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

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Abstract

Changes in fish assemblages were examined before and after a culvert was modified to improve the fish passage at Mirror Lake Complex (MLC), located along the Columbia River Gorge, Oregon. Conditions at the culvert limited water flow between the Columbia River and the MLC during certain portions of the year; thus, the outlet and interior of the culvert were modified to improve fish passage. Prior to the culvert modification, three sites were sampled monthly between April and August 2008, 5.0 km and 0.5 km upstream of the culvert, and immediately downstream of the culvert. Following the culvert modification in the late summer of 2008, the same sites were sampled from 2009–2012, with two additional sites added in 2010. Prior to the culvert modification, the lower sites (i.e., the sites closest to the Columbia River) supported native and non-native fish species, while the upper sites were dominated by native species. During the four years of monitoring post-culvert modification, these distinctions between the upper and lower sites remained. A significant increase in water temperature and species richness was observed at the site just upstream of the culvert, but other changes in fish composition (density, diversity, % of non-native species) were not observed. However, at the upper sites, while non-native species were absent pre-culvert modification, they were present post-modification. Modifications made at the culvert, in combination with seasonal variation in water level and water temperature, may have influenced fish communities in the MLC.

Introduction

The Columbia River is the largest river in the Pacific Northwest of North America. Historical evidence indicates that since 1870 more than half of Columbia River estuarine wetlands have been lost as a result of human activities such as diking, draining, filling, dredging and flow regulation (NRC 1996; Marcoe and Pilson 2017). Over 100 large hydroelectric and multipurpose dams exist within the basin (NRC 1996); and the river supports numerous commercial and recreational activities including aquaculture, boating, fishing, hydroelectric power generation, irrigation, and shipping (Sytsma et al. 2004). Dam and jetty construction has changed the timing and magnitude of river flow, affecting water depth and velocity, sedimentation rates, and the extent of salinity intrusion (Kukulka and Jay 2003). These alterations have affected the distribution, abundance, life histories, and migration patterns of aquatic species (Merritt and Wohl 2002; Roegner et al. 2012).

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). Pacific salmon runs have declined to the point that many stocks are listed as threatened or endangered under the U.S. Endangered Species Act (Ford 2011). A variety of efforts to restore physical habitats in freshwater ecosystems are underway; an assumption is that these activities will mitigate historical losses caused by human activities (Bond and Lake 2003; Roni et al. 2002, 2008, 2014). 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, 2014; Kiffney et al. 2009; Pess et al. 2012, 2014; Bennett et al. 2016; Krueger et al. 2017; Seifert and Moore 2018).

Fish passage improvement at the Mirror Lake Complex (MLC), Columbia River Gorge (river km 208) at Rooster Rock State Park, Oregon, is such an example. The MLC includes two lakes and two streams connected with the Columbia River through a culvert that passes under I-84. 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). In the late summer of 2008, 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 (Parametrix 2008).

It was hypothesized that culvert modifications would facilitate fish passage between the Columbia River and the MLC, so juvenile salmonids could use the areas for feeding and rearing, and also facilitate migration of juvenile Coho Salmon O. kisutch from the upper sites. Sol et al. (2019) showed that the restoration of the culvert at the MLC was successful to some extent. The lower sites (i.e., the sites closest to the Columbia River) supported primarily Chinook Salmon O. tshawytscha and a variety of native and non-native fish species, with summer water temperatures above those favorable for salmonids. The upper sites were dominated by Coho Salmon, supported few non-native species, and had lower summer water temperatures. While salmonid assemblages and density did not change dramatically at the lower sites, in the years with higher spring water levels, Chinook Salmon were not present at the upper sites prior to culvert modification but were observed at these sites following the culvert modification.

However, it was also anticipated that culvert modification would also provide increased access to the MLC for other fish species. Accordingly, it was also hypothesized that the culvert modifications would allow passage of other fish species from the Columbia River into the MLC, yielding fish assemblages, particularly at the lower sites, that more closely resembled those in undisturbed portions of the river, with dominance by non-native species (Johnson et al. 2011; Sather et al. 2016).

Reducing the dominance of non-native species is an important objective of restoration efforts, as the introduction and establishment of non-indigenous species (NIS) has contributed to the decline of native species worldwide (Hughes and Herlihy 2006; Helfman 2007), including many threatened and endangered species (Sanderson et al. 2009). NIS are cited as a cause of endangerment of 48% of the species listed under the US Endangered Species Act (Czech and Krausman 1997; Wilcove et al. 1998). In 2005, NIS cost the US economy in excess of $120 billion, and the occurrence and ranges of NIS are steadily increasing (Pimentel et al. 2005). Some of these introduced species (e.g., Channel Catfish Ictalurus punctatus, Largemouth Bass Micropterus salmoides, Smallmouth Bass M. dolomieu, and Walleye Sander vitreus) have been identified as a factor in the decline of Pacific Northwest salmon that could equal or exceed that of four commonly addressed causes of adverse impacts: habitat alteration, harvest, hatcheries, and the hydrosystem (Fritts and Pearson 2004; Sanderson et al. 2009). High summer water temperatures in the off channel and backwater habitats are thought to be a major contributing factor to these changes observed in fish community composition (Gadomski and Barfoot 1998), causing native taxa (species) to move out of these habitats, and introduced warm-water taxa (species) to move in (Barfoot et al. 2002), thus, minimizing the impacts of NIS is essential for salmon recovery.

In the current study, we describe changes in the overall fish assemblage and community structure which could potentially affect/compete with juvenile salmonids by 1) characterizing fish assemblages before culvert modification in 2008; 2) comparing these data with post-modification (2009–2012) data to assess whether fish assemblages upstream of the culvert changed with time; and 3) describe water conditions and compare water temperature with fish assemblages.

Methods

<A> Study sites—Study sites are described in detail in Sol et al. (2019). Briefly, prior to the culvert modification in the late summer of 2008, three sites were monitored at MLC for fish assemblage and abundance: lagoon, Mirror Lake, and Young Creek (Figure 1). Lagoon is located just downstream of the culvert; Mirror Lake and Young Creek is 0.5 km and 5 km upstream of the culvert, respectively. Following the culvert modification, these sites were sampled 2009–2012, with two additional sites (confluence and Latourell Creek, 3 km and 4 km upstream of the culvert, respectively) sampled 2010–2012.

<B> Fish Collection Methods—Fish sampling was generally initiated in April and continued monthly through August. Water level at the MLC can vary throughout the year (Sol et al. 2019). Due to the variability in water level at the sites, several types of gear were used. During moderate to high water level (> 1 m depth), fish were collected with a Puget Sound beach seine (PSBS) (37 x 2.4 m, 10 mm mesh size) deployed from a boat. During low water levels when boat deployment was not possible (0.5-1 m depth), a modified Puget Sound beach seine (7.5 × 2.4 m, 10 mm mesh size) was deployed on foot. During extremely low water conditions (< 0.5 m depth) when fishing with the PSBS or

MPSBS was not efficient or feasible, a modified block net (MBN) whereby the middle portion of the MPSBS was used as a block net and a second net (2 x 1.5 m, 10 mm mesh size) was used as a fish chase net to herd the fish into the MBN. At each sampling event, the coordinates of the sampling locations, the time of sampling, area covered by the gear used, and water temperature were recorded. All fish collected were identified to the species level when possible and counted.

