Horsetail Creek Floodplain Restoration: Water Temperature and Fish Monitoring Summary Report

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Executive Summary

The Horsetail Creek Floodplain Restoration Project was undertaken by Lower Columbia Estuary Partnership in 2013 in partnership with the US Forest Service Columbia River Gorge National Scenic Area and Oregon Department of Transportation, and with funding from Bonneville Power Administration, Oregon Watershed Enhancement Board, US Forest Service, Oregon Community Foundation and East Multnomah Soil and Water Conservation District. The Horsetail Creek floodplain had undergone severe anthropogenic modifications throughout the past century (Figure 3) which had negatively impacted ecological functions at the site. Several studies in the Lower Columbia indicate that this site is frequently used by Endangered Species Act (ESA)-listed salmon, lamprey and other non-salmonid species as migration and rearing habitat. Restoration activities were focused on:

- Improving access to the site for all life stages of ESA-listed salmon and steelhead and lamprey over a wide range of hydrologic conditions by modifying passage through a highway culvert.
- Increasing the diversity, quality, and quantity of instream habitat by adding large wood structures.
- Reducing stream temperatures by restoring riparian habitats and eliminating the diversion of Oneonta Creek through the gravel pond.

The project was the first phase of a multi-phased restoration project. Restoration activities included restoring the historic alignment of Oneonta Creek (Figure 2), converting an existing gravel pond into an emergent wetland with a network of open water channels, and adding native vegetation and large woody debris to improve habitat complexity. The culvert beneath I-84 was also modified to improve fish and lamprey passage (Figure 4). This report presents findings of pre- and post-restoration temperature and fish use monitoring at the site undertaken to determine the effectiveness of the restoration project. The goal of this summary to provide a brief overview of the study and results.

Stream temperature

We collected hourly water temperature data by deploying Hobo dataloggers at seven monitoring stations (Figure 5) at the Horsetail Creek restoration site from 2010 and 2014-2016 and again between 2018 and 2019. Loggers were placed at stream junctions to evaluate the temperature influence of various flow inputs, at the beginning and ends of stream reaches to evaluate heating through these sections, and in the gravel pond/wetland complex. No temperature data was collected in 2017 as the site was inaccessible due to high water levels throughout most of the summer of that year. 7-day average daily maximum (7-DADM) temperatures were calculated for each monitoring station between June to September or over the available time-period. These were summarized as yearly maximum and average 7-DADM temperatures.

Pre-restoration monitoring data are very limited. Due to this and other factors discussed below, the results of our study into whether restoration actions were effective at cooling site temperatures are inconclusive. Pre-restoration monitoring was performed in one year only, 2010, whose summer months were notably cooler and wetter relative to both historical conditions and post-construction monitoring years. Post-restoration 7-DADM summer water temperatures at the site were seen to frequently exceed 16°C, an optimal temperature threshold defined by both Oregon and Washington state water quality

standards (Core Coldwater Habitat: [OR DEG Water Quality Standard Implementation IMD, April 2008, Table 3-2]; Core Summer Salmonid Habitat: [Washington Administrative Code 173-201A-210, Table 200 (1)(c)]), for all years monitored. We observed the highest post-restoration summer water temperatures in 2015 and 2019, and the lowest in 2016. In 2014, 2015, and 2019, 7-DADM water temperatures throughout the site frequently exceeded the adult migration and juvenile rearing temperature threshold of 18°C (same standards as cited above for OR and WA) throughout the summer. When summer ambient air temperature and precipitation data were compared to site water temperatures, we observed that while the ambient air conditions varied widely on a year-to-year basis, water temperatures at the site remained within a narrower range (12.7°C – 20°C), suggesting that the resiliency of the site may be improving. The native vegetation planting and large wood placements helped encourage beaver activity and improve habitat quality. Post-restoration monitoring indicates that Oneonta Creek was successfully realigned during construction and while average summer water temperatures remain within a constant range (12.7°C – 20°C), it is expected that temperatures throughout the site will decrease as plantings mature. Restoration activities in the Horsetail Creek floodplain may also be helping to maintain summer site water temperatures below levels that can be dangerous to salmonids, in contrast to the Columbia River mainstem where summer temperatures often exceed these levels.

While the study was able to determine the general summer water temperature characteristics of the site after restoration, several questions remain unanswered and certain patterns observed at some of the monitoring stations could not be resolved. To assess the complete temperature evolution of the site since restoration, year-round temperature and flow data are required. However, temperature data is available only for the summer (June–September) for most monitoring years and flow measurements were made only instantaneously between 2010 and 2014–2016. These measurements do not allow us to draw conclusions on the current flow patterns of the site, which are ever changing due to increased beaver activity after restoration. The study also does not consider the effect of several groundwater seeps that were discovered during restoration and year one post-restoration monitoring.

It is recommended that future monitoring efforts include regular flow measurements at the monitoring stations and collection of year-round temperature and water surface elevation data to provide an in-depth analysis of temperature reduction efforts. A comprehensive study will help in understanding other potential areas for future restoration at the site and provide insight into thermal assessments for potential cold water refugia in the area.

Fish Monitoring

We collected fish presence data for five years post-restoration (2014–2019) using a passive integrated transponder (PIT) tag detection system installed at both ends of the culvert that carries Horsetail and Oneonta creeks beneath I-84, installed after construction in 2013 (Figure 8). Each year the array was operational from late March or April to October or November.

Salmon from throughout the Columbia River Basin were detected at the Horsetail PIT array. Chinook salmon were the most numerous species detected of juvenile fish and coho were the most numerous species detected of adult/jacks. The mid-Columbia Basin was the origin of the largest number of PIT tagged salmon detected at Horsetail. Juvenile residence times were relatively short with most lasting less than one day and in most cases less than one minute. However, steelhead, spring/summer run and fall run Chinook showed greater variability in residence times with several fish residing five or more days. For adult/jack salmon detected at the Horsetail array, residence times did not have the same range as for juveniles. Coho salmon had the longest residence times with a maximum of 18 days followed by steelhead with a maximum of 12 days. Residence times were impacted by whether salmon successfully navigated the culvert. Combining juveniles and adults, the median residence time for salmon that did not pass the culvert was 5 minutes, whereas the median residence time for salmon that did pass the culvert was 33 hours. In summary, juvenile and adult salmon have the potential to access and benefit from the cold water refugia at the Horsetail Creek restoration site. Whether a salmon can access the site depends on the time of year and water levels, as the culvert may block access during times of low water levels.

1. Introduction

In 2013, the Lower Columbia Estuary Partnership completed the Horsetail Creek Floodplain Restoration project within the Horsetail Creek floodplain of the Columbia River in Oregon. The 180-acre site is located eight miles downstream of Bonneville Dam in Multnomah County, and 35 miles east of Portland in the Columbia River Gorge National Scenic Area (Figure 1). The project actively restored 36 acres of riparian wetlands and 1.1 miles of salmon-bearing stream, and improved fish passage to 96 acres of floodplain habitat. The project was aimed at restoring ecological function to a site that has been heavily modified by human use over many decades. Specific objectives included, among others, improving fish access by modifying passage through a highway culvert; and improving water quality for salmonids through actions that would help to reduce summer water temperatures within the site, including revegetation and re-routing of flows that had been adversely affecting temperatures.

Figure 1: Location of Horsetail Creek Floodplain restoration site.

Water temperature in the Columbia River, including its floodplain and tributaries, has become an increasing concern in the last few decades, particularly in relation to the health of species that they support. These waterbodies are important rearing and migration corridors for several anadromous salmonid species. Unfortunately, since the 1860s, anthropogenic activities such as land use conversions, levee and dam construction, and introduction of contaminants have significantly altered the flow and water quality of the Columbia River (Rao et al., 2020). Coupled with the additional influence of global warming, these factors have led to increasingly warm temperatures in the mainstem and tributaries (Marcoe et al., 2018). Summer water temperatures in the mainstem Columbia River have increased steadily over the last several decades (Rao et al., 2020) and are expected to increase further based on predictions from various climate models. Peak summer temperatures now typically range from 21°C – 24°C and are expected to increase by as much as 1.7 °C by 2040 and 3.0 °C by 2080 (Isaak et al., 2016). Furthermore, the duration of time that water temperatures meet or exceed these values is also expected to increase.

Studies indicate that mixed stock-assemblages of adult and juvenile Pacific salmonids (*Oncorhynchus* spp.), many of which are endangered or threatened, utilize the Columbia River from spring through fall, with peak migration and rearing windows for some species occurring during the summer (Goniea et al., 2006; Hess et al., 2016). Salmonids have narrow temperature tolerances and are highly susceptible to behavioral and physiological changes under temperature duress. The negative effects that water temperatures exhibited by the Columbia River during the summer can have on salmonids are well documented (Lee et al., 2003; Goniea et al., 2006; Howell et al., 2010; Hasler et al., 2012). Keefer et al. (2015) suggest that temperatures above 19 °C induce stress in adult migrants, and that higher temperatures are associated with stronger negative costs. Beechie et al. (2013) summarizes established temperature thresholds and recommended temperature criteria for a variety of Pacific salmon and steelhead at various life cycle stages. The U.S. Environmental Protection Agency (EPA) recommends using the 7-day average daily maximum (7-DADM) temperature as a criterion for determining suitable water quality for salmonids. As shown in Table 1, 7-DADM temperatures above 19°C are considered sub-optimal for all salmonid life phases, and those exceeding 22°C can potentially be considered lethal given long-term exposure.

Table 1: 7-DADM temperature ranges and thresholds for ESA-listed salmon and Trout Life stages in the Pacific Northwest (U.S. Environmental Protection Agency, 2003)

Salmon and Trout Life Stages	7-DADM temperature Threshold in °C
Spawning and Egg incubation	*Optimal range*: 6°C - 10°C *Lethal*: >13°C
Juvenile rearing	*Optimal range*: 10°C - 16°C *Lethal*: >22°C
Adult Migration	*Optimal Range:* 15°C - 19°C *Lethal:* >22°C

The temperature and metabolic characteristics described above suggest that during their respective upstream and downstream migrations, adult and juvenile populations of salmonids using the Columbia River during the summer are exposed to harmful, and even lethal, temperatures. Research has shown that these fish are responding by seeking out cold-water sources as thermal refuge, particularly in the mid-Columbia reach. Adult steelhead in particular are known to use these thermal refuge zones for days to weeks (Hess et al., 2016). As water temperatures continue to rise, the importance of thermal refuge in the Columbia River Basin will continue to increase. EPA recently finalized a Cold Water Refuges Plan for the entire U.S. reach of the Columbia River (U.S. Environmental Protection Agency, 2021). In 2015, Marcoe et. al conducted a study that investigated strategies for identifying and enhancing cold water refuge zones at mainstem-tributary confluence zones in the lower Columbia River, with a focus on lower Columbia Gorge streams. The study monitored 15 Gorge tributary complexes. Of these, five had confluence zones that showed potential for providing summer thermal refuge for adult and juvenile salmonids. One of these (Eagle Creek) currently functions as a refuge zone based on our monitoring, while the other four could potentially provide this benefit through enhancement techniques. One of these four is the Horsetail/Oneonta complex confluence zone (because Horsetail Creek and Oneonta Creek merge within the floodplain and then enter the Columbia River together through a single culvert, we use the term 'complex' here to refer to these combined tributary flows entering the Columbia at a single confluence zone).

This report presents findings of a water temperature monitoring study that was conducted at the Horsetail Creek Floodplain Restoration site from 2010–2019 to determine the effectiveness of the restoration project. We also report results from a PIT array that was installed at the entrance to the site during roughly the same period (via a culvert under the I-84 highway overpass) to monitor fish passage into and out of the site. Water temperatures at floodplain sites such as Horsetail Creek have taken on increased importance in recent years as more has been learned about how Columbia River salmonids are responding to elevated temperature conditions during the summer. A good understanding of how this restoration effort has affected water temperatures at the site is essential for evaluating the capacity of the floodplain site to provide thermal refuge to summer-rearing juvenile salmonids in a warming climate and will also help to inform restoration actions at similar sites. If the project has indeed succeeded in decreasing water temperatures in the floodplain and thereby improving juvenile rearing conditions, it will also have achieved a secondary benefit of providing cooler water to the Columbia mainstem. As mentioned above, the Estuary Partnership has been looking at ways to enhance thermal refuge conditions for summer-migrating adult and juvenile salmonids at tributary-mainstem confluence zones where conditions are suitable. We are currently conducting one such feasibility study, funded by OWEB, at the Horsetail/Oneonta complex confluence zone. Any thermal improvements that are being realized by the Horsetail Creek Floodplain Restoration project will serve to benefit this potential future project stage should it go forward.

This report references two separate project phases which are similar, requiring some clarification of terminology that will be used going forward. The report is focused on water temperature effects of the 'Horsetail Creek Floodplain Restoration Project', the project phase completed in 2013. Because Oneonta Creek merges with Horsetail Creek within the floodplain, its floodplain reach is implicitly assumed to be included under this title, despite it not being mentioned. For the future thermal enhancement project phase at the mainstem/tributary confluence, we use the term 'Horsetail/Oneonta tributary complex' when referring to this confluence zone, for reasons described above.

1.1 Project Site Characteristics

Aerial imagery and 19th century Government Land Office survey maps indicate that the Horsetail Creek floodplain was historically a dynamic portion of the Columbia River floodplain. A network of six separate sloughs and streams conveyed flow coming off the steep hillslope to the south through heavily forested floodplain and into the Columbia River (Figure 2). Throughout the last century, morphology of the site was significantly impacted by the construction of the railroad (1882, across the southern margin), Historic Highway (1912–1914, also across the southern margin), and Interstate 84 (1950s–1960s, across the northern margin) resulting in the placement of new fill, ditches, culverts, and bridges, which have severely impacted the site's hydrology. During construction of I-84, the Oregon Department of Transportation excavated a large gravel borrow pit to source material for road fill and re-routed the six former sloughs through the floodplain so that all flow coming off the hillslope was conveyed into Oneonta Creek, which was then routed through a single highway underpass culvert to the Columbia River (Figure 3). In addition, the proximity of the borrow pit and porosity of alluvial fan material resulted in a portion of Oneonta Creek flow upstream of the slough confluence to be diverted through the borrow pit (Figure 3, dashed line). Imagery from 1935 shows that the site remained heavily forested at this time, with some clearing at the east end. In subsequent decades most of the vegetation at the site was cleared to facilitate agricultural activity. By 1995, agriculture had ceased and much of the site had re-colonized with overstory vegetation (Horsetail Creek Baseline Assessment, 2010), however significant cleared areas remain.

