Multnomah Channel Wetland Restoration Monitoring Project

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Report prepared for

Sustainability Center, Oregon Metro Natural Areas Program
600 NE Grand Avenue
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July 2017

Executive Summary

From 2014 to 2016, we surveyed the Multnomah Channel Marsh Natural Area to determine the temporal composition and abundance of fish assemblages, as well as habitat use and residency by juvenile salmonids. The marsh is a floodplain wetland of ~120 ha acquired and managed by Metro near Portland, Oregon.

This research was funded by the Metro *Natural Areas Program* with support from the Oregon Watershed Enhancement Board and Ducks Unlimited. The work was implemented through a collaborative effort among researchers with the U.S. National Marine Fisheries Service, the Oregon Department of Fish and Wildlife, and the Oregon State University College of Earth Ocean and Atmospheric Sciences. The West Multnomah Soil and Water Conservation District and Lower Columbia Estuary Partnership were also engaged in this effort as key conservation groups associated with salmon recovery in the region. Surveys were designed to evaluate the effectiveness of a 2014 restoration project at the Multnomah Channel Marsh, which was directed by Metro and partners.

Researchers have employed a variety of methods to sample the freshwater tributaries entering the wetland, the north and south wetland ponds, and nearby shoreline habitats along Multnomah Channel and the mainstem Columbia River. These surveys were intended to document use of the wetland by fish during the spring and early summer immediately preceding a planned restoration project to lower portions of the natural riparian berm separating the wetland from Multnomah Channel.

Some of the highest-value aquatic habitat was consistently observed in the wetland tributaries of Patterson and Crabapple Creek. These creeks were inhabited almost entirely by native fish and amphibians, including reticulate sculpin *Cottus perplexus* and coastal cutthroat trout *Oncorhynchus clarki clarki*. In contrast, wetland ponds were inhabited by a greater proportion of non-native taxa, including a high proportion of pollution-tolerant species.

Over the three study years, introduced species made up a substantial percentage of the catch in north and south wetland ponds. However, three salmonid species were present in small numbers: Chinook salmon *O. tshawytscha*, coho salmon *O. kisutch*, and coastal cutthroat trout. A variety of potential salmonid predators also occupied the ponds, including an apparent resident spawning population of largemouth bass *Micropterus salmoides*. For most of the sampling periods, native and non-native fish communities in the wetland ponds were more diverse than those in Multnomah Channel or in the mainstem Columbia River.

In Multnomah Channel and the mainstem Columbia River, we captured four salmonid species and a variety of other native and non-native species. Chinook salmon was the most common salmonid species. Catches of juvenile Chinook salmon peaked in April and May and were consistently higher in the mainstem than in Multnomah Channel. However, non-native species dominated most collections in the mainstem Columbia River and in Multnomah Channel, where yellow perch *Perca flavescens* and banded killifish *Fundulus diaphanous* occurred throughout sampling periods.

A higher proportion of native species was observed at mainstem locations, but the proportion of non-native taxa steadily increased, and by July of each year, dominated mainstem as well as Multnomah Channel sites. In July, salmon had nearly disappeared from the mainstem, and none were captured at survey sites in Multnomah Channel.

We also monitored the marsh for fish tagged and released for other studies at various upriver locations. Fish were detected as they entered the Multnomah Channel Marsh north and south outlet channels. These detections indicated volitional movement of fish from Multnomah Channel toward the flooded wetland. However, we found no evidence that any tagged fish migrated into the marsh ponds through the closed water control structures that regulate pond elevation.

We also conducted a series of experimental releases of tagged salmon into the north and south ponds to evaluate salmon residence times and egress from the ponds. These experiments showed that juvenile Chinook salmon had difficulty passing the half-round riser-style water control structure on the south pond, but were better able to pass the full-round riser-style water control structure on the north pond.

Detections from these releases also indicated that juvenile Chinook salmon in Multnomah Channel would benefit from improved access to the Multnomah Channel Marsh, provided barriers do not obstruct their ability to exit the marsh as water temperatures rise, dissolved oxygen levels decline, and smoltification progresses.

We also conducted growth experiments, and results indicated that juvenile Chinook salmon had greater growth in areas of natural emergent vegetation than in areas dominated by invasive reed canarygrass *Phalaris arundinacea* L. These differences could not be attributed to differences in prey availability, diet, water temperature, or dissolved oxygen levels.

The Multnomah Channel Marsh area provides foraging opportunities and refuge from high flows for juvenile salmonids; however, the hydrologic disconnect of the Multnomah Channel Marsh from Multnomah Channel limits access of juvenile salmonids to the wetlands, provides habitat for non-native species, and degrades water quality.

Contents

Introduction

In the Columbia River, Pacific salmon *Oncorhynchus* spp. have lost approximately 70% of historical tidal wetland habitat (Marcoe and Pilson 2013), and 13 stocks are listed under the U.S. Endangered Species Act. An extensive estuarine wetland restoration program has been implemented to aid recovery of these salmon (Thom et al. 2013). Restoration projects in recent years have expanded to include floodplain wetlands and other off-channel habitats in tidal freshwater reaches of the upper estuary.

Genetic studies have documented a diverse mixture of juvenile Chinook salmon *O. tshawytscha* stocks in the vicinity of the Willamette and Columbia River confluence, where upper Columbia, lower Columbia, and Willamette River stocks consistently congregate (Teel et al. 2009; 2014). As the first large off-channel area below Bonneville Dam, the Willamette River confluence may provide an important transitional habitat for upriver stocks adjusting to a tidal environment (Teel et al. 2014). This report summarizes results of surveys designed to evaluate the response by juvenile salmon to a wetland restoration project at the Multnomah Channel Marsh, a floodplain wetland managed by Metro (Oregon) in the upper estuary near the Willamette and Columbia confluence.

Habitat restoration efforts confront difficult challenges in the tidal-freshwater reaches of this estuary, where fluvial processes shape physical habitat and fish rearing opportunities. In these habitats, annual average flows are impacted by the Federal Columbia River Power System, which regulates seasonal timing, magnitude, and duration of the spring freshet. Such regulation has reduced the historical frequency and duration of floodplain inundation, decreased the total area of wetted land, and limited salmon access to off-channel rearing habitats (Kukulka and Jay 2003; Bottom et al. 2005).

The spread of non-native reed canarygrass *Phalaris arundinacea* L. may have been accelerated by changes to hydrological patterns and nutrient availability, as well as other disturbances (Kercher and Jedler 2004a, 2004b; Jenkins et al. 2008). Reed canarygrass has replaced native vegetation in floodplains across much of the tidal-fluvial estuary (Diefenderfer et al. 2013). Historical changes to the Columbia River hydrograph and ecological responses to these changes may limit the opportunities for and effectiveness of floodplain restoration efforts for salmon.

An objective of many salmon restoration projects in the tidal-fluvial estuary is to control or eliminate invasive reed canarygrass. Yet the effects of this grass on floodplain habitat quality and capacity for juvenile salmon are poorly understood. Control measures generally involve physical manipulation, for example, "scraping down" a site to remove reed canarygrass, lowering site elevations to increase flooding frequency, or installing water control structures to artificially retain water on the floodplain.

Unfortunately, the effectiveness of such measures is often speculative, and in some cases may be counterproductive for salmon recovery. For example, water control structures can impede the ability of migrating juveniles to freely access or exit floodplain habitats. Such structures can also degrade water quality and create "hotspots" for non-native species (Scott et al. 2016).

Uncertainties about the risks and benefits of floodplain restoration to juvenile salmon are reflected in seemingly contradictory management actions in the tidal-fluvial estuary. In some cases, water control structures are used to control reed canarygrass (Lavergne and Molofsky 2006) while in others, these structures have been removed to improve salmon access (P.C. Trask and Associates et al. 2013).

The research described here evaluates the response of salmon to a series of floodplain restoration actions implemented at the Multnomah Channel Marsh over the past 15 years. In addition to restoring a more natural seasonal flood regime to the wetlands, goals for restoration include suppression of pasture weeds such as reed canarygrass, meadow foxtail *Alopecurus pratensis* L., thistles *Cirsium* spp., and blackberry *Rubus* spp. Weed suppression is part of the larger goal of expanding native emergent and shrub wetland vegetation to improve habitat for native wetland species including salmon, pond-breeding amphibians, birds, and mammals.

The Multnomah Channel Marsh Natural Area (Multnomah Channel Marsh or MCM) is a ~120 ha floodplain wetland located approximately 24 km northwest of Portland. The marsh is owned and managed by Metro, a regional government in Oregon serving nearly 1.5 million people in Clackamas, Multnomah, and Washington counties.

The wetland stretches 2.9 km along the west bank of Multnomah Channel, a large secondary channel connecting the lower Willamette to the mainstem Columbia River on the west side of Sauvie Island (Figure 1). Two tidal creeks at either end of the property drain each of two hydrologically connected wetland ponds, where water is stored annually from January to July using water control structures located in each creek.

An extensive monitoring program from 2001 to 2006 evaluated the potential risks and benefits of floodplain use by fish and the capacity of salmon and other species to enter and leave the marsh through the water control structures (Baker 2008). Survey results at the north wetland pond depicted three general patterns:

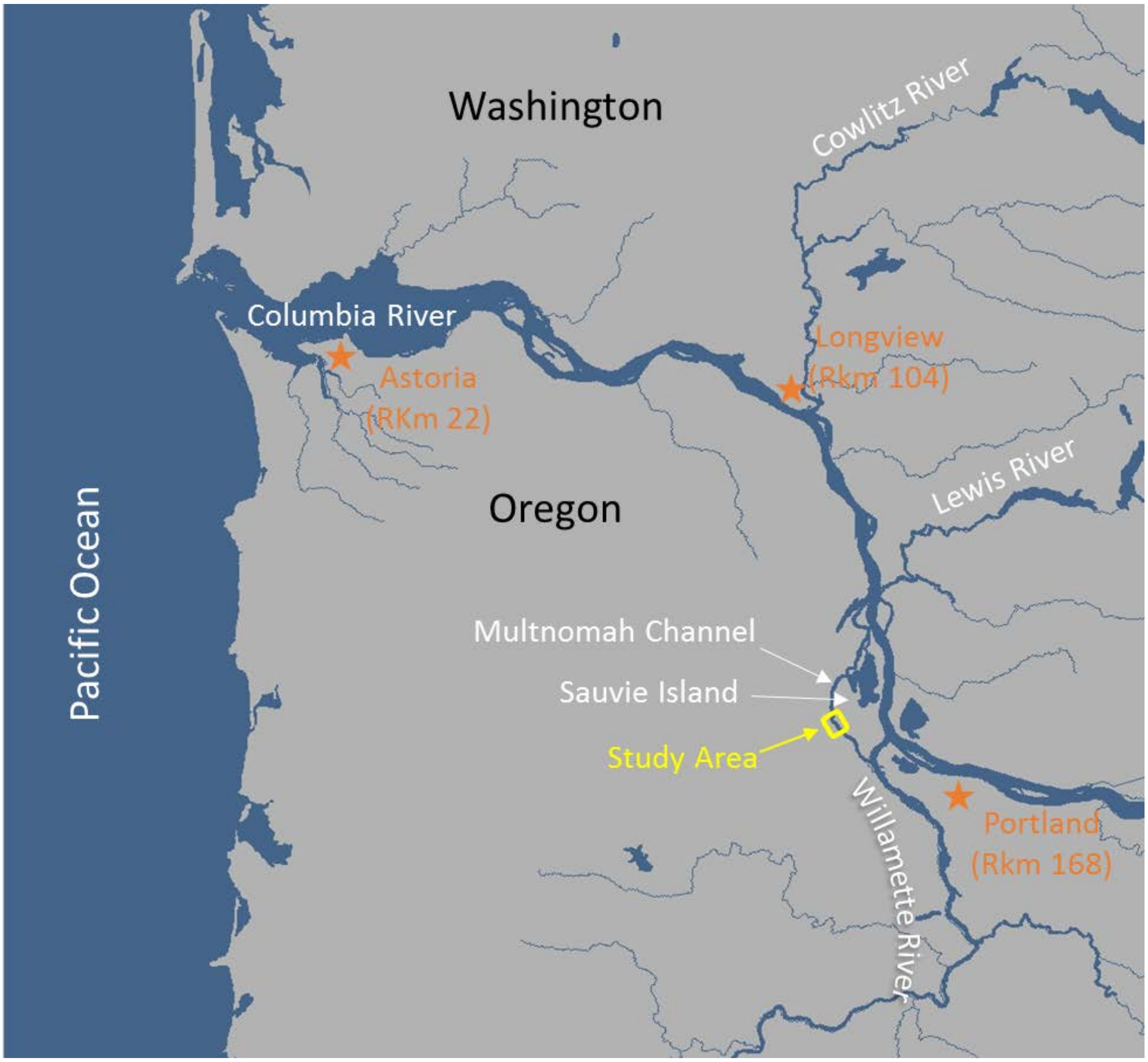


Figure 1. Area map of study site, 2014-2016.

1. The relative abundance of native fish species decreased from winter to spring.
2. Most salmon entered the wetland before April, and juvenile migrants were caught primarily in April and May.
3. Catches in the north wetland pond were generally greater than catches at similar wetlands nearby, where the distance from Multnomah Channel was greater (Baker and Miranda 2003).

In 2009, Patterson Creek, a perennial stream feeding the marsh, was realigned to maintain positive flows from the two outlet creeks and to benefit salmon egress from the site. More recent restoration actions were undertaken in October 2014 to further improve habitat connectivity and floodplain-rearing opportunities for aquatic species, particularly juvenile salmon. The natural berm along the periphery of the MCM was breached in two locations to improve fish access from Multnomah Channel during high-flow events. Culverts between the north and south wetland ponds were also replaced with a bridge, and a segment of the access road was lowered to facilitate intra-wetland movement by fish in the marsh.

From January 2014 to May 2016, we conducted surveys to re-examine fish use of the MCM since the 2009 Patterson Creek realignment and immediately before and after the planned breach of the barrier berm along Multnomah Channel. We evaluated fish abundance, species composition, and salmon residency to provide before/after data for evaluating the effects of berm breaches on floodplain connectivity, fish access from Multnomah Channel, and fish egress from the MCM.

However, low river flows persisted for most of 2015 and 2016, limiting direct evaluation of potential effects from berm breaching on fish movement to and from Multnomah Channel. The one exception was a brief high-flow event in December 2015 that restored MCM connectivity with Multnomah Channel for several hours and enabled a partial assessment of fish response.

The purpose of this study was to measure the biological response to recent changes at the MCM by comparing habitat conditions and fish use before and after completion of 2014 restorations. Our study design addressed five principal objectives:

1. *Characterize wetland use by fish populations at Multnomah Channel Marsh*—before and after restoration actions, focusing on salmonids but including other fish species in the two large wetland ponds at the MCM.

2. *Characterize stream movements of juvenile salmon*—specifically focusing on the ability of these fish to pass through culverts under Highway 30.

3. *Characterize movements of juvenile salmon to and from Multnomah Channel and the Multnomah Channel Marsh wetlands*—specifically focusing on the ability of these fish to pass through possible barriers presented by the two large water control structures present near the outlets of the two large wetland ponds.

4. *Compare relative habitat capacities and juvenile salmon performance in reed canarygrass and natural emergent marsh vegetation*—Test experimentally the relative growth potential of juvenile Chinook salmon in areas of the MCM that are dominated by natural emergent vegetation vs. reed canarygrass, and monitor the residency and distributions of tagged individuals within each vegetation type.

5. *Characterize effects of river flow and water elevation on salmon dispersal and access to floodplain habitats in the upper estuary*—Monitor temporal variations in fish abundance, species composition, and river flow and water elevation in the mainstem Columbia River and Multnomah Channel to assess remote influences on fish use of the MCM.

To fulfill these objectives, we surveyed fish assemblages and environmental conditions along a habitat gradient encompassing varying water depths, velocities, and vegetative assemblages. Survey areas included floodplain wetlands, the adjacent channel, and the mainstem Columbia River. We compared fish abundance and composition across the entire habitat gradient and evaluated whether fish sources from Multnomah Channel and the Columbia mainstem accessed the Multnomah marsh floodplain.

We also monitored fish species composition in Patterson and Crabapple Creeks to determine whether these smaller upstream tributaries may serve as additional sources of juvenile salmonids entering the wetland. Passive integrated transponder (PIT) detection arrays were installed on outlet channels of the north and south ponds to measure how long juvenile salmon would remain in the wetland habitat and to determine whether they could successfully pass the water control structures.

Finally, we conducted a series of captive rearing experiments in the south pond to determine whether invertebrate prey availability and the diets and relative growth rates of juvenile Chinook salmon differ between native wetland vegetation and non-native reed canarygrass. All studies began in early spring 2014, prior to the restoration actions, and have continued seasonally through May 2016.

Low flow conditions in 2015 and 2016 restricted evaluation of fish responses to the MCM breaches. Nonetheless, our research provided new information about the effects of floodplain modification on salmon rearing opportunities and capacities in the tidal-fluvial region of the Columbia River estuary. These results have broad application to estuary restoration and salmon recovery efforts in the Columbia Basin and elsewhere. This report details methods and results for individual surveys during the 2014, 2015, and 2016 study periods. The final section summarizes our findings and their implications for estuary restoration and salmon recovery.

Water Quality Monitoring

Wetland Ponds

Methods

2014—Temperature data in north and south MCM ponds were collected at each fish sampling site with a hand-held 15-cm glass thermometer enclosed in a plastic jacket. We did not deploy continuous data loggers in ponds during 2014.

2015—North and south MCM ponds were monitored for temperature, dissolved oxygen and water depth in 2015. Sensors were deployed inside a protective 2-inch vented PVC pipe attached to a metal t-post that was driven into the substrate. Sensors inside the pipe were approximately 10-15 cm above the substrate.

The north pond sensor was in a deep segment of the drainage channel that runs central to the pond. The south pond sensor was attached to a metal t-post in the native vegetation area where the captive rearing experiments were conducted. Continuous temperature and DO data were collected with a dissolved oxygen logger (HOBO U26-001). Continuous temperature and water level data were collected with a water level logger (HOBO U20-001). A water level logger was also placed on site in the air to use as local atmospheric compensation in the water level calculations.

2016—In 2016, flow control gates for the north water control structure were left open to determine whether hydrological input from Multnomah Channel would impact water quality within the north pond.

Water quality methods and sensor placement were the same as those described for 2015 except that sensors were attached to t-posts in both native vegetation and reed canarygrass habitats where the captive rearing experiments were conducted. Dissolved oxygen, temperature, and water level data were collected using the same loggers as in 2015, and a water level logger was again placed in air for local atmospheric compensation in water level calculations.

Results

2014—Temperatures in the north and south pond followed nearly identical trends during the 2014 sampling season and reflected seasonal changes (Figure 2), ranging 4-24°C in the north and 3-24°C in the south pond from January to June 2014.

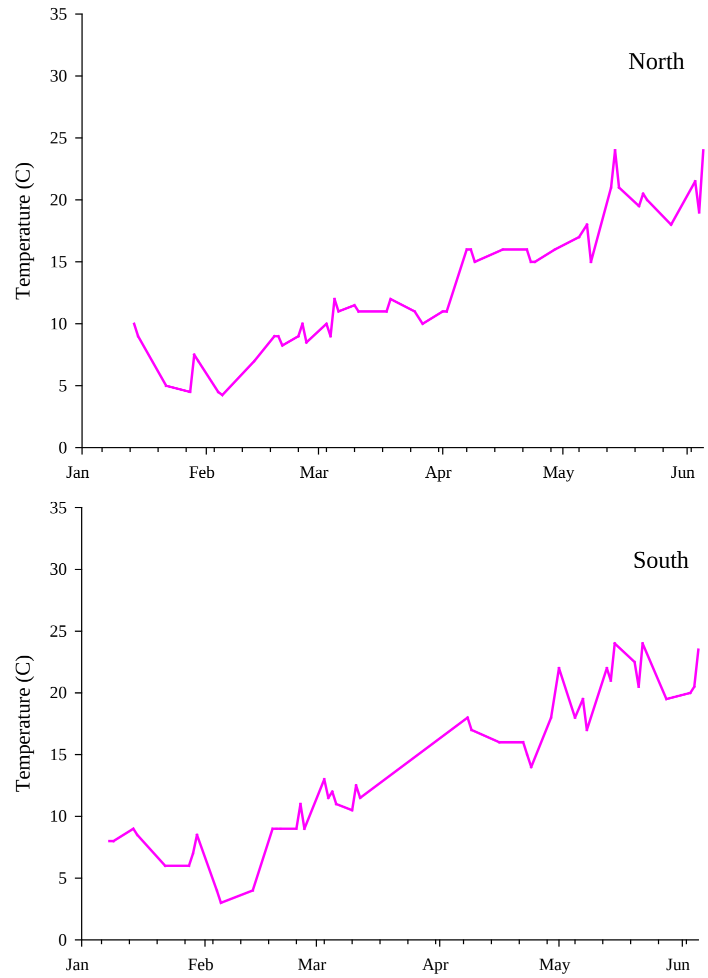


Figure 2. Temperatures collected at Oneida Lake trap nets during deployment in the north and south ponds, 2014.

2015—Temperature and dissolved oxygen patterns were very similar between north and south ponds from March to July 2015. During this period, temperature ranged 10-35°C in the north pond and 10-34°C in the south pond, and dissolved oxygen ranged 0-10 mg/L in the north pond and 0-11 mg/L in the south pond. Water level in the south pond was 0-1.3 m.

Responses to several high water events from increased tributary runoff or rain accumulation can be seen in the water quality. However, the overall trend was a decrease in water quality as the season progressed from spring to summer, with decreasing depth, increasing temperature, and decreasing available dissolved oxygen (Figure 3).

2016—In 2016, the flow control gates for the north water control structure were left open to allow waters in the north pond to continuously respond to input from Multnomah Channel. Waters in Multnomah Channel are influenced by tides and river discharge from the Willamette and Columbia Rivers. As a result, water temperatures in the north pond were highly variable in 2016 and had a slightly greater range (5-31°C) than those in the south pond (8-26°C; Figure 4).

Average temperature was also lower in the north pond (15°C) than in the south pond (17°C). The north pond connection to Multnomah Channel improved the dissolved oxygen levels throughout the duration of the sampling season. In the north pond, DO levels remained higher (range 0-16 mg/L, average 8.1 mg/L) than in the south pond (range 0-11 mg/L, average 1.4 mg/L). South pond oxygen levels declined rather quickly early in the sampling season and by 1 April 2016 remained at or near 0 mg/L due to a lack of other fresh water input.