<C>Calculations and statistical analyses—We followed the recommended guideline for beach seining in Puget Sound (PSEP 1990). Gear efficiencies can be different across species and for different types of habitats (Hahn et al. 2007, Bayley and Herendeen 2000, Steele et al. 2006). Gear efficiency test was not performed for this study; however, we assumed similar catch efficiency for the various gear types, while acknowledging that different gear types and fishing techniques may have had some influence on fishing efficiency.

Fish density, defined as the number of fish captured by the fishing technique 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 (Lower Columbia River Estuary) (Bottom et al. 2008; Johnson et al. 2011; Sather et al. 2016). To allow comparison to other LCRE studies (Bottom et al. 2008; Roegner et al 2009), species diversity was estimated using the Shannon-Wiener Index (Shannon and Weaver 1949; Margalev 1958), which provides equal sensitivity to rare and abundant species (Morris et al. 2014).

The Confluence and Latourell sites were excluded from statistical analyses due to the limited datasets at these sites. Two factor ANOVA was used to compare fish attributes and water temperature to site and BACM (years before and after nested within site); and slice (t-test) used to compare before versus after for each site. Tukey's HSD (honestly significant difference) was used to compare inter-site differences in density, species diversity, species richness, % of native and non-native species. Linear regression was used to examine the relationship between temperature and various fish community attributes (species diversity, non-native species and percentage of non-native species in catch). Statistical analyses were conducted with the JMP statistical package, with values considered significantly different at alpha = 0.05.

Results

<A> Species Composition—Species composition varied according to the site location (Table 1). In the pre-modification year (2008), 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. Species composition varied slightly from year to year, but the total number of species observed at each site was higher in the post-modification years (2009-2012) (Table 1). Similarly, at the confluence and at Latourell Creek, a number of new species not noted in 2010 appeared at the site during 2011-2012 (Table 1).

<B>Species Richness—Species richness at the MLC varied from year to year (Table 2, Figure 2A), but species richness was consistently higher at the lake in the post-modification years than the pre-modification year (Table 2). Species richness at the lagoon was higher than either the lake or Young Creek, and the lake was higher than Young Creek (Figure 2A). Species richness was higher during the summer months (July-August) than in early spring (April) (ANOVA, Tukey's HSD, $P < 0.05$). Species richness at both confluence and Latourell Creek increased from 2010-2012 (Figure 2A).

<C> Shannon-Wiener Species Diversity Index—Species diversity at the MLC varied from year to year but showed no clear pattern relative to the culvert modification (Table 2, Figure 2B). Species diversity at the lagoon was higher than both the lake and Young Creek; and the lake was higher than at Young Creek (Table 2, Figure 2B). Similarly, species diversity was higher in August than in April (ANOVA, Tukey's HSD, $P < 0.05$). At the confluence, species diversity remained fairly constant from 2010-2012, while species diversity at Latourell Creek decreased slightly in 2012 compared to 2010 (Figure 2B).

<D> Percentage of non-native species— The percentage of non-native species, based on number of species caught, and based on the total number of fish caught, at MLC sites varied from year to year but showed no clear pattern relative to the culvert modification (Table 2, Figure 3). Young Creek had a lower percentage of non-native species than either the lagoon or the lake (Table 2, Figure 3). The percentage of non-native species observed in 2009 was higher than in 2010 and 2012; and 2011 was higher than in 2012 (ANOVA, Tukey's HSD, $P < 0.05$). The percentage of non-native species observed and fish caught in July-August were higher than for April-June (ANOVA, Tukey's HSD, $P < 0.05$). At the confluence, the percentage of non-native species increased in 2011

compared to 2010, but decreased slightly in 2012 (Figure 3A), while the percentage of non-native fish caught increased from 2010 to 2012 (Figure 3B). At Young Creek non-native fish were observed for the first time in 2011, while at Latourell Creek non-native fish were observed for the first time in 2012 (Figure 3B).

<E>Density—The density of fish at MLC varied from year to year but showed no clear pattern relative to the culvert modification (Table 2, Figure 4A). The density of fish at Young Creek was higher than either the lagoon or the lake (Table 2, Figure 4A). The density of fish from July-August were found to be higher than during April and May (ANOVA, Tukey's HSD, $P < 0.05$). The density of fish at the confluence and at Latourell Creek increased 2010-2012 (Figure 4A).

The density of native species at MLC also did not change relative to the culvert modification (Table 2, Figure 4B). Young Creek had a higher density of native species than either the lagoon or the lake (Table 2, Figure 4B). The density of fish was higher in June-July than in May (ANOVA, Tukey's HSD, $P > 0.05$). The density of native species at the confluence and at Latourell creek increased 2010-2012 (Figure 4B).

Similarly, the density of non-native species also did not change relative to the culvert modification (Table 2, Figure 4C). Young Creek had a lower density of non-native species than both the lagoon and the lake (Table 2, Figure 4C). The density of non-native species was higher in July-August than in April, and August densities were higher than April-May (ANOVA, Tukey's HSD, $P < 0.05$). The density of non-native species at the confluence and at Latourell creek increased 2010-2012, while at Latourell Creek non-native species were observed for the first time in 2012 (Figure 4C).

<F>Water Conditions and Fish Community—The water level at the MLC was not measured during the course of this study; however, it was strongly influenced by water discharges by Bonneville Dam (Figure 5A). The water level at the MLC varied by the season and year. The water level generally increased in April-May and decreased in July-August. The highest water level was observed in 2011 and an extended period of high-water level was observed in 2012. The water temperature at the MLC also varied by season, year and site (Figure 5B). The water temperature generally increased April-May (8–17ºC) to a peak in July-August (> 20ºC). The highest temperatures were observed in 2009 (31.5ºC at the lagoon and lake). Significant inter-site differences in water

temperature were observed. Across all years, temperature was the highest at the lagoon (20.6 ± 5.8ºC), followed by the lake (18.0 ± 5.5ºC), and lowest at Young Creek (13.0 ± 2.8ºC) (ANOVA, Tukey's HSD, $P < 0.05$). Temperatures at the confluence and at Latourell Creek were similar to Young Creek.

The water temperature at the MLC was generally higher in the years following the culvert modification but only the lake showed significantly higher temperature compared the pre-modification year (Table 2). Positive relationships were observed between water temperature and species richness (Figure 6A), species diversity (Figure 6B), percentage of non-native species (Figure 6C), and fish density (Figure 6D).

Discussion

Habitat restoration actions are important to the recovery of endangered and threatened species, and also are important in restoring other ecosystem attributes to their natural conditions, including resident fish assemblages (Bond and Lake 2003; Roni et al. 2002, 2008, 2014; 2019). In this study, our survey of the MLC prior to culvert modification revealed that while the upper site (Young Creek) supported healthy populations of Coho Salmon and other native fish, at the lower sites (lagoon and lake) resident fish assemblages included native fish as well as high proportions of non-native species. The species caught at the lower sites included both native and non-native species that can compete, prey upon, or otherwise interact with salmonids and other native fishes in ways that may be harmful (Rieman et al. 1991; Vigg et al. 1991; Zimmerman 1999; Sanderson et al. 2009; Johnson et al. 2011; Sather et al. 2016). For example, Northern Pikeminnow Ptychocheilus oregonensis, found at both the lake and lagoon, is a native piscivorous fish species that is known to feed on Columbia River juvenile salmonids during their emigration from natal streams to the ocean (Sanderson et al. 2009). Also, non-native introduced species, such as Smallmouth Bass, are known predators of juvenile salmonids (Weitkamp et al. 2012). In addition, in contrast to the upper sites, summer water temperatures were above those suitable for salmonids as well as some native fish species (Marine and Czech 1998, McCullough 1999). At the lower MLC sites, water temperatures during the summer months were consistently above 20°C, whereas the water temperature at the upper sites rarely exceeded 20°C (Sol et al. 2019).