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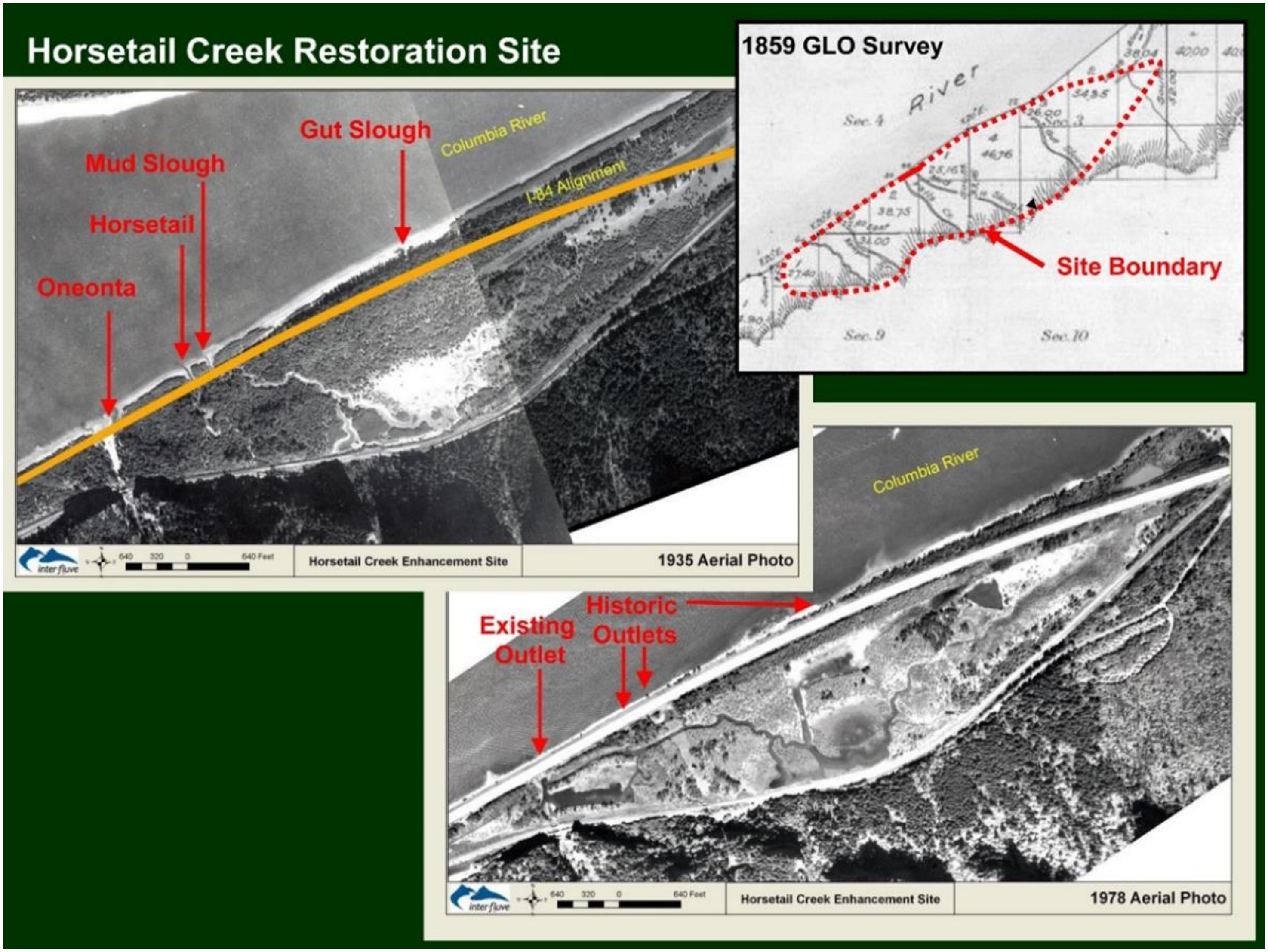

Figure 2: Historical images and maps illustrating trajectory of site hydrology at the Horsetail Creek Floodplain restoration site.

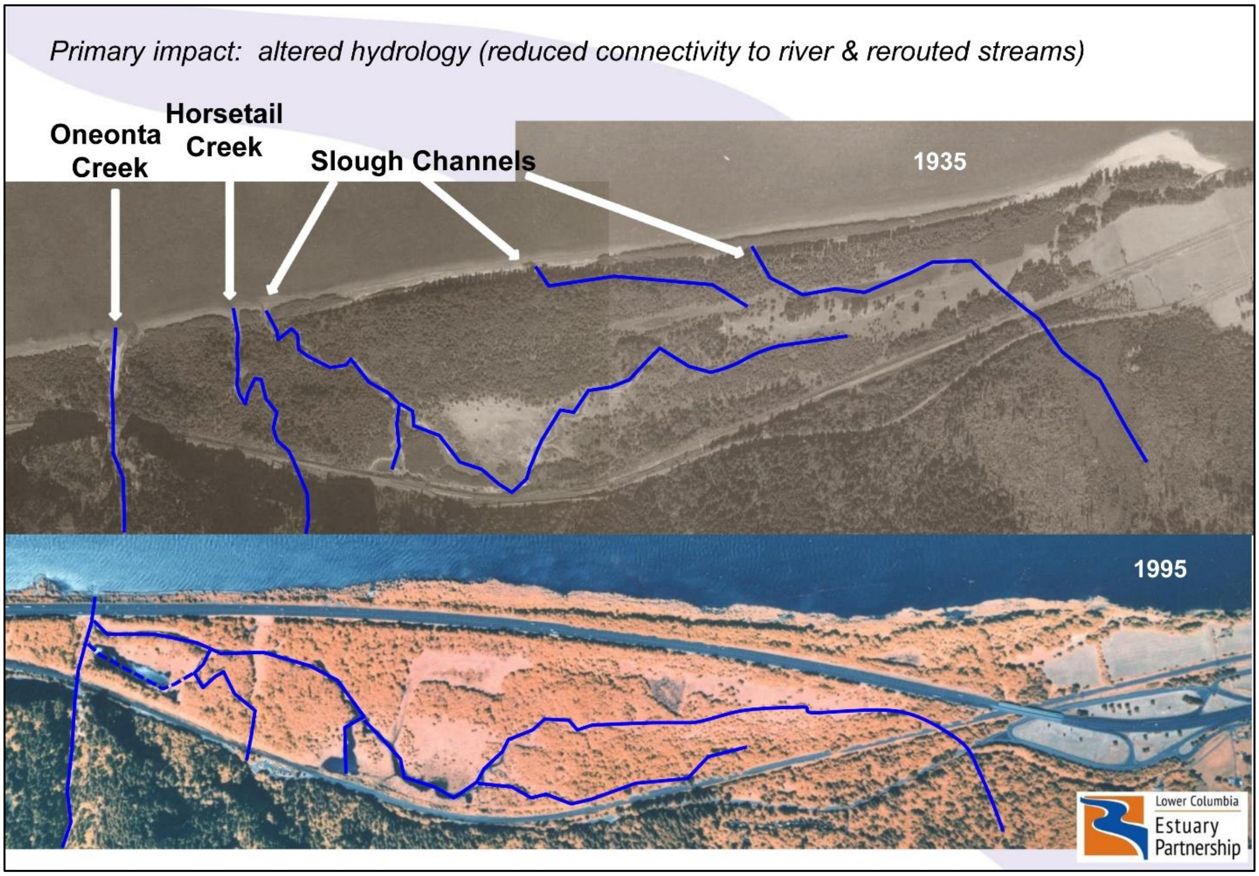

Figure 3: Historical image sequence with flow paths overlain to illustrate how flow was re-routed through the Horsetail Creek Floodplain restoration site during construction of Interstate 84 in the 1950s and 1960s. Six connections to the Columbia River were reduced to a single connection. Note: the 6th connection at the far east end of the site is not shown here but is visible on the 1859 GLO survey map in Figure 2.

The activities mentioned above have severely impacted ecological function of the Horsetail Creek Floodplain site. The six-to-one reduction of connections to the Columbia River significantly reduced habitat complexity and fish access to the site. Clearing has allowed proliferation of invasive plant species which have outcompeted native vegetation. In-stream habitat complexity has been reduced, limiting habitat opportunity for juvenile salmonids. Water temperature, the focus of this report, has been negatively impacted in a variety of ways. In general, the combined re-routing of flows, clearing of lands, and creation of ponded areas throughout the floodplain have had an overall effect of increasing both the residence time of water and solar insolation, resulting in elevated water temperatures at the site, to levels that are at or even above mainstem Columbia River temperatures during the summer.

1.2 Project Summary

To address ecological issues at the site, the Estuary Partnership implemented the Horsetail Creek Floodplain Restoration project in 2013 in partnership with the US Forest Service Columbia River Gorge National Scenic Area and Oregon Department of Transportation, and with funding from Bonneville Power Administration, Oregon Watershed Enhancement Board, US Forest Service, Oregon Community

Foundation, and East Multnomah Soil and Water Conservation District. This effort is considered as the first phase ("Phase I") of a multi-phased restoration project. Major objectives of Phase I restoration included:

- Improving access to the site for all life stages of ESA-listed salmon and steelhead and lampreys over a wide range of hydrologic conditions.
- Increasing the diversity, quality, and quantity of instream habitat by adding large wood structures.
- Reducing stream temperatures by restoring riparian habitats and eliminating the diversion of Oneonta Creek through the gravel pond.

Reducing stream temperatures by restoring riparian habitats and eliminating the diversion of Oneonta Creek through the gravel pond. Phase I was constructed in summer 2013 with plant establishment occurring through 2015. Construction activities included (Figure 4):

- Retrofitting the I-84 culvert at the site's interior to improve fish passage. The existing passage weirs were replaced with weirs that meet current fish passage criteria and an existing concrete apron and diversion weir were replaced with a constructed riffle. Restoring the historic alignment of Oneonta Creek by eliminating the diversion of Oneonta Creek through the gravel pond.
- Converting the gravel pond to an emergent wetland with a network of open-water channels.
- Placing 540 pieces of large woody debris throughout the site to improve habitat complexity.
- Re-grading two historic outlet channels and removing two man-made berms, thereby improving access and eliminating entrapment of fish within the floodplain habitat.
- Native revegetation of 36 acres of riparian forest and wetland.

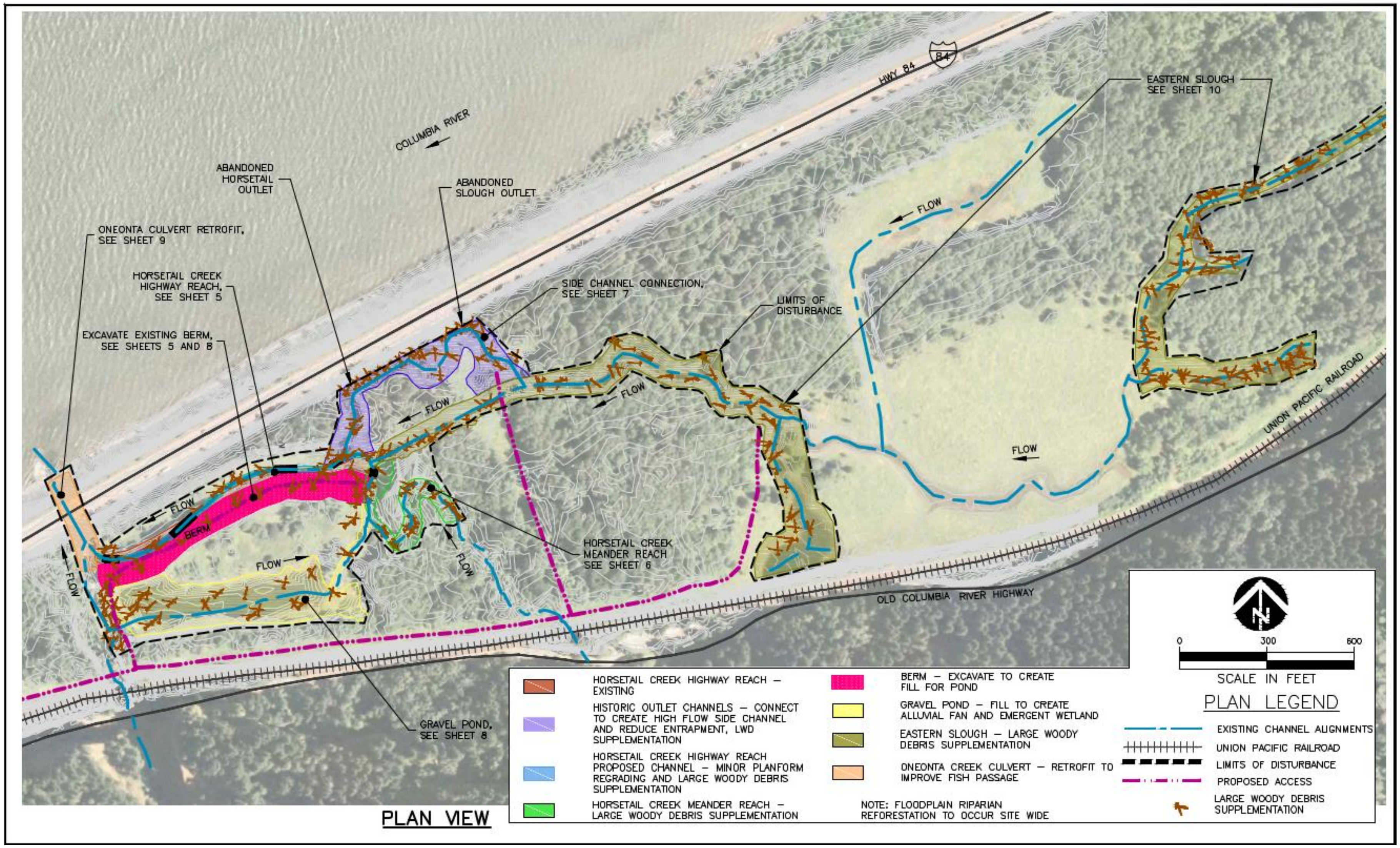

Figure 4: Plan view of restoration activities at Horsetail Creek Floodplain restoration site

The Estuary Partnership collected stream temperature data for one year prior to restoration and five years after restoration throughout the site. We collected fish presence data for six years post-restoration using a passive integrated transponder (PIT) tag detection system installed at both ends of the culvert that carries Horsetail and Oneonta creeks beneath I-84. The following sections of this report present the methods used to analyze changes in water temperature and fish presence at the site when comparing the pre-restoration and post-restoration data, and the results of this analysis.