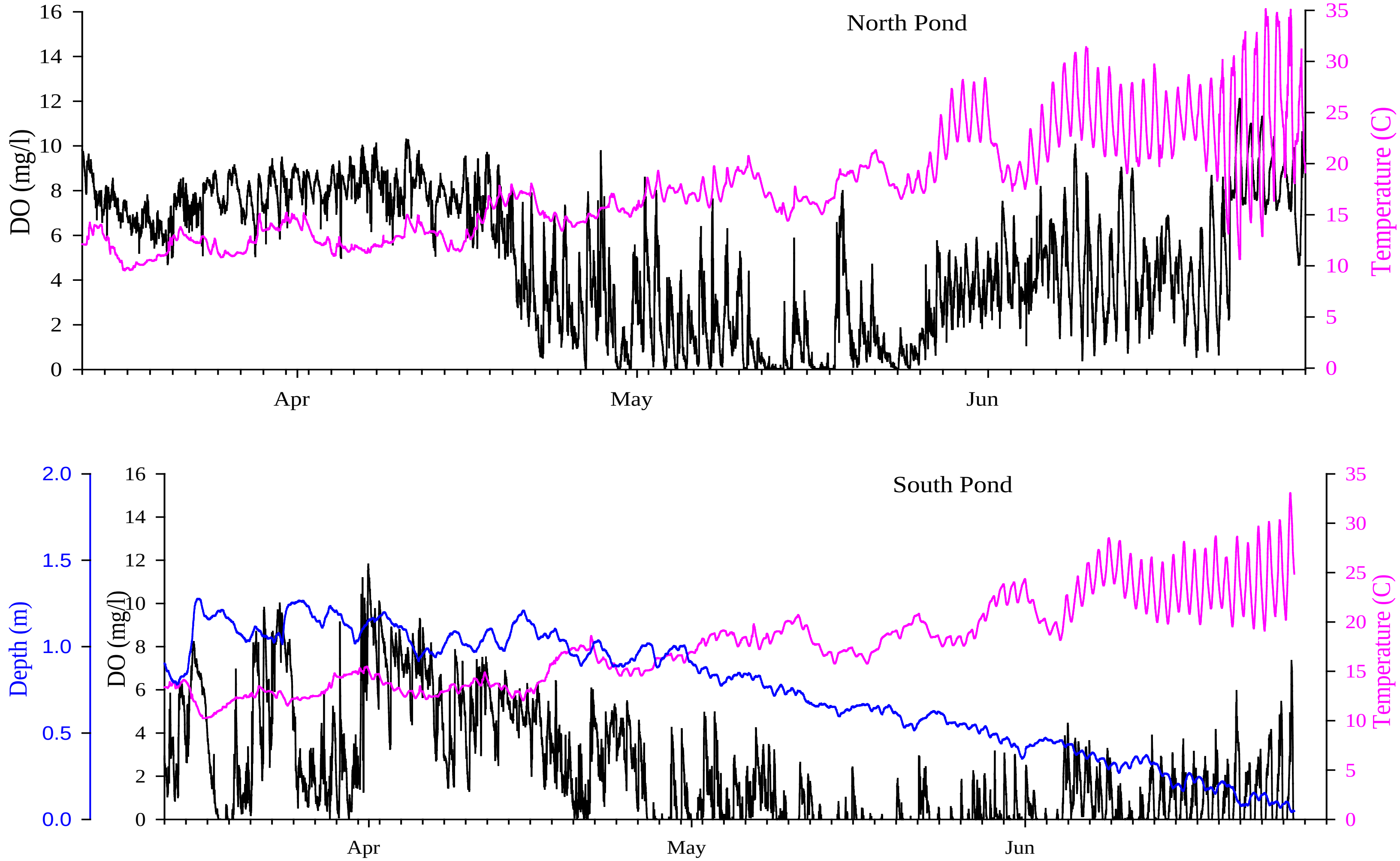


Figure 3. Water quality data for the north and south ponds near natural emergent vegetation net-pens, 2015.

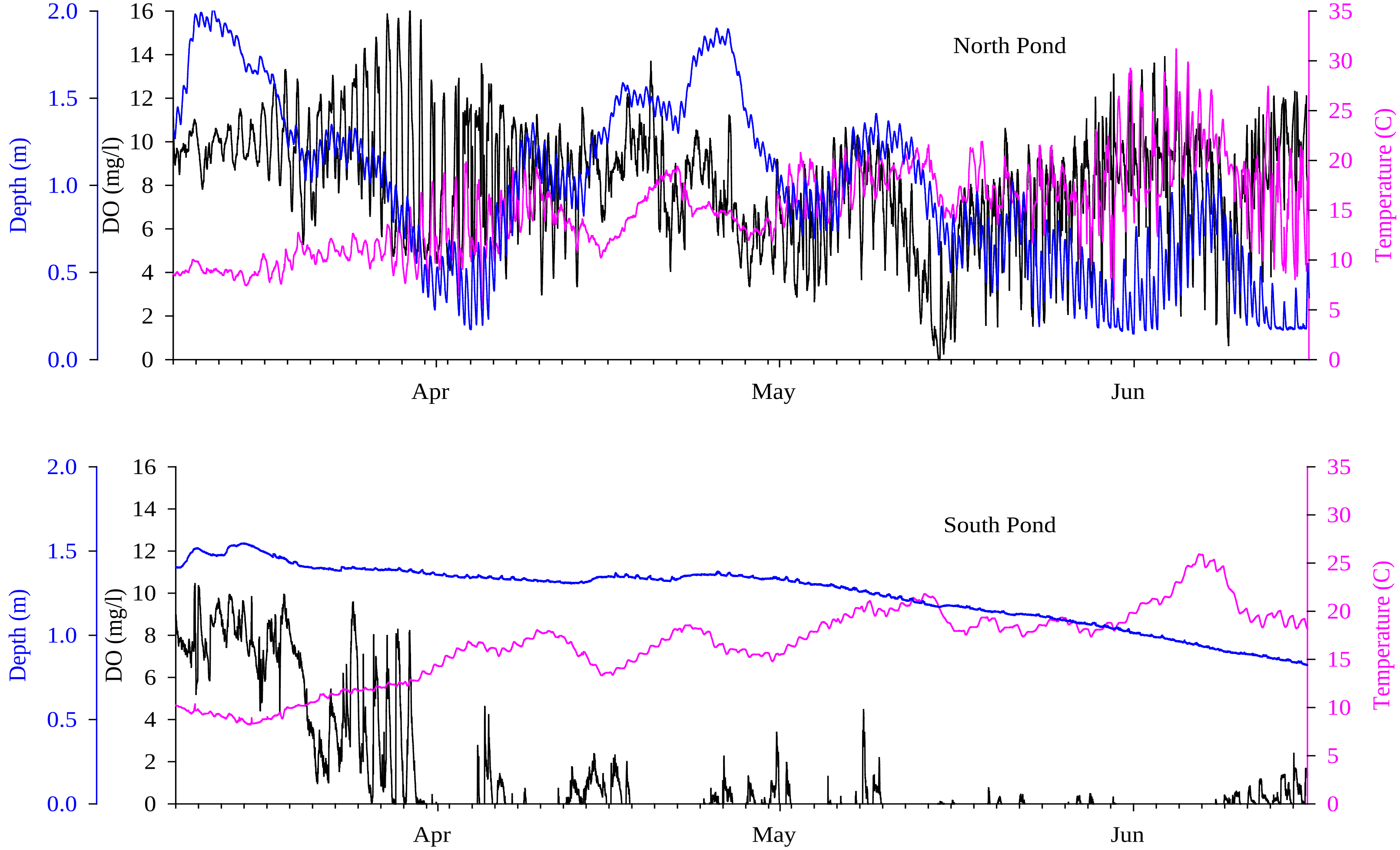


Figure 4. Water quality data for the north and south pond near the natural emergent vegetation net-pen, 2016.

Wetland Tributaries

During sampling surveys each year, temperature data were collected in each wetland tributary stream reach with a handheld thermometer. In 2014, average monthly temperatures in Patterson and Crabapple Creek ranged from 6.0°C in January to 14.0°C in June. In 2015, average monthly temperatures in both creeks were 6.0°C in February, 9.2°C in April and 12°C (only one sample day) in May sampling surveys. During sample events in 2016, average monthly temperatures were in Patterson and Crabapple Creeks were 8.0°C in March, 12.8°C in April and 13.0°C (only one sample) in May.

Multnomah Channel and Columbia River Mainstem

Methods

Temperature and dissolved oxygen were measured monthly at each fish sampling site in the mainstem Columbia River and Multnomah Channel. In 2014, temperature was recorded with a traceable waterproof food thermometer (model #14-648-43) or temperature and dissolved oxygen were recorded with a hand-held meter (Thermo-Scientific Orion Star A326 Portable pH/RDO/DO meter). In 2015, both temperature and dissolved oxygen were recorded with a hand-held ph/RDO/DO meter (Thermo-Scientific Orion Star A326 Portable). Water quality in Multnomah Channel and the mainstem Columbia River was not monitored in 2016.

During all three study years, we monitored Columbia River water levels and potential wetland inundation events using the Columbia River gauge at Vancouver, WA operated by the USGS National Water Information System (14144700). Water levels were an important indicator of when the MCM breaches would be overtopped, and water from Multnomah Channel would flow into the marsh, providing juvenile salmon access to the wetland habitat. We estimated that the gauge at Vancouver, WA would need to exceed 10.7 ft before marsh breaches were topped.

Results

2014—Columbia River water levels varied seasonally, with peak flows associated with the spring freshet in April-May and consistent declines into the dryer and warmer months of summer and early fall (Figure 5). Temperature and dissolved oxygen exhibited associated seasonal changes during March-July sampling. As river levels declined, temperatures increased (range 10.0-24.5°C) and dissolved oxygen decreased (range 12.0-9.5 mg/L) in both areas over time (Figure 6). Few differences in temperature trends were observed between the mainstem Columbia River and Multnomah Channel.

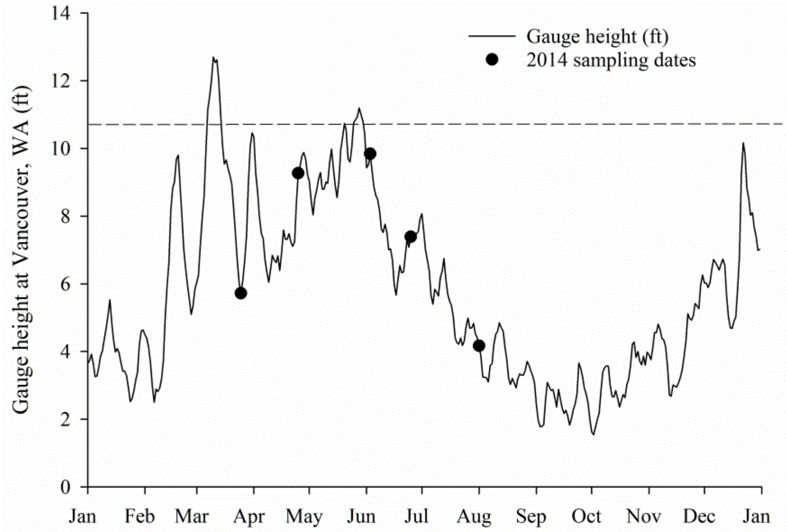


Figure 5. Columbia River gauge height (ft) at Vancouver, WA vs. fish sampling dates in the mainstem Columbia River and Multnomah Channel, 2014. Horizontal dashed line represents the river height necessary to allow water to flow from Multnomah Channel through breaches into the Multnomah Channel Marsh (breaches were not constructed until October 2014).

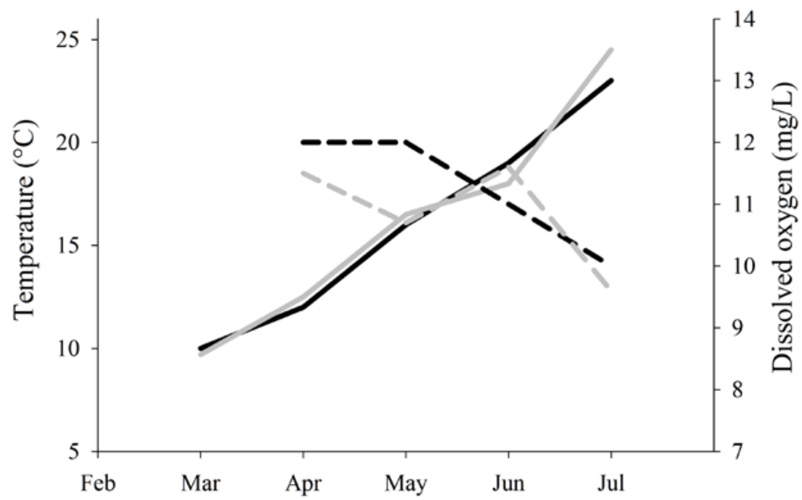


Figure 6. Temperature (solid lines) and dissolved oxygen (dashed lines) levels in the mainstem Columbia River (black) and Multnomah Channel (gray) at fish sampling locations, March-July 2014.

2015—Columbia River water levels varied little among seasons in 2015. Except for a slight spike in February, there was essentially no spring freshet; instead, river levels dropped to those typical of summer by late March (Figure 7). River levels did not reach the 10.7 ft threshold required to overtop breaches during the spring sampling period.

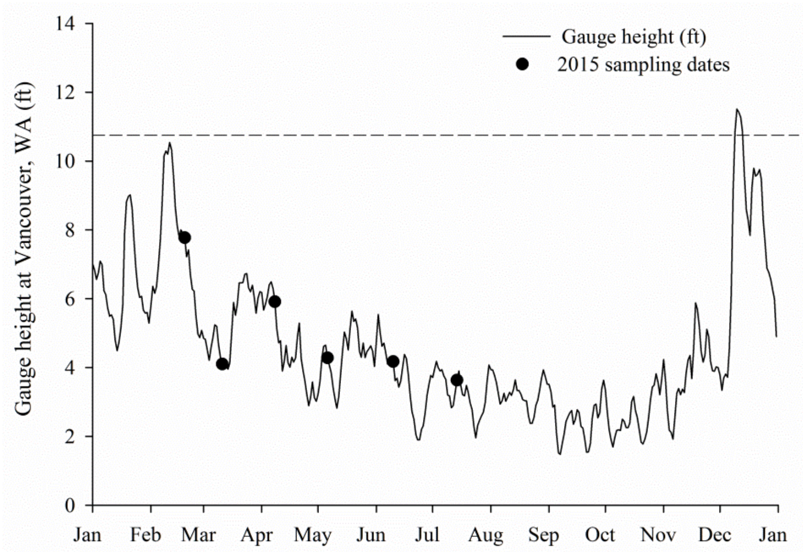


Figure 7. Columbia River gauge height (ft) at Vancouver, WA 2015 and Columbia River mainstem and Multnomah Channel sampling dates for fishes. The horizontal dashed line represents the river level necessary to allow water to flow from Multnomah Channel through the breaches into the marsh.

In contrast, temperature and dissolved oxygen levels exhibited seasonal changes in both sampling areas. Temperature steadily increased (range 6-24.5°C) and dissolved oxygen steadily decreased (range 13.0-7.5 mg/L; Figure 8) from March to July. Temperatures were consistently higher and dissolved oxygen levels consistently lower in Multnomah Channel than in the Columbia River mainstem. In June/July channel temperatures appeared to change more rapidly,

In December, there was a high water event that temporarily overtopped the breaches during a high tide cycle. Extra sampling was initiated during this period, and the methods and results of this effort are reported in the Fish Sampling section on Wetland Ponds.

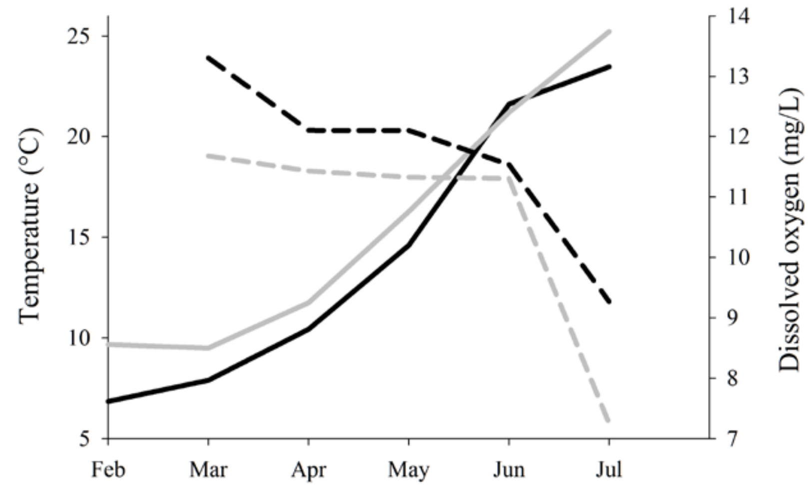


Figure 8. Temperature (solid line) and dissolved oxygen (dashed line) levels in mainstem Columbia River (black) and Multnomah Channel (gray) fish sampling locations, February-July 2015.

2016—Columbia River levels began dropping in May 2016 (Figure 9), which coincided with a steady increase in temperature and decline in dissolved oxygen levels in the pond. For the south pond, water quality rapidly declined at the end of March, likely due to low regional rainfall and a minimal influx of water from pond tributaries.

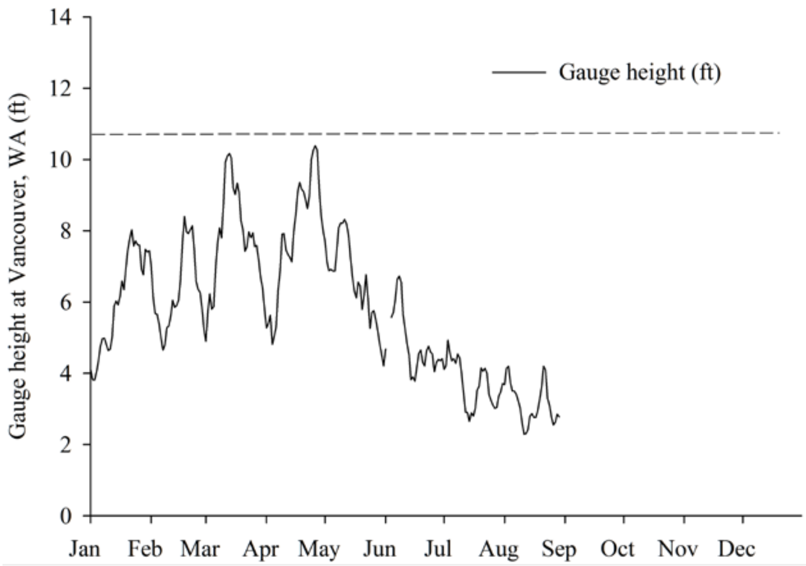


Figure 9. Columbia River gauge height (ft) at Vancouver, WA, 2016. The horizontal dashed line represents the river level necessary to allow water to flow from Multnomah Channel through the breaches into the Multnomah Channel Marsh.

Fish Sampling

Methods

Wetland Ponds

During each study year from 2014 to 2016, we sampled fish in the two largest MCM ponds. When fully inundated, the north pond was 17 ha and the south pond 26 ha (Figure 10).

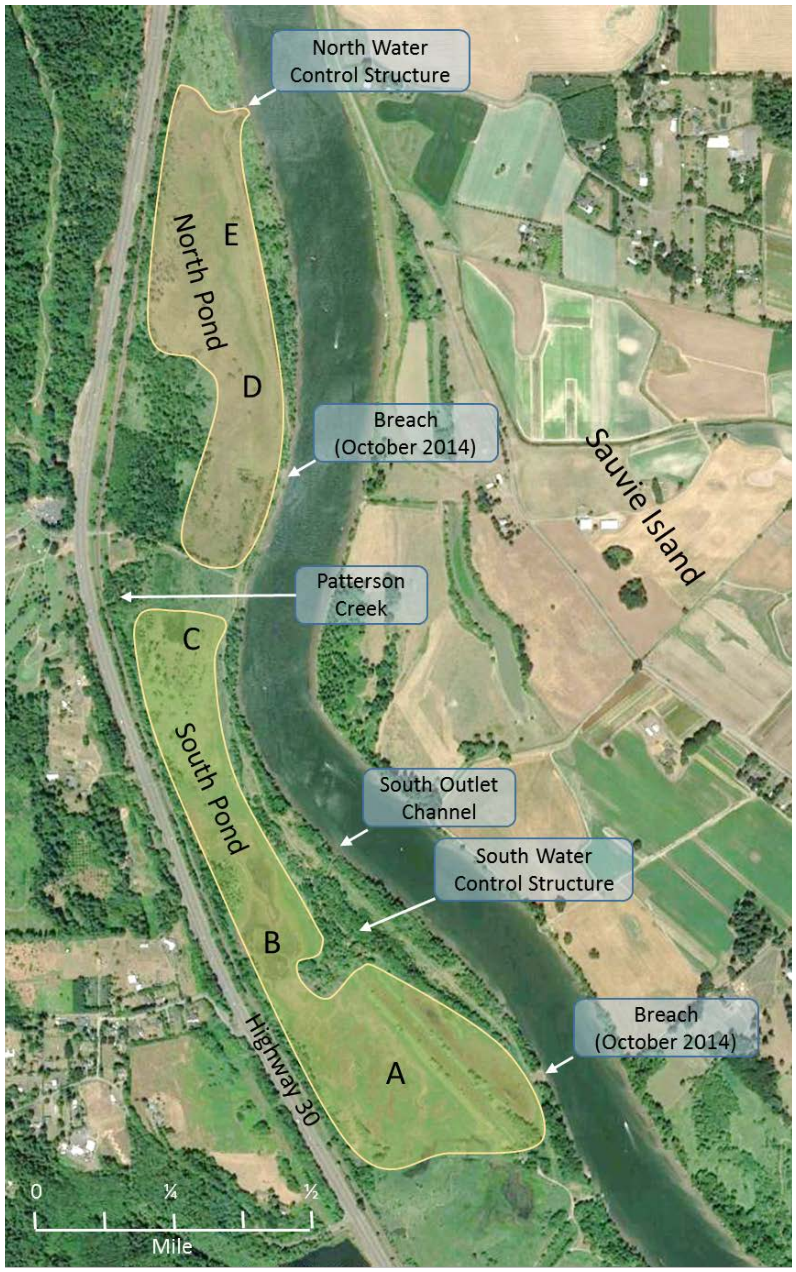


Figure 10. Map of Multnomah Channel Marsh. North and south ponds are highlighted, and letters A-E indicate release sites for tagged salmon, 2014-2016.

Figure 11. Oneida Lake trap deployed in the south Multnomah Channel Marsh pond, winter 2014. Similar traps were used to sample marsh ponds during all three study years.

Fish were captured using a mini Oneida Lake trap, which consisted of a 1.2-m^3 box with net wings of 2.1- by 1.8-m (3.1-mm mesh) and a 22.9-m lead (Figure 11). In each year, two Oneida traps were deployed in each pond. Traps were set in various locations within each pond, including channels, open areas, and shallow areas with emergent vegetation (Figures 12-14).

Trap locations were distributed in a variety of habitat types and water depths with sites chosen to represent available habitat or to target juvenile salmonids entering and leaving the wetland. Traps were set mid-morning and checked approximately 24 h later. Oneida traps were set for 2 weeks in each location and then cleaned and moved to a new location.

Trap location within ponds (UTM coordinates), water depth (m) and species captured were recorded each time traps were checked. Large crustaceans and amphibians were incidentally captured during these surveys, and these catches were recorded but not classified or analyzed. Amphibians and fish were identified to species. During processing, fork length (FL; mm) and wet weight (g) was recorded for salmonids only. Amphibians were measured using the snout-vent length. Captured fish were transported to shore in buckets and separated into 5-gallon buckets with aerators.

Captured fish were anesthetized with tricaine methanesulfonate (50 mg/L). Sodium bicarbonate solution and VIDALIFE® water conditioner were added to the sampling water to reduce gill injury, stress and abrasion during handling. Salmonids were scanned for previously inserted PIT tags. During each sample week, only the first 30 fish of each species were measured, with subsequent fish tallied. Chinook or coho *O. kisutch* salmon without tags were measured and tagged with a 12-mm PIT tag, and a genetic sample was taken from the caudal fin. Fish were released in the general area of the pond where captured.

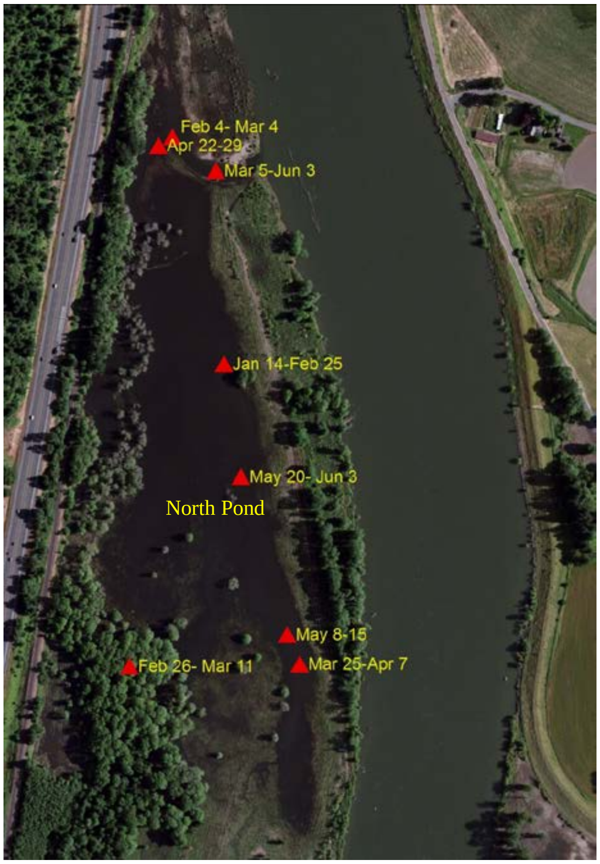


Figure 12. Locations of Oneida Lake traps and dates sampled in north (upper left) and south (lower right) Multnomah Channel Marsh ponds, 2014.