While our pre-culvert modification survey established that there were signs of disturbance at the lower sites of the MLC, we saw few major changes in fish assemblages at the MLC that could be linked to the modification of the culvert. In the years following the culvert modification, varying degrees of inter-site differences in species richness, diversity, and percentage of non-native species were observed at the sites; however, in both pre-and post-culvert modification years, the sites near the culvert (lagoon and lake) had higher water temperature, species richness, diversity, and a higher percentage of non-native species compared to the upper sites (Young Creek, and limited sampling post-modification at the confluence and Latourell Creek).

Still, a few interesting trends were observed following the culvert modification. First, we observed an increase in species richness (both native and non-native) at all sites, significant only at the lake. The importance of this change is difficult to interpret as it did not appear to be associated with changes in other fish composition metrics, though it does suggest increased access of a variety of species to the MLC. The increase in species richness could also be due to additional sampling efforts made following the culvert modification and the opportunity to catch more species.

Second, although the change was not statistically significant, we found that non-native species at the upper MLC sites (confluence, Latourell Creek and Young Creek) increased during the high water level years (2011–2012). However, it is uncertain whether the movement of non-native species to the upper MLC sites can be directly attributable to culvert modification. Dam construction has changed the timing and magnitude of river flow, affecting water depth in the Columbia River (Kukulka and Jay 2003; Sanderson et al. 2009). Accordingly, water levels in the MLC changed drastically across seasons, coinciding with the Bonneville Dam discharge fluctuations (Parametrix 2006; Sol et al. 2019). Modifications made at the culvert may allow more water through the culvert to inundate upper sites, but unusually high Columbia River flows in 2011 and 2012 may have been equally or even more important. Annual inundation in a river floodplain system can provide higher biotic diversity (Junk et al. 1989), and increased species richness at upper MLC sites may have been facilitated by high water conditions. Other restoration efforts focused on floodplain connections in the Pacific Northwest have shown increases in native fish species abundance (Pess et al. 2012; Ogston et al. 2014; Liermann et al. 2017); however, these studies did not look at abundance of non-native fish species. Limited information is available on changes in the abundance of non-native species following restoration efforts in the Pacific Northwest. However, an increase in Brook Trout Salvelinus fontinalis abundance was shown as an indirect impact of restoration efforts in Utah (Belk et al. 2016), and removal of exotic species dramatically increased native fish species abundance in a restoration monitoring study in Arizona (Marks et al. 2010).

At this point, it is not clear whether non-native fish species will become established at the upper MLC sites, or what effect they might have on other native fish species established at these sites. It is possible that the lower temperature at upper sites could reduce habitat suitability for many warm-water species and limit their ability to become established in these areas, even if they occasionally have access, though this is uncertain in the face of climate change (U.S. Global Change Research Program 2009; Climate Impacts Group 2019). In any case, the potential colonization of the upper MLC sites by non-native species is a concern, as introductions of non-native species have been associated with declines in native fishes in the Columbia River, and non-native species may prey on native species or compete for prey resources (Sanderson et al. 2009).

High temperatures are a recognized problem for salmonids and other native fish in many nearshore sites in the Columbia River (Richter and Kolmes 2005; Bottom et al. 2008), as well as a factor encouraging the establishment of warm-water species (Poe et al. 1991, 1994). Culvert modification may have increased the flow of water between the lagoon and the lake, as observed by the increase in water temperatures at the lake that approached the water temperatures observed at the lagoon. However, at the lower MLC sites, water temperatures during the summer months remained consistently high following culvert modification, suggesting that action did little to alleviate high temperature problem at lower sites. Our data show a strong correlation between water temperature and species richness, species diversity, the percentage of non-native species, and the density of non-native species at the MLC sites. Both pre- and post-culvert modification, the lower sites had higher species diversity and a higher number of non-native species compared to the upper sites, perhaps due in part to higher water temperatures in these areas. At the lake, observed differences in species richness, pre- and post-modification, may have been influenced by differences in water temperature.

There are a variety of possible reasons that culvert modification did not appear to have the anticipated beneficial effects on fish assemblages in the MLC. First, natural annual and seasonal variation in fish assemblage composition may have made it difficult to detect changes following culvert modification. This is especially true since we had only one year of data on these sites prior to the restoration action, which may not have fully captured the degree of variability at the sites. Variability in catches associated with the use of different gear types may have contributed as well. Also, it is possible that the culvert was not as great an impediment to fish passage as it had initially been supposed, so post-modification changes were not dramatic. Finally, the abundance of non-native, predatory, and competitive fish species at the lower sites may have exhibited little change because these species are found throughout the Columbia River, including relatively undisturbed habitats located near MLC (Sather et al. 2016; Johnson et al. 2011). In all cases, the fish assemblages included not only species that are native to the Columbia River and the Pacific Northwest, but a number of other species that have been introduced to the Columbia River (Wydoski and Whitney 2003).

Conclusions and Management Implications

The United States is experiencing a global warming trend in which average temperatures have risen by 1^{o}C over the past 50 years and are projected to rise another 4–6^{o}C by the end of this century (Karl et al. 2009). Global warming is bringing winter rains, earlier spring runoff, and drier summers to the Columbia River Basin and the Pacific Northwest (Payne et al. 2004; Mantua et al. 2010; Hamlet et al. 2013). Such a climatic regimen would make current habitats less suitable for salmonids and other cold-water fish species and encourage establishment of warm-water species (native and non-native) (see review by Lynch et al. 2016). While the upper MLC sites currently serve as cold water refugia for juvenile salmon and other native species, this could change in the future in light of global warming trends.

Many restoration actions with the intent to restore connectivity have been successful (Galat et al. 1998; Gouraud et al. 2008; Roni et al. 2014, 2019). However, given the current dataset and the limitations described above, it is difficult to determine whether the improvements made to the MLC have successfully restored fish populations. Culvert modification alone did not appear sufficient to restore fish populations at the

MLC, for a variety of reasons discussed above (elevated water temperature, flow, natural variation in fish community). Despite the limitations presented here, there are some positive signs of fish assemblage recovery. Young Creek and Latourell Creek show strong native fish communities, while those at the lake and lagoon sites seem to have grown somewhat similar to those at other lower Columbia River sites (Johnson et al. 2011; Sather et al. 2016). Although culvert modification did not appear to reduce summer temperatures at the lower sites, the cooler water input from the upper reaches of the site may help mitigate high temperatures in the lake, and the upper sites might also serve as refugia for species intolerant of warm-water. However, our findings highlight that improving access to a site may also improve access not only for desirable native species, but for non-native species as well, with uncertain consequences. The apparent increased access and potential for non-native species to become established at the Young Creek and Latourell Creek sites is an area of concern. Additional attention to the problem of non-native species in the Columbia River as a whole may be needed to avoid similar problems at other restoration sites. Our study shows that long-term monitoring of restoration sites with respect to non-native species presence and the effects of environmental variables, such as water temperature, are increasingly important, particularly in light of climate change predictions.