2. Methods

2.1 Stream Temperature

We collected hourly water temperature data by deploying Hobo dataloggers at seven monitoring stations (Figure 5) at the Horsetail Creek restoration site. Data was collected in 2010 prior to restoration, and again from 2014-2016 and 2018–2019 post restoration. Loggers were placed at stream junctions to evaluate the temperature influence of different inputs, at the beginning and ends of stream reaches to evaluate heating through these sections, and in the gravel pond/wetland complex. Time periods for which data were collected are shown in Table 2. No temperature data was collected in 2017 due to high water levels throughout that summer that made the site inaccessible.

Table 2: Water Temperature data availability for Horsetail Creek Floodplain site monitoring locations. Blue colored boxes indicate that data is available for those months. Construction period is indicated in Yellow.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2019												
2018								Year 5 Post				
2017												
2016						Year 3 Post						
2015												
2014							Year 1 Post restoration					
2013	Restoration											
2012												
2011												
2010						Pre-restoration						

The Pond Outlet station was added after restoration when changes in flow direction were observed at the site. Prior to restoration, the majority of Oneonta Creek flowed through the gravel pond and pond inlet station to connect to Horsetail Creek, with the Pond Inlet station measuring Oneonta Creek temperature (Figure 6). At that time there was no hydrologic connection at the Pond Outlet location. After the re-alignment of Oneonta Creek as part of project construction, flow patterns changed, with a portion of Horsetail Creek now diverging and flowing southwest through the emergent wetland (the former gravel pond) and re-connecting with the main Horsetail Creek/East Slough flow near the Pond Outlet station (Figure 7). Thus, during post-restoration monitoring the Pond Outlet station monitors flow that diverts from Horsetail Creek and flows through the wetland before it re-converges with Horsetail Creek/East Slough, and the Pond Inlet station monitors this same flow before it enters the emergent wetland. An additional temperature monitoring station was also added at the Created Emergent Wetland location during post-restoration monitoring.

Figure 5: Temperature monitoring locations at Horsetail Creek Floodplain restoration site. Monitoring locations are represented by red dots. The outlet of the I-84 culvert which was retrofitted during construction is shown as the yellow arrow.

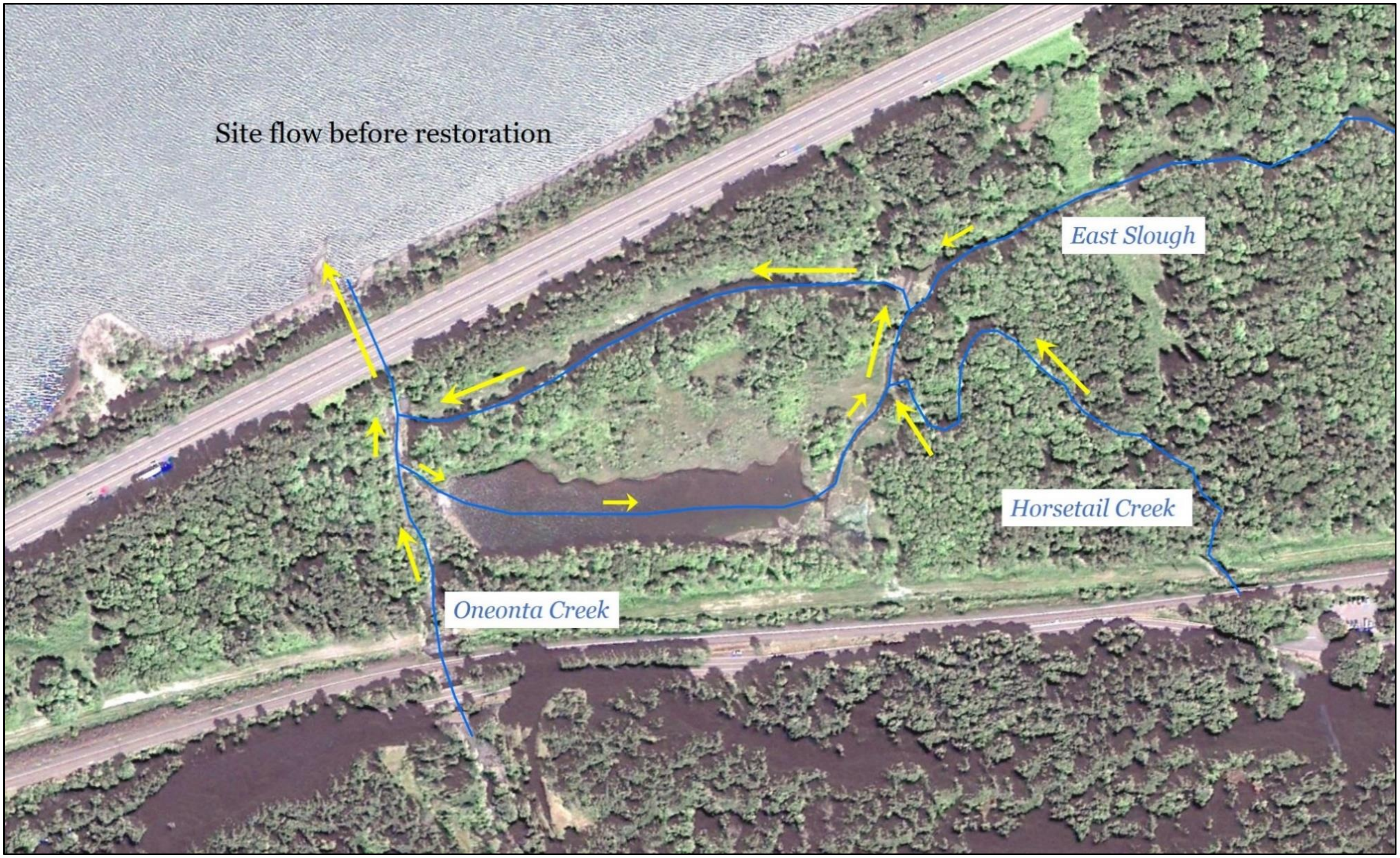

Figure 6: Pre-restoration flow patterns of Oneonta and Horsetail creeks. A portion of Oneonta Creek enters the gravel pond and exits through the spot where Pond Inlet station is located (From instantaneous flow measurements collected in 2010).

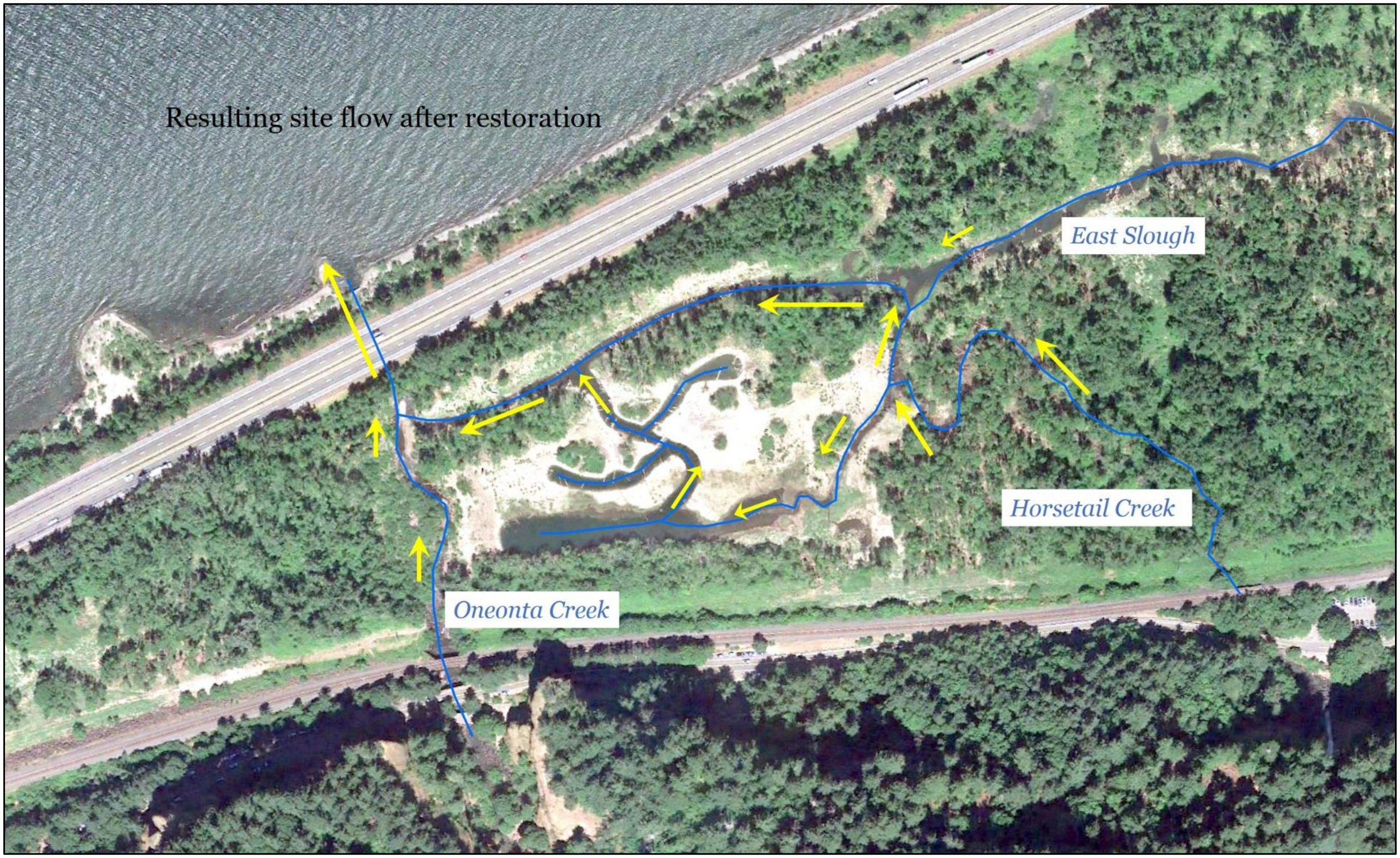

Figure 7: Post-restoration flow patterns of Oneonta and Horsetail creeks. Oneonta Creek was restored to historic alignment through a berm. A portion of Horsetail Creek enters the pond through the spot where Pond Inlet station is located and exits by flowing through the network of open channels. Another portion converges with the East Slough (From instantaneous flow measurements collected during 2014–2016).

EPA's recommended metric to study temperature influences on salmonids is the 7-day average daily maximum (7-DADM) water temperature, as it depicts the average of daily maximum temperatures that salmonids are exposed to at a particular location over a weekly period. 7-day average daily maximum (7-DADM) temperatures were calculated for each monitoring station between June to September or over the available time-period. These were summarized as summer maximum and average 7-DADM temperatures. Changes from pre-restoration temperature, if available, were calculated as percent difference in 7-DADM Temperatures. We calculated the annual number and percentage of days that water temperatures exceeded Oregon and Washington water quality temperature thresholds of 16°C (Core Coldwater Habitat: OR DEG Water Quality Standard Implementation IMD, April 2008, Table 3-2; Core Summer Salmonid Habitat: Washington Administrative Code 173-201A-210, Table 200 (1)(c)), and 18°C (same standards as cited above for the 16°C threshold) as well as the 22°C potential lethal temperature threshold listed by the U.S. EPA (U.S. Environmental Protection Agency, 2003) and State of Washington (Washington Administrative Code 173-201A-210, Table 200 (1)(c), note vii).

To test the success of restoration actions, a series of regression tests were performed to determine whether Horsetail Creek may be influencing temperatures in the two confluence areas (Horsetail-Oneonta confluence and Horsetail-Pond confluence) and in the created emergent wetland. The Horsetail-Oneonta confluence is the location where the combined Horsetail Creek and East Slough meet Oneonta Creek. The Horsetail-Pond confluence is the location where Horsetail Creek diverges to flow north and combine with the East Slough, and south through the wetland (Figure 5). **Error! Reference source not found.**

2.2 Fish Monitoring

The PIT detection array at Horsetail Creek was installed in 2013 following the restoration actions in Horsetail Creek. The array is situated on the upstream and downstream sides of a culvert passing underneath I-84 which connects the confluence of Horsetail and Oneonta creeks with the Columbia River. The array consisted of 10 antennas, five on each side of the 5-barrel culvert (Figure 8). Each year the array was operational from late March or April to October or November. During winter, there was not enough daylight on the southern side of the Columbia River Gorge to provide ample solar power, so operations were intermittent. Due to the dynamic and extreme flows that can occur in the area, individual antennas often sustained damage and had to be repaired or replaced. Often repairs could not be done immediately because high water precluded access. Yet, each year we had antenna coverage on each side of the culvert (Table 3).

Data collected at the Horsetail PIT array are intended to document the presence of salmon stocks accessing the restoration site, not to give an estimate of numbers of salmon using the site. Detection data are dependent upon the population of salmon in the Columbia River Basin that are PIT tagged each year. The number of salmon and the specific stock that are PIT tagged varies annually, which impacts the patterns of detections from year to year.

Tagging information for each unique tag ID was downloaded from the PTAGIS regional PIT tag data depository (www.ptagis.org) from which we could determine species, rear type, and release location and date. Using these metrics, we developed a map of origin, enumerated salmon species and life history type from each major sub-basin, and calculated residence time for salmon detected at Horsetail array. We also documented the percentage of each species/life history that successfully traversed the culvert to access the restoration site.