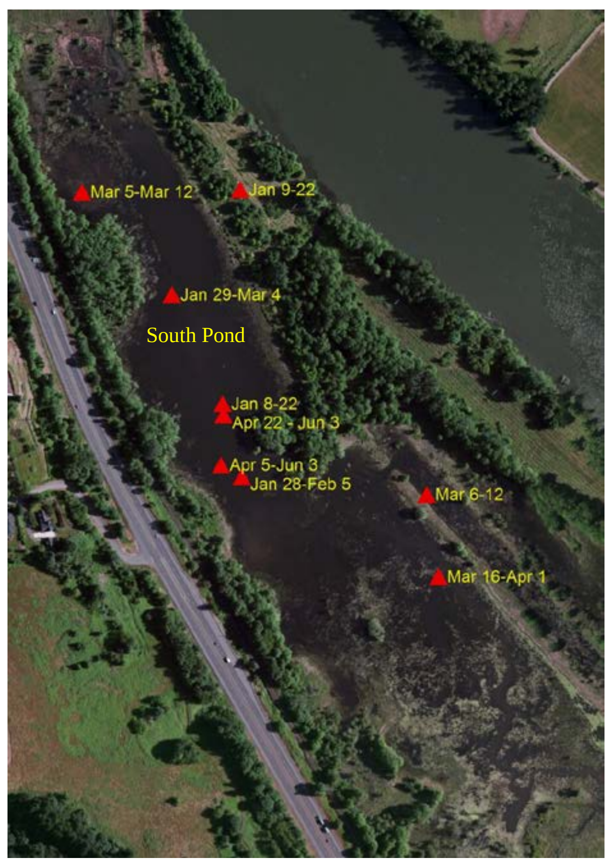


Figure 13. Location of Oneida Lake traps in the north (upper left) and south (lower right) ponds of the Multnomah Channel Marsh with respective dates sampled in 2015.

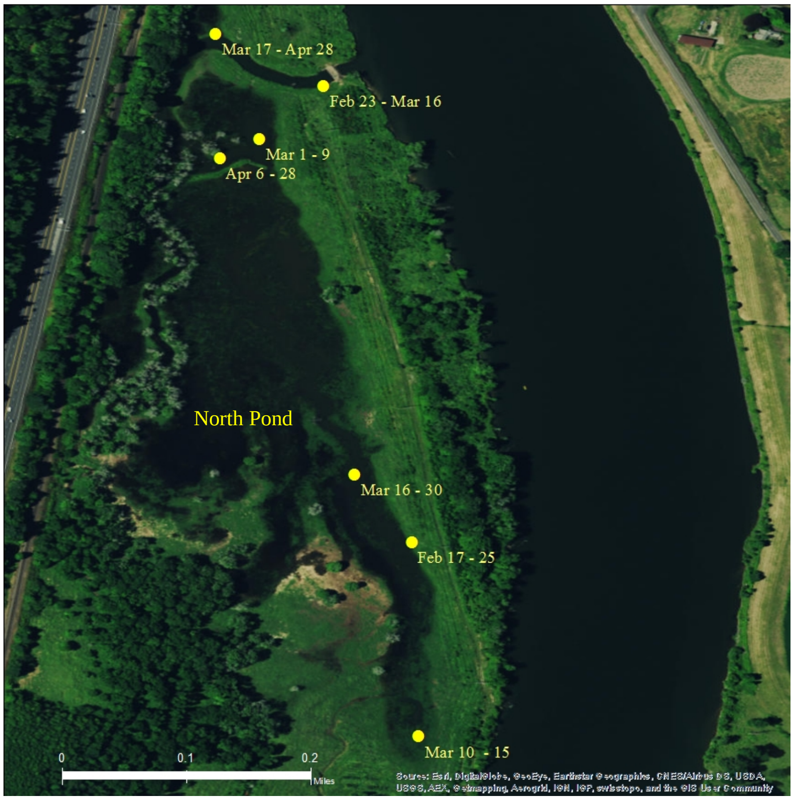
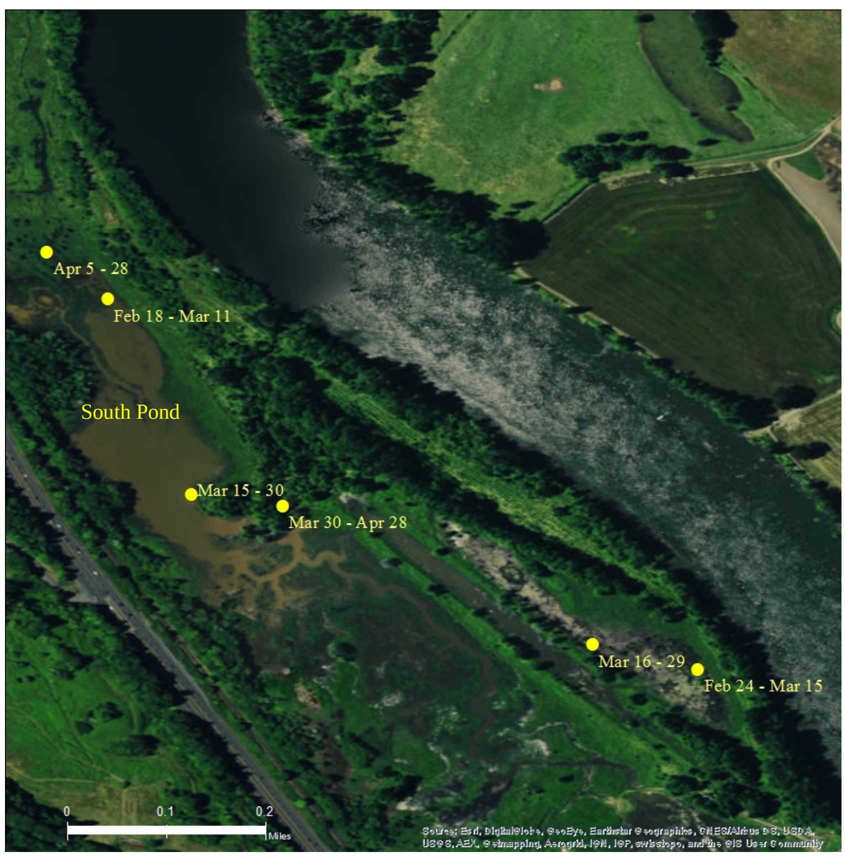


Figure 14. Locations of Oneida Lake traps with dates sampled in Multnomah Channel Marsh north (upper left) and south (lower right) ponds, 2016.



In all three study years, fish sampling was conducted 4 d/week in each pond during the sample period. In 2014, sampling was conducted from 8 January to 5 June (Figure 12). In 2015, fish were sampled from 7 January to 21 May (Figure 13). In 2016, we sampled fish from 17 February to 28 April (Figure 14).

In 2014, the north pond was sampled on one occasion using a 5.5-m aluminum electrofishing boat equipped with a generator-powered electrode set on DC current (Smith-Root GPP 2.5, 400 V, 60-70 hz, 6.0 ms). Sampling consisted of one person operating the boat and two controlling the electrode and netting disabled fish. The boat was operated at speeds below 3 mph along shorelines and throughout the main pond. Continuous electrofishing time was recorded. Fish were processed following the same protocols as those described for fish collected in Oneida Lake traps.

During a high water event in December 2015, heavy rain brought river heights up to the breach threshold, allowing water to flow into the ponds from Multnomah Channel during high tide. This was the only time during 2015-2016 that water entered the MCM through the breaches. Therefore, we conducted additional sampling of both ponds around the breaches and restoration areas. We set two Oneida Lake trap nets in each pond from 10 to 23 December 2015 and used a beach seine to sample the shallow areas of both ponds near the breaches. The inflow of water was brief and relatively shallow.

Wetland Tributaries

In all three study years, we sampled fish in in 100-m reaches of Patterson and Crabapple Creek using backpack electrofishers (Figure 15). Reaches were sampled monthly, as conditions allowed, using a backpack electrofishing unit (Smith-Root LR24). Settings were determined by the auto tuning feature of the unit, but were typically 150-300 V with 30 hz and a 12% pulse rate.

During each sample effort, block nets were placed across the stream at the upper and lower ends of the reach. The three-pass removal method was used to sample each reach, with an operator and assistant capturing stunned fish. After each pass, elapsed continuous sampling time was recorded and reset to determine catch per unit of effort. Shocker settings (voltage, hz, pulse rate) remained unchanged during each pass. Fish processing followed the same protocol as described for catch from the Oneida Lake traps. In addition, crayfish *Pacifastacus* spp. caught in streams were identified to species and counted.

In 2014, we sampled two 100-m reaches Patterson and one in Crabapple Creek (Figure 15). In 2015 and 2016, we sampled three reaches in Patterson Creek and one in Crabapple Creek. The third reach in Patterson Creek was added to sample additional stream habitat opened up by restoration of the area between ponds.

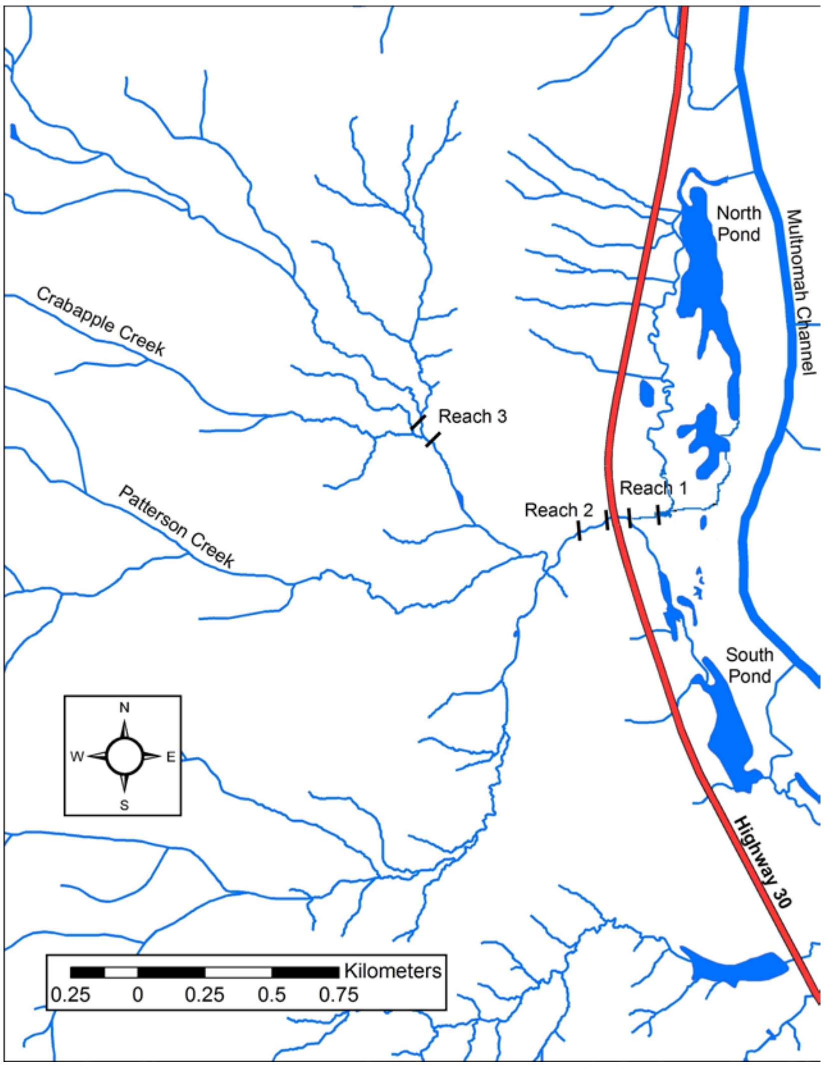


Figure 15. Reaches within Crabapple and Patterson Creek that were sampled by backpack electrofishing, 2014-2016.

Multnomah Channel and Columbia River Mainstem

In 2014 and 2015, we collected fish along the margins of Multnomah Channel at four sites associated with the marsh study area and three sites on mainstem channels of the Columbia and Willamette Rivers (Figure 16). In Multnomah Channel, two sites were located on the marsh property and two adjacent sites were located along Sauvie Island. Mainstem sites were located on Kelly Point Park near the mouth of the Willamette River and two sites in the Columbia River (OR and WA shorelines) 2.8 km downstream from the Willamette River mouth.

Fish were collected using a 38- by 2.7-m bag seine with variable knotless mesh panels of 1.9 and 1.3 cm and a 0.32-cm center bag. A standard deployment consisted of towing the seine from shore with a boat, sweeping the water column in a half-circle, and then retrieving the seine sides equally to guide fish into the center bag.

Fish were then transferred to buckets or held in the net until processed. Every effort was made to sample each site consistently; however, seasonal variation in water levels altered the area swept and effectiveness of the seine, hampering the ability to make quantitative comparisons of fish abundances among sites.

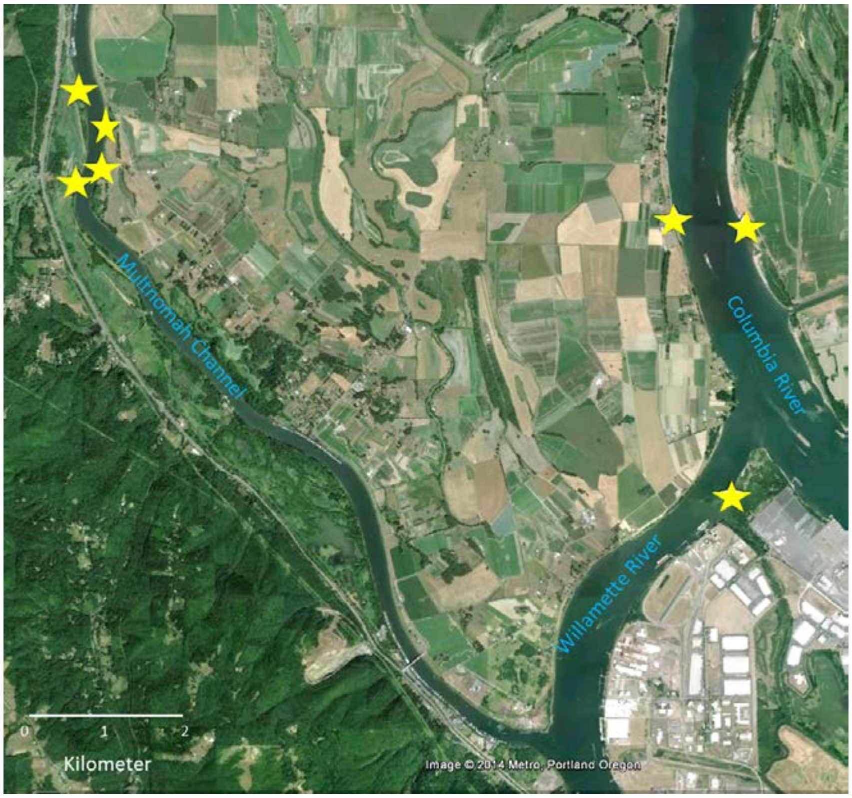


Figure 16. Confluence of the Willamette and Columbia River showing upstream end of Multnomah Channel. Stars indicate bag seine sampling sites.

For salmonid species regardless of location, the first 100 randomly selected fish were processed as follows: The first 30 fish were measured (FL, mm) and weighed (nearest 0.1 g), checked for CWT or PIT tags and any external markings or anomalies (latex tags, adipose fin clip, parasites). The next 70 fish were measured and checked for tags/marks. Any individuals remaining after processing these first 100 fish were counted only. A small tissue sample from the caudal fin was removed from each of the first 30 Chinook salmon and any salmon with CWT or PIT tag. Tissues were archived in ethanol for future genetic analysis. Salmon with coded wire tags (CWT) were retained to retrieve the codes.

Fish were identified to the lowest practical taxonomic level, most often genus/species. Introduced larval or post-larval fish were grouped by family and enumerated. In Multnomah Channel all non-salmonids were individually counted at each sample location, and the first 30 of each species (all locations combined) were measured. In the Columbia River mainstem the first 30 at each sample location were measured and remaining individuals counted.

Bag-seine samples were collected monthly from March to July 2014 and from February to July 2015. In 2016, no fish sampling was conducted in Multnomah Channel or the Columbia River.

Data Analysis

Communities with high biotic integrity are generally dominated by native species that are pollution-intolerant, inferring that habitat and other environmental conditions are of high quality. To provide an initial broad-scale assessment of biotic integrity across sampling sites, we used the fish species classifications established by Zaroban et al. (1999) as biological indicators of aquatic habitat quality.

In each study year, we summarized fish community structure by tolerance to environmental disturbance and adult freshwater feeding guild. Evaluations were made for north and south MCM ponds in all three years. In 2014 and 2015, separate evaluations were conducted for Multnomah Channel and the mainstem Columbia River.

In addition to this broad-scale assessment, we developed community structure indices to provide insight into observed changes within communities of particular habitats or study areas. In all three years, we calculated three fish community structure indices for each sampled area: species richness (number of species per sample site), Shannon-Weiner diversity index, and species evenness.

The Shannon-Weiner diversity index includes two components of diversity: 1) number of species and 2) evenness of individuals among those species (Krebs 1978). Species evenness measures proportional abundance among species in a sample (Pielou 1966) and has a possible range of 0.00-1.00, where 1.00 indicates all species in the sample are numerically equal.

Results

Wetland Ponds

Species Composition 2014—In 2014, we caught 27 species of fishes and crustaceans in the MCM ponds, of which 12 were native and 15 non-native (Table 1). The two species of crustaceans caught were native signal crayfish *P. leniusculus* and non-native Siberian shrimp *Exopalaemon modestus*. Fish species represented 12 families, with the largest percentages from the families Cyprinidae and Centrarchidae (Figure 17). Most species caught in ponds were pollution tolerant (Figure 18).

Invertivores were the most common adult feeding guild, either as obligate invertivores or combined with piscivory (Figure 19). Native threespine stickleback *Gasterosteus aculeatus* was by far the most abundant species in our catch, followed by non-native brown bullhead *Ameiurus nebulosus* (Table 2). Threespine stickleback had a fairly narrow range of lengths, with a mean of 52.7 mm fork length. Brown bullhead was caught in a wide range of sizes, including some large adults (Table 3).

Table 1. Common and scientific names of fishes, crustaceans, and amphibians sampled by location, January–July 2014.

		Location			
Common Name	Scientific Name	Tributary streams	N and S Ponds	Multnomah Channel	Mainstem Columbia
Fishes					
American shad	*Alosa sapidissima*			x	x
Amur goby	*Rhinogobius similis*		x	x	x
Banded killifish	*Fundulus diaphanus*		x	x	x
Black crappie	*Pomoxis nigromaculatus*		x	x	x
Bluegill	*Lepomis macrochirus*		x	x	
Brown bullhead	*Ameiurus nebulosus*		x	x	
Chinook salmon	*Oncorhynchus tshawytscha*		x	x	x
Chiselmouth	*Acrocheilus alutaceus*		x		
Coho salmon	*Oncorhynchus kisutch*		x	x	
Common carp	*Cyprinus carpio*		x	x	
Coastal cutthroat trout	*Oncorhynchus clarkii clarkii*	x	x	x	x
Golden shiner	*Notemigonus crysoleucas*			x	
Goldfish	*Carassius auratus*		x	x	
Largemouth bass	*Micropterus salmoides*		x	x	x
Largescale sucker	*Catostomus macrocheilus*		x	x	
Mosquitofish	*Gambusia affinis*			x	
Mountain whitefish	*Prosopium williamsoni*				x
Northern pikeminnow	*Ptychocheilus oregonensis*		x	x	x
Oriental weatherfish	*Misgurnus anguillicaudatus*	x	x		
Pacific lamprey	*Entosphenus tridentatus*	x			
Peamouth	*Mylocheilus caurinus*		x	x	x
Prickly sculpin	*Cottus asper*			x	x
Pumpkinseed	*Lepomis gibbosus*		x	x	
Rainbow trout (steelhead)	*Oncorhynchus mykiss*			x	x
Redside shiner	*Richardsonius balteatus*		x		
Reticulate sculpin	*Cottus perplexus*	x			
Smallmouth bass	*Micropterus dolomieu*			x	x
Starry flounder	*Platichthys stellatus*			x	x
Threespine stickleback	*Gasterosteus aculeatus*	x	x	x	x
Unidentified centrarchid	*Centrarchidae*		x	x	x
Unidentified cyprinid	*Cyprinidae*		x	x	
Unidentified fish				x	
Unidentified sculpin	*Cottidae*			x	x
Warmouth	*Lepomis gulosus*		x		
Western brook lamprey	*Lampetra richardsoni*	x			
White crappie	*Pomoxis annularis*		x		
Yellow perch	*Perca flavescens*		x	x	x
Crustaceans					
Signal crayfish	*Pacifastacus leniusculus*	x	x		
Amphibians					
American bullfrog	*Lithobates catesbeianus*	x	x		
Long-toed salamander	*Ambystoma macrodactulum*		x		
Northwestern salamander	*Ambystoma gracile*		x		
Pacific Giant salamander	*Dicamptodon tenebrosus*	x			
Red-legged frog	*Rana aurora*	x	x		
Rough skinned newt	*Taricha granulosa*		x		

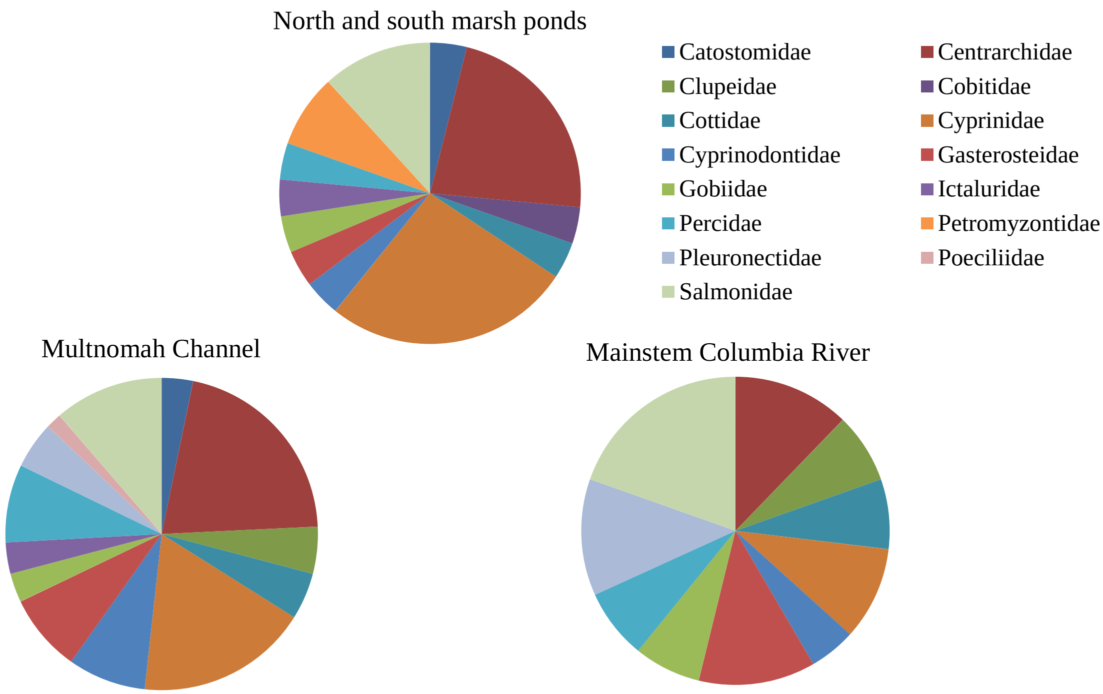


Figure 17. Composition of fish species by family in north and south marsh ponds, January-June 2014 (Oneida Lake trap catch only) vs. in Multnomah Channel and the mainstem Columbia River, March-July 2014.