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Table 1. Native and non-native species caught at Mirror Lake Complex (MLC) sites. Numbers below the site name denote percentage range of total catch observed at each site for all years sampled, 2008, 2009-2012.

Common name		Lagoon		Lake[2]		Confluence	Latourell Creek	Young Creek	
Native species	scientific name	2008	2009-2012	2008	2009-2012	2010-2012	2010&2012	2008	2009-2012
chiselmouth	Acrocheilus alutaceus	25.35	0.11-46.31	16.97	0.03-7.83	0-31.97	0.00-0.38		0.00-2.22
chub, tui	Gila bicolor		0.00-0.80		0.00-0.40		0.00-0.19		
lamprey, Pacific	Entosphenus tridentatus					0.00-0.07	0.00-0.10	0.07	0.00-0.32
peamouth	Mylocheilus caurinus	9.22	0.00-2.10	0.90	0.00-2.25				
pikeminnow, northern	Ptychocheilus oregonensis	2.52	0.44-4.30	3.62	0.07-16.95				
salmon, Chinook	Oncorhynchus tshawytscha	4.91	1.50-16.04	6.56	0.14-7.55	0.00-7.90			0.00-26.48
salmon, chum	O. keta		0.00-0.10						
salmon, coho	O. kisutch	21.77	0.69-6.30	0.23	0.00-1.44	0.53-25.72	27.01-90.77	81.66	24.89-95.88
sculpins[1]	Cottida spp.	0.27	0.00-1.35	0.23	0.14-1.44	0.00-0.79	0.00-0.31	0.89	0.28-2.53
smelts[1]	Osmeridae spp.		0.00-0.04						
stickleback, threespine	Gasterosteus aculeatus	2.52	4.21-52.14	52.49	0.42-80.28	28.95-73.43	8.31-70.40	17.11	2.86-45.40
sucker, largescale	Catosmtomus macricheilus	1.79	0.00-1.97		0.02-12.09		0.00-0.62		
trout, rainbow/steelhead	O. mykiss		0.00-0.010					0.27	0.00-0.09
trout, cutthroat	O. clarkii				0.00-0.03				0.00-0.25
whitefish, mountain	Prosodium williamsoni				0.00-0.06				
species count		8	12	7	11	6	7	5	8
# fish caught		1,034	6,264	394	16,279	26,359	8,243	2,174	6,282

Common name		Lagoon		Lake		Confluence	Latourell Creek	Young Creek	
Non-native species	scientific name	2008	2009-2012	2008	2009-2012	2010-2012	2010&2012	2008	2009-2012
bass, smallmouth	Micropterus dolomieu	1.92	0.20-1.94	0.23	0.05-3.71				
bluegill	Lepomis macrochirus	1.19	0.00-6.27	0.45	0.02-2.12				
bullheads[1]	Ameiurus spp.		0.00-6.90	0.23	0.00-0.07				
common carp	Cyprinus carpio	0.86	0.40-17.26	4.98	0.14-19.74	0.00-24.56	0.00-0.86		0.00-1.33
crappies	Pomoxis spp.		0.00-0.56		0.00-0.19				
goby	Rhinogobius brunneus				0.00-0.02				
killifish, banded	Fundulus diaphanus	7.90	0.18-19.19	1.36	3.13-23.31	0.00-24.56			
mosquitofish	Gambusia affinis				0.00-8.40	0.00-31.57	0.00-0.48		
perch, yellow	Perca flavescens	0.27	0.00-0.32						
pumpkinseed	Lepomis gibbosus	15.73	0.30-7.01	11.76	1.22-34.71	0.00-0.88	0.00-0.58		
shad, American	Alosa sapidissima	3.78	0.21-15.3						
shiner, golden	Notemigonus crysoleucas				0.00-0.80				
walleye	Sander vitreus		0.00-0.09						
species count		7	10	6	10	4	3	0	1
# fish caught		532	2,039	468	2,866	321	65	0	18

[1] Due to difficulties in identifying fish, various species of bullhead, sculpins, and smelts are each categorized as a single species. [2]An unidentifiable larvae was caught at the Lake.

Table 2. ANOVA results from Mirror Lake Complex (MLC) sites showing the influence of two factors, site and BACM (the years before and after culvert modification) nested within site. Slice (t-test) used to compare before versus after for each site. The

Confluence and Latourell sites were excluded due to the limited datasets at these sites. Species richness is total number of species caught, and density is defined as the number of fish captured per 1,000 m^2. * denotes parameter estimates where individual interactions were found to be significant at $P < 0.05$.

		Effects test			Slice (t-test)	
ANOVA		DF	Prob > F		F	Prob > F
Species richness	Site	2	<0.0001*			
F = 13.4206	BACM[Site]	3	0.2236	Lagoon (BACM)	0.0012	0.9729
P < 0.0001*				Lake (BACM)	4.3540	0.0389*
				Young Cr (BACM)	0.0774	0.7812
Diversity index	Site	2	<0.0001*			
F = 8.7933	BACM[Site]	3	0.9340	Lagoon (BACM)	0.0110	0.9167
P < 0.0001*				Lake (BACM)	0.1850	0.6678
				Young Cr (BACM)	0.2330	0.6301
% non-native species	Site	2	<0.0001*			
F = 15.7256	BACM[Site]	3	0.9596	Lagoon (BACM)	0.0724	0.7883
P < 0.0001*				Lake (BACM)	0.0013	0.9711
				Young Cr (BACM)	0.2275	0.6342
% non-native total catch	Site	2	<0.0001*			

F = 6.7522	BACM[Site]	3	0.8332	Lagoon (BACM)	0.8535	0.3573
P < 0.0001*				Lake (BACM)	0.0138	0.9066
				Young Cr (BACM)	0.0001	0.9911
Total density	Site	2	0.0010*			
F = 3.1521	BACM[Site]	3	0.3332	Lagoon (BACM)	0.1922	0.6618
P = 0.0101				Lake (BACM)	1.8850	0.1721
				Young Cr (BACM)	1.3597	0.2457
Native species density	Site	2	0.0001*			
F = 4.1685	BACM[Site]	3	0.3846	Lagoon (BACM)	0.0485	0.8260
P = 0.0015*				Lake (BACM)	1.4960	0.2235
				Young Cr (BACM)	1.5256	0.2190
Non-native species density	Site	2	0.0969			
F = 3.0356	BACM[Site]	3	0.2737	Lagoon (BACM)	2.1544	0.1446
P = 0.0126*				Lake (BACM)	1.7723	0.1854
				Young Cr (BACM)	0.0051	0.9432
Water temperature	Site	2	<0.0001*	Lagoon (BACM)	0.0140	0.9061
F = 11.0011	BACM[Site]	3	0.0758	Lake (BACM)	6.8662	0.0099*
P = 0.0001*				Young Cr (BACM)	0.1674	0.6832