Figure 8: Downstream side of PIT tag array at Horsetail/Oneonta creeks outlet culvert.

Table 3: Number of working antennas on the downstream and upstream sides of the I-84 culvert each year.

Year	Downstream	Upstream
2014	5	5
2015	5	5
2016	3	5
2017	3	3
2018	2	3
2019	3	4

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3. Results

3.1 Stream Temperature

Table 4 shows 7-DADM maximum and average water temperatures at the monitoring locations and respective percent changes from 2010 (pre-restoration) average 7-DADM temperatures. Highest post-monitoring water temperatures were observed in 2015 and 2019, and lowest were observed in 2016.

Table 4: Maximum, Average 7-DADM Temperatures between June to September and percent increase of post-restoration temperatures from pre-restoration temperature

Site	Year	Number of days of data collected	Max 7-DADM Temperature (°C)	Average 7-DADM Temperature (°C)	% Change from pre-restoration average 7-DADM temperature [2]
Oneonta Creek	**2010**[1]	107	18.07	13.93	NA
	2014	82	19.32	16.94	21.6%
	2015	122	21.38	17.36	24.6%
	2016	85	18.49	15.53	11.5%
	2019	110	19.5	16.47	18.2%
Horsetail Creek	**2010**[1]	45	15.79	14.22	NA
	2014	82	17.32	15.3	7.6%
	2015	122	18.02	15.13	6.4%
	2016	85	16.2	14.25	0.2%
	2018	50	18.67	15.65	10.1%
	2019	110	18.32	15.98	12.4%
Horsetail-Oneonta Confluence	**2010**[1]	101	18.32	15.64	NA
	2014	82	20.55	17.85	14.1%
	2015	122	22.16	17.87	14.2%
	2016	85	19.44	17.18	9.9%
Horsetail-Pond Confluence	**2010**[1]	107	15.79	12.7	NA
	2014	82	18.55	16.05	26.4%
	2015	122	18.49	15.5	22.1%
	2016	85	17.13	14.74	16.1%
	2018	50	19.01	16.06	26.5%
	2019	110	19.3	16.73	31.8%
Pond Inlet	**2014**	82	17.24	15.46	NA [3]
	2015	122	19.75	16.91	
	2016	85	17.61	15.37	
	2018	50	19.36	16.41	
	2019	110	20.74	17.13	
Pond Outlet	**2014**	14	18	16.96	NA [3]
	2015	61	22.35	20.03	

	2016	79	21	19	
Emergent Wetland	**2015**	25	15.53	14.41	NA [3]
	2016	85	16.1	14.25	
	2018	50	20.33	18.68	
	2019	110	19.13	17.11	

Notes:

1. indicates pre-restoration temperature monitoring year.
2. positive percentage indicates increases in pos-restoration temperature from pre-restoration temperature.
3. NA: Percent change not calculated as pre-restoration temperature data was unavailable.

Figure 9–12 display time series of pre and post restoration water temperatures at the monitoring locations shown in Figure 5. The data show that Oneonta Creek was consistently warmer than Horsetail Creek throughout the project study timeline (Figure 9). This may be attributed to upstream characteristics of these watersheds that influence the temperature of each stream however we did not include these assessments as part of this study. The Horsetail-Oneonta Confluence was warmer than the Horsetail- Pond Confluence (location where the East Slough joins Horsetail Creek) (Figure 10). It should be noted that data from the Pond Outlet station and the Horsetail-Oneonta Confluence station are only available only through 2016, hence, the complete temperature profiles cannot be displayed. 7-DADM temperatures are higher at the Pond Outlet station compared to the Pond Inlet station (Figure 11), which suggests that the emergent wetland may be heating the water at it flows through. However, it should be noted that temperature in the created emergent wetland (Figure 12) itself was observed to be lower than temperatures at Pond Inlet and Pond Outlet stations.

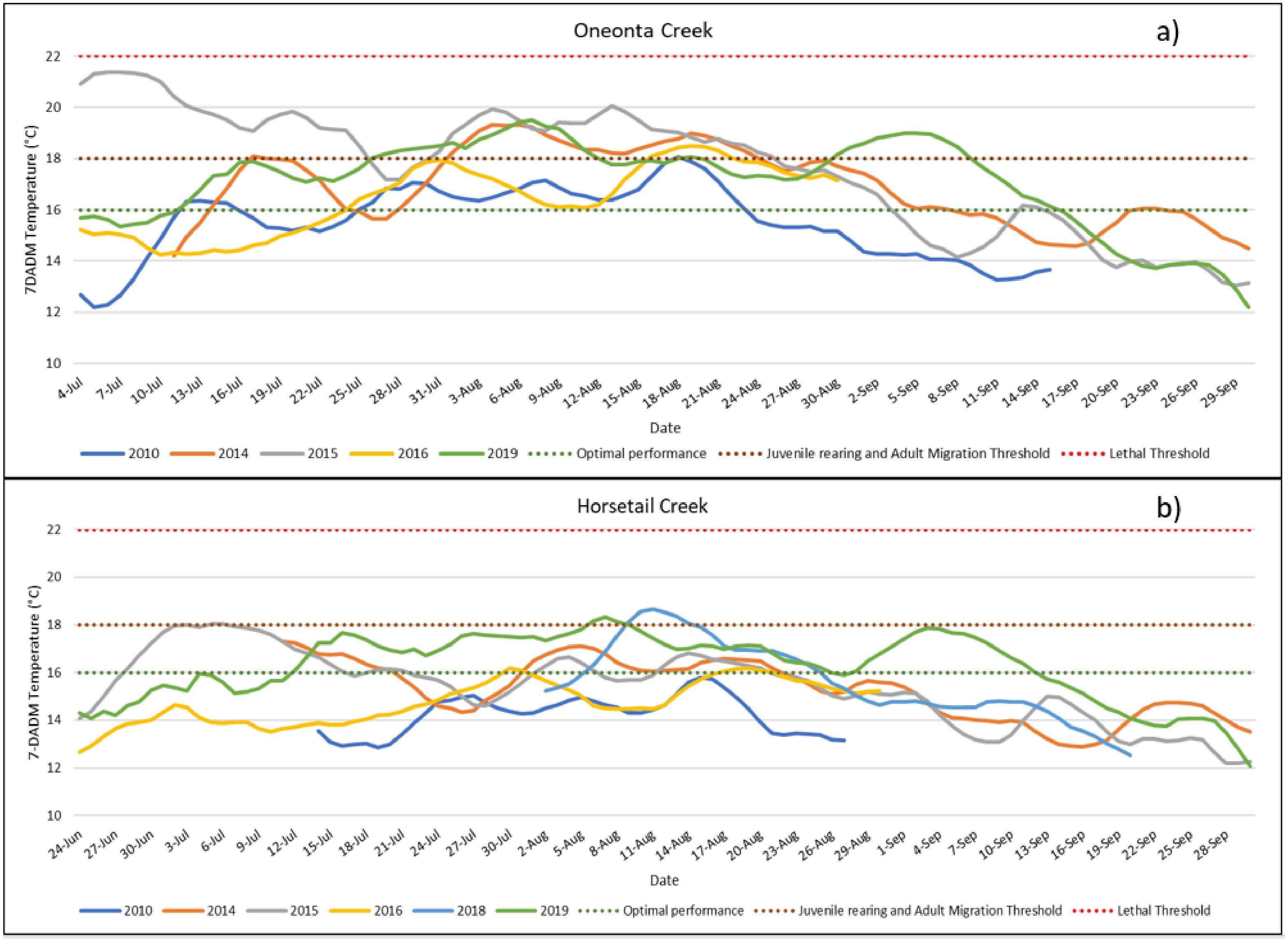

Figure 9: 7-DADM temperatures of a) Oneonta Creek and b) Horsetail Creek

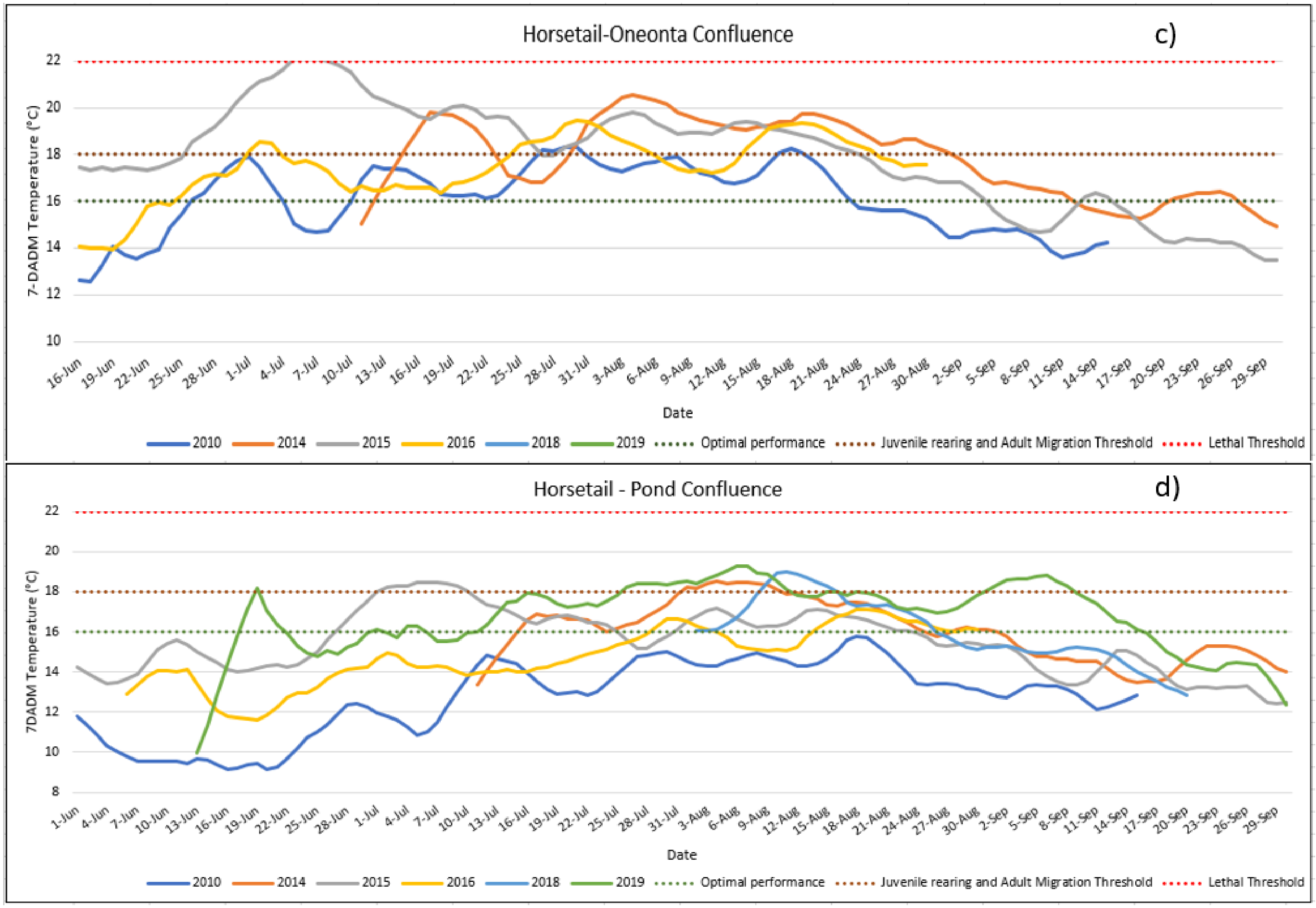

Figure 10: 7-DADM temperatures of c) Horsetail – Oneonta confluence and d) Horsetail – Pond confluence.

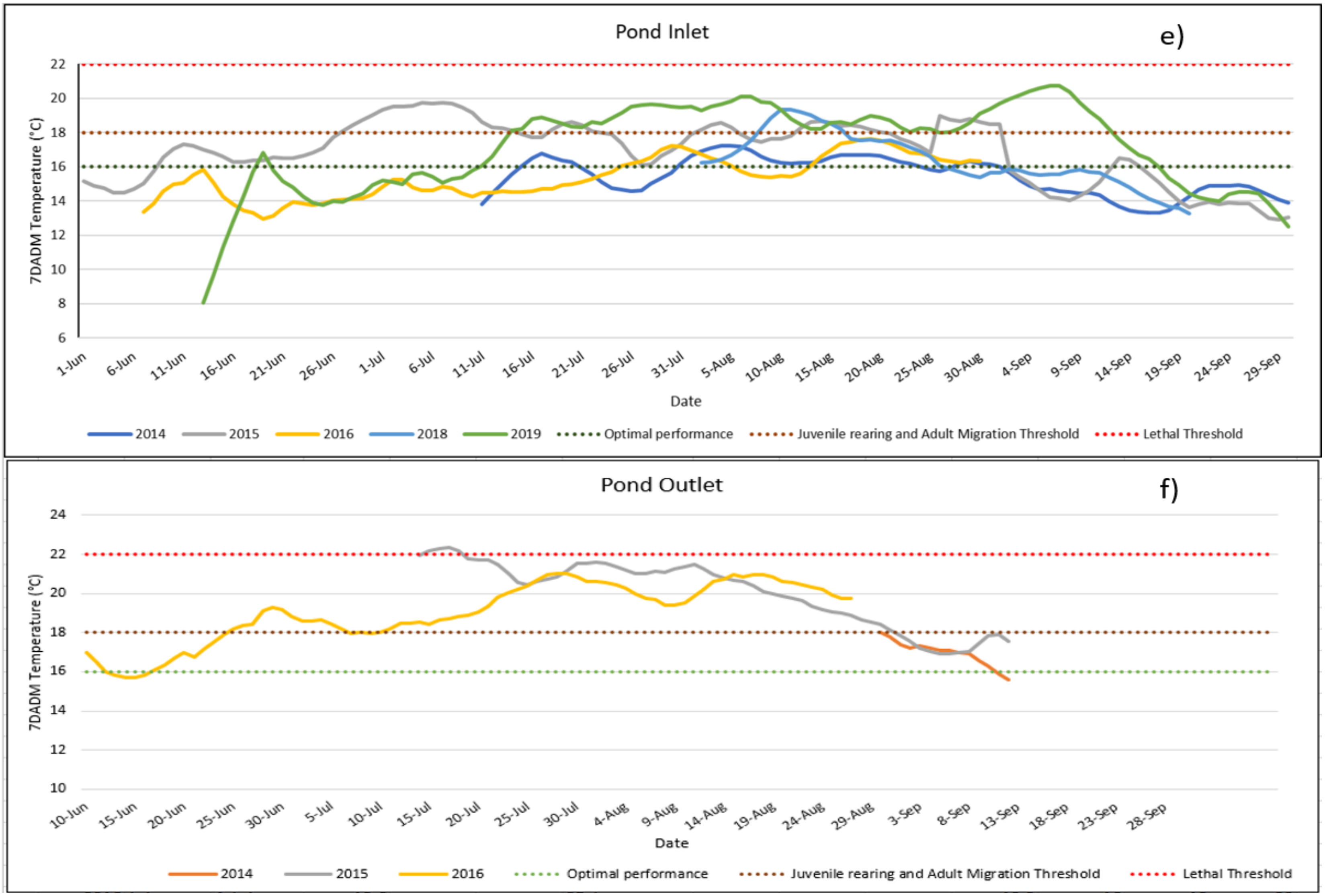

Figure 11: 7-DADM temperatures of e) Pond Inlet and f) Pond Outlet.