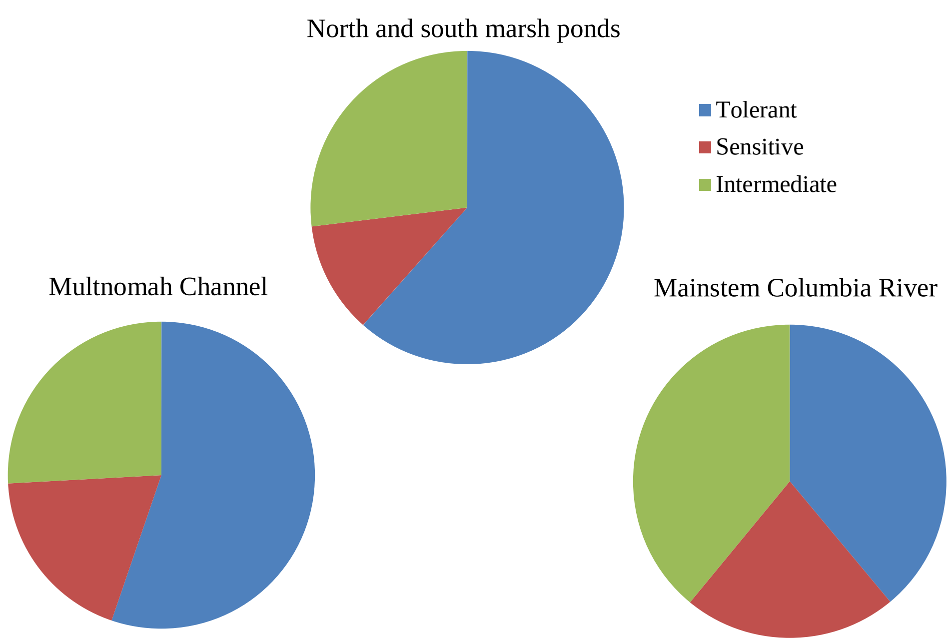


Figure 18. Composition of fish species by pollution tolerance in north and south marsh ponds, January-June 2014 (Oneida Lake trap catch only) vs. in Multnomah Channel and the mainstem Columbia River, March-July 2014.

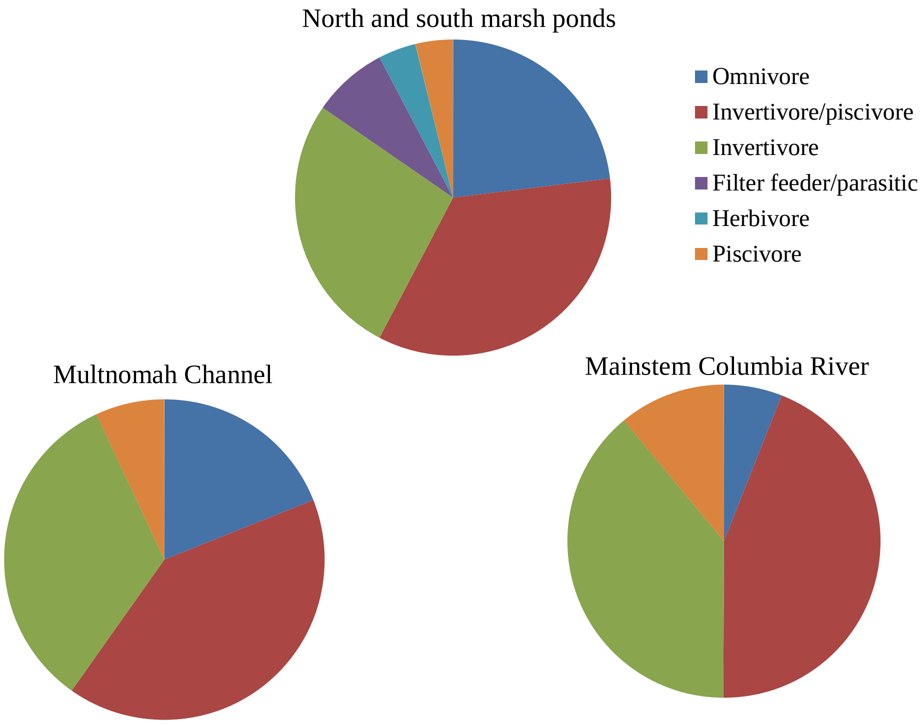


Figure 19. Composition of fish species by adult feeding guild in north and south marsh ponds, January-June 2014 (Oneida Lake trap catch only) vs. in Multnomah Channel and the mainstem Columbia River, March-July 2014.

Table 2. Monthly catch of fish and crustacean species from Oneida Lake traps in the north and south Multnomah Channel Marsh wetland ponds combined, January–June 2014. Sampling effort in trap-days is shown in parentheses.

	Oneida net catch 2014						
Species	January (26)	February (60)	March (58)	April (34)	May (42)	June (11)	Total
Salmonids							
Chinook salmon (juvenile)				2	3		5
Coho salmon (juvenile)		1	2	14			17
Native species							
Chiselmouth		1					1
Largescale sucker		3	7	4	5	6	25
Northern pikeminnow	31	22	6	1	1	6	67
Pacific lamprey					1	2	3
Peamouth	2	10	664	180	6		862
Redside shiner	17	206	116	5	20		364
Reticulate sculpin	5	23	212	85	80	15	420
Threespine stickleback	5,966	3,847	868	766	16,044	2,340	29,831
Western brook lamprey	1	7	4	2			14
Signal crayfish			1				1
Non-native species							
Amur goby			1	3	2		6
Banded killifish	1		3	1	10	4	19
Bluegill	6	3	17	50	67	13	156
Black crappie				7	4	115	126
Brown bullhead	470	1,547	2,438	713	309	456	5,933
Common carp		1	5			1,475	1,481
Golden shiner	467	9	7	13	26	4	526
Goldfish	82	92	712	20	138	8	1,052
Largemouth bass			1	1	3	881	886
Oriental weatherfish	106	196	497	408	310	40	1,557
Pumpkinseed	43	18	59	109	242	66	537
Siberian shrimp				2	5		7
Warmouth	5	9	5	4	25	3	51
White crappie	5		4				9
Yellow perch	2	3	11	13	4	27	60
Total catch	7,209	6,004	5,640	2,401	17,301	5,477	44,023

Table 3. Fork length data (mm) for fish species caught with Oneida Lake trap nets in Multnomah Channel ponds, January-June and March-July 2014 and in the mainstem Columbia River, March-July 2014. SD = standard deviation.

	Fork length (mm)											
	Multnomah Channel Marsh ponds				**Multnomah Channel**				**Mainstem Columbia River**			
Species	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
American shad					46	24	96	28	97	85	127	13
Amur goby	54	46	63	9	39	26	57	9	33	28	37	3
Banded killifish	66	36	82	12	63	24	91	17	75	58	89	11
Black crappie	58	29	223	52	83	83	83	----	62	54	68	7
Bluegill	107	33	180	28	105	80	130	35				
Brown bullhead	124	34	367	69	51	43	87	8				
Chinook salmon	102	45	135	34	64	36	158	28	69	34	218	25
Chiselmouth	64	64	64	----								
Coho salmon	128	74	149	19	138	138	138	----				
Common carp	78	28	480	93	68	52	104	12				
Coastal cutthroat trout	160	71	264	89	162	162	162	----	210	210	210	----
Golden shiner	71	34	165	29	70	49	122	22				
Goldfish	151	29	582	72	62	54	69	8				
Largemouth bass	36	20	400	49	73	42	114	22	42	40	45	3
Largescale sucker	138	57	181	31	131	67	152	32				
Mosquitofish					35	29	39	4				
Mountain whitefish									67	67	67	
Northern pikeminnow	68	39	136	20	74	74	74	----	93	89	97	4
Oriental weatherfish	130	21	220	23								
Peamouth	154	32	267	61	83	28	126	31	55	25	124	35
Prickly sculpin					116	99	133	24	65	65	65	----
Pumpkinseed	97	30	171	29	96	68	135	16				
Rainbow trout (steelhead)					230	230	230	----	213	195	226	13
Redside shiner	68	32	148	22								
Smallmouth bass					79	40	140	54	152	152	152	----
Starry flounder					93	76	129	13	97	70	157	18
Threespine stickleback	53	21	72	10	38	20	65	12	48	24	72	12
Unidentified centrarchid	38	26	89	12	47	23	87	11	41	32	48	4
Unidentified cyprinid	42	34	48	7	44	34	58	6				
Unidentified fish					31	27	35	4				
Unidentified sculpin					25	20	31	4	46	38	60	12
Warmouth	104	49	166	38								
White crappie	97	55	160	44								
Yellow perch	99	28	183	42	78	35	182	35	62	35	150	15

Community Structure 2014—Community structure indices were higher for non-native species in most months sampled during 2014. In ponds, diversity and evenness of non-native species increased over the sample period, while representatives of the native fish community declined (Figure 20). This trend likely reflected a response to higher temperatures and lower dissolved oxygen concentrations during summer months.

Population structure indices showed that both diversity and evenness in north and south ponds was greatest for native species in March, while diversity and evenness of non-native species peaked in May (Figure 20). The percentage of native species in our catch varied by month, averaging 62% for the entire sampling period (range 33-93%; Table 4).

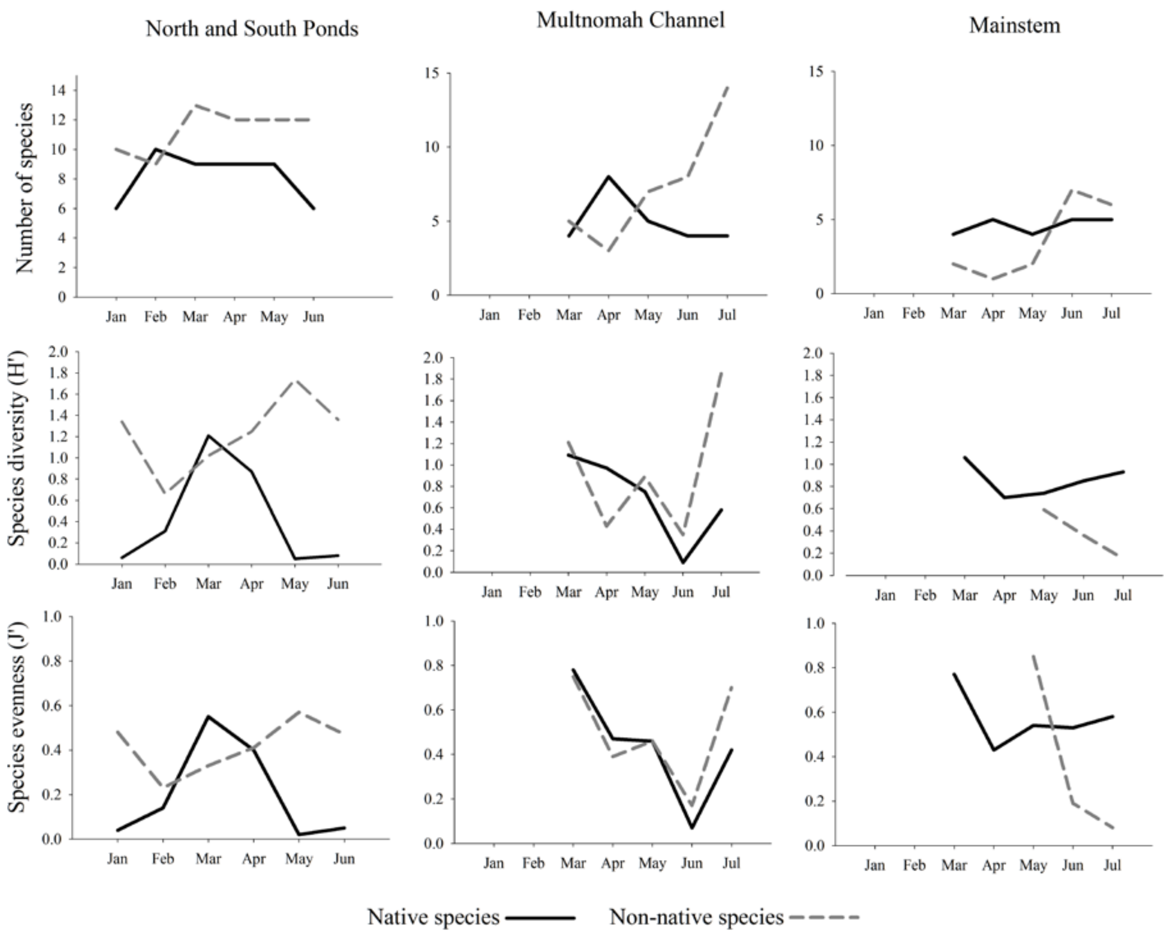


Figure 20. Community structure indices for all fishes captured at sampling sites in the mainstem Columbia River, Multnomah Channel, and north and south wetland ponds, 2014.

Table 4. Monthly percentages of native and non-native fishes and amphibians from Oneida nets in the north and south Multnomah Channel Marsh ponds combined, January-June 2014 (total catch in parentheses).

	Combined catch from north and south pond, 2014					
Species type	January	February	March	April	May	June
Fishes						
Native	84 (6,022)	69 (4,124)	33 (1,880)	44 (1,059)	93 (16,161)	43 (2,370)
Non-native	16 (1,187)	31 (1,878)	67 (3,760)	56 (1,342)	7 (1,140)	57 (3,092)
Amphibians						
Native	42 (93)	17 (155)	6 (85)	11 (5)	19 (3)	67 (2)
Non-native	58 (130)	83 (742)	94 (1,250)	89 (40)	81 (13)	33 (1)

Three species of salmonids were caught in the MCM ponds: juvenile Chinook salmon, coho salmon, and coastal cutthroat trout *O. clarkii clarkii*. Abundance of salmonids was low relative to most other species. Among salmonids, juvenile coho salmon was the most abundant, with a total of 17 caught from February-mid April. We caught two juvenile Chinook salmon in April and three in May.

Fish likely entered the ponds during a high water event on 10-11 March 2014, when water levels at the Vancouver gauge peaked above 13 ft, and water from Multnomah Channel was high enough to overtop the bank near the north water control structure. We caught juvenile salmon intermittently from 18 March until early May.

Chinook salmon had a mean fork length of 101.6 mm. One was an age-0 juvenile, while the others were age-1 juveniles. Juvenile coho salmon had a mean fork length of 124.2 mm; most were age-1 (Table 3). We caught four cutthroat trout in February, when Crabapple Creek was high, and one in March, May, and June.

Amphibians were frequently caught in Oneida Lake traps, with tadpoles of American bullfrogs *Lithobates catesbeianus* the most common catch (Table 5). Bullfrogs were caught all six months, with the most caught in March. Northwestern salamanders *Ambystoma gracile* were the most common native species of amphibian caught in the ponds. Native amphibians were caught primarily January through March, during their breeding season.

A single boat electrofishing survey of the north pond in March captured many of the same species caught in Oneida Lake traps, although some individuals were much larger than those caught in trap nets (Table 6). For example, we caught largemouth bass *Micropterus salmoides* and largescale sucker *Catostomus macrocheilus* that were too big to fit into the Oneida Lake trap nets. The most common fish caught by boat electrofishing was peamouth *Mylocheilus caurinus*. We also collected additional juvenile Chinook and coho salmon (one each) via boat electrofishing; both were PIT-tagged and released back into the pond.

Table 5. Monthly catch of amphibian species from Oneida nets in the north and south Multnomah Channel Marsh ponds, January-June 2014.

Species	January	February	March	April	May	June
American bullfrog	130	742	1,250	40	13	1
Long-toed salamander	6	29	7			
Northwestern salamander	54	69	16			
Red-legged frog	10	16	5			1
Rough skinned newt	23	41	57	5	3	1

Table 6. Species, number, and fork length of fish captured by electrofishing in the north Multnomah Channel Marsh pond, 18 March 2014.

		Fork length (mm)			
Species	Number	Mean	Min	Max	SD
Brown bullhead	1	236.0	236.0	236.0	--
Chinook salmon (juvenile)	1	45.0	45.0	45.0	--
Coho salmon (juvenile)	2	95.5	89.0	102.0	9.2
Common carp	2	457.5	430.0	485.0	38.9
Goldfish	6	239.0	218.0	288.0	27.9
Largemouth bass	3	378.7	338.0	423.0	42.6
Largescale sucker	1	438.0	438.0	438.0	--
Peamouth	19	112.8	79.0	185.0	35.5
Pumpkinseed	2	87.5	77.0	98.0	14.8

Species Composition 2015—Of the 26 species of fishes and crustaceans caught in ponds, 12 were native and 14 non-native (Table 7). The two crustacean species caught were native signal crayfish and non-native Siberian shrimp. Fish species represented 12 families, with the largest percentages from the families Cyprinidae and Centrarchidae (Figure 21).

Most species caught in ponds were pollution tolerant (Figure 22). Invertivores were the most common adult feeding guild, either as obligate invertivores or combined with piscivory (Figure 23). Native threespine stickleback was by far the most abundant fish species in our catch, followed by non-native brown bullhead (Table 8). Threespine stickleback had a fairly narrow length range, with a mean of 52.7 mm FL. Brown bullhead was caught in a wide range of sizes, including some large adults (Table 9).

Table 7. Common and scientific names of fishes, crustaceans, and amphibians sampled by location, January–July, 2015.

		Location			
Common Name	Scientific Name	Streams	Ponds	Multnomah Channel	Mainstem
Fishes					
American shad	*Alosa sapidissima*			x	x
Amur goby	*Rhinogobius similis*			x	x
Banded killifish	*Fundulus diaphanus*	x	x	x	x
Black crappie	*Pomoxis nigromaculatus*	x	x	x	
Bluegill	*Lepomis macrochirus*		x	x	
Brown bullhead	*Ameiurus nebulosus*		x	x	
Chinook salmon	*Oncorhynchus tshawytscha*		x	x	x
Chiselmouth	*Acrocheilus alutaceus*		x		
Chum salmon	*Oncorhynchus keta*				x
Coho salmon	*Oncorhynchus kisutch*		x		
Common carp	*Cyprinus carpio*		x	x	
Coastal cutthroat trout	*Oncorhynchus clarkii clarkii*	x	x		
Golden shiner	*Notemigonus crysoleucas*	x	x	x	
Goldfish	*Carassius auratus*	x	x	x	x
Largemouth bass	*Micropterus salmoides*		x	x	x
Largescale sucker	*Catostomus macrocheilus*		x	x	
Mosquitofish	*Gambusia affinis*	x	x	x	
Mountain whitefish	*Prosopium williamsoni*				x
Northern pikeminnow	*Ptychocheilus oregonensis*		x	x	x
Oriental weatherfish	*Misgurnus anguillicaudatus*	x	x		
Pacific lamprey	*Entosphenus tridentatus*	x	x		
Peamouth	*Mylocheilus caurinus*		x	x	x
Prickly sculpin	*Cottus asper*		x	x	x
Pumpkinseed	*Lepomis gibbosus*	x	x	x	
Rainbow trout (steelhead)	*Oncorhynchus mykiss*			x	
Redside shiner	*Richardsonius balteatus*	x	x		
Reticulate sculpin	*Cottus perplexus*	x	x		
Smallmouth bass	*Micropterus dolomieu*			x	x
Starry flounder	*Platichthys stellatus*			x	x
Threespine stickleback	*Gasterosteus aculeatus*	x	x	x	x
Unidentified centrarchid	*Centrarchidae*			x	
Unidentified cyprinid	*Cyprinidae*		x	x	
Unidentified fish					x
Warmouth	*Lepomis gulosus*		x		
Western brook lamprey	*Lampetra richardsoni*	x	x		
White crappie	*Pomoxis annularis*		x	x	x
Yellow perch	*Perca flavescens*		x	x	x
Crustaceans					
Siberian shrimp	*Exopalaemon modestus*		x		
Signal crayfish	*Pacifastacus leniusculus*	x	x		
Amphibians					
American bullfrog	*Lithobates catesbeianus*	x	x		
Long-toed salamander	*Ambystoma macrodactulum*		x		
Northwestern salamander	*Ambystoma gracile*		x		
Pacific giant salamander	*Dicamptodon tenebrosus*	x			
Red-legged frog	*Rana aurora*	x	x		
Rough skinned newt	*Taricha granulosa*		x		

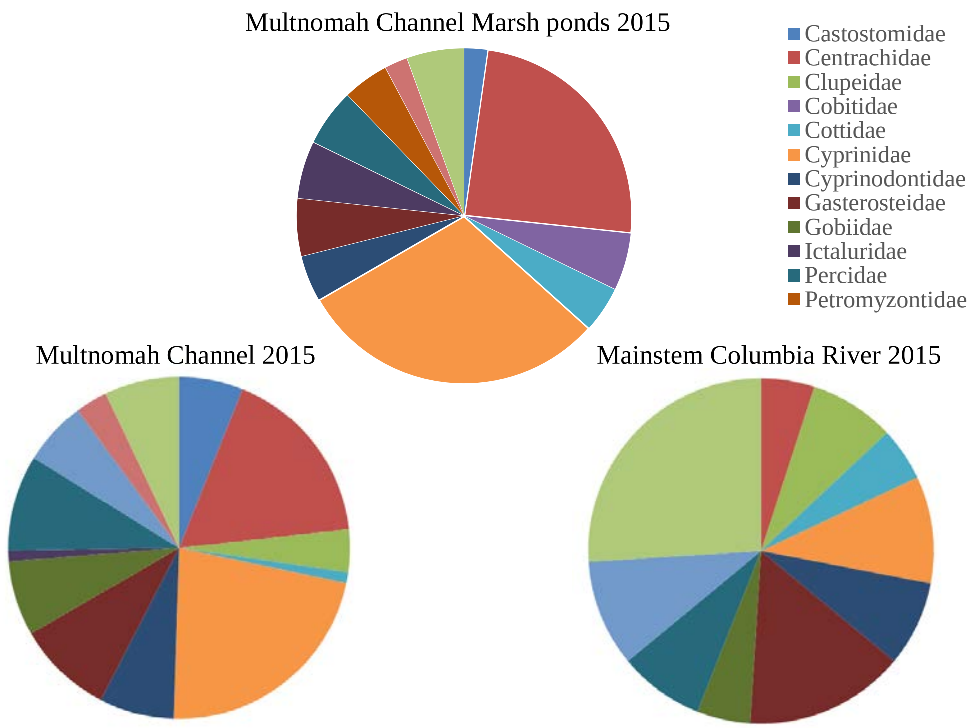


Figure 21. Composition of fish species by family in north and south Multnomah Channel Marsh ponds, January-May (Oneida Lake trap catch only) and in Multnomah Channel and the mainstem Columbia River, February-July 2015.

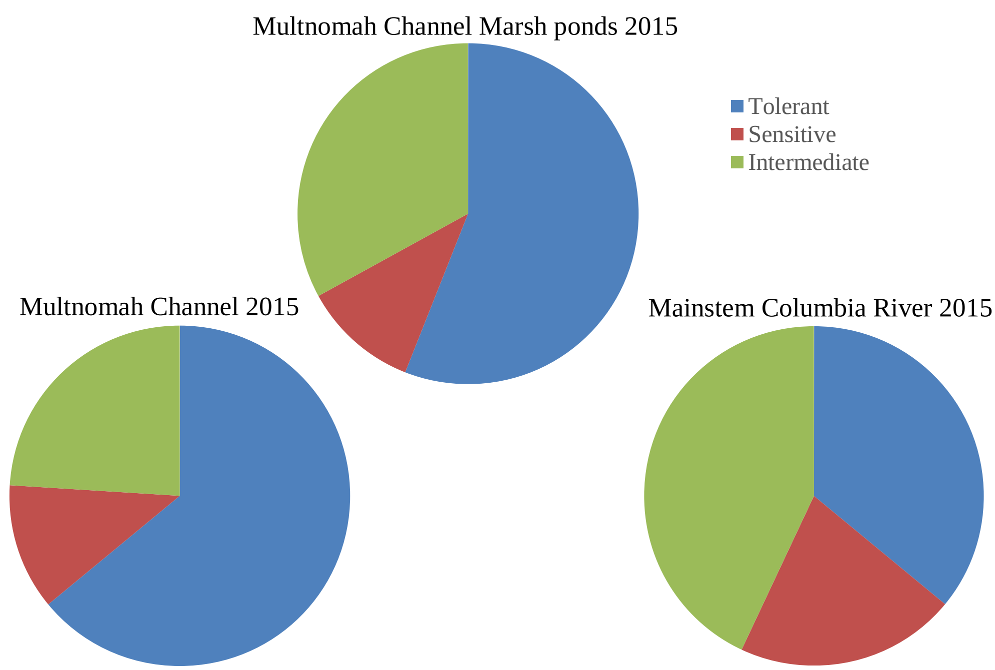


Figure 22. Composition of fish species by pollution tolerance in north and south Multnomah Channel Marsh ponds, January-May (Oneida Lake trap catch only) and in Multnomah Channel and the mainstem Columbia River, February-July 2015.