Figures

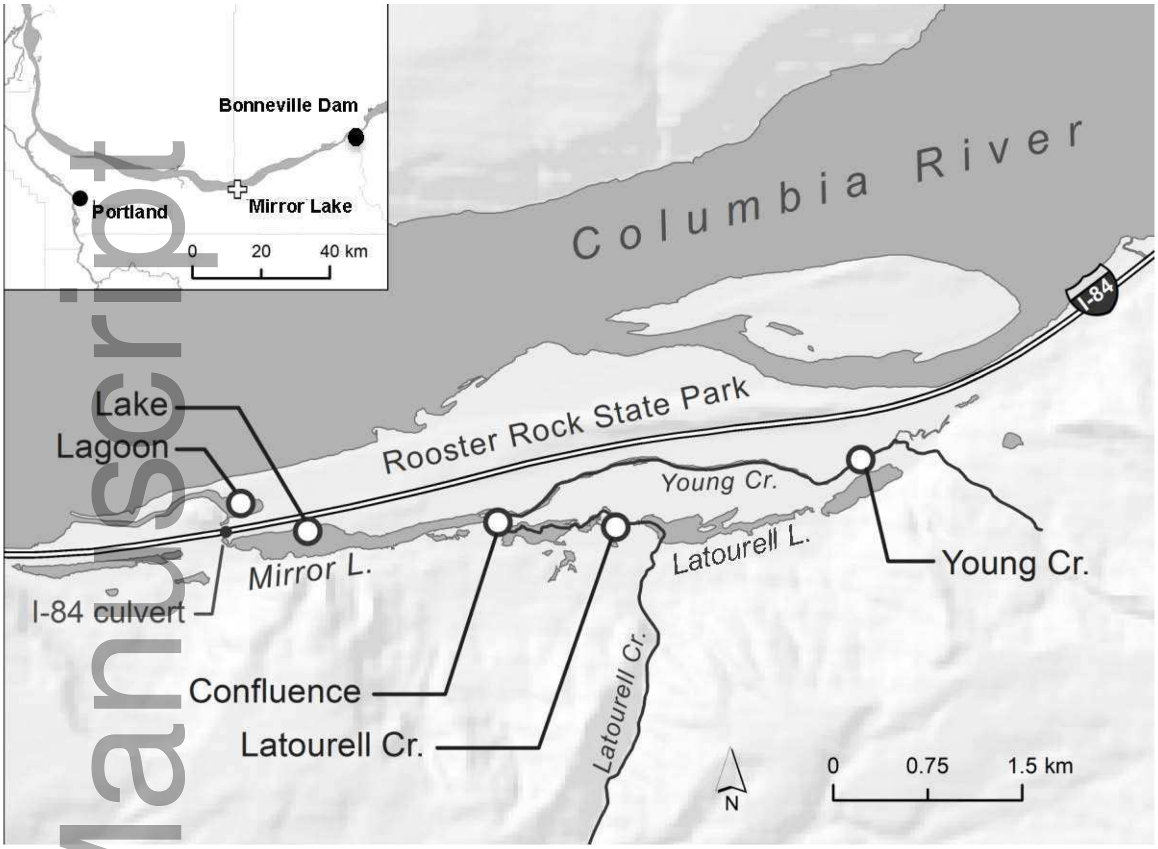


Figure 1. Areas of fish collection at the Mirror Lake Complex (MLC) sites.

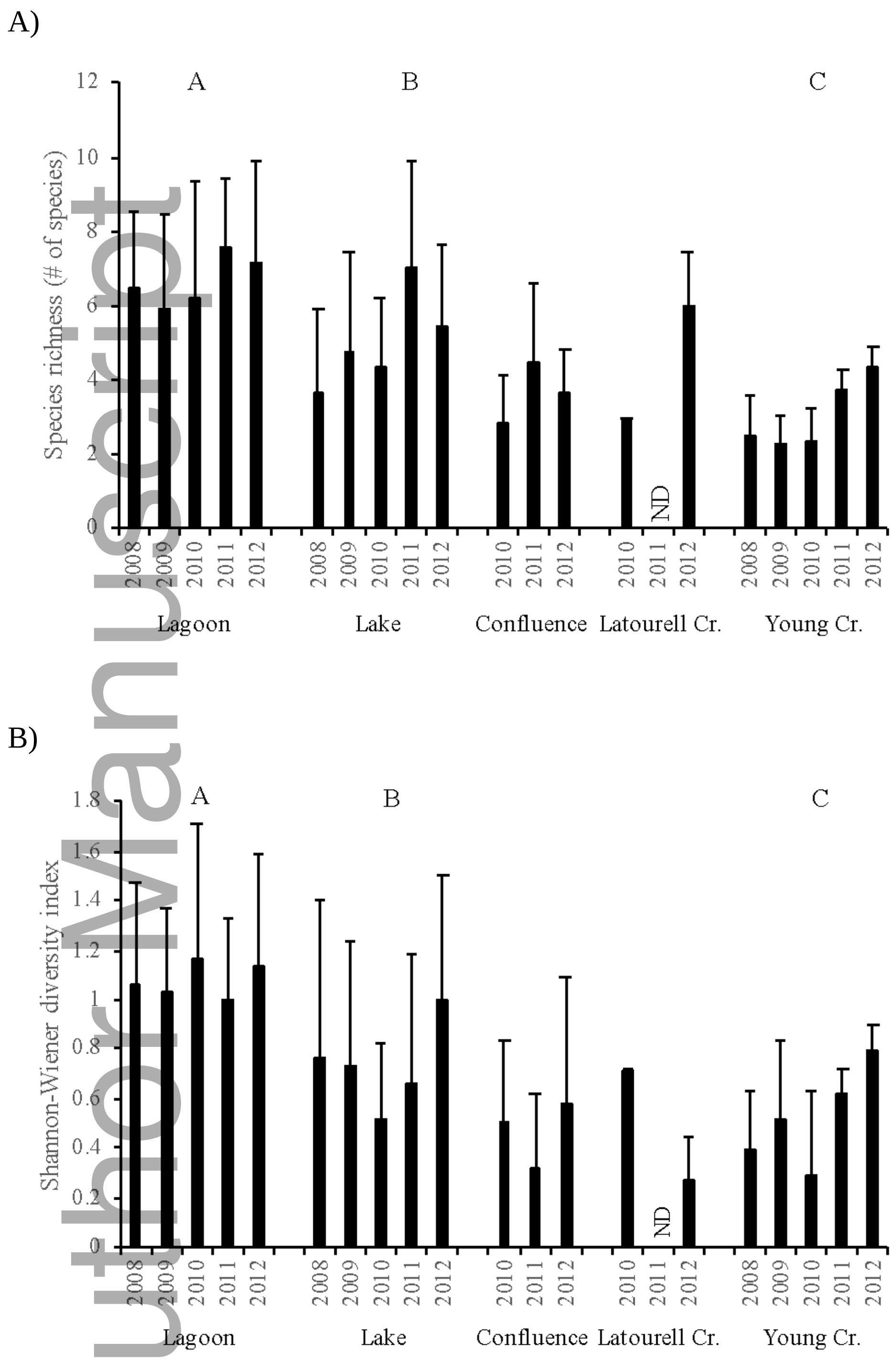


Figure 2. Mean ± STDEV of A) species richness and B) Shannon-Wiener species diversity index at the Mirror Lake Complex (MLC) sites. Letters above the bars, not connected by the same letter denote significant difference between sites for all years sampled (ANOVA, $P < 0.05$). ND=no data.