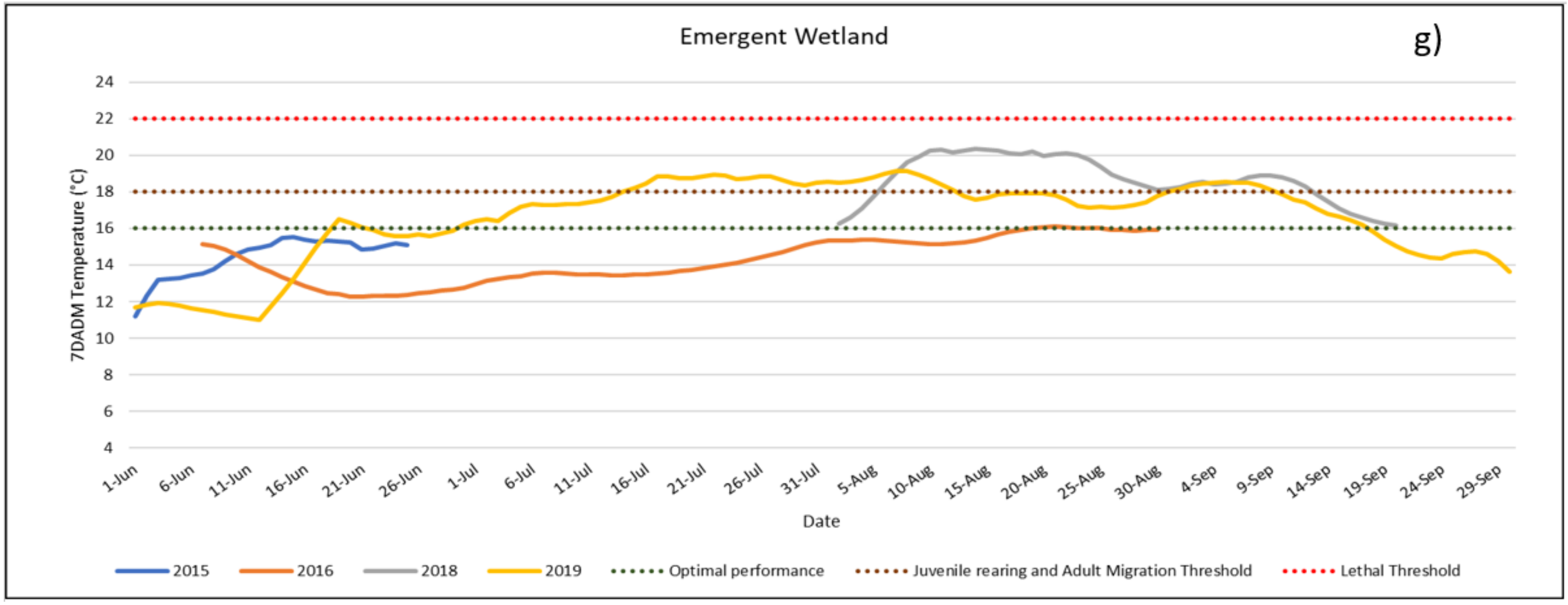

Figure 12: 7-DADM Temperature of Emergent Wetland for summers of 2015 to 2019

Post-restoration summer water temperatures at the site have exceeded state and federal temperature thresholds for salmonids (16°C and 18°C, as noted above) more often compared to our pre-restoration (2010) results. During 2015 and 2019 temperatures at multiple monitoring locations exceeded the 18°C criteria for continuous periods of up to several weeks. This was not observed during the single year of pre-restoration monitoring in 2010. Despite these warm temperatures seen after restoration, the potentially lethal threshold temperature of 22°C was exceeded only by two monitoring stations for brief periods of time in 2015. This contrasts with the neighboring Columbia River, whose mainstem water temperatures now exceed all these threshold levels during extended periods of the summer during many years (Marcoe et al. 2018). Figure 13 provides a real-time comparison of Horsetail Creek temperature and Columbia River temperature during a portion of the 2016 summer. With temperatures consistently remaining well below those of the mainstem, the site can provide cold water refuge to salmonids migrating through the Columbia River system during these months.

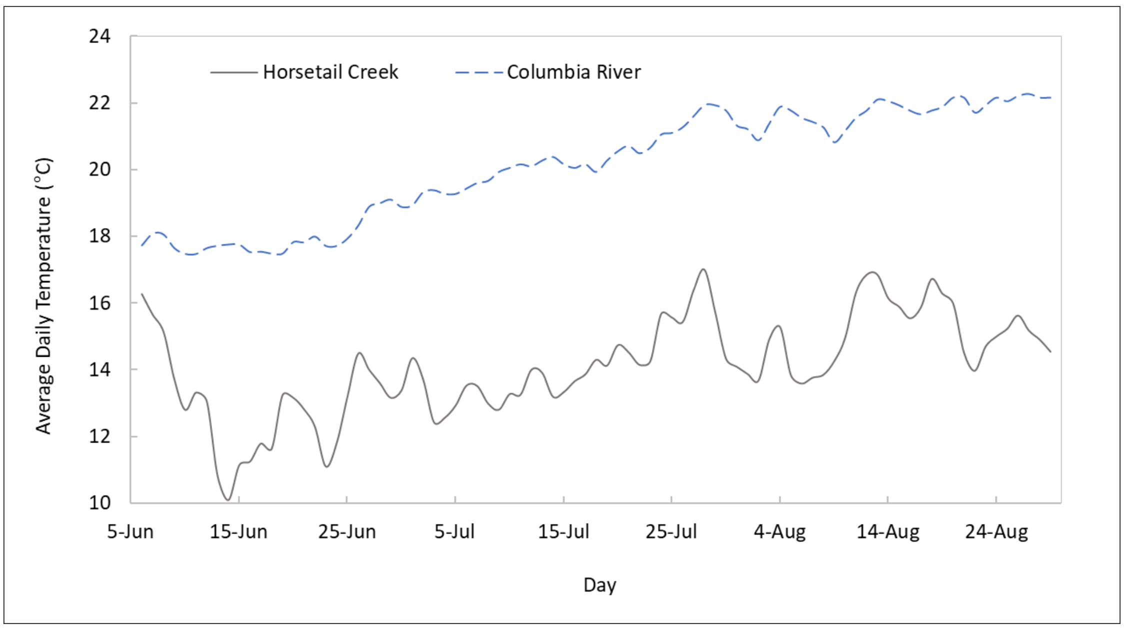

Figure 13. Daily average water temperatures for the Columbia River and Horsetail Creek during summer of 2016. Columbia River data source: Columbia River DART.

Table 5 and Table 6 illustrate the frequency of time in summer that water temperatures observed at the site exceeded the 16°C and 18°C temperature thresholds for salmonids described above. In 2010, 21% of monitoring days were over 16°C in August at Oneonta Creek (Table 5), while 24% of days exceeded 16°C at the Horsetail-Oneonta Confluence (Table 5). 1% of days exceeded 18°C during August 2010 at Oneonta Creek and 4% of days exceeded 18°C at the Horsetail-Oneonta Confluence (Table 6). In general, these observations indicate heating of water as it transits the site both pre and post restoration.

Temperatures in Horsetail Creek and the Horsetail-Pond Confluence remained below the 16°C and 18°C thresholds in 2010. In the post-restoration years of 2014 and 2015, temperatures exceeded 16°C at all monitoring stations for much of the monitoring period. A similar trend was observed for the 18°C threshold during these years. 2016 saw these percentages drop at most monitoring stations between July and August. However, percentage of days over 16°C during August 2016 were greater than those observed in August 2015 at the two confluences and Pond Inlet station. Temperatures at the site during August 2018 exceeded 16°C and 18°C more often than previously observed at the site. In 2019, percentage of days that exceeded 18°C at all monitoring stations between July and September were greater than previous years. While these are comparisons are noteworthy, we cannot draw definitive conclusions because of both high variability in the number of monitoring days each year (Table 4) and the flow patterns that reversed after project construction occurred and continue to evolve due to the influence of beaver activity and other factors.

Table 5: Percentage of days that exceeded the 16°C temperature threshold for all monitoring years and stations.

Percent days over 16°C							
Date	Oneonta Creek	Horsetail Creek	Horsetail – Oneonta confluence	Horsetail – Pond Confluence	Emergent Wetland	Pond Inlet	Pond Outlet
Jun-10	0%	NA	5%	0%	NA	NA	NA
Jul-10	10%	0%	24%	0%	NA	NA	NA
Aug-10	21%	0%	23%	0%	NA	NA	NA
Sep-10	0%	NA	0%	0%	NA	NA	NA
Jun-14	NA	NA	NA	NA	NA	NA	NA
Jul-14	18%	12%	23%	20%	NA	9%	NA
Aug-14	38%	26%	38%	34%	NA	34%	14%
Sep-14	11%	0%	22%	0%	NA	0%	71%
Jun-15	16%	2%	16%	3%	0%	18%	NA
Jul-15	25%	16%	25%	21%	NA	25%	30%
Aug-15	25%	11%	25%	19%	NA	25%	51%
Sep-15	4%	0%	4%	0%	NA	3%	20%
Jun-16	0%	0%	7%	0%	0%	0%	22%
Jul-16	8%	2%	36%	4%	0%	8%	39%
Aug-16	4%	6%	35%	24%	7%	27%	34%
Sep-16	NA	NA	NA	NA	NA	NA	NA
Jun-18	NA	NA	NA	NA	NA	NA	NA
Jul-18	NA	NA	NA	NA	NA	NA	NA
Aug-18	NA	40%	NA	48%	60%	50%	NA
Sep-18	NA	0%	NA	0%	40%	0%	NA
Jun-19	1%	2%	NA	4%	4%	1%	NA
Jul-19	18%	18%	NA	22%	28%	19%	NA
Aug-19	28%	27%	NA	28%	28%	28%	NA
Sep-19	14%	11%	NA	14%	15%	15%	NA

Table 6: Percentage of days that exceeded the 18°C adult migration and juvenile rearing threshold for salmonids for all monitoring years and stations.

Percent days over 18°C							
Date	Oneonta Creek	Horsetail Creek	Horsetail – Oneonta confluence	Horsetail – Pond Confluence	Emergent Wetland	Pond Inlet	Pond Outlet
Jun-10	0%	NA	0%	0%	NA	NA	NA
Jul-10	0%	0%	4%	0%	NA	NA	NA
Aug-10	1%	0%	3%	0%	NA	NA	NA
Sep-10	0%	NA	0%	0%	NA	NA	NA
Jun-14	NA	NA	NA	NA	NA	NA	NA
Jul-14	1%	0%	9%	0%	NA	0%	NA
Aug-14	29%	0%	21%	12%	NA	0%	0%
Sep-14	0%	0%	0%	0%	NA	0%	0%
Jun-15	2%	0%	8%	0%	0%	3%	NA
Jul-15	21%	2%	24%	7%	NA	16%	30%
Aug-15	20%	0%	19%	0%	NA	16%	51%
Sep-15	0%	0%	0%	0%	NA	1%	0%
Jun-16	0%	0%	0%	0%	0%	0%	8%
Jul-16	0%	0%	40%	0%	0%	0%	35%
Aug-16	8%	0%	20%	0%	0%	0%	34%
Sep-16	NA	NA	NA	NA	NA	NA	NA
Jun-18	NA	NA	NA	NA	NA	NA	NA
Jul-18	NA	NA	NA	NA	NA	NA	NA
Aug-18	NA	12%	NA	14%	52%	18%	NA
Sep-18	NA	0%	NA	0%	0%	0%	NA
Jun-19	0%	0%	NA	1%	0%	0%	NA
Jul-19	5%	0%	NA	5%	16%	16%	NA
Aug-19	14%	3%	NA	12%	12%	27%	NA
Sep-19	8%	0%	NA	7%	8%	11%	NA

A series of regressions were performed to partially assess the relative influences of Horsetail and Oneonta creeks' source temperatures on the overall site temperatures, as an attempt to help evaluate the effect of restoration actions, particularly the re-alignment of Oneonta Creek to its historical condition and resulting flows within the emergent wetland. When 7-DADM temperatures from 2014–2019 at Horsetail and Oneonta creeks were compared to the 7-DADM temperature at the Horsetail-Pond confluence a significant, positive linear relationship was observed (Figure 14, R^2= 0.98, p<0.000). The 7-DADM temperature at the emergent wetland (2016–2019) also had a significant, positive linear relationship with Horsetail Creek for years 2016–2019 (Figure 15, R^2= 0.91, p=0.004).

