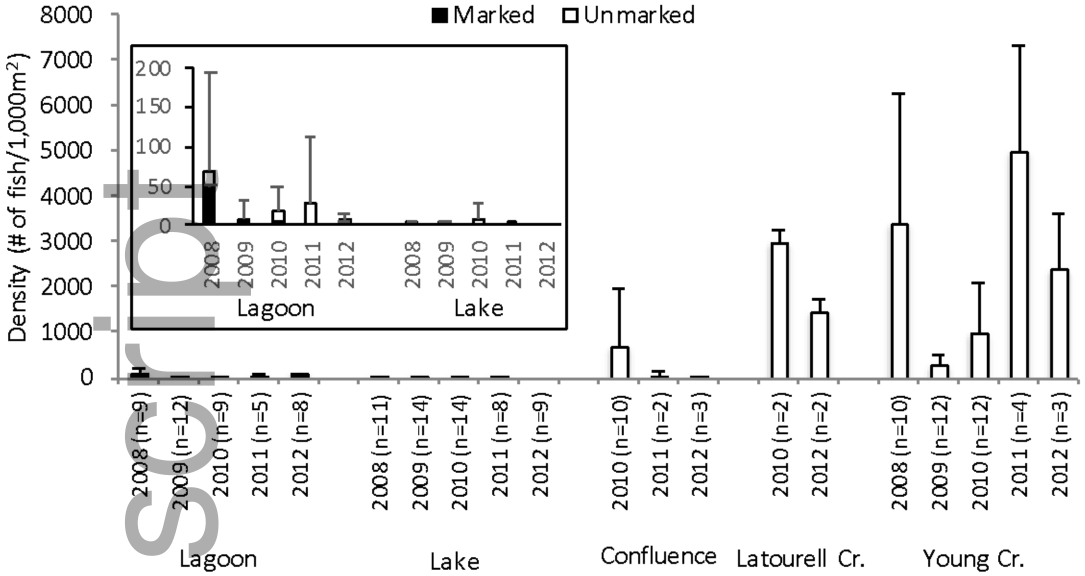

Figure 6. Mean ± SD density (number of fish per 1,000 m^2) of juvenile Coho Salmon at the Mirror Lake Complex (MLC) sites. n indicates total number of sets conducted at each site in a given year.

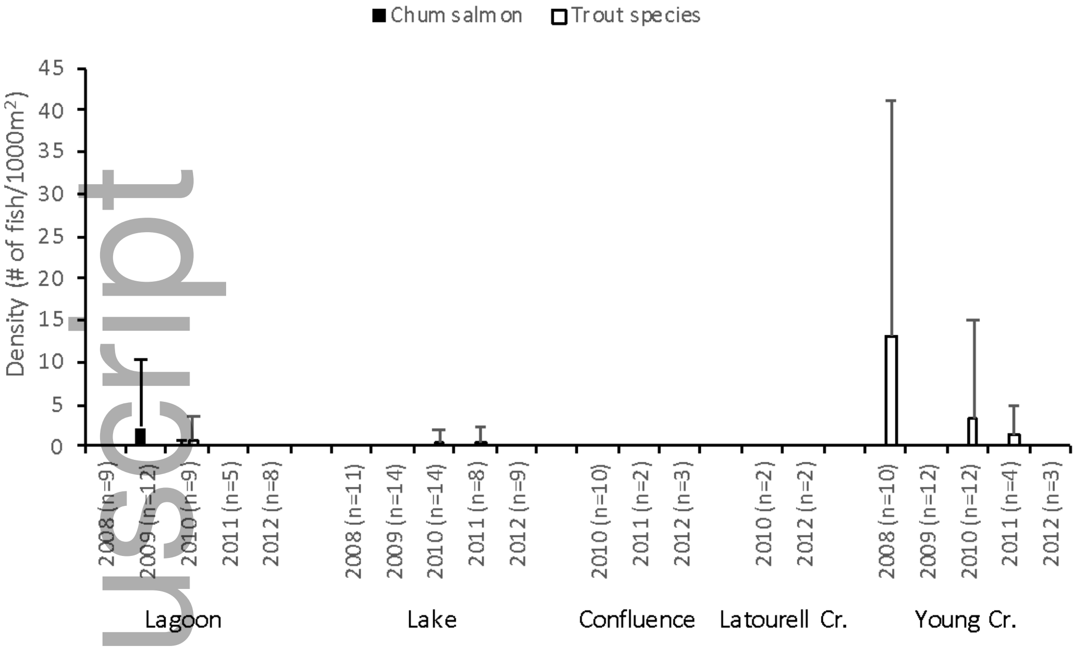

Figure 7. Mean ± SD density (number of fish per 1,000 m^2) of juvenile Chum Salmon at the Mirror Lake Complex (MLC) sites. n indicates total number of sets conducted at each site in a given year.