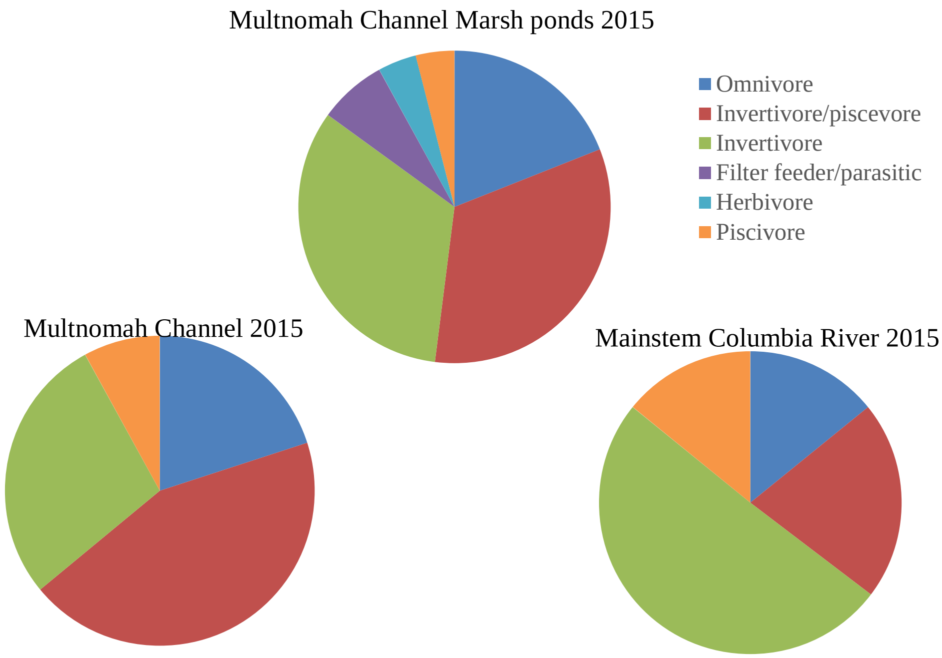


Figure 23. Composition of fish species by adult feeding guild in north and south Multnomah Channel Marsh ponds during January-May (Oneida Lake trap catch only) and in Multnomah Channel and the mainstem Columbia River, February-July 2015. Feeding guilds follow those of Zaroban et al. (1999).

Table 8. Monthly Oneida Lake trap net catch of fish and crustacean species in the north and south Multnomah Channel Marsh ponds, January–June 2015 (data combined for both ponds). Parentheses indicate sampling effort in trap-days.

Species	January (26)	February (32)	March (56)	April (56)	May (16)	Total
Salmon						
Chinook salmon	2				3*	5
Coastal cutthroat trout				1		1
Coho salmon				4	1	5
Native Species						
Chiselmouth				3		3
Largescale sucker		1		1		2
Northern pikeminnow	4	1	5	2	1	13
Pacific lamprey			2	1		3
Peamouth				1		1
Prickly sculpin		1		1		2
Redside shiner	211	162	14			387
Reticulate sculpin	3		2			5
Threespine stickleback	3,579	1,633	8,259	25,832	86,044	125,347
Unidentified cyprinid	10		3			13
Western brook lamprey	1				1	2
Non-Native Species						
Banded killifish	3	2		6	1	12
Black crappie	314	113	238	89	15	769
Bluegill	7	4	60	12	9	92
Brown bullhead	599	351	2,489	2,342	1,321	7,102
Common carp	19	16	50	136	5	226
Golden shiner	88	49	124	289	12	562
Goldfish	244	61	308	418	25	1,056
Largemouth bass	2		2	6	5	15
Mosquitofish	4			1		5
Oriental weatherfish	25	32	864	1,804	197	2,922
Pumpkinseed	43	21	67	50	96	277
Warmouth			6	2	2	10
Yellow perch	23	1	5	26	2	57
Total catch	5,181	2,448	12,498	31,027	87,741	138,895

* Two hatchery fish

Table 9. Fork length (FL) data for fish species caught in Multnomah Channel Marsh ponds with Oneida Lake trap nets (Jan-May 2015), in Multnomah Channel (Feb-Jul 2015), and in the mainstem Columbia River (Feb-Jul 2015). SD = standard deviation.

	Multnomah Channel Marsh Ponds				Multnomah Channel				Mainstem Columbia River			
Species	Mean FL	Min FL	Max FL	SD	Mean FL	Min FL	Max FL	SD	Mean FL	Min FL	Max FL	SD
American shad					113	77	139	20	115	76	133	14
Amur goby					44	22	60	9	36	32	43	4
Banded killifish	84	51	101	14	69	31	97	13	71	21	98	13
Black crappie	76	46	143	13	33	27	41	5				
Bluegill	105	44	145	24	63	62	64	1				
Brown bullhead	86	36	298	38	222	199	239	20				
Chinook salmon	103	93	119	11	72	40	199	31	59	35	185	24
Chiselmouth	53	43	60	9								
Coastal cutthroat trout	223	223	223	0								
Coho salmon	156	148	167	9								
Chum salmon									49	39	80	10
Common carp	87	54	228	20	134	66	246	60				
Golden shiner	97	50	161	21	90	59	132	13				
Goldfish	94	55	283	28	134	111	207	23	90	90	90	0
Largemouth bass	121	67	225	46	148	118	177	24	53	53	53	0
Largescale sucker	63	58	67	6								
Mosquitofish	36	27	52	10	31	28	36	4				
Mountain whitefish									60	60	60	0
Northern pikeminnow	96	54	127	25	53	53	53	0	90	90	90	0
Oriental weatherfish	131	46	212	27								
Pacific lamprey	121	113	127	6								
Peamouth	96	96	96	0	28	28	28	0	49	37	201	22
Prickly sculpin	143	138	149	6	72	72	72	0	38	24	62	21
Pumpkinseed	74	37	142	22	101	73	151	17				
Rainbow trout (steelhead)					218	218	218					
Redside shiner	67	30	101	12								
Reticulate sculpin	97	75	126	19								
Smallmouth bass					46	34	61	6	41	29	53	9
Starry flounder					136	117	162	20	114	90	153	19
Threespine stickleback	57	13	84	9	49	18	68	13	51	26	67	9
Unidentified centrarchid	43	21	54	9	32	18	54	11				
Unidentified cyprinid	39	30	48	5	44	37	54	4				
Unidentified fish									24	24	24	0
Unidentified sculpin												
Warmouth	128	53	169	39								

Community Structure 2015—As in 2014, community structure indices were higher for non-native species during most sample months of 2015. Diversity and evenness of non-native species in the ponds increased over the sampling period, while representatives of the native fish community declined (Figure 24). This trend likely reflected a response to the higher temperatures and lower dissolved oxygen concentrations during summer months. Population structure indices showed that both diversity and evenness of native species in the north and south ponds was greatest in February, while the diversity and evenness of non-native species peaked during January-February (Figure 24). The percentage of native species in our catch varied among months, averaging 90.5% for the 2015 sampling period overall (range 66-98%; Table 10).

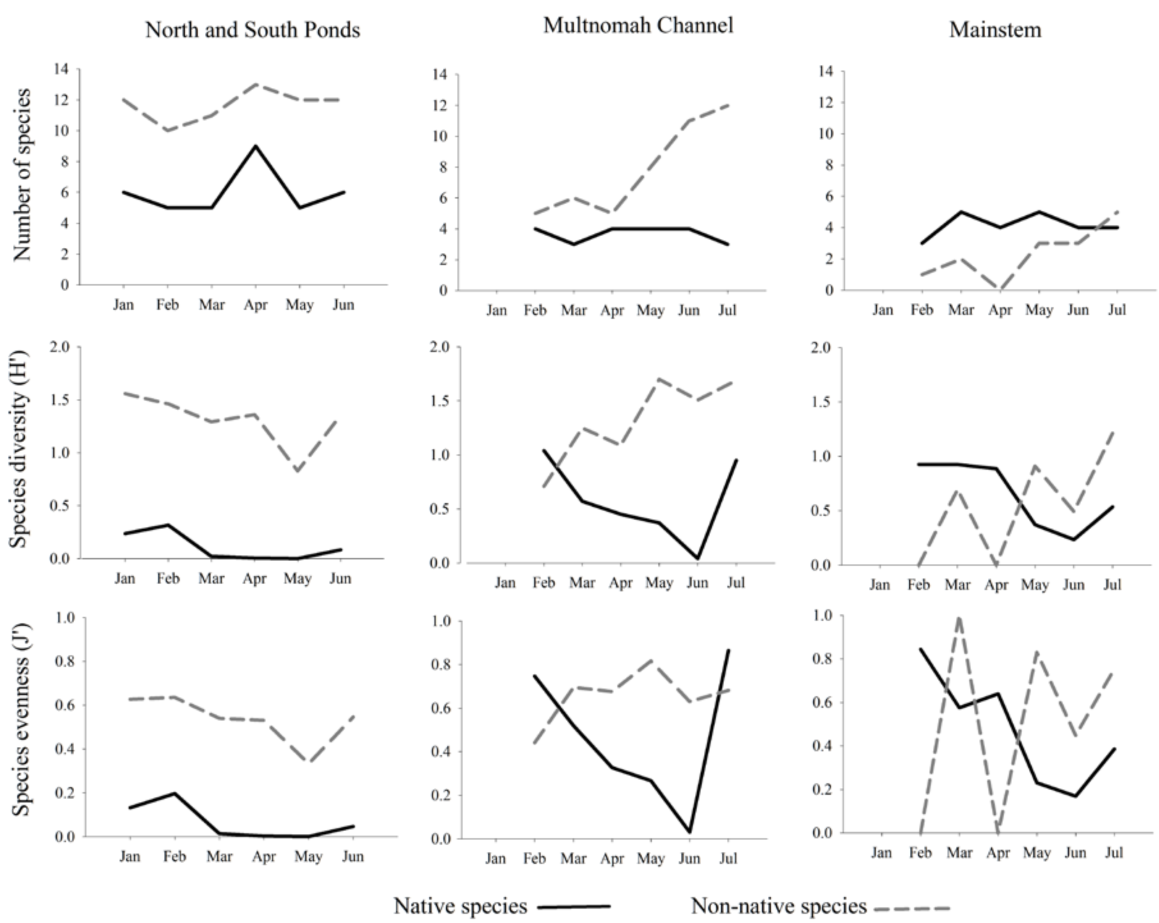


Figure 24. Community structure indices for all fishes captured at sampling sites in the mainstem Columbia River, Multnomah Channel, and north and south Multnomah Channel Marsh ponds in 2015.

Table 10. Monthly percentages of native and non-native fishes and amphibians from Oneida Lake nets in the north and south Multnomah Channel Marsh ponds, January-May 2015 (ponds combined; total catch in parentheses).

Species type	January 2015	February 2015	March 2015	April 2015	May 2015
Native fishes	73 (3,800)	73 (1,798)	66 (8,282)	83 (25,847)	98 (86,051)
Non-native fishes	27 (1,382)	27 (652)	34 (4,225)	17 (5,182)	2 (1,690)
Native amphibians	4 (35)	14 (90)	38 (3)	32 (286)	31 (21)
Non-native amphibians	96 (806)	86 (572)	97 (1,384)	68 (596)	69 (47)

Three species of salmonids were caught in the north and south ponds: juvenile Chinook salmon, juvenile coho salmon, and coastal cutthroat trout. Salmonid abundance in ponds was low relative to that of most other species. Coho salmon juveniles were the most abundant salmonid, with a total of five caught in late April-early May. We caught three juvenile Chinook salmon in the south pond—two in January and one in May 2015. Also, we recaptured four PIT-tagged juvenile Chinook salmon released in the ponds in April to examine water control structure passage. Coho salmon had a mean length of 156.4 mm FL and were age-1 juveniles. Juvenile Chinook salmon had a mean length of 109.3 mm FL, indicating they were age-1 (Table 9). We caught one cutthroat trout in May in the north pond.

Amphibians were frequently caught in the Oneida Lake traps; tadpoles of American bullfrogs were the most common (Table 11). Bullfrogs were caught all five months, with most caught in March. Red-legged frogs *Rana aurora* were the most common native amphibian species caught in ponds. Native salamanders were caught primarily during their breeding season in January and February. Bullfrogs, red-legged frogs, and rough skinned newts *Taricha granulosa* were caught throughout the season, with highest counts in March and April.

Table 11. Monthly catch of amphibian species from Oneida nets in the north and south Multnomah Channel Marsh ponds, January-May 2015.

Species	January 2015	February 2015	March 2015	April 2015	May 2015
American bullfrog	806	572	1,384	596	47
Long-toed salamander	4	23			
Northwestern salamander	13	19			1
Red-legged frog	13	13	9	258	15
Rough skinned newt	5	35	29	28	5

On 11 May, a single boat electrofishing survey of the north and south ponds captured many of the same species as the Oneida Lake traps, and individuals were similar in size to those caught in the trap nets (Table 12). The two most common fish species caught by boat electrofishing were black crappie *Pomoxis nigromaculatus* and golden shiner *Notemigonus crysoleucas*. We also recaptured two PIT-tagged juvenile Chinook salmon in the north pond from a release on 29 April 2015 to examine water control structure passage.

Table 12. Species and number of fish captured by electrofishing in north and south Multnomah Channel Marsh ponds, 11 May 2015 and length statistics of captured fish.

		Fork length (mm) 2015			
Species	Number	Mean	Min	Max	SD
Black crappie	34	88.7	67	130	12.6
Bluegill	15	70.3	41	142	28.8
Chinook salmon (juvenile)	2	86.5	78	95	12.0
Common carp	1	113.0	113	113	--
Golden shiner	36	91.5	62	147	20.9
Goldfish	17	91.1	69	124	17.0
Largemouth bass	8	139.3	98	200	32.7
Northern pikeminnow	1	93.0	93	93	--
Oriental weatherfish	2	140.0	130	150	14.1
Pumpkinseed	31	71.2	53	96	12.0
Threespine stickleback	18	41.0	27	70	16.0
Yellow perch	30	86.0	71	111	9.3

Species Composition 2016—Of the 26 species of fishes and crustaceans caught in the MCM ponds, 11 were native and 15 were non-native (Tables 13 and 14). Two species of crustaceans caught: the native signal crayfish and the non-native Siberian shrimp. Fish species represented 12 families, with the largest percentages from the families Cyprinidae and Centrarchidae (Figure 25). Most species in ponds were pollution tolerant (Figure 26). Invertivores were the most common adult feeding guild, either as obligate invertivores or combined with piscivory (Figure 27).

Table 13. Common and scientific names of fishes, crustaceans, and amphibians sampled by location, February-April, 2016.

		Location 2016	
Common name	Scientific name	Streams	Multnomah Channel Marsh ponds
Fishes			
Amur goby	*Rhinogobius similis*		x
Banded killifish	*Fundulus diaphanus*	x	x
Bluegill	*Lepomis macrochirus*		x
Brown bullhead	*Ameiurus nebulosus*		x
Chinook salmon	*Oncorhynchus tshawytscha*		x
Coho salmon	*Oncorhynchus kisutch*	x	x
Common carp	*Cyprinus carpio*		x
Coastal cutthroat trout	*Oncorhynchus clarkii clarkii*	x	x
Golden shiner	*Notemigonus crysoleucas*		x
Goldfish	*Carassius auratus*	x	x
Largemouth bass	*Micropterus salmoides*		x
Largescale sucker	*Catostomus macrocheilus*		x
Mosquitofish	*Gambusia affinis*	x	
Northern pikeminnow	*Ptychocheilus oregonensis*		x
Oriental weatherfish	*Misgurnus anguillicaudatus*		x
Pacific lamprey	*Entosphenus tridentatus*	x	x
Peamouth	*Mylocheilus caurinus*		x
Prickly sculpin	*Cottus asper*		x
Pumpkinseed	*Lepomis gibbosus*		x
Redside shiner	*Richardsonius balteatus*		x
Reticulate sculpin	*Cottus perplexus*	x	x
Smallmouth bass	*Micropterus dolomieu*		x
Threespine stickleback	*Gasterosteus aculeatus*	x	x
Unidentified centrarchid	*Centrarchidae*		x
Warmouth	*Lepomis gulosus*		x
Western brook lamprey	*Lampetra richardsoni*	x	
White crappie	*Pomoxis annularis*		x
Yellow perch	*Perca flavescens*		x
Crustaceans			
Siberian prawn	*Exopalaemon modestus*		x
Signal crayfish	*Pacifastacus leniusculus*	x	
Amphibians			
American bullfrog	*Lithobates catesbeianus*	x	x
Long-toed salamander	*Ambystoma macrodactulum*		x
Northwestern salamander	*Ambystoma gracile*		x
Pacific giant salamander	*Dicamptodon tenebrosus*	x	
Red-legged frog	*Rana aurora*	x	x
Rough skinned newt	*Taricha granulosa*		x

Table 14. Monthly Oneida net catch of fish species from north and south Multnomah Channel Marsh wetland ponds combined, February-April 2016. Parentheses indicate sampling effort in trap-days.

		Oneida Lake trap catch 2016 (trap days)			
Common name	Scientific name	Feb (14)	Mar (60)	Apr (47)	Total (121)
Salmonids					
Chinook salmon (juvenile)	*Oncorhynchus tshawytscha*		3	2	5
Coho salmon (juvenile	*O. kisutch*	2	17	6	25
Coastal cutthroat trout	*O. clarkii clarkii*			1	1
Native Species					
Largescale sucker	*Catostomus macrocheilus*		1	2	3
Northern pikeminnow	*Ptychocheilus oregonensis*	1	2	1	4
Pacific lamprey	*Lampetra tridentata*		1	3	4
Peamouth	*Mylocheilus caurinus*	2	2	1	5
Prickly sculpin	*Cottus asper*		1		1
Redside shiner	*Richardsonius balteatus*		6	3	9
Reticulate sculpin	*Cottus perplexus*	13	73	31	117
Threespine stickleback	*Gasterosteus aculeatus*	168	345	12,086	12,599
Non-Native Species					
Amur goby	*Rhinogobius brunneus*			1	1
Banded killifish	*Fundulus diaphanus*			3	3
Bluegill	*Lepomis macrochirus*	14	78	56	148
Brown bullhead	*Ameiurus nebulosus*	19	127	723	869
Common carp	*Cyprinus carpio*			5	5
Golden shiner	*Notemigonus crysoleucas*	1	112	32	145
Goldfish	*Carasius auratus*	3	27	86	116
Largemouth bass	*Micropterus salmoides*			5	5
Oriental weatherfish	*Misgurnus anguillicaudatus*	3	45	177	225
Pumpkinseed	*Lepomis gibbosus*	1	9	203	213
Smallmouth bass	*Micropterus dolomieu*			3	3
Unidentified centrarchid			3		3
Warmouth	*Lepomis gulosus*			1	1
White crappie	*Pomoxis annularis*	1	13	45	59
Yellow perch	*Perca flavescens*	1	13	52	66
Total		**229**	**878**	**13,528**	**14,635**

Multnomah Channel Marsh Ponds 2016

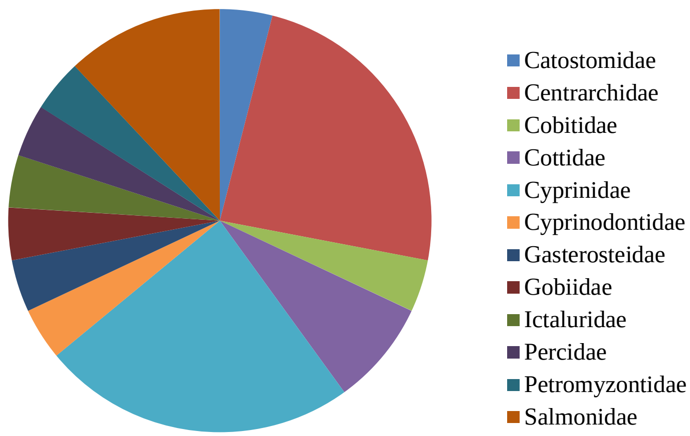


Figure 25. Composition by family of fish species from Oneida Lake trap catches in north and south Multnomah Channel Marsh ponds, February-April 2016.

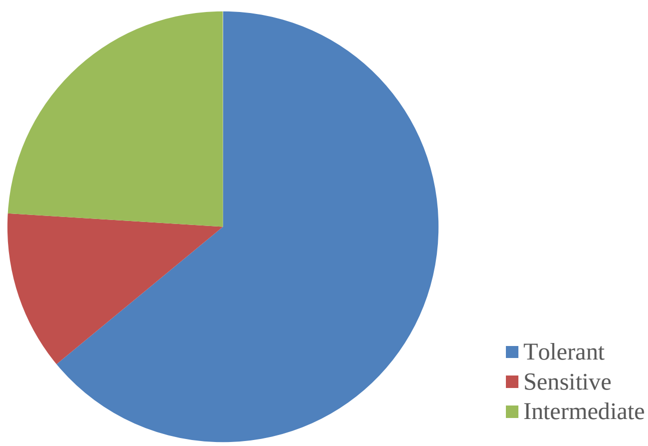


Figure 26. Composition by pollution tolerance of fish species from Oneida Lake trap catches in north and south Multnomah Channel Marsh ponds, February-April 2016.

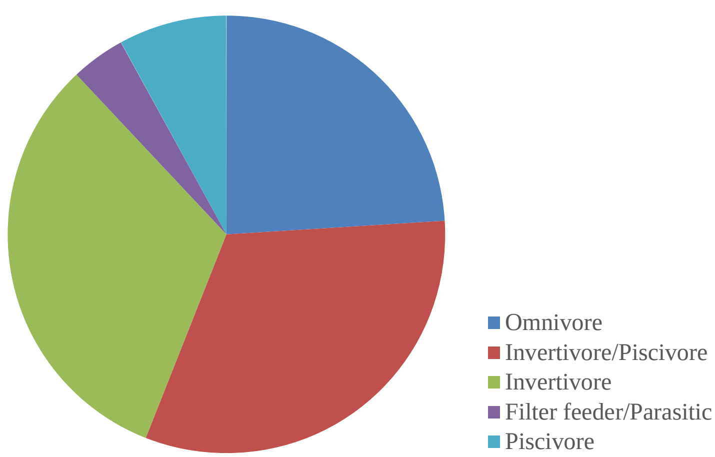


Figure 27. Composition by adult feeding guild of fish species in from Oneida Lake trap catches in north and south Multnomah Channel Marsh ponds, February-April 2016.

Native threespine stickleback was by far the most abundant fish caught in ponds, followed by non-native brown bullhead. Threespine stickleback had a fairly narrow range of lengths, with a mean of 63.3 mm FL. Brown bullhead was caught in a wide range of sizes, including some large adults (Table 15).

Table 15. Fork length statistics for fish species caught in Multnomah Channel Marsh ponds using Oneida Lake trap nets, February-April 2016.

	Fork length (mm) in Multnomah Channel Marsh Ponds, 2016			
Species	Mean	Min	Max	SD
Amur goby	66	66	66	--
Banded killifish	86	75	97	16
Bluegill	96	42	195	32
Brown bullhead	179	26	286	43
Chinook salmon	59	43	71	12
Coho salmon	140	98	174	22
Common carp	203	139	325	87
Coastal cutthroat trout	192	192	192	--
Golden shiner	107	28	192	19
Goldfish	149	69	275	39
Largemouth bass	161	72	240	81
Largescale sucker	111	91	134	22
Northern pikeminnow	84	59	124	29
Oriental weatherfish	138	97	184	17
Pacific lamprey	126	110	144	17
Peamouth	85	62	120	23
Prickly sculpin	171	171	171	--
Pumpkinseed	105	54	162	27
Reticulate sculpin	116	44	163	16
Redside shiner	65	43	131	24
Smallmouth bass	215	179	264	44
Threespine stickleback	63	19	75	7
Unidentified centrarchid	48	45	49	2
Warmouth	111	111	111	--
White crappie	132	73	175	25
Yellow perch	137	74	204	22

Community Structure 2016—As observed in both 2014 and 2015, community structure indices in most months were higher for non-native than native species for catch during sample months of 2016. Diversity and evenness increased in February and March for both non-native and native communities, while representatives of both fish communities declined in spring (Figure 28). These declines were likely in response to higher temperatures and lower dissolved oxygen concentrations during the unusually warm spring of 2016. Population structure indices showed that both diversity and evenness of non-native and native species in the north and south ponds was greatest in March (Figure 28). The percentage of native species in our catch varied by month, averaging 87.3% over the entire sampling period (range 51-90%; Table 16).