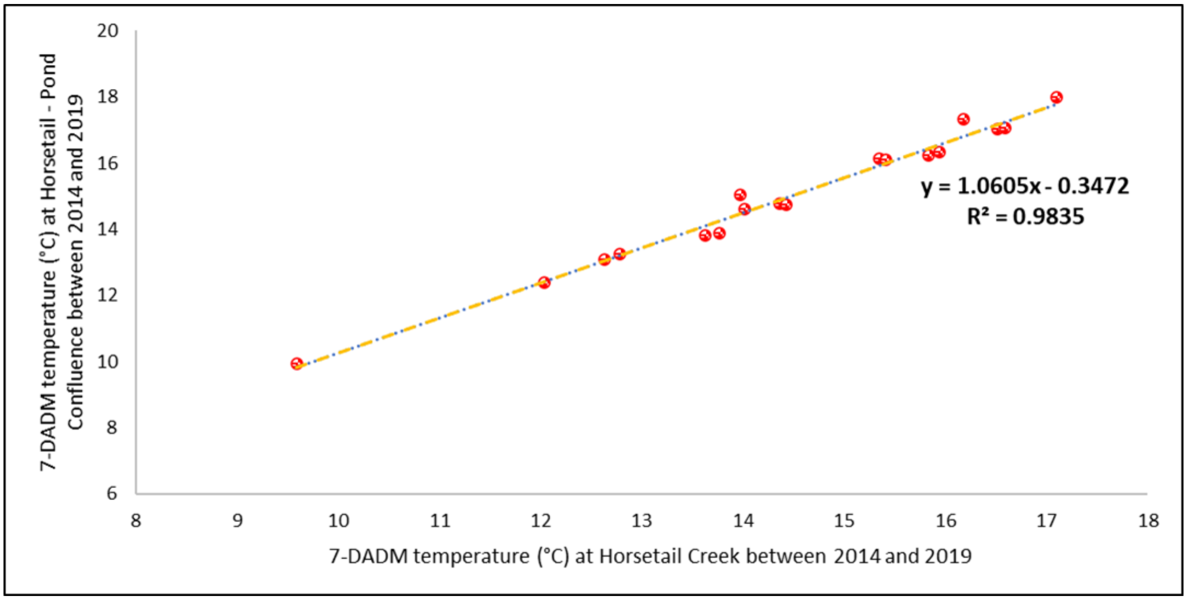

Figure 13: Relationship between monthly average 7-DADM temperatures of Horsetail Creek and Horsetail-Pond Confluence for the post-restoration monitoring period 2014–2019.

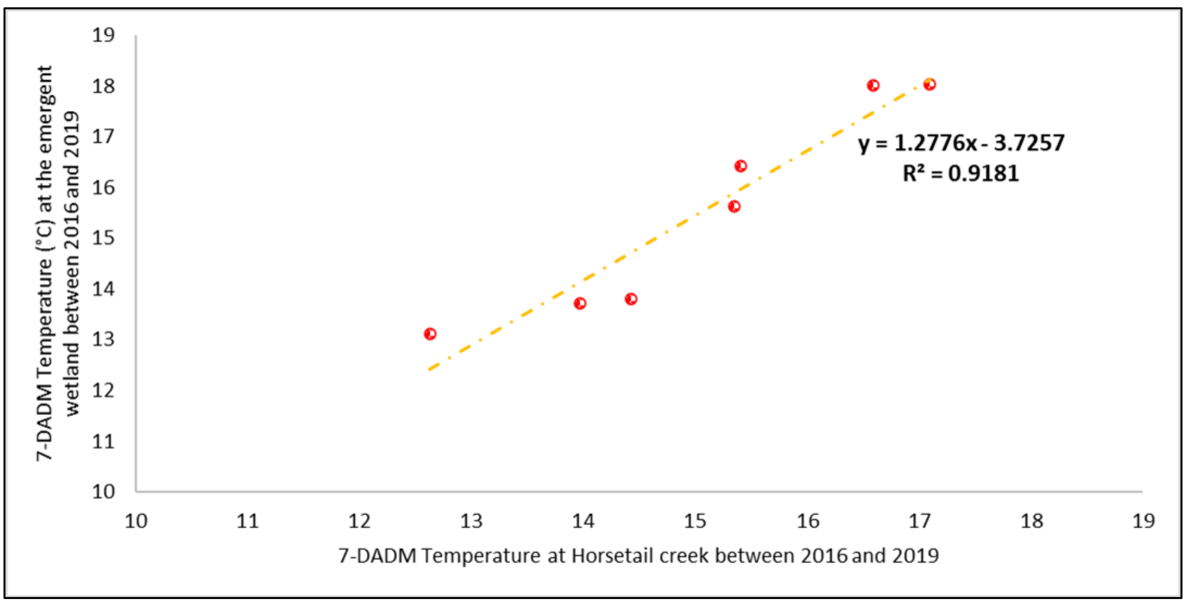

Figure 14: Relationship between monthly average 7-DADM temperatures of Horsetail Creek and emergent wetland for the post-restoration monitoring period 2016–2019.

7-DADM temperatures at Horsetail Creek and Oneonta Creek were compared separately to temperature at the Horsetail–Oneonta Confluence location from 2014–2016. Results are shown in Figure 16 and show a strong relationship for each of the creeks (Horsetail: R^2= 0.91, p = 0.001; Oneonta: R^2= 0.9, p=0.000). Because Oneonta Creek merges with the Horsetail Creek/East Slough downstream of the Horsetail-Oneonta Confluence monitoring station and is separated from it by a large gravel bar, it is unlikely to be influencing water temperature at the station and the observed relationship is likely more coincidental than causal, however.

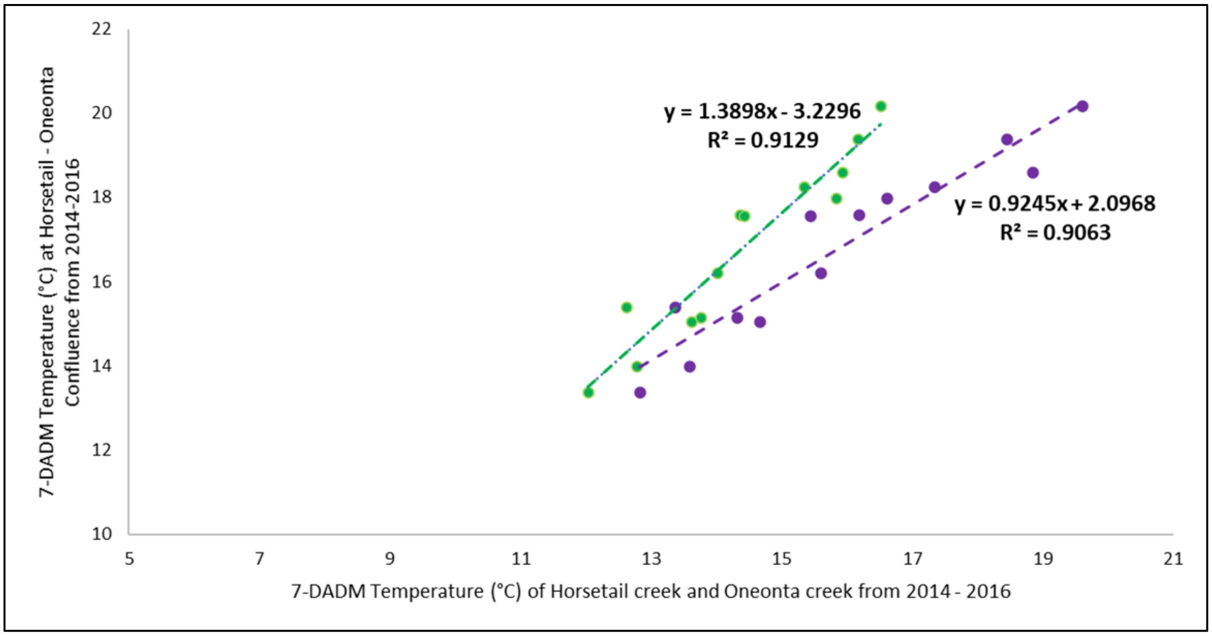

Figure 15: Temperature (°C) relationships between Horsetail Creek (in green) and Oneonta Creek (in Purple), respectively, and the Horsetail-Oneonta Confluence for post monitoring years 2014–2016.

While the relationships shown above suggest potential influences on temperatures observed at various monitoring stations, more comprehensive flow data and flow modeling is required to better understand how both Horsetail Creek and Oneonta Creek are driving overall site temperatures. Post-monitoring efforts saw change in flow directions due to increased beaver activity and realignment of Oneonta Creek and these flow changes have not been monitored regularly.

3.2 Fish Monitoring

Salmon originating from throughout the Columbia River Basin were detected at the Horsetail PIT tag array (Figure 16). Species originating from the mid-Columbia Basin included Chinook, coho, and steelhead. Species originating from the upper Columbia Basin included Chinook, coho, sockeye, and steelhead. Coho was the only species originating from the Yakima Basin, and Chinook, coho, sockeye, and steelhead from the Snake River Basin were detected.

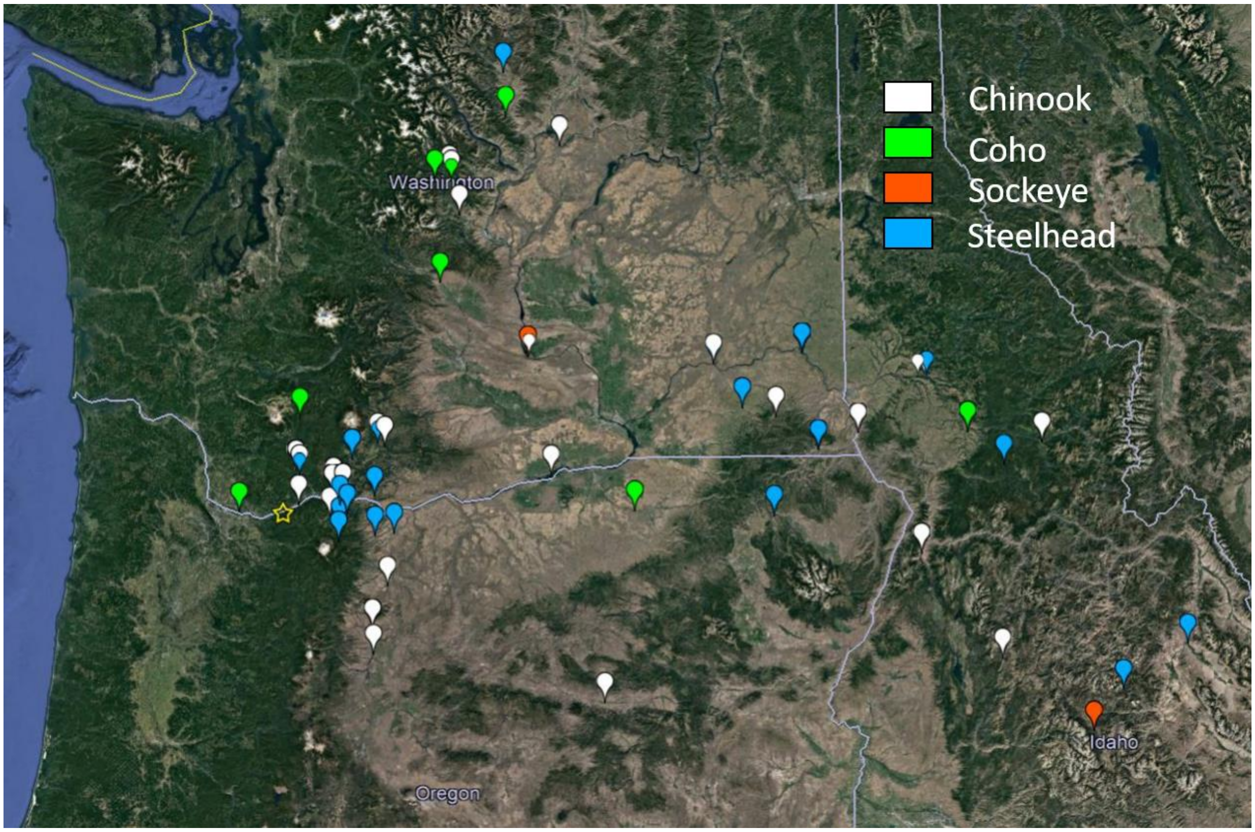

Figure 16: Origins of salmon detected at Horsetail array, 2014-2019

From 2013-2019[1], four species of salmonids were detected at the Horsetail array: coho, Chinook, sockeye, and steelhead. A combination of juvenile and adult/jack coho, Chinook, and steelhead were detected (Table 7). Almost a quarter (23%) of salmon detections were of adults or jacks that were migrating upstream (i.e., detected at Bonneville fish ladders soon after detection at Horsetail array). Of the adults/jacks, sixteen coho and one steelhead were tagged as adults in the lower Columbia River. The remaining adult/jacks were a combination of Chinook (N=4); steelhead (N=7); and coho (N=4) that were tagged as juveniles. 77% of salmon detections were of juvenile fish. Within juvenile salmon,

[1] Data from 2013 was not acquired in time to be incorporated into this analysis. However, a summary of 2013 data can be found in Sagar et al., 2014.

spring/summer Chinook and fall Chinook each comprised 34%, steelhead comprised 23%, coho comprised 5%, and sockeye comprised 4%

In addition to salmon, eight northern pikeminnow were detected from 2014-2019 and there were 41 tags detected for which no information could be found in the PTAGIS data repository.

Table 7: Number of juvenile and adult/jack salmon detected at Horsetail array by species, basin of origin, and year.