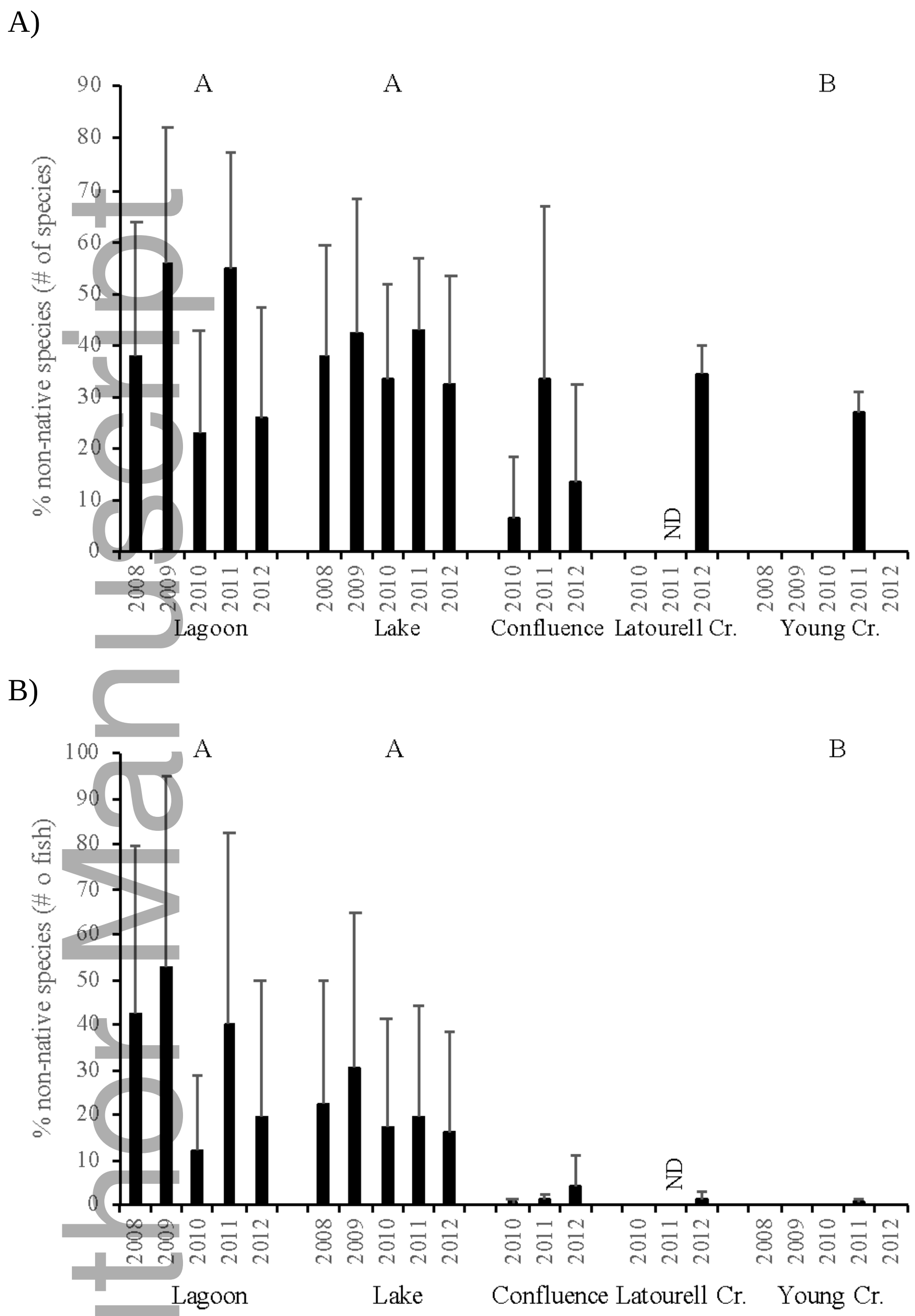
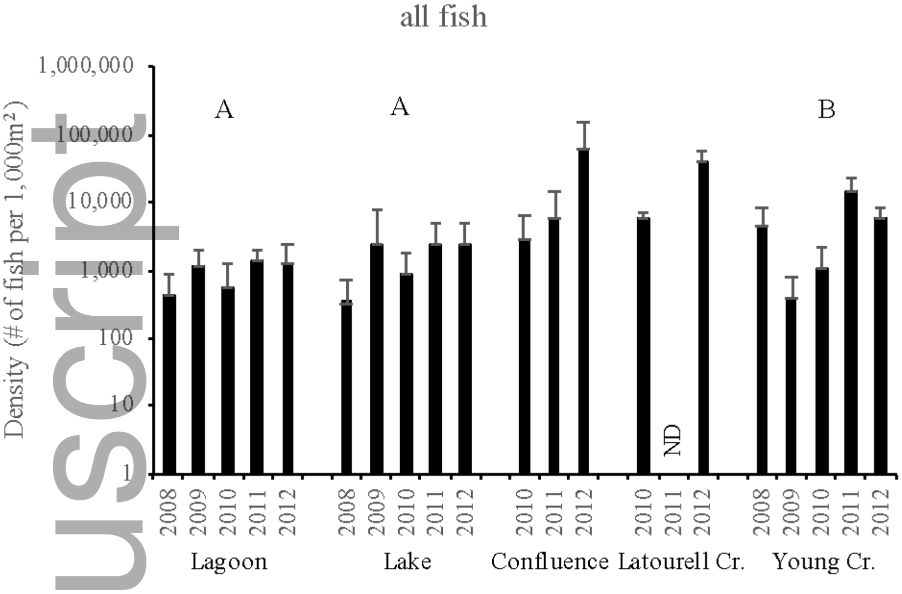
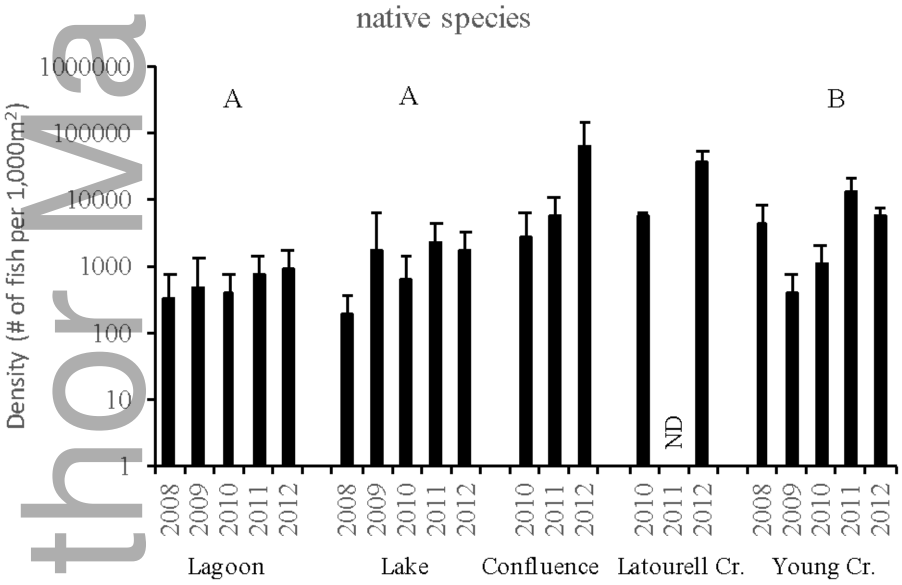


Figure 3. Percentage (mean± STDEV) of non-native species caught at the Mirror Lake Complex (MLC) sites A) based on total number of species caught, and B) based on total number of fish caught. Letters above the bars, not connected by the same letter denote significant difference between sites for all years sampled (ANOVA, *P* < 0.05). ND=no data.