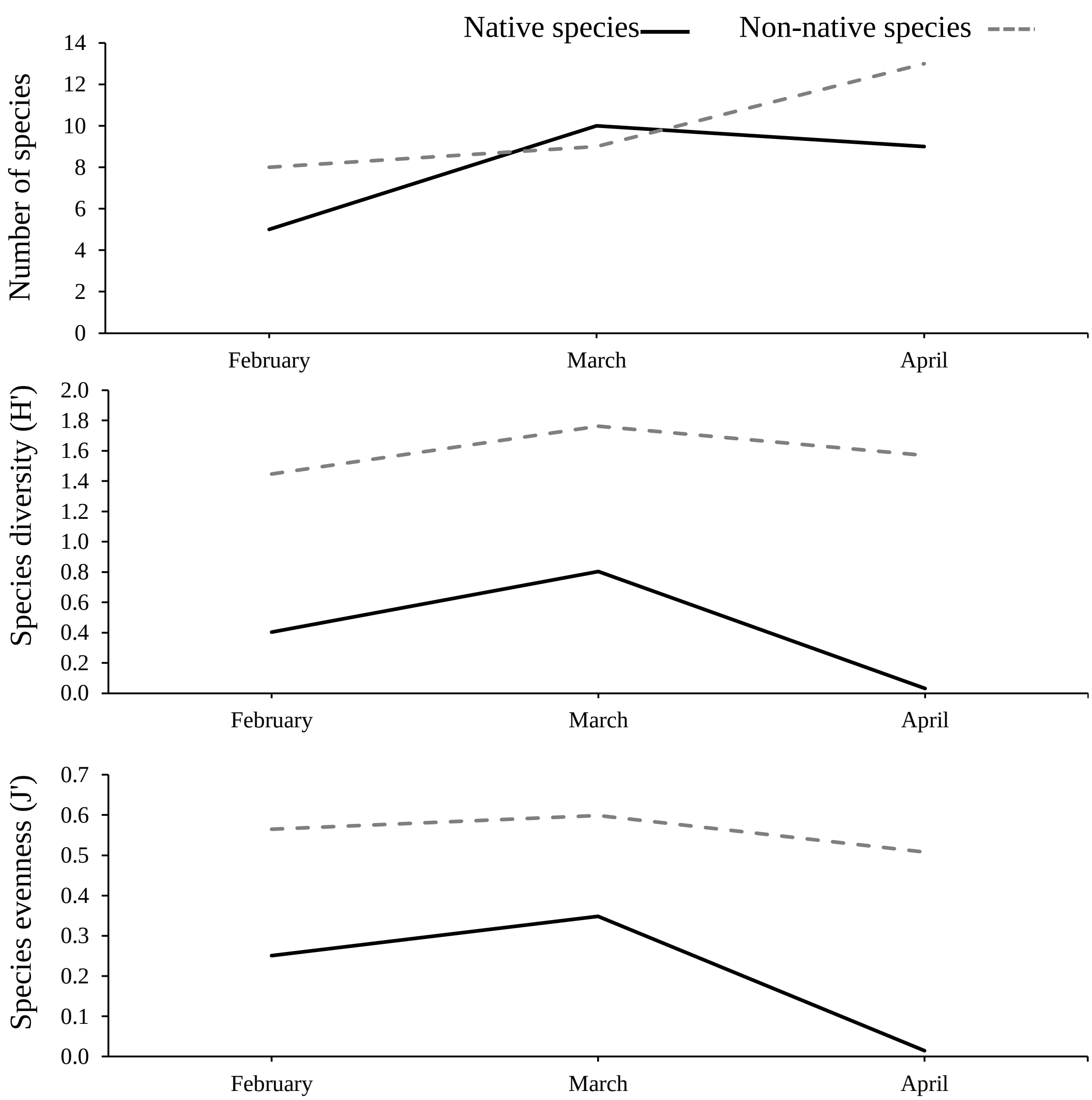


Figure 28. Community structure indices for all fishes captured in 2016 at sampling sites in the north and south Multnomah Channel Marsh ponds.

Table 16. Monthly numbers and percentages of native vs. non-native fishes and amphibians caught in Oneida nets from north and south Multnomah Channel Marsh ponds combined, February-April 2016.

	February 2016		March 2016		April 2016	
Species type	(n)	(%)	(n)	(%)	(n)	(%)
Fishes						
Native	186	81	451	51	12,136	90
Non-native	43	19	427	49	1,392	10
Amphibians						
Native a	8	12	20	5	9	12
Non-native	61	88	384	95	68	88

Salmonid species caught in marsh ponds during 2016 were juvenile Chinook salmon, juvenile coho salmon, and coastal cutthroat trout. Abundance of salmonids was low relative to many other species. Juvenile coho salmon was most abundant, with a total of 25 caught in late February-April (Table 14). In the north pond, we caught six juvenile Chinook salmon in late March-early April. We also recaptured two PIT-tagged hatchery Chinook salmon from the south pond group released to examine water control structure passage.

Greater numbers of salmon caught in 2016 was likely due to the north water control structure remaining open, allowing fish access to the wetlands. Coho salmon had a mean length of 140.0 mm FL and were age-1 juveniles. Juvenile Chinook salmon had a mean length of 57.2 mm FL as most of them were age-0 (Table 15). We caught one cutthroat trout in April in the north end of the south pond.

Amphibians were caught frequently in Oneida Lake traps; tadpoles of American bullfrog were the most common species (Table 17). Rough-skinned newt was the second most common native amphibian species in pond catches. Native salamanders were caught only during the February breeding season. Bullfrog, red-legged frog, and rough skinned newt were caught throughout the season, with highest numbers in March and April.

Table 17. Monthly catch of amphibian species from Oneida nets in the north and south Multnomah Channel Marsh ponds, February-April 2016.

Species	February	March	April
American bullfrog	61	384	68
Long-toed salamander	1		
Northwestern salamander	1		
Red-legged frog	1	3	9
Rough skinned newt	5	17	

During the high water event of December 2015, we caught 18 juvenile coho salmon in the ponds near the breaches. Of these, 15 were caught with the beach seine as water was entering the ponds and the other three were caught in Oneida Lake traps. Mean fork length of these 18 fish was 84 mm FL, and all fish had been PIT tagged before being released.

Both water control structures were open during this high-water event, providing uninterrupted access to the wetlands. However, the prevalence of fish caught near the breaches suggests that juvenile salmonids were moving into the marsh through the restoration breaches to take advantage of the rearing habitat. The composition of other species caught in the Oneida Lake traps was similar to that observed in catches at other times of the year, with many brown bullhead, peamouth, goldfish *Carassius auratus*, and threespine stickleback.

Wetland Tributaries

2014—Native species dominated the catch from backpack electrofishing in Patterson and Crabapple creeks during 2014 (Table 18). Reticulate sculpin *Cottus perplexus* and coastal cutthroat trout were the most common fish species caught upstream of Highway 30, where only native species were caught. Downstream from Highway 30, both native and non-native fish species were caught, with reticulate sculpin and western brook lamprey *Lampetra richardsoni* most abundant. We caught cutthroat trout of a wide range of sizes, suggesting a number of different age classes (Table 19). Native signal crayfish were the only crustacean caught in the streams. Three species of amphibians were caught in these creeks: non-native American bullfrog, native Pacific giant salamander *Dicamptodon tenebrosus*, and native red-legged frog.

Table 18. Total number of fish, amphibians, and crayfish captured in Patterson and Crabapple creeks by electrofishing, January-June 2014. Parentheses indicate the number of days sampled.

	Patterson and Crabapple creeks, 2014					
Species	January (3)	February (4)	March (3)	April (7)	May (3)	June (2)
Coastal cutthroat trout	24	44	24	54	25	13
Pacific lamprey						2
Reticulate sculpin	123	161	118	324	190	98
Threespine stickleback	2	2	1	6	1	4
Western brook lamprey	4	2	11	35	5	2
Oriental weatherfish			1	1		
American bullfrog		1				
Pacific giant salamander		1		2	1	
Red-legged frog					1	
Signal crayfish				1		1

Table 19. Mean, minimum, and maximum fork length (FL) and standard deviation (SD) of fish species captured in Patterson and Crabapple Creeks by backpack electrofishing, 2014.

	Fork length (mm) 2014			
Species	Mean	Min	Max	SD
Coastal cutthroat trout	117.7	41	243	47.3
Oriental weatherfish	137.0	131	145	5.8
Pacific lamprey	152.5	145	160	10.6
Reticulate sculpin	60.4	24	142	17.9
Threespine stickleback	39.5	26	52	7.5
Western brook lamprey	116.2	47	158	24.8

2015—Native species again dominated the catch during 2015 in Patterson and Crabapple Creeks (Table 20). Upstream from Highway 30, only native species were caught; reticulate sculpin and coastal cutthroat trout were the most common fish species. Downstream from Highway 30, both native and non-native fish species were caught, with reticulate sculpin and western brook lamprey the most abundant.

Table 20. Total number of fish and amphibians captured in Patterson and Crabapple creeks by electrofishing, January-May 2015. Parentheses indicate the number of days sampled.

	Total catch from tributary creeks 2015				
Species	January (4)	February (4)	March (3)	April (3)	May (4)
Coastal cutthroat trout	40	59	12	69	43
Pacific lamprey	2			3	1
Redside shiner				1	
Reticulate sculpin	112	224	57	84	42
Threespine stickleback	3	12	2	21	38
Western brook lamprey	25	33	16	9	8
Pacific giant salamander		1			
Banded killifish			1		
Black crappie			1		32
Golden shiner					33
Goldfish	1	1	15	1	2
Mosquitofish	2	18	1	2	
Oriental weatherfish	1	1	1	1	2
Pumpkinseed				1	58
American bullfrog	1				

We caught coastal cutthroat trout from a wide range of sizes, suggesting a number of different age classes (Table 21). We recaptured 48 coastal cutthroat trout, most of them in the same reach where they were tagged. Two fish were recaptured in reaches different from the reach where they had been tagged. One of these fish was tagged downstream from Highway 30 in reach 1 and recaptured upstream from the highway in reach 2. The second fish was tagged in reach 3 and recaptured downstream in reach 2.

Table 21. Mean, minimum, and maximum fork length and standard deviation (SD) of fish species captured in Patterson and Crabapple Creeks by backpack electrofishing, 2015.

		Fork length (mm) 21			
Species	Number	Mean	Min	Max	SD
Banded killifish	1	96.0	96.0	96.0	––
Coastal cutthroat trout	223	126.4	25.6	268.0	45.7
Goldfish	4	75.3	65.0	84.0	9.7
Mosquitofish	22	32.3	22.0	49.0	8.6
Oriental weatherfish	4	151.3	142.0	175.0	15.9
Pacific lamprey	8	114.6	44.0	146.0	36.8
Pumpkinseed	2	56.0	56.0	56.0	0.0
Reticulate sculpin	375	65.4	34.0	111.0	15.1
Redside shiner	1	60.0	60.0	60.0	––
Threespine stickleback	45	46.7	34.0	55.0	4.8
Western brook lamprey	95	119.8	51.0	163.0	22.6
American bullfrog	1	110.0	110.0	110.0	––
Pacific giant salamander	1	160.0	160.0	160.0	––

For recaptured cutthroat trout, growth rates were 0.15 mm/d in fork length and 0.02 g/d in weight (Table 22). Several trout were recaptured two or three times throughout the season. Native signal crayfish was the only crustacean caught in the streams. Three species of amphibians were caught in the streams: non-native American bullfrog, native Pacific giant salamander and red-legged frog.

Table 22. Growth rate statistics for recaptured coastal cutthroat trout caught in Patterson and Crabapple creeks, 2015.

	Number	Mean	Min	Max	SD
Fork length (mm/d)	48	0.15	0.00	0.37	0.09
Weight (g/d)	48	0.02	-0.55	0.23	0.15

2016—Native species again dominated the catch in Patterson and Crabapple creeks during 2016 (Table 23). Reticulate sculpin and coastal cutthroat trout were the most common fish species caught upstream of Highway 30, where only native fish species were caught. One adult non-native bullfrog was captured in reach 1, just above Highway 30. This was the first non-native fish or amphibian encountered above the Highway 30 culvert. Native and non-native fish and amphibian species were caught in the two reaches downstream of Highway 30, with native reticulate sculpin and western brook lamprey the most abundant.

Table 23. Total number of fish and amphibians captured in Patterson and Crabapple creeks by electrofishing, March-May 2016. Parentheses indicate the number of days sampled.

Species	March (2)	April (4)	May (4)
Coastal cutthroat trout	5	27	17
Coho salmon	1		
Pacific lamprey	7	3	
Reticulate sculpin	56	120	96
Western brook lamprey	3		
Pacific giant salamander			1
Red-legged frog		1	
American bullfrog	1	2	
Banded killifish	1		
Goldfish		1	
Mosquitofish	1	26	

We caught coastal cutthroat trout of a wide range of sizes, suggesting a number of different age classes (Table 24). Of the 49 coastal cutthroat trout captured, 48 were caught in the same reach where they were tagged. One was tagged in reach 1, downstream from Highway 30, and recaptured in reach 2, above Highway 30.

For recaptured cutthroat trout, mean growth was 0.19 mm/day in length and 0.15 g/day in weight (Table 25). Several of these trout were recaptured two or three times throughout the season. Native signal crayfish was the only crustacean caught in the streams. Three species of amphibians were caught in the streams: non-native American bullfrog, native Pacific giant salamander and native red-legged frog.

Table 24. Fork length statistics of fish and amphibians captured in Patterson and Crabapple Creeks by backpack electrofishing, 2016.

		Fork length (mm)			
Species	Number	Mean	Min	Max	SD
Banded killifish	1	68	68	68	--
Coho salmon	1	129	129	129	--
Coastal cutthroat trout	49	138	70	300	49.7
Goldfish	1	90	90	90	--
Mosquitofish	26	29	22	40	4.7
Pacific lamprey	10	122	99	135	12.7
Reticulate sculpin	159	66	30	112	16.2
Threespine stickleback	1	49	49	49	--
Western brook lamprey	5	119	96	143	17.8
American bullfrog	3	36	23	55	16.8
Pacific giant Salamander	1	58	58	58	--
Red-legged frog	1	59	59	59	--

Table 25. Growth rate statistics for recaptured coastal cutthroat trout caught in Patterson and Crabapple Creeks, 2016.

	Coastal cutthroat trout				
Growth	Number	Mean	Min	Max	SD
Fork length (mm/day)	16	0.19	0.04	0.39	0.10
Weight (g/day)	6	0.15	0.10	0.20	0.04

Multnomah Channel and Columbia River Mainstem

2014—The number of river sites sampled via bag seining at each location remained consistent throughout the 2014 sampling season (Table 26). However, effort at each site was influenced by river flow, which affected the ability to sample and collect our target of 30 salmon at each location. Between March and July 2014, four salmonid species, seven non-salmonid native species and 14 non-native species were captured in Columbia River mainstem and Multnomah Channel locations (Table 27).

Table 26. Number of sites sampled and total bag-seining effort (in parentheses) by month and sampling area, March-July, 2014.

	March	April	May	June	July
Multnomah Channel	5 (6)	4 (8)	4 (7)	4 (7)	4 (5)
Mainstem Columbia River	3 (5)	3 (5)	3 (4)	3 (7)	3 (6)

Catch rates per effort in both locations for native species were consistently low throughout the sampling period, with the exception of threespine stickleback, typically >10/effort. Juvenile starry flounder *Platichthys stellatus* and peamouth were also common in both locations in much lower numbers, <3/effort. Non-native species were dominant in most samples in both the mainstem (9 species) and Multnomah Channel (14 species) locations. Yellow perch *Perca flavescens* and banded killifish *Fundulus diaphanous* were commonly found during the entire sampling period.

Chinook salmon was the most common salmonid species in each location; however, catch rates were consistently higher in the mainstem. The peak abundances in April and May are consistent with spring migration and hatchery releases in the region. Thirteen families were represented in Multnomah Channel and ten families in the mainstem. There were fewer pollutant tolerant species in the mainstem vs. Multnomah Channel; likewise, the greatest percentage of invertivore/piscivore and obligate invertivores was found in the mainstem Columbia River.

Table 27. Average abundance of each species captured with a bag seine by location and month, March-July 2014. Abbreviations: Unk, unknown species.

	Mainstem Columbia River					Multnomah Channel				
Species	March	April	May	June	July	March	April	May	June	July
Salmon										
Chinook salmon	9	36	41	14	2	6	4	2	1	
Coho salmon							<1			
Cutthroat trout		<1							<1	
Rainbow trout (steelhead)		1					<1			
Native species (7)										
Largescale sucker								1		<1
Mountain whitefish				<1						
Northern pikeminnow					1		<1			
Peamouth			1	2	1	<1	<1	3	<1	2
Prickly sculpin	<1						<1			<1
Starry flounder	3	<1	1	1	<1	4	<1	1		
Threespine stickleback	5	12	69	30	9	2	<1	24	81	10
Non-native species (14)										
American shad			1	3	1			1	<1	46
Amur goby	<1	1		<1		3			1	
Banded killifish				1	1	2	<1	<1	6	4
Black crappie					1					<1
Bluegill							<1	<1		
Brown bullhead						<1				197
Common carp										91
Golden shiner										37
Goldfish										1
Largemouth bass				<1				<1		3
Mosquitofish										1
Pumpkinseed						<1		1		1
Smallmouth bass					<1				<1	<1
Unk centrarchid				2	<1			<1	<1	107
Unk cyprinid									<1	35
Unk fish							<1			<1
Unk sculpin	<1			<1					1	
Yellow perch			2	79	120	2	2	11	106	135

Several taxa did not appear until later summer such as juvenile centrarchids, brown bullheads, juvenile cyprinids, golden shiner, and common carp *Cyprinus carpio*. Seasonal changes in proportional abundance generally coincided with increasing water temperature and decreasing dissolved oxygen levels in both the mainstem and channel, March-July (Figure 29). The mainstem Columbia had a higher proportion of native species than the channel from March through May. Both locations transitioned between May and June, with nearly equal proportions. By July non-native species were dominant everywhere.

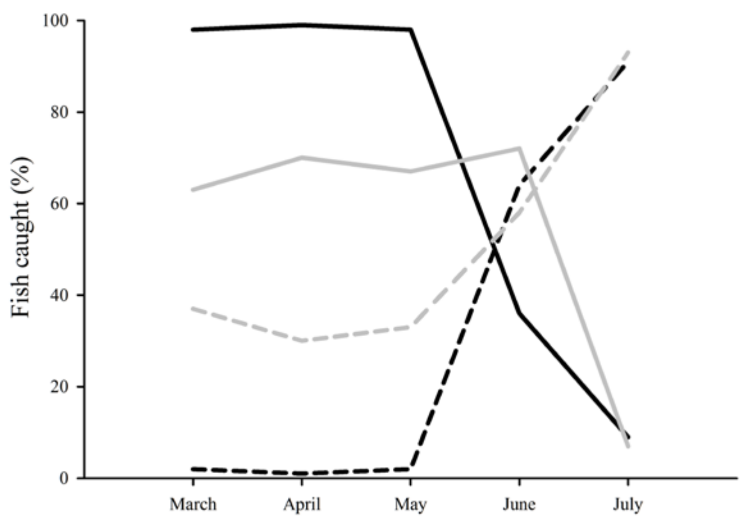


Figure 29. Relative percent of native (solid lines) vs. non-native (dashed lines) fish species sampled in the mainstem Columbia River (black) and Multnomah Channel (gray), March-July 2014.

More salmon were captured in mainstem Columbia River than in Multnomah Channel locations, with Chinook salmon the predominant species in both locations. Length frequencies depicted fry (<60 mm) and yearling (>100 mm) size classes in March, hatchery-reared (marked) fingerlings (60-89 mm) in April, and peak numbers of unmarked fry in May 2014 (Figure 30). By July, salmon had nearly disappeared from the mainstem, and none were found in Multnomah Channel.

For most sampling periods in 2014, native and non-native fish communities in wetland ponds were more diverse than those in Multnomah Channel and the mainstem Columbia River (Figure 15). The mainstem had a relatively low and equal number of species until river temperatures warmed later in the sampling period. By June the non-native species component increased and was dominated by a single species (yellow perch). Community structure indices generally were higher for non-native than for native fish species at Multnomah Channel survey sites (Figure 18). Index values for non-native fish increased during the sampling period; however, evenness values were mid-range, indicating that several species were well represented.

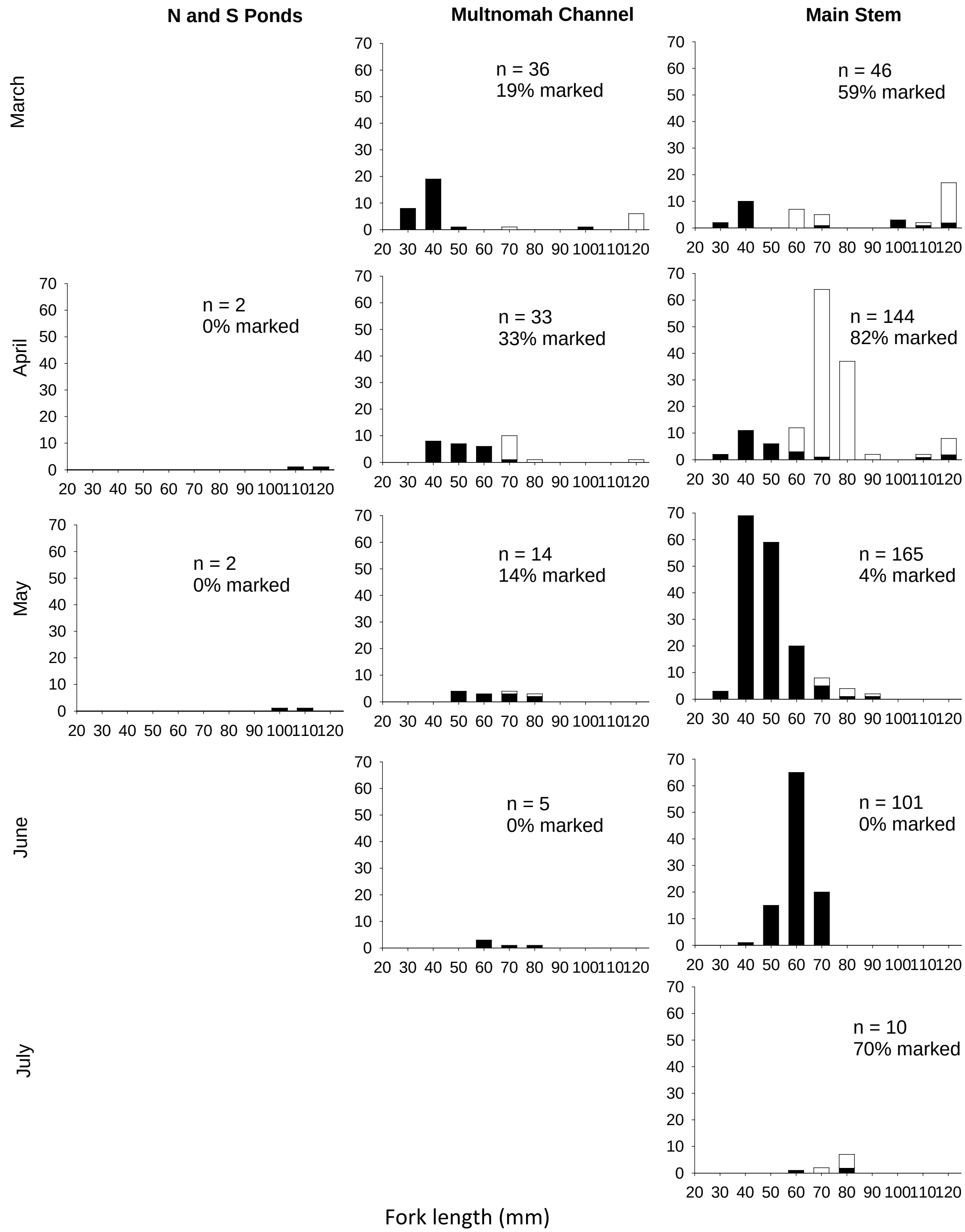


Figure 30. Chinook salmon length frequency and percent with (open bars) and without (black bars) adipose fin clips by location during March-July 2014.