<table>
<tr><th>Year</th><th>Basin</th><th>Species</th><th>Juvenile</th><th>Adult/Jack</th></tr>
<tr><td rowspan="7">2014</td><td>Lower Columbia</td><td>coho</td><td>1</td><td>15</td></tr>
<tr><td>Mid-Columbia</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td rowspan="2">Snake River</td><td>coho</td><td></td><td>1</td></tr>
<tr><td>steelhead</td><td>1</td><td>1</td></tr>
<tr><td rowspan="2">Upper Columbia</td><td>Chinook</td><td>1</td><td></td></tr>
<tr><td>coho</td><td></td><td>1</td></tr>
<tr><td>Yakima River</td><td>coho</td><td></td><td>1</td></tr>
<tr><td rowspan="12">2015</td><td>Lower Columbia</td><td>Chinook</td><td>1</td><td></td></tr>
<tr><td rowspan="3">Mid-Columbia</td><td>Chinook</td><td>7</td><td>1</td></tr>
<tr><td>coho</td><td>1</td><td></td></tr>
<tr><td>steelhead</td><td>5</td><td>1</td></tr>
<tr><td rowspan="3">Snake River</td><td>Chinook</td><td>4</td><td></td></tr>
<tr><td>steelhead</td><td>7</td><td>1</td></tr>
<tr><td>Sockeye</td><td>2</td><td></td></tr>
<tr><td rowspan="4">Upper Columbia</td><td>Chinook</td><td>2</td><td></td></tr>
<tr><td>coho</td><td></td><td>1</td></tr>
<tr><td>steelhead</td><td>1</td><td></td></tr>
<tr><td>Sockeye</td><td>1</td><td></td></tr>
<tr><td>Yakima River</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td rowspan="7">2016</td><td>Lower Columbia</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td rowspan="2">Mid-Columbia</td><td>Chinook</td><td>11</td><td></td></tr>
<tr><td>steelhead</td><td></td><td>1</td></tr>
<tr><td rowspan="2">Snake River</td><td>Chinook</td><td>1</td><td></td></tr>
<tr><td>sockeye</td><td>1</td><td></td></tr>
<tr><td>Upper Columbia</td><td>coho</td><td>1</td><td></td></tr>
<tr><td>Yakima River</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td rowspan="6">2017</td><td>Lower Columbia</td><td>coho</td><td></td><td>2</td></tr>
<tr><td rowspan="2">Mid-Columbia</td><td>Chinook</td><td>10</td><td>1</td></tr>
<tr><td>steelhead</td><td>3</td><td></td></tr>
<tr><td rowspan="2">Snake River</td><td>Chinook</td><td>2</td><td>2</td></tr>
<tr><td>steelhead</td><td>4</td><td></td></tr>
<tr><td>Upper Columbia</td><td>--</td><td>--</td><td>--</td></tr>
</table>

	Yakima River	--	--	--
2018	Lower Columbia	--	--	--
	Mid-Columbia	Chinook	23	
		steelhead	1	3
	Snake River	Chinook	2	
		coho	1	
		steelhead	4	1
	Upper Columbia	--	--	--
	Yakima River	--	--	--
2019	Lower Columbia	--	--	--
	Mid-Columbia	Chinook	9	
	Snake River	Chinook	2	
	Upper Columbia	coho	1	
	Yakima River	--	--	--

Juvenile salmon residence times ranged from a single detection to 115 days (Figure 17). Most salmon were detected for less than one minute. Steelhead had the longest residence time with one individual residing for 115 days. A second steelhead was detected shortly after being barged, resided for 67 days, after which it was detected on the Bonneville ladder, indicating that it had used the Horsetail Creek area to rear until it was ready to return upriver. Spring/summer Chinook and fall run Chinook had similar residency patterns with approximately 75% residing for less than a minute and a few residing for 15–19 days. Juvenile coho and sockeye had the shortest residence times of one day or less for coho and one hour or less for sockeye.

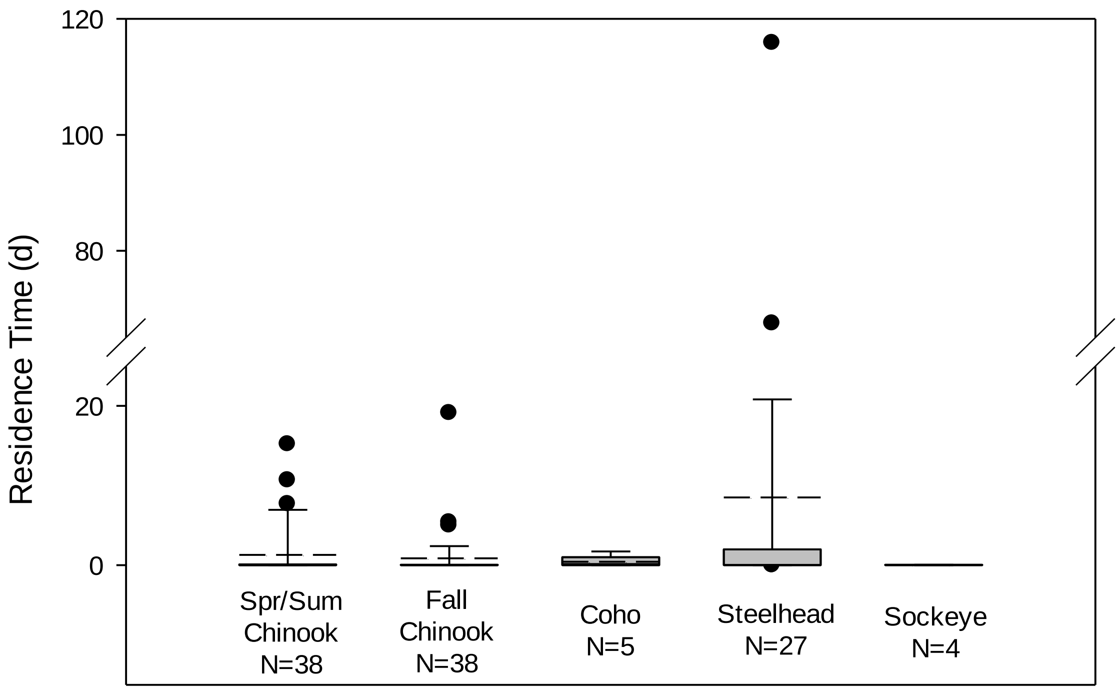

Figure 17: Residence times for juvenile spring/summer Chinook, fall Chinook, coho, steelhead, and sockeye. Box boundaries indicate 25th and 75th percentiles, error bars represent 10th and 90th percentiles, and dots are outliers. The solid line is the median (not always visible), and dashed line is the mean.

Adult salmon residence times ranged from a single detection to 18 days (Figure 18). Coho were the most numerous adults detected at Horsetail (N=20), likely because of an adult tagging study in the lower Columbia River. Coho also exhibited the longest adult residence time of 18 days. Steelhead were the second most numerous species of adult salmonid detected (N=8) and exhibited the second longest residence time of 12 days. Spring/summer run and fall run adult Chinook were detected in low numbers; three and one, respectively. These stocks also exhibited the shortest residence times with the sole fall Chinook residing 1.8 days and the spring/summer Chinook residing an hour or less.

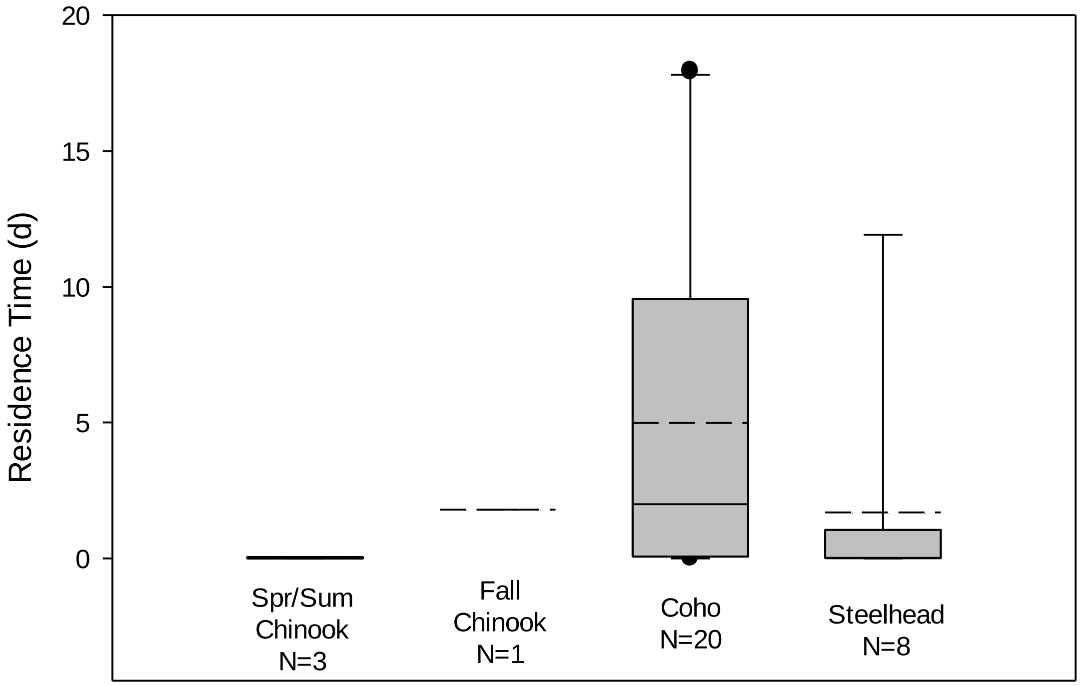

Figure 18: Residence times for adult spring/summer Chinook, fall Chinook, coho, and steelhead. Box boundaries indicate 25th and 75th percentiles, error bars represent 10th and 90th percentiles, and dots are outliers. The solid line is the median (not always visible), and dashed line is the mean.

With antennas located on both sides of the culvert we were able to determine when a fish had passed through the culvert to the Horsetail Creek floodplain site. Our estimates are minimal because there were times when not all ten antennas were properly functioning, during which PIT tagged fish could have passed through the culvert undetected. Thirty-six (25%) of salmon that were detected on the Horsetail array were detected on both sides of the culvert, indicating that the individuals managed to pass through (Table 8). Of those 36, 14 were adults/jacks and 22 were juveniles. Twelve adult coho, one adult steelhead, and one adult fall Chinook salmon swam through to the upstream side of the culvert and potentially accessed the restoration areas. For juvenile salmon, twelve steelhead, six spring/summer Chinook, two coho, and one each of fall Chinook and sockeye salmon reached the upstream side of the culvert and potentially access the restoration areas. Two of the eight northern pikeminnow also transited the culvert.

Table 8: Number, species, and basin of origin of juvenile and adult/jack salmon that were detected on the upstream side of the Horsetail array.

Basin	Species	Juvenile	Adult/Jack
Lower Columbia	coho		12
Mid-Columbia	Chinook	5	1
	Steelhead	1	1
Snake River	Chinook	1	
	Coho	1	
	Steelhead	11	
	Sockeye	1	
Upper Columbia	Chinook	1	
	Coho	1	
Yakima River	--	--	--

4. Discussion

4.1 Stream Temperature

The Horsetail Creek Floodplain Restoration Project was aimed at increasing habitat access and complexity for ESA-listed salmon and lamprey as well as reducing stream temperatures at the site. Restoration activities included restoring the historic alignment of Oneonta Creek (Figure 2) and converting a previously present gravel pond into an emergent wetland with a network of open water channels (Figure 5). Post-restoration, Horsetail Creek has split at the Pond Inlet monitoring location (Figure 5), with a portion now flowing southeast through the emergent wetland complex and the remainder flowing to the north where it combines with the East Slough to flow west through the highway reach to the outlet culvert (Figure 7). Prior to restoration, all of Horsetail Creek took the northerly path, in combination with much of Oneonta Creek, which was diverted to the east through the previously existing gravel pond (Figure 6). This change in flow patterns after restoration has made it challenging to effectively assess the influence on site water temperature that the restoration actions have had to date. These changes were not anticipated prior to project construction and so the monitoring locations were not chosen to account for them. Additional challenges present themselves as beaver continue to re-work the site and channels respond to these and other factors.

Post-restoration summer temperatures at the site are higher and exceed Washington, Oregon, and U.S. EPA performance thresholds for salmonid use more consistently compared to those observed prior to restoration. In 2019, temperatures at the site exceeded the 18°C adult migration and juvenile rearing threshold throughout the summer (June–September). This was not observed previously (Table 5 and Table 6). Site temperatures exceeded the potential lethal threshold of 22°C for 4 days in 2015 at the Pond Outlet and Horsetail-Oneonta Confluence monitoring locations. Pre-restoration (2010) stream temperatures at the site ranged from 10°C to 21°C whereas post-restoration temperatures at the site ranged from 12°C to 22.5°C, however post restoration monitoring occurred in six years, versus one year prior to restoration. The highest post-restoration average temperatures at various monitoring stations were observed in 2015 and 2019, while the lowest were observed in 2016.

Stream temperatures at a site can be influenced by ambient air temperature and precipitation (Morrill et al., 2001). Air temperature and precipitation data were collected from a local weather station at Bonneville Dam (Tables 9 and 10) for the years monitored as well as historic conditions, to see if any correlation could be observed between changes in water temperature at the site and these data. 2010 was observed to be cooler and wetter compared to both the historic and post-monitoring period. 2015 was the hottest and driest of all the post-restoration monitoring years. These observations are consistent with observed water temperature results at the site. However, while ambient air temperature and total precipitation varied significantly from year to year, average water temperatures at the site maintained a relatively consistent range (12.7°C – 20°C). This may indicate some resiliency of the site to climate change post-restoration.