A)


all fish
Density (# of fish per 1,000m^2)
1,000,000
100,000
10,000
1,000
100
10
1
A
A
B
ND
2008
2009
2010
2011
2012
2008
2009
2010
2011
2012
2010
2011
2012
2010
2011
2012
2008
2009
2010
2011
2012
Lagoon
Lake
Confluence
Latourell Cr.
Young Cr.

B)


native species
Density (# of fish per 1,000m^2)
1000000
100000
10000
1000
100
10
1
A
A
B
ND
2008
2009
2010
2011
2012
2008
2009
2010
2011
2012
2010
2011
2012
2010
2011
2012
2008
2009
2010
2011
2012
Lagoon
Lake
Confluence
Latourell Cr.
Young Cr.

C)

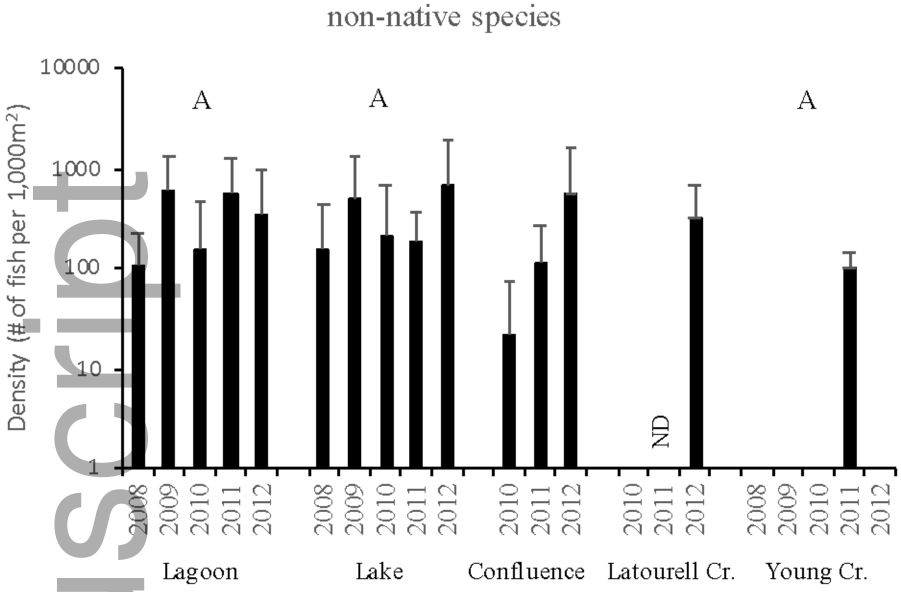


Figure 4. Density (mean ± STDEV) of A) all species B) native species and C) non-native species at the Mirror Lake Complex (MLC) sites. Letters above the bars not connected by the same letter denote significant difference between sites for all years sampled (ANOVA, $P < 0.05$). ND= no data.

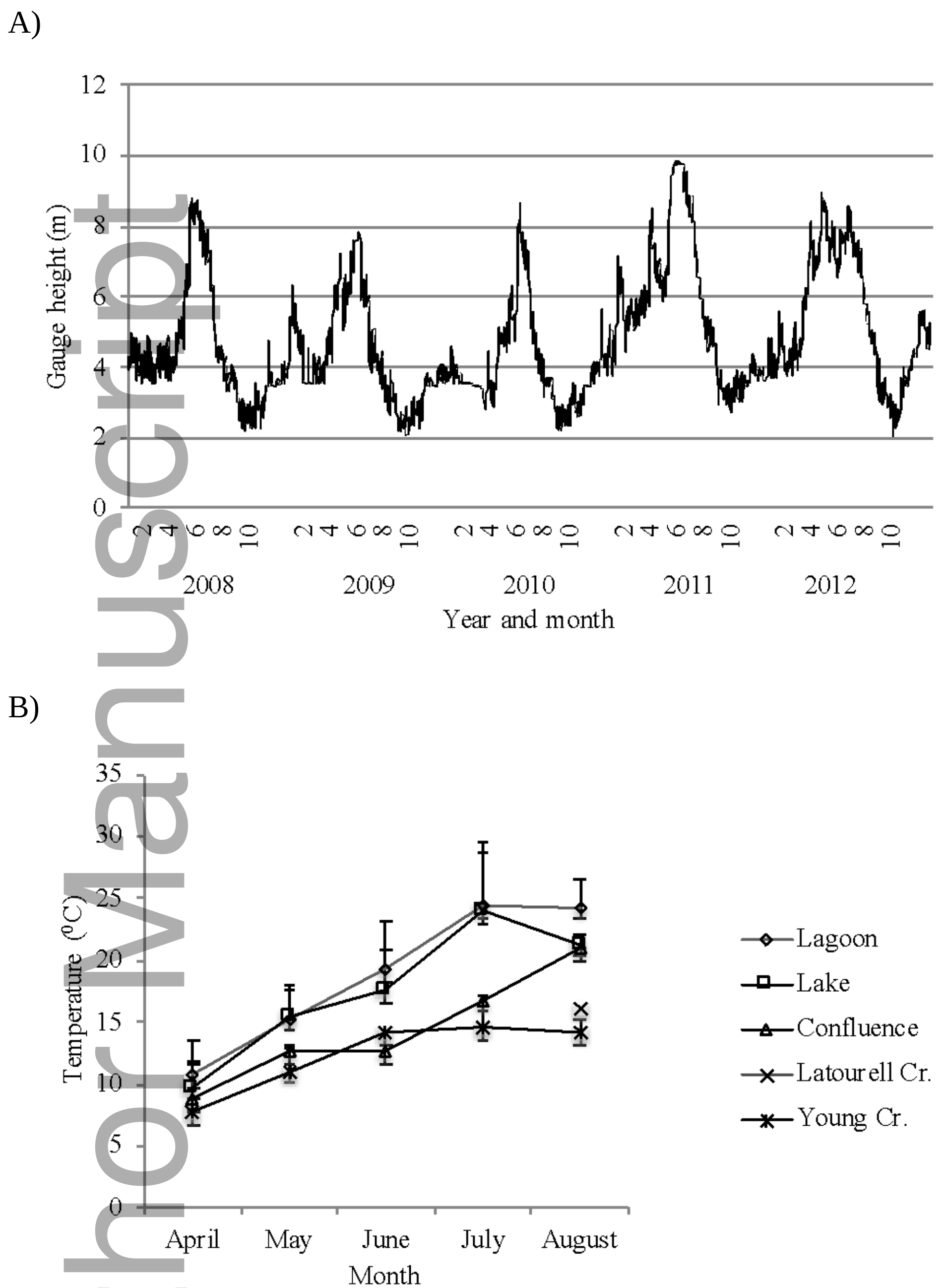
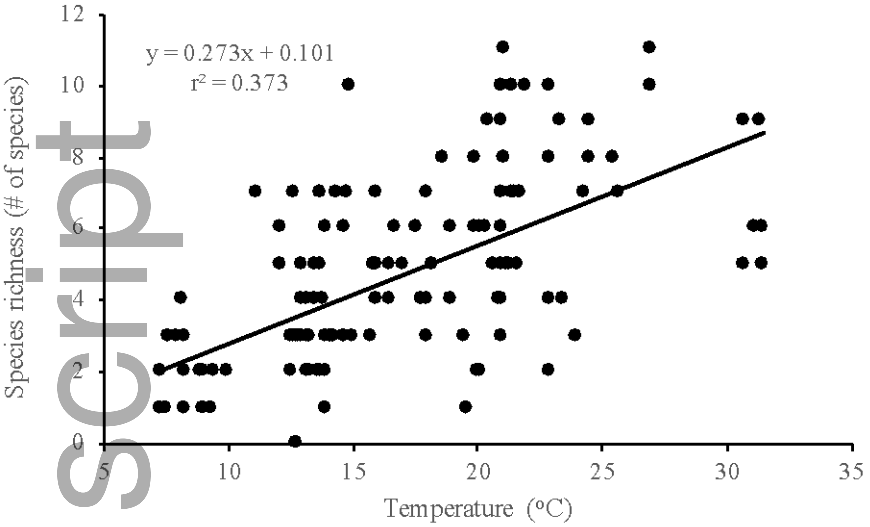
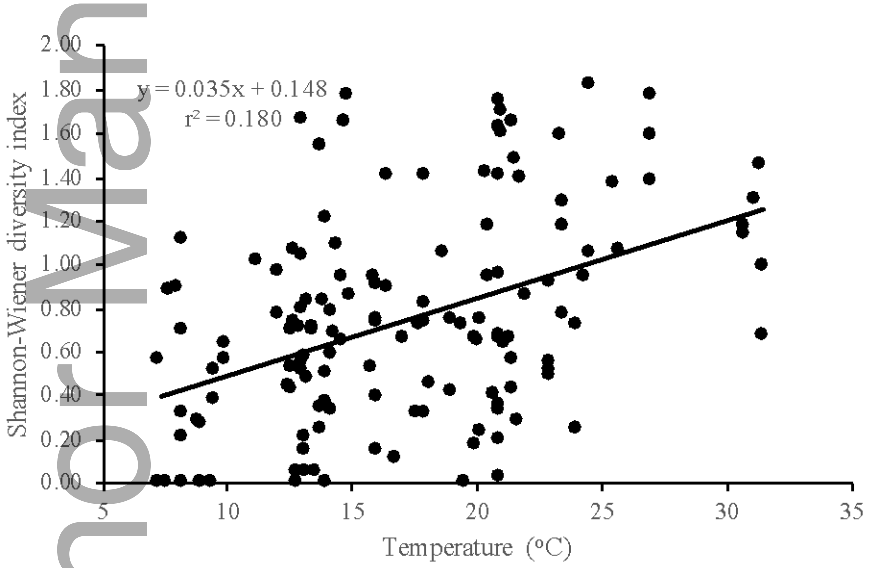