Fifteen coded-wire tags (CWTs) were recovered from Chinook salmon captured in mainstem and channel locations, representing nine different codes (Table 28). The majority of CWTs were from Willamette River spring Chinook salmon, with one from the Sandy River. Fall-run Chinook salmon were primarily from Spring Creek Hatchery on the mainstem Columbia River. After hatchery release, fish were at large 12-140 d, with most at large 14-34 d. It was not possible to estimate growth between release and capture because lengths at the time of hatchery release were not recorded. Mean weight was also difficult to compare because size at release can vary significantly with duration of hatchery rearing and degree of feeding competition among hatchery fish.

Table 28. Coded-wire tag recoveries for Chinook salmon captured in the mainstem of the Columbia River and in Multnomah Channel, March-July 2014.

Coded-wire tagged Chinook salmon							
Release information			Recapture information				
						Tags recovered (n)	
Location	Last date	Ave. weight (g)	Length range (mm)	Weight range (g)	Days at large	Main stem	Mult-nomah channel
Fall run, 2013 brood year							
Little White salmon R	2 Jul 2014		83	6.4	30	1	
Spring Cr, Columbia R	11 Apr 2014		74-84	4.0-7.3	14	3	2
Spring Cr, Columbia R	11 Apr 2014		81	5.2	14		1
Spring run, 2012 brood year							
Bull Run/Sandy River	4 Apr 2014	44.50	132-183	20.5-59.1	~14*	3	
Clackamas River	14 Apr 2014	45.36	140-169	28.1-47.9		2	
McKenzie River	4 Nov 2013	39.44	165	40.2	140	1	
McKenzie River	1 Mar 2014	44.25	151	35.3	24	1	

* One Chinook salmon was captured prior to the last release date.

2015—In both Multnomah Channel and the mainstem Columbia River, the number and location of bag-seine sites remained consistent throughout the 2015 season (Table 29). The number of efforts per site was overwhelmingly influenced by low river levels that adversely affected the ability to collect the target of 30 Chinook salmon at each location.

Table 29. Number of sites sampled and total bag-seining effort (in parentheses) by month and sampling area, February-July, 2015.

	Year	February	March	April	May	June	July
Multnomah Channel	2015	4 (9)	4 (8)	4 (9)	4 (8)	4 (8)	4 (6)
Mainstem Columbia River	2015	3 (8)	3 (9)	3 (8)	3 (3)	3 (3)	3 (3)

Chinook and chum *O. keta* salmon and rainbow trout *O. mykiss* were the three salmonid species captured in 2015. In the Columbia River mainstem and Multnomah Channel, an additional seven native non-salmonid species and 15 non-native species were captured (Table 30; Figure 31). Chinook salmon was the most common salmonid species in each location; however, catch rates were consistently higher in the mainstem.

Peak abundances in April-June 2015 were consistent with spring migration and hatchery releases in the region. Composition of fish species by family was more diverse in the wetland ponds (12) and Multnomah Channel (13) areas than in the mainstem Columbia River (10) (Figure 21).

Multnomah Channel and marsh pond areas were dominated by pollution-tolerant species; however, more fishes with intermediate pollution tolerance levels were captured in the mainstem river (Figure 22). In the Columbia River mainstem, the largest feeding guild was the invertivore, while in both the MCM ponds and Multnomah Channel, the largest guilds were the invertivore/piscivore and invertivore. The ponds had the most diverse feeding community with all guilds represented (Figure 23).

In 2015, catch rates per effort by location for native species were very low throughout the sampling period. The primary exception was threespine stickleback: while captured consistently, it was most dominant in Multnomah Channel with a typical abundance CPUE over (>15/effort). For all other native species, catch rates were 1/effort or less, and catch rates for non-native species were also very low in both areas. Later in the sampling season, non-native species increased in both diversity and quantity, primarily in Multnomah Channel area (Table 30).

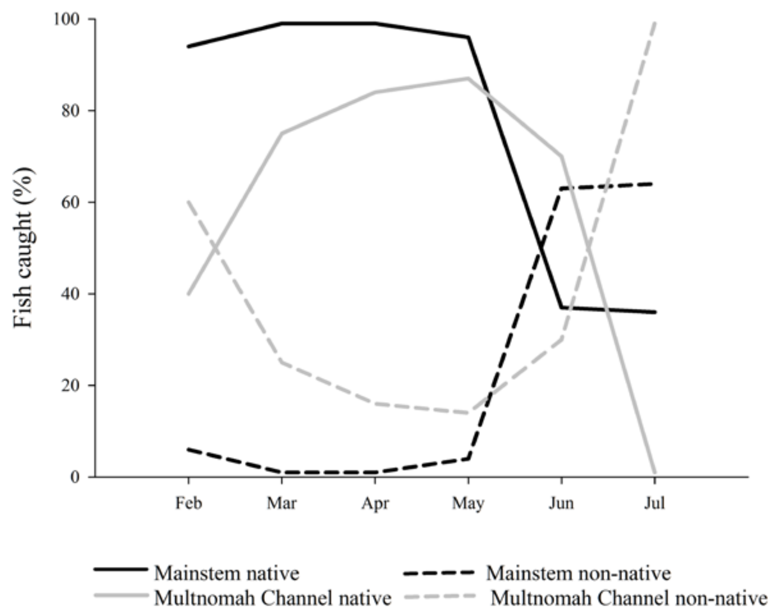
The increase in non-native species as a percentage of total catch composition also coincided with changes in water quality as the season progressed (increased temperatures, decreased DO; Figures 24 and 31). Size ranges for many fish species clearly demonstrated that juveniles and adults were present in all sampling areas (Table 16). Many non-native species had the greatest range of sizes in Multnomah Channel and the MCM pond sampling areas.

Table 30. Average abundance of each species captured with a bag seine by location and month, February-July 2015.

	Species abundance 2015 (n)											
	Mainstem Columbia River						Multnomah Channel					
Species	Feb	Mar	Apr	May	Jun	Jul	Feb	Mar	Apr	May	Jun	Jul
Salmonid												
Chinook salmon	4	4	15	93	51	<1	3	4	3	10		
Chum salmon		<1	5	1					<1			
Rainbow trout (steelhead)									<1			
Native species (7)												
Largescale sucker							1			<1	<1	<1
Mountain whitefish					<1							
Northern pikeminnow						<1				<1		
Peamouth					<1	13					<1	
Prickly sculpin		<1		1					<1			
Starry flounder	1	1	1	<1			<1	<1			<1	<1
Threespine stickleback	1	9	1	3	2	2	1	15	22	77	64	1
Non-native species (15)												
American shad			2	4	11					2	<1	9
Amur goby		<1		2	<1		1	1	2	2	<1	
Banded killifish				<1	9	10	<1	<1	<1		5	34
Black crappie									1			
Bluegill											<1	<1
Brown bullhead										<1		
Common carp										1	2	10
Golden shiner							<1	<1		1	14	7
Goldfish		<1					<1			2	1	15
Largemouth bass						<1					1	1
Mosquitofish								<1	<1			
Pumpkinseed										<1	2	3
Smallmouth bass						1						6
Unidentified centrarchid									<1			1
Unidentified cyprinid												72.5
Unidentified fish			<1									
White crappie											<1	
Yellow perch	<1				80	5	5	4	2	6	2	2

For most sampling periods, diversity and number of non-native fish species were higher in marsh ponds than in Multnomah Channel and the mainstem Columbia River (Figure 26). Numbers of native species were more moderate and similar among the three areas. In the Multnomah Channel and marsh ponds, Shannon diversity indices (H') were lower for native than non-native fish, but in the mainstem Columbia H' was greater for non-native than for native fish. Measures of species evenness (J') were lower for native than non-native fish in Multnomah Channel and marsh ponds. These patterns suggest that non-native fish were captured in greater numbers and more consistently throughout the study than native fish.

Figure 31. Relative percent of native (solid lines) and non-native (dashed lines) fish species sampled in the mainstem Columbia River (black) and Multnomah Channel (gray), February-July 2015.



In the mainstem Columbia River and Multnomah Channel, species evenness (*J′*) was consistently moderate for native fish but variable for non-natives. This variation of *J′* reflects the introduction of juvenile yellow perch and threespine stickleback, which tend to dominate seasonal catches. For native fish species, the low diversity and evenness in the MCM ponds indicates a dominant species (threespine stickleback). For non-native fish species, the moderate diversity was a result of high number of species with more than one dominant species (brown bullhead, oriental weatherfish *Misgurnus anguillicaudatus*; Table 15).

The majority of Chinook salmon were captured in the Columbia River mainstem. In both the mainstem Columbia and Multnomah Channel, length frequencies of captured fish depicted unmarked fry (<60 mm) and marked and unmarked yearling (>100 mm) size classes during February and March. Hatchery-reared (marked) fingerlings (60-89 mm) peaked in Multnomah Channel during May and in the mainstem Columbia during May and June (Figure 32). By July most Chinook salmon had essentially disappeared from both sampling areas.

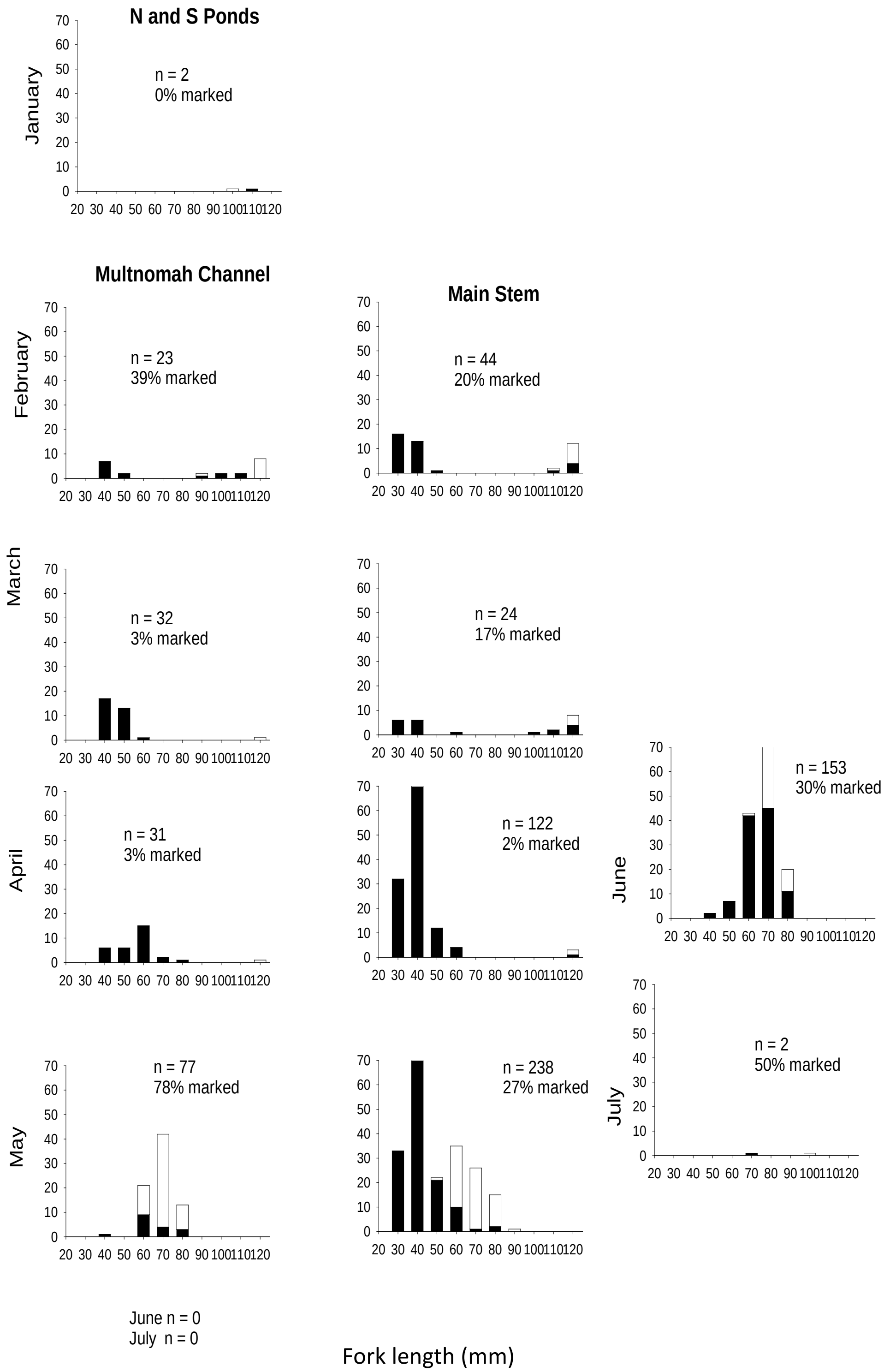


Figure 32. Chinook salmon length frequency (fork length, mm) and percent marked (adipose fin clipped or not clipped) by location and month, February-July 2015. Black bars indicated fish that were not marked; open bars represent fish with an adipose fin clip.

Twenty-two coded wire tags were recovered at the mainstem and Multnomah channel sites in 2015 representing eight different codes (Table 31). All spring Chinook salmon originated from the Willamette River Basin, while fall-run Chinook salmon were primarily from Wind River on the mainstem Columbia. Days-at-large after hatchery release varied 4-61 d. It was not possible to estimate growth between release and capture because length at the time of hatchery release was not recorded. Mean weight was also difficult to compare because of variation in release sizes related to duration of rearing and degree of feeding competition among hatchery fish.

Table 31. Coded-wire tag recoveries for Chinook salmon captured in the mainstem of the Columbia River and in Multnomah Channel, February-July 2015.

Release information			Recapture information (2015)			Tags recovered (n)	
Location	Last date	mean weight (g)	Length range (mm)	Weight range (g)	Days at large	Mainstem	Channel
Fall run, 2014 brood year							
Sandy River	20 Apr 2015	5.87	78-89	4.6-6.8	17	1	1
Wind River	27 Apr 2015	4.25	70	3.6	9		1
Wind River	27 Apr 2015	4.94	65-83	2.6-5.6	9	4	4
Washougal R	5 Jun 2015	5.59	65-85	2.7-6.8	4	4	
Spring run, 2013 brood year							
Willamette R	12 Mar 2015	42.39	139	26.6	30	1	
Willamette R	30 Dec 2014	42.79	134-166	23.1-45.5	61	2	
Willamette R	10 Feb 2015	44.91	179-194	60.3-73.4	9		3
Willamette R	5 Feb 2015	38.54	126	18.4	34	1	

Detection of Tagged Salmonids

Sites and Infrastructure

To detect salmonids tagged with passive integrated transponder (PIT) tags, we installed two antenna arrays on the south pond outlet channel (Figure 33). The first array, referred to as the SOC array, was located near the confluence of Multnomah Channel and the south outlet channel. The second array, referred to as the SWCS array, was located at the south outlet channel water control structure.

Each array consisted of six antennas connected to a multiplexing transceiver (Destron Fearing FS1001M). Each transceiver was provided with 24-V DC power from a bank of four 12-V batteries supplemented by photovoltaic panels. Data were stored locally on transceivers and transmitted daily via cellular modem.

The SOC array was configured with two parallel sets of three antennas that transected the thalweg of the channel (Figure 33). These two sets created downstream and upstream detection lines approximately 2 m apart, so that directional movement of tagged fish could be ascertained. Each antenna was 1.2 m wide by 3.1 m high. Fish were guided through the array with block nets that spanned from the outermost antenna to shore.

For the SWCS array, detection antennas were installed on both the upstream and downstream side of the water control structure (Figure 34). On the upstream side, three 1.2- by 3.1-m antennas were installed close to the east bank, and a block net was extended from the westernmost antenna to the west bank. On the downstream side, antennas were aligned with the downstream ends of the two culverts and one fishway. Two 1.2- by 3.1-m antennas were installed approximately 0.3 m downstream from the trash rack of each culvert. A third antenna (1.2 × 1.8-m) was installed approximately 0.3 m from the downstream opening of the fishway. Block nets were not used on the downstream side of this array.

Water temperature and depth data loggers were deployed at SOC array and on both the upstream and downstream sides of the SWCS array.

Figure 33. Front view (upper panel) and side view (lower panel) of the antenna configuration at the SOC array, which was operational in 2014 and 2015.

Figure 34. Upstream view (upper panel) and downstream view (lower panel) of antenna configuration at the SWCS array, which was operational during 2014–2016.

In 2015 and 2016, we used the same PIT-tag detection arrays installed and operated in 2014 at the south outlet channel and south water control structure (Figures 33-34). However, the SOC array was removed in September 2015. Dates of operation for each array are shown by study year in Table 32.

A third PIT-tag detection system, referred to as the NWCS array, was installed in fall 2014 on the downstream side of the water control structure on the north outlet channel (Figure 10). This new array consisted of two 1.2 by 3.1-m antennas aligned with the downstream ends of the two water control structure culverts (Figure 35). Block nets were used to guide fish through the antennas. Due to a limited number of available antennas, the NWCS array antennas were placed only on the downstream side of the water control structure. The NWCS array was operational from 20 November 2014 to 20 June 2015 (Table 32).

Figure 35. Antenna configuration at the NWCS array, which was operational in 2015 and 2016.

Table 32. Dates of operation for each of three PIT-tag monitoring arrays installed in Multnomah Channel Marsh, 2014-2016.

	PIT-tag monitoring array operation		
	SOC array	SWCS array	NWCS array
2014	13 Feb-17 Jul	26 Feb-17 Jul	n/a
2015	17 Oct-30 Jun	27 Mar-20 Jun	20 Nov-20 Jun
2016	n/a	21 Mar-28 Jun	21 Mar-28 Jun

Run-of-River Fish

Methods

For all three study years, we obtained release information to determine the species and origin of tagged fish from upriver sources that were detected on any of our PIT-tag monitoring arrays. Information was downloaded from the *PIT Tag Information System* (PTAGIS; www.ptagis.org), a regional database for the storage and dissemination of information on PIT tagged fish.

These fish had been tagged for other studies, but their detections indicated the number and species of fish that would potentially approach wetland access points from Multnomah Channel and utilize marsh rearing areas if they had access. For these individuals, we measured two metrics: 1) travel time, defined as total time between release and first detection, and 2) residence time, defined as time from first to last detection on any array.

Results

2014—Sixteen fish from upriver sources were detected at the SOC array in 2014 (Table 33). Only one was detected on the SWCS array; however, 11 of the 16 fish were detected before the SWCS array was installed. Detection dates ranged from 14 February to 29 October 2014.

Eight fish were hatchery spring Chinook salmon from a single release on the North Santiam River (Willamette River Basin); seven were detected between 14 and 17 February 2014, during the run-up to a high water event. In addition to the 16 hatchery fish, three wild spring Chinook salmon were detected during this time frame. These fish had been tagged at Leaburg Dam on the McKenzie River (Willamette River Basin).

One hatchery summer steelhead released on 29 April 2014 in the lower Salmon River, Idaho (Snake River Basin) was detected on 9 May 2014. Two fish were detected for which no species or location information was available. On 26 March 2014 one of these "orphans"—a wild juvenile Chinook salmon—was recaptured by staff of the Oregon Department of Fish and Wildlife (ODFW). It was released near the south water control structure and detected at the downstream SWCS array. The remaining two fish that entered the site from an outside source were northern pikeminnow *Ptychocheilus oregonensis* tagged in the mainstem Columbia River in 2012 and 2014.

Table 33. Tagging information and PIT detection timing for 16 fish from upriver sources detected on the SOC array in 2014. Start date is the date of first detection and end date is the date of last detection.

	Release					Tagging		
Tag ID	Date	Site	rkm	Migration year	Rear type/run/species	fork length (mm)	Start date (2014)	End date (2014)
3DD.003BC534A6	1/29/2014	Leaburg Dam, OR	501	2014	Wild spring Chinook salmon	114	2/14	2/14
3DD.003BC57C23	10/17/2013	Leaburg Dam, OR	501	2013	Wild spring Chinook salmon	108	2/14	2/16
3D9.1C2E082345	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	69	2/14	2/15
384.3B239EE0CD	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	71	2/14	2/15
384.3B23A1DC05	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	67	2/15	2/16
3D9.1C2E02D58C	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	61	2/15	2/16
3D9.1C2E07B945	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	70	2/16	2/16
384.3B239D81A5	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	81	2/16	2/16
3DD.003BC57E08	10/28/2013	Leaburg Dam, OR	501	2013	Wild spring Chinook salmon	93	2/17	2/19
3D9.1C2E07EB46	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	73	2/17	2/17
3D9.1C2D934496	4/18/2012	Columbia R, OR/WA	95	2012	Northern pikeminnow	400	2/21	4/5
3D9.1C2D6D1491	--	Unknown	--	2014	Unknown	--	3/7	3/7
3D9.1C2D6BBEDE	--	Unknown	--	2014	Wild Chinook salmon	--	3/23	3/31
3D9.1C2E07C1D4	6/27/2013	N Santiam R, OR	356	2013	Hatchery spring Chinook salmon	69	4/19	4/22
3DD.00774DBB8A	4/29/2014	Lower Salmon R, ID	965	2014	Hatchery summer steelhead	--	5/9	5/9
384.3B239BA253	4/17/2014	Columbia R, OR/WA	95	2014	Northern pikeminnow	325	10/26	10/29

Residence time of juvenile salmonids ranged 2 seconds to 8 d, with a median of 6.9 h. For a large group of fish detected during the high water event, median residence time was 6.8 h, with a maximum of 2 d. The orphan wild Chinook salmon resided for 8.1 d, the longest residence time for a salmonid. Residence time for the single summer steelhead was 31 minutes. The longest residence was expressed by one northern pikeminnow, which was detected intermittently (almost daily) for 42 d from 21 February to 5 April 2014.

2015—Twelve PIT-tagged salmonids from upriver sources were detected on our arrays in 2015 (Table 34). Chinook salmon was the most predominant species, with eight individuals detected. Two wild run coho salmon were also detected, as were two more individuals for which there was no information in the PTAGIS database.

All Chinook salmon were from the Willamette River, except two that had been released from hatcheries above Bonneville Dam (Spring Creek and Warm Springs NFH). Hatchery fish released in the North Santiam River were the most prevalent among Chinook salmon. All other Willamette River Chinook salmon were wild run fish tagged in Tryon Creek, Oregon. Both wild run coho salmon were also tagged in Tryon Creek.

Median travel time of juvenile Chinook salmon was 155 d and ranged 27-220 d. Residence time of juvenile Chinook salmon ranged 2 seconds-5 d with a median of 7 minutes. The two hatchery Chinook salmon that were not from the Willamette Basin had shorter travel (27–29 d) and residence time (3–11 minutes) than Chinook salmon from within the basin.

There was a marked difference in the travel time between the two wild coho salmon vs. the two wild Chinook salmon from Tryon Creek. The Chinook salmon were tagged on 3 December 2014 and took 109-113 d to reach the MCM. The coho salmon had not been tagged at similar times (31 Dec 2014 vs. 4 Feb 2015), yet they each traveled to the marsh more quickly, 20–26 d, and one resided near the NWCS array for 47 d.

Most upriver salmonids were detected in winter (83% in January-March and 17% in April–May). This pattern was even stronger for Willamette River stocks, with 95% detected during January-March and 5% during April.

2016—Only two individuals from upriver sources were detected on our PIT detection arrays in 2016 (Table 35). Reasons for this decline may include a reduced number of PIT-tagged fish released in the Columbia and Willamette Basins and the fact that our arrays were not operational until the latter part of March.

Table 34. Tagging information and detection timing for 12 fish from upriver sources that were detected on PIT arrays, 2015. Start date is the date of first detection and End date is the date of last detection.