Table 9: Average ambient air temperature (°C) at Bonneville Dam weather station for the monitoring period

Air temperature (°C)							
Date	**Historic**	**2010**	**2014**	**2015**	**2016**	**2018**	**2019**
June	17.1	15.2	16.2	20.3	17.7	17.0	16.4
July	20.3	19.4	21.1	22.9	19.4	22.0	18.4
August	20.5	20.0	21.9	21.8	21.1	21.1	20.5
Sept	17.7	17.0	19.0	16.4	16.4	16.8	17.1
Average	**18.9**	**17.9**	**19.6**	**20.3**	**18.6**	**19.2**	**18.1**
% difference from 2010	**5.7%**		**9.3%**	**13.7%**	**4.2%**	**7.4%**	**1.1%**

Data collected from: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?or0897

Table 10: Total Precipitation in inches at weather station located at Bonneville dam during the monitoring period (negative values indicate decrease in total precipitation since 2010)

Precipitation (in)							
Date	**Historic**	**2010**	**2014**	**2015**	**2016**	**2018**	**2019**
June	2.8	8.1	3.5	0.9	3.9	1.9	1.8
July	0.9	0.6	0.7	0.1	1.2	0.0	0.7
August	1.3	0.0	0.2	1.5	0.0	0.2	0.8
Sept	2.8	4.6	1.0	2.3	2.6	2.6	4.6
Average	1.9	3.3	1.4	1.2	1.9	1.2	2.0
difference in average precipitation from 2010	-1.4		-2.0	-2.1	-1.4	-2.2	-1.3

Data collected from: http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?or0897

Restoration undertaken at the Horsetail Creek Floodplain restoration site should also help to maintain water temperatures below those observed in the adjacent mainstem Columbia river. Several studies in the Lower Columbia indicate that summer temperatures consistently have been above Washington, Oregon, and U.S. EPA threshold levels for salmonids since 2013. Figure illustrates mainstem Columbia River summer temperature characteristics over the past decade. depicts temperature trends over the past decade. In contrast, temperatures at Horsetail have stayed below the potentially lethal threshold of 22°C throughout nearly the entirety of the summer and have remained below the 16 and 18 °C for extended periods of the summer for the years monitored to date. As riparian plantings undertaken along stream channels and adjacent to the emergent wetland continue to mature, shading from this vegetation is expected to reduce some of the solar heating that is, and has (pre-restoration) been occurring at the site. Because water temperatures within the site at a given time have been observed to be considerably less than those of the adjacent Columbia River mainstem (Figure 13), the site can provide cold water refuge for summer migrating salmon. This capacity is expected to increase as the Columbia River continues to warm and benefits provided by the site continue to increase with improved shading.

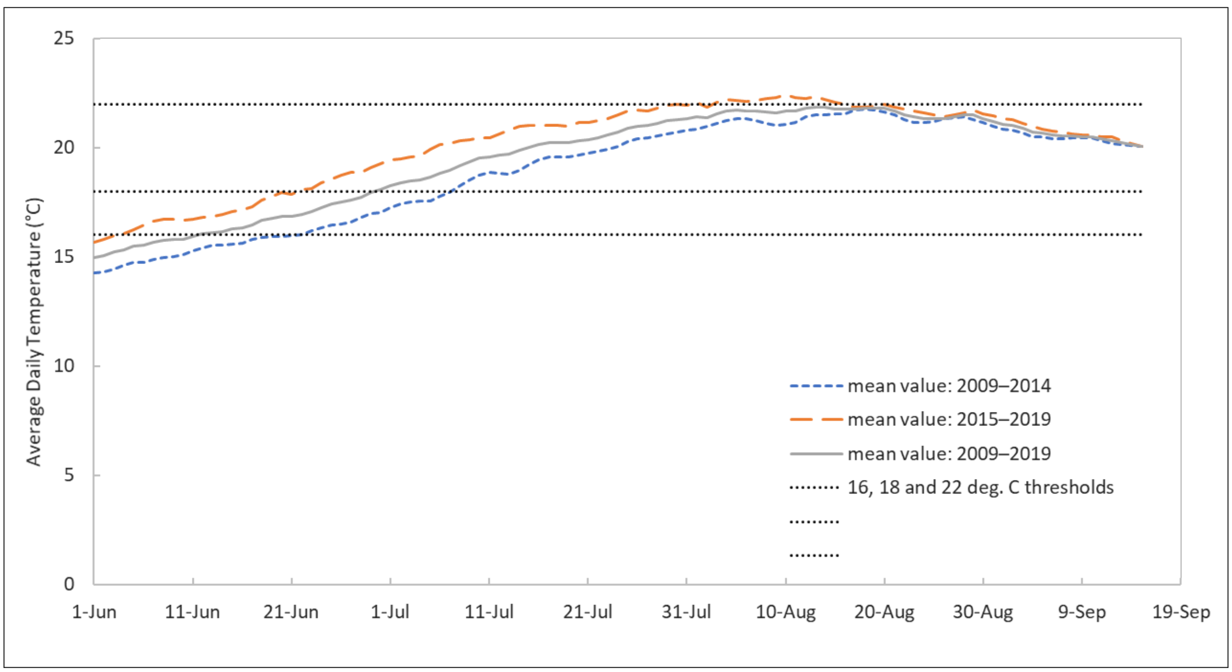

Figure 20: Average daily summer water temperature for the mainstem Columbia River, 2009–2019, recorded below Bonneville Dam. Source: Columbia River DART.

While the project has improved habitat complexity and restored tidal scrub-shrub habitat in the lower Columbia Gorge, several questions remain unanswered in terms of temperature reduction. Restoring the historic alignment of Oneonta Creek and increased beaver activity at the site have led to unforeseen flow changes post-restoration. Stream temperatures are highly dependent of stream flow rates (Constantz, 1998). When changes in flow were observed during monitoring efforts in 2014 only instantaneous measurements were collected during summer until 2016. Since then, how much of Horsetail Creek flow influences other parts of the site remains unknown and hence no conclusions can be drawn on the current flow dynamics at the site. Reduction in size of the gravel pond may have helped in reducing temperature of water in the emergent wetland, however, this study shows that while average summer temperatures in the emergent wetland are low (17°C), temperatures in the outlet channels remain high (20°C). The cause of low temperature in the wetland is theorized to be due to groundwater seeps which were discovered during construction and year one post-restoration monitoring, however, due to data losses resulting from loss of dataloggers, these influences could not be studied in detail.

Another shortcoming of this study is the large variability in the number of days of data collection per year. To draw concrete conclusions from this study, full diurnal temperature profiles of the site are required. However, since site access is dependent on water levels it was not feasible to deploy and maintain loggers throughout the year. Moreover, to assess the extent of warming or cooling being offered by the site it is important to know the incoming temperatures of Oneonta and Horsetail creeks. This aspect is missing from the current monitoring efforts.

The study also does not consider the effect Columbia River temperatures have on site temperatures during backwater periods in June. Figure 19 shows discharge rates of Columbia River between April and October, indicating that Horsetail Floodplain is susceptible to backwater temperature influences in June. Hence some of the monitoring stations at the site may be collecting river backwater temperature rather than that of Horsetail and Oneonta creeks.

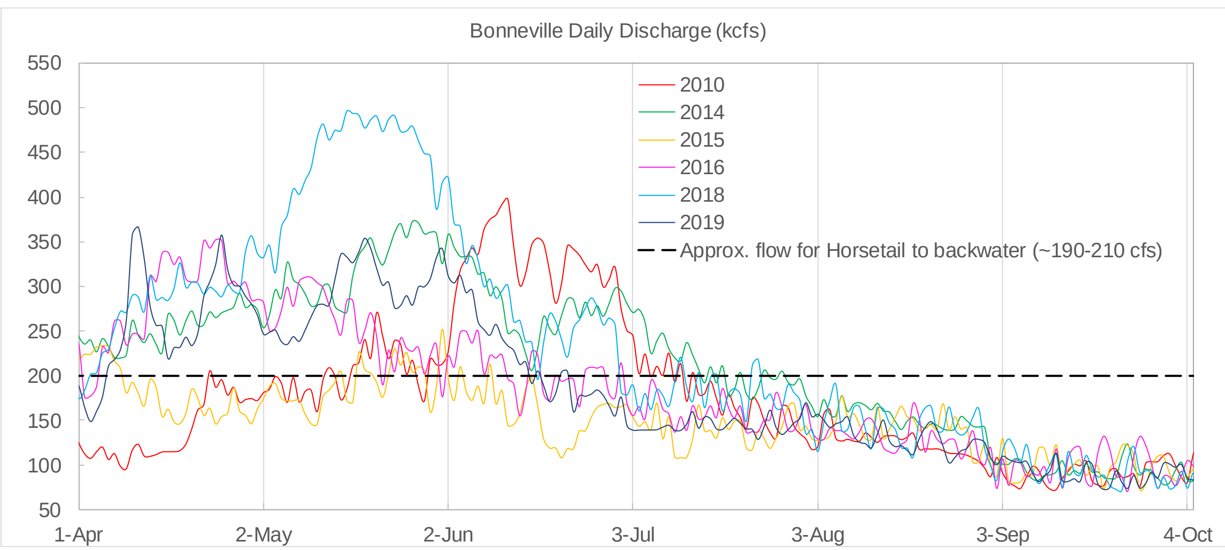

Figure 19: Columbia River discharge, in thousands of cubic feet per second (kcfs) for the study period. The black dotted line depicts the approximate flow above which the Horsetail Creek floodplain experiences backwater flow from the Columbia.

Studying temperature influences of streams and rivers on wetlands and critical zones that have the potential for serving as thermal refuges is an essential aspect in restoration. Salmonid life stages have optimal temperature ranges, and higher temperatures result in reduced spawning, decreased juvenile growth, increased risk of disease and high mortality rates (Howell et al., 2010; Hasler et al., 2012; Hess et al., 2016). Warmer air and ocean temperatures attributed to climate change is thought to be a driving factor of changing weather patterns in the lower Columbia River. Temperature studies will be a useful tool for restoration practitioners to model and adapt restoration design to create zones of potential thermal refuges.

4.2 Fish Monitoring

Salmon from throughout the Columbia River Basin were detected at the Horsetail PIT array. Chinook salmon were the most numerous species detected of juvenile fish and coho were the most numerous species detected of adult/jacks. The mid-Columbia Basin was the origin of the largest number of PIT tagged salmon detected at Horsetail, followed by the Snake River Basin, the lower Columbia River, the upper Columbia Basin, and the Yakima Basin. These patterns of detection are most likely the result of how many PIT tagged salmon of each species were released from each basin as well as the proximity of the release site to the Horsetail array.

Juvenile residence times were relatively short with most lasting less than one day and in most cases less than one minute. However, steelhead, spring/summer run and fall run Chinook showed greater variability in residence times with several fish residing five or more days. Two juvenile steelhead appear to have used the Horsetail restoration site as prolonged rearing area. Both steelhead had been barged and were detected a short time after the barge release date. One individual resided for an impressive 115 days. The second steelhead resided for 67 days, and was then detected on an adult ladder at Bonneville, The Dalles, and John Day Dams. The detection history of both fish indicates that the Horsetail restoration site may be used as an extended rearing site for precocious juveniles.

For adult/jack salmon detected at the Horsetail array, residence times did not have the same range as for juveniles. Coho salmon had the longest residence times with a maximum of 18 days followed by steelhead with a maximum of 12 days. Coho were the most numerous adults detected, and their residency patterns indicate that adult salmon also tuck into small tributaries. The Horsetail and Oneonta creeks may provide cool water refuge for returning adults. Fish that were tagged as adults tended to be detected in October, shortly after they had been tagged and released, and were not likely to be seeking thermal refuge. However, one third of salmon that were tagged as juveniles and then detected as an adult were first detected during August or September when river temperatures tend to be highest. This indicates that adults may be using Horsetail/Oneonta creeks as a cold water refuge during their upstream migration. Additionally, of those adults detected during August and September, all but one originated from either the upper Columbia or Snake River Basins.

Residence times were impacted by whether salmon successfully navigated the culvert. Combining juveniles and adults, the median residence time for salmon that did not pass the culvert was 5 minutes, whereas the median residence time for salmon that did pass the culvert was 33 hours. There could be two explanations for this observance; 1) salmon that are able to pass the culvert will spend more time in the area, or, 2) because it takes more time to pass the culvert, those fish that do pass have longer residence times. A more intensive analysis of the data would be able to look at the average length of time it took to pass from the downstream to upstream side of the culvert and determine whether explanation 2) above is valid.

Time of year influenced whether salmon were able to successfully pass the culvert. During August when water levels are seasonably low and water temperatures high, no salmon were detected on the upstream antennas. This includes adult salmon from interior basins that nosed into Horsetail/Oneonta Creek, potentially for cold water refuge. However, 15% salmon that were detected only on the downstream antennas were detected in August.

In summary, juvenile and adult salmon have the potential to access and benefit from the Horsetail Creek restoration site. Whether a salmon can access the site depends on the time of year and water levels, as the culvert may block access during times of low water levels. However, the PIT detection array has demonstrated that salmon from every major interior subbasin interact with the confluence of Horsetail/Oneonta creeks and the Columbia River, and that some individuals, especially some steelhead, reside for extended periods in the area.

5. Conclusion and Next Steps

The restoration effort undertaken in 2013 and described above is considered Phase I of a multi-phase project. Phase I helped in restoring scrub-shrub wetland habitat in the Columbia Gorge and improved fish access to the site. The native vegetation planting and large wood placements helped encourage beaver activity and improve habitat quality. Post-restoration monitoring of the site indicates that Oneonta Creek was successfully realigned during construction and while average summer temperatures remain within a constant range (12.7°C – 20°C), it is expected that water temperatures at the site will reduce as plantings mature. It is recommended that future monitoring efforts include regular stream flow measurements at monitoring stations and deployments of loggers capable of collecting temperature and water surface elevation data throughout the year.

Phase II is an in-progress (as of early 2021) 30-acre floodplain reforestation and large wood debris placement project to the east of the Phase 1 project location. Focused in and adjacent to the East Slough, Phase 2 will treat an additional 0.5 stream miles by placing 25 pieces of in-stream large wood, installing beaver dam analog structures (BDAs), and revegetating an additional 30 acres of floodplain habitat by removing an invasive understory of reed canary grass and planting 65,000 native forested wetland species. The goal of this phase is to jumpstart recovery of native vegetation impacted by the 2017 Eagle Creek fire and use the trees that did not survive the fire to increase habitat complexity.

We are currently assessing feasibility of a potential third phase of work at the Horsetail Creek Floodplain site, which would involve enhancing cold water refuge opportunity at the confluence of Horsetail/Oneonta Creek with the mainstem Columbia so that it functions similarly to other well-used thermal refuge zones further upstream in the Columbia River. The importance of cold water refuges to Columbia Basin salmon and steelhead during summer months is well documented; steelhead are known to use these refuges for days to weeks. Summer water temperatures in the mainstem Columbia River have increased steadily over the last several decades, and recent annual peak temperatures have regularly exceeded 21°C and been as high as 24°C. These stressful summer temperatures are predicted to continue to warm and the duration of that warm period is expected to increase, making cold water refuges vital for cold water species.

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