Figure 5. A) average daily water level at Bonneville Dam (rkm 234) on the Columbia River from 2008-2012 (data source: https://waterdata.usgs.gov/nwis/uv?site_no=14128870), and B) average monthly temperature at the Mirror Lake Complex (MLC) sites.

A)


y = 0.273x + 0.101
r² = 0.373
Species richness (# of species)
0
2
4
6
8
10
12
5
10
15
20
25
30
35
Temperature (°C)

B)


y = 0.035x + 0.148
r² = 0.180
Shannon-Wiener diversity index
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
5
10
15
20
25
30
35
Temperature (°C)

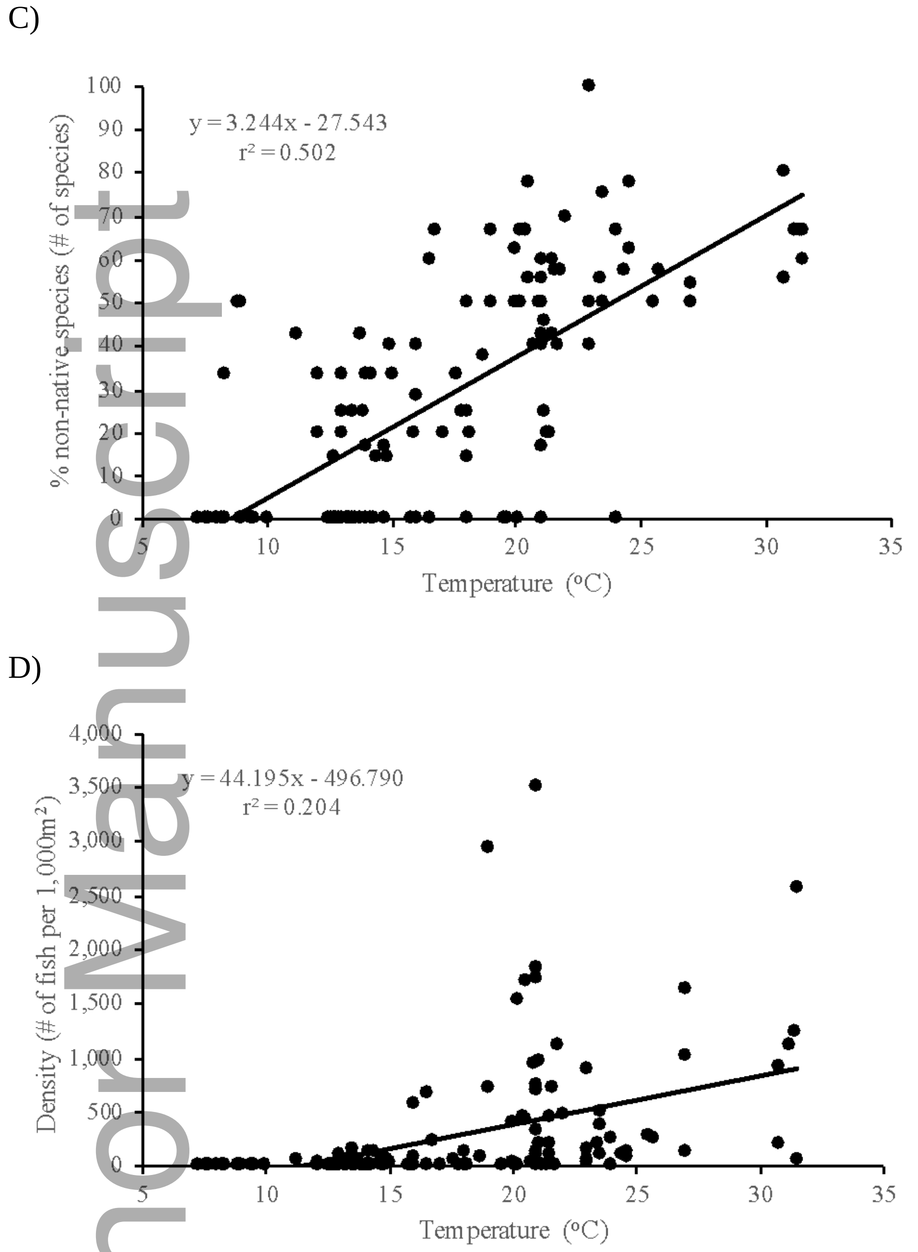


Figure 6. Relationship between water temperature and A) species richness B) Shannon-Wiener diversity index C) % non-native species based on the total number of species caught, and D) density of non-native fish at the Mirror Lake Complex (MLC) sites.