Array	Tag id	Release date	Release site	Release site (rkm)	Migration year	Rear type/run/species	Tagging fork length (mm)	Start date (2015)	End date (2015)
NWCS	3D9.1C2DA01962	7/9/2014	North Santiam R	356	2014	Hatchery spring Chinook	73	2/10	2/10
NWCS	3D9.1C2D6C3BD6	--	Unknown	--	2015	Unknown	--	2/21	4/15
NWCS	3D9.1C2CBCB081	2/4/2015	Tryon Creek	195	2015	Wild coho	95	2/24	4/12
NWCS	3D9.1C2D6C33AF	--	Unknown	--	2015	Unknown	--	3/29	3/29
NWCS	384.3B23A4274B	3/31/2015	Warm Springs Hatchery	480	2015	Hatchery spring Chinook	113	4/29	4/29
NWCS	384.3B23A5796D	4/13/2015	Spring Creek Hatchery	269	2015	Hatchery fall Chinook	62	5/10	5/10
SOC	3D9.1C2DA2F50C	7/9/2014	North Santiam R	356	2014	Hatchery spring Chinook	73	1/22	1/22
SOC	3DD.007760B3B0	7/9/2014	North Santiam R	356	2014	Hatchery spring Chinook	77	1/22	1/22
SOC	3D9.1C2CBDDEA1	12/31/2014	Tryon Creek	195	2014	Wild coho	115	1/26	1/28
SOC	3DD.0077627D7A	7/9/2014	North Santiam R	356	2014	Hatchery spring Chinook	84	2/14	2/14
SOC	3D9.1C2D08C3E1	12/3/2014	Tryon Creek	195	2014	Wild Chinook	103	3/22	3/22
SWCS	3D9.1C2D059E44	12/3/2014	Tryon Creek	195	2014	Wild Chinook	108	3/26	3/31

Table 35. Tagging information and detection timing for two fish from upriver sources that were detected on PIT arrays, 2016. Start date is the date of first detection and End date is the date of last detection.

Array	Tag id	Release date	Release site	Release site (rkm)	Migration year	Rear type/run/species	Tagging fork length (mm)	Start date (2016)	End date (2016)
NWCS	384.3B23B05144	5/9/2016	Spring Cr Hatchery	269	2016	Hatchery fall Chinook	62	5/14	5/16
SWCS	3D9.1C2DEF80A5	4/25/2013	Columbia River	95	2013	Northern Pikeminnow	230	5/16	5/16

One fish was detected on each array. On the NWCS array a fall Chinook salmon from Spring Creek hatchery was detected in mid-May. It traveled for 5 d and resided 2.3 d. A northern pikeminnow tagged in 2013 was detected on the SWCS array; it swam up the south outlet channel until it reached the south water control structure, where it lingered for 1.5 h.

Individual Releases in Ponds

Methods

During all three study years, we monitored all PIT arrays for juvenile salmonids that had been collected from fish sampling in wetland ponds. As described in the methods section for fish sampling in wetland ponds, these fish were caught in Oneida Lake traps, PIT tagged, and released back to the ponds near where they were caught. We also monitored for fish that had been collected during supplemental winter sampling in December 2015.

Results

2014—None of the fish we released to either the north or south pond were later detected on either the SOC or SWCS arrays.

2015—We detected two coho salmon on the SWCS array that had been released to the south pond. One of these fish was detected repeatedly for 2 d before it passed the structure. This fish was subsequently detected on the SOC array for 45 minutes and then exited to Multnomah Channel. The second fish was detected for 25 d at the SWCS array but never passed. We also detected one wild Chinook salmon on the SWCS array. This fish was detected repeatedly for 1 h but was never recorded passing the structure.

On the NWCS array, we detected one coastal cutthroat trout that had been captured and PIT-tagged in the north pond (Table 36). This fish was first detected 32 d after tagging and remained in the vicinity of the NWCS array for 3.7 d.

Table 36. Release and detection timing for fish captured by Oneida Lake trap, tagged, released to Multnomah Channel Marsh ponds, and subsequently detected on PIT arrays in 2015. Start date is the date of first detection and end date is the date of last detection per array.

Tag ID	Release date (2015)	Release site	Salmon species (all wild origin)	Tagging fork length (mm)	Start date (2015)	End date (2015)
SWCS						
3DD.0077731B45	16 Apr	S Pond, net 1	Coho salmon	167	18 Apr	21 Apr
3DD.007773DAC2	22 Apr	S Pond, net 1	Coho salmon	153	23 Apr	18 May
3DD.0077742E75	12 May	S Pond, net 2	Chinook salmon	101	15 May	15 May
SOC						
3DD.0077731B45	16 Apr	S Pond, net 1	Coho salmon	167	22 Apr	22 Apr
NWCS						
3DD.007772D3A4	30 Apr	N Pond, net 3	Coastal cutthroat trout	223	1 Jun	5 Jun

2016—A greater number of juvenile salmon were collected in Oneida Lake traps, PIT-tagged and released in the north and south ponds in 2016 than in 2014 and 2015. As a result, we detected more tagged fish on the PIT arrays. In the north pond we detected nine juvenile coho salmon and one juvenile Chinook salmon that had been released mostly during March (Table 37).

The median time spent by coho salmon in the north pond prior to detection on the NWCS array was 27 d and the median residence time was 28 d, indicating that once they exited the north pond they did not remain in the area. The maximum time spent in the north pond was 117 d. The single Chinook salmon that was captured, tagged and released in the north pond had the shortest residence time,11 h.

In the south pond we detected 18 coho salmon and one coastal cutthroat trout. Eleven of the coho salmon were tagged and released in December 2015 during the supplemental high water sampling, while the remainder were tagged and released in late March through April (Table 37). The median time spent by coho salmon in the south pond prior to detection was 96 d, and the median residence time was 114 d, indicating that these fish remained in the area for an additional 18 d before they either passed the SWCS (n = 4) or were no longer detected (n = 14). The single coastal cutthroat trout tagged and released in the south pond was detected for 20 d after being released, but it did not pass the SWCS.

Table 37. Tagging information and detection timing for fish captured by Oneida Lake trap or pole seine, tagged, and released in Multnomah Channel Marsh ponds that were detected on PIT arrays in 2016. Start date is the date of first detection and End date is the date of last detection per array.

Tag id	Release date	Release site	Salmon species (all wild origin)	Tagging fork length (mm)	Start date (2016)	End date (2016)
NWCS array						
3DD.00775F0B3B	12/11/2015	North pond, Net 4	Coho	87	4/7	4/7
3DD.0077643431	2/24/2016	North pond, Net 1	Coho	98	3/31	4/22
3DD.0077680EAA	3/1/2016	North pond, Net 2	Coho	122	3/29	3/29
3DD.007768C9B3	3/2/2016	North pond, Net 2	Coho	128	3/18	3/30
3DD.00776416A8	3/3/2016	North pond, Net 2	Coho	114	3/30	3/31
3DD.0077680AED	3/3/2016	North pond, Net 2	Coho	121	3/30	3/30
3DD.007763E6C9	3/22/2016	North pond, Net 2	Coho	126	3/31	3/31
3DD.00776815D4	3/22/2016	North pond, Net 2	Coho	128	3/28	3/28
3DD.0077459AE4	3/24/2016	North pond, Net 2	Coho	148	3/29	3/29
3DD.00774625D6	4/13/2016	North pond, pole seine	Chinook	75	4/13	4/13
SWCS array						
3DD.00775E95D9	12/11/2015	Seine near S. breach	Coho	82	3/31	6/4
3DD.00775D461C	12/16/2015	Seine near S. breach	Coho	96	3/21	4/2
3DD.00775E04D3	12/16/2015	Seine near S. breach	Coho	86	4/1	5/8
3DD.00775E0AB5	12/16/2015	Seine near S. breach	Coho	71	4/6	4/14
3DD.00775F46D1	12/16/2015	Seine near S. breach	Coho	91	3/20	5/28
3DD.00775F65FD	12/16/2015	Seine near S. breach	Coho	90	3/23	5/21
3DD.00775DD586	12/17/2015	Seine near S. breach	Coho	81	4/5	4/25
3DD.00775E8AF8	12/17/2015	Seine near S. breach	Coho	74	3/26	5/2
3DD.00775EFDC1	12/17/2015	Seine near S. breach	Coho	86	3/29	4/15
3D9.1C2DED33B8	12/20/2015	Seine near S. breach	Coho	85	3/23	3/23
3D9.1C2DED616A	12/20/2015	Seine near S. breach	Coho	72	3/30	5/10
3DD.0077409999	3/30/2016	South pond, Net 3	Coho	150	3/31	5/22
3DD.007746BBA6	3/30/2016	South pond, Net 4	Coho	169	3/31	4/15
3DD.00773FC817	4/12/2016	South pond, Net 3	Coho	163	4/14	4/24
3DD.00774629D1	4/12/2016	South pond, Net 3	Coastal cutthroat trout	192	5/2	5/2
3DD.00774547B4	4/14/2016	South pond, Net 3	Coho	167	4/15	4/19
3DD.007746D6CD	4/26/2016	South pond, Net 3	Coho	169	5/10	5/10
3DD.0077406F82	4/28/2016	South pond, Net 3	Coho	161	5/19	5/28
3DD.0077454FD4	4/28/2016	South pond, Net 3	Coho	174	5/2	6/2

Group Releases in Ponds

Methods

We released groups of PIT-tagged juvenile salmon into the north and south ponds to measure residence and passage time. Detections of these fish were used to gain insight into the ability of salmon to pass water control structures and return to Multnomah Channel to continue seaward migration.

2014—We captured, PIT-tagged, and released groups of juvenile salmon on four occasions. On 26 March and on 17 and 28 April 2014, ODFW used electrofishing to collect juvenile salmon in areas of Multnomah Channel near its confluence with the south outlet channel. Electrofishing methods were the same as those described in the methods section for fish sampling in wetland ponds. On 7 May, we used a bag seine to collect juvenile salmon from the Columbia River mainstem sampling site on the Washington shore (Figure 13). Bag seine sampling methods are described in the methods section for fish sampling in Multnomah Channel and Columbia River Mainstem.

All juvenile salmon were anesthetized using tricaine methanesulfonate (50 mg/L), identified to species, and checked for external marks, such as an adipose fin clip, and for previously inserted PIT or CWT tags. If a fish already had a PIT tag, the code was recorded and the fish was identified as a "recapture." Fork length (nearest mm), and weight (nearest 0.1 g) were recorded for all individuals, and a 12-mm PIT tag was inserted into the body cavity of individuals that were not previously PIT-tagged, following regional guidelines for PIT marking (PTSC 2014). Genetic samples were collected from fish with an intact adipose fin and archived. Salmon collected from the mainstem Columbia River were transported via boat and truck to the MCM after processing.

Tagged fish were allowed to recover for 1-2 h before release into wetland ponds (Figure 10). Fish tagged on 26 March were released the same day in the south outlet channel downstream of the south water control structure. Fish tagged and released on 17 and 28 April were divided into two groups and released into two separate locations within the south pond.

Fish tagged and released on 7 May were divided into five groups and released at three locations in the south pond and two locations in the north pond. We monitored the SOC and SWCS arrays for detection data from PIT-tagged fish, and we monitored the Oneida Lake traps in the north and south ponds for PIT-tagged fish, as described in the methods section for fish sampling in *Wetland Ponds*.

For each release group we measured four metrics: 1) time-to-first detection, which for most groups was a measure of how long it took fish to maneuver through the south pond to the water control structure; 2) residence time, defined as time between release and last detection on either array; 3) south outlet channel residence time, defined as time spent in the south outlet channel downstream of the SWCS array; and 4) inter-array transit time, defined as elapsed time between last detection at the SWCS array and first detection at the SOC array.

Inter-array transit time was a positive value only for fish that moved in a downstream direction past both SWCS and SOC arrays. However, fish that moved back and forth between arrays had negative transit time values because their last detection at the SWCS array occurred after their first detection at the SOC array. We also monitored upstream vs downstream passage at the south water control structure.

For tag-recovery analyses we assumed that: 1) tagging mortality did not affect detection probability; 2) survival in the MCM was equal among all fish released; and 3) detections depicted the behavior of tagged salmon rather than the movement of salmon predators through the electromagnetic field of the antennas.

2015—In 2015, fish were collected for passage and timing evaluation using the bag seine methods described for fish collection in the Multnomah Channel and Columbia River mainstem.

All juvenile salmon were anesthetized using tricaine methanesulfonate (50 mg/L), identified to species, and checked for external marks such as an adipose fin clip and previously inserted PIT or CWT tags. If a fish already had a PIT tag, the code was recorded and the fish was identified as a “recapture.” Fork length (nearest mm), and weight (nearest 0.1 g) were recorded for all individuals, and a 12-mm PIT tag was inserted into the body cavity of individuals that were not previously PIT-tagged, following regional guidelines for PIT marking (PTSC 2014).

Tagged salmon were transported via boat and truck to the MCM after processing. The first group of tagged salmon were released into ponds on the same day they were tagged. The second and third release groups were held overnight in an oxygenated tank and released into the ponds the following day.

Fish were divided into groups and released in 1–2 separate locations within the north and south ponds, with one group released into Patterson Creek. All three PIT tag arrays were monitored for detection data from these fish. We also monitored Onieda Lake traps for these fish in the north and south ponds, as described in the fish sampling methods for wetland ponds.

For groups of PIT-tagged fish released in the north pond, we measured two metrics 1) time from release to first detection, which indicated the time needed for fish to maneuver through the north pond and negotiate the water control structure to the NWCS array; and 2) residence time, or time from release to last detection on any array.

For groups of juvenile salmon released in the south pond, we measured three metrics: 1) time to first detection, which indicated the time needed for fish to maneuver through the south pond to the SWCS; 2) residence time, or time from release to last detection; and 3) residence time within the south outlet channel, which reflected the amount of time spent in the south outlet channel downstream of the SWCS.

2016—We released one group of hatchery-reared, PIT-tagged juvenile Chinook salmon into the north and south ponds to measure residence time and ability of salmon to negotiate the water control structures and return to Multnomah Channel to continue their seaward migration.

Study fish were obtained from the Smith Farm Genetics and Performance Lab of Oregon State University. On 6 April 2016, 215 juvenile Chinook salmon were PIT-tagged, following regional guidelines (PTSC 2014) and those of the OSU Institutional Animal Care and Use Committee. Fork length (nearest mm), and weight (nearest 0.1 g) were recorded for each individual.

On 11 April 2016, PIT-tagged Chinook salmon were transported via truck from the hatchery to the MCM, where they were divided into groups and released to two separate locations within the north and south ponds. Both PIT tag arrays were monitored for detection data from PIT-tagged fish, and traps in the north and south ponds were monitored for these fish as well (Methods section: Wetland Ponds).

For groups of PIT-tagged fish released in the north pond we measured two metrics 1) time to first detection, which is a measure of how long it took fish to maneuver through the north pond and negotiate the water control structure to reach the NWCS array; and 2) residence time, which is the time from release to time of last detection on any array. For groups released in the south pond we measured three metrics: 1) time to first detection, which is a measure of how long it took fish to maneuver through the south pond to the SWCS array; 2) residence time; and 3) residence time within the south outlet channel, defined as time spent in the south outlet channel downstream of the SWCS array.

Results

Passage Rates and Timing 2014—Numbers of salmon tagged, dates and locations of release, and numbers detected on each array or recaptured in traps are listed in Table 38. None of the fish released to north pond (areas D and E) or near the culverts connecting the north and south ponds (area C) were detected on PIT arrays or recaptured in Oneida Lake traps. Fish released in the south pond or directly into the south outlet channel were detected on both SWCS and SOC arrays.

Table 38. Date of release, number, and species of PIT-tagged juvenile salmon detected and recaptured in 2014. Detection arrays were located in the south outlet channel and at the south water control structure. See Figure 10 for location of release sites.

				Number detected		
Date	Release site	Salmonid species	Number released	SWCS array	SOC array	Oneida trap recaptures
17 April	A	Chinook	13	7	4	
	B	Chinook	12	6	2	
28 April	A	Chinook	14	9	3	1
	A	Coho	3	3	1	
	B	Chinook	14	9	7	1
	B	Coho	2	2	1	
7 May	A	Chinook	40	15	8	
	A	Coho	5	2	1	
	B	Chinook	38	13	8	
	B	Coho	7	2	1	
	C	Chinook	9			
	C	Coho	3			
	D	Chinook	42			
	D	Coho	4			
	E	Chinook	39			
	E	Coho	6			

Overall, 46% (n = 68) of the 148 juvenile salmon released in the south pond were detected at the SWCS array, but only 26% (n = 38) successfully passed the south water control structure. In addition, 22% (n = 33) of fish released in the south pond were detected upstream of the SWCS array but were not detected downstream or at the SOC array (Figure 36).

These fish are presumed to have not passed. No single release group was more or less likely to pass the SWCS array, as proportions of fish from each release group that passed and did not pass were similar. There was no evidence of fish moving from the downstream side of the south water control structure to the upstream side.

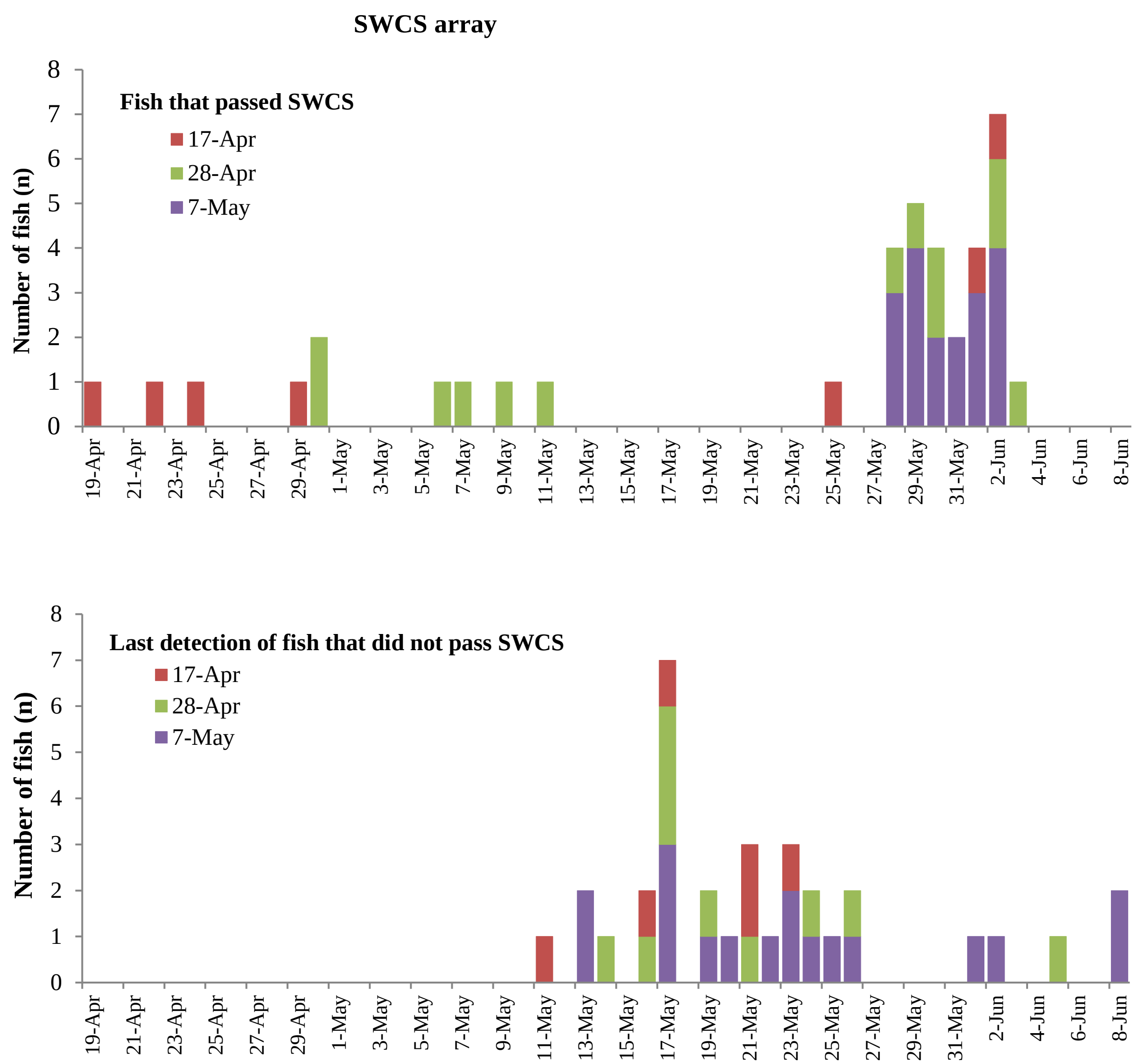


Figure 36. Dates of passage (upper panel) and last detection (lower panel) at the SWCS array for juvenile salmon tagged and released to north and south Multnomah Channel Marsh ponds in 2014. Top panel shows the date of passage for 38 salmon. Lower panel shows date of last detection for 33 salmon that did not pass the SWCS array.

Passage Conditions 2014—Salmon passage typically occurred during distinct periods, as did detections of salmon that did not ultimately pass (Figure 37). Passage initially occurred between 19 April and 11 May. During this time, the water level upstream of the south water control structure fluctuated between 1.9 and 2.3 m, water was spilling over the riser boards of the water control structure, and all passage detections occurred at a depth of 2.0 m or greater.

A period of detections that indicated non-passage occurred from 11 to 28 May. During this time, water had ceased spilling from the upstream side of the south water control structure. This period was interrupted on 28 May by rising water on the downstream side of the water control structure due to increased outflow from Bonneville Dam and coincidental spring tides.

Downstream water depth increased enough to overtop the riser boards of the water control structure. At this point salmon were again able to pass. However, passage continued even as the water level receded downstream from the riser boards. During the high water event, some boards on the fishway became dislodged, and as the water receded, debris was trapped between the boards, allowing water and salmon to pass. The debris was removed and the boards were reseated on 3 June, which coincided with the date that the last salmon successfully passed the south water control structure.

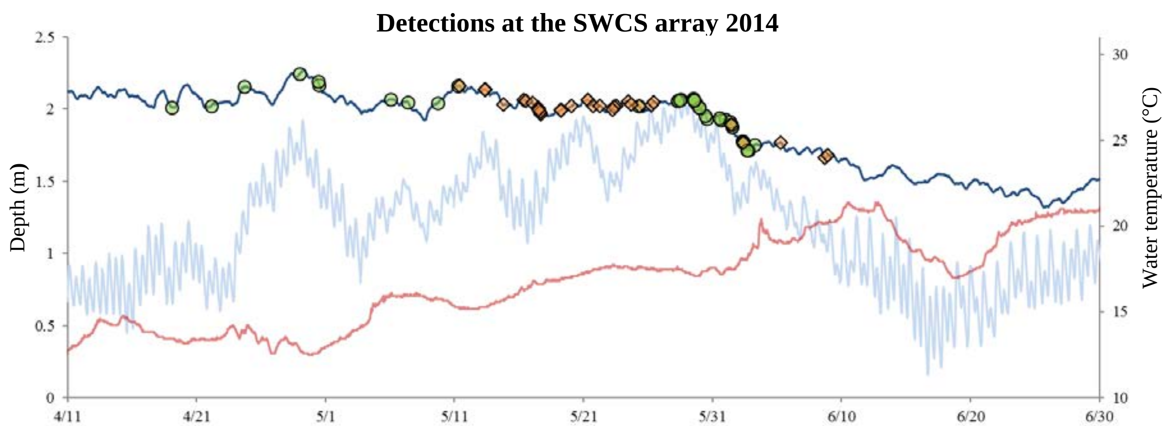


Figure 37. Passage detections and last detection without passage data overlaid on water level and temperature at the south water control structure and SWCS array, 2014. Green circles indicate successful passage for an individual; orange diamonds indicate individual passage attempts that were unsuccessful. Dark and light blue lines indicate water levels upstream and downstream of the water control structure, respectively. Red line indicates temperature.

Residence Time 2014—Time-to-first detection data indicated that fish typically spent at least two weeks in the south pond before navigating to the south water control structure (Figure 38, upper panel). Median time to first detection was 24, 19, and 16 d for groups released on 17 and 28 April and 7 May, respectively. The group released just downstream of the south water control structure on 26 March had a much shorter median time to first detection of 1 d, since this group was released near the downstream SWCS array.

Residence time was slightly greater than time-to-first detection (Figure 38, lower panel). Median residence time was 30, 21, and 22 d for groups released in the south pond on 17 April, 28 April, and 7 May, respectively. Median residence time was 6 d for fish released downstream of south water control structure on 26 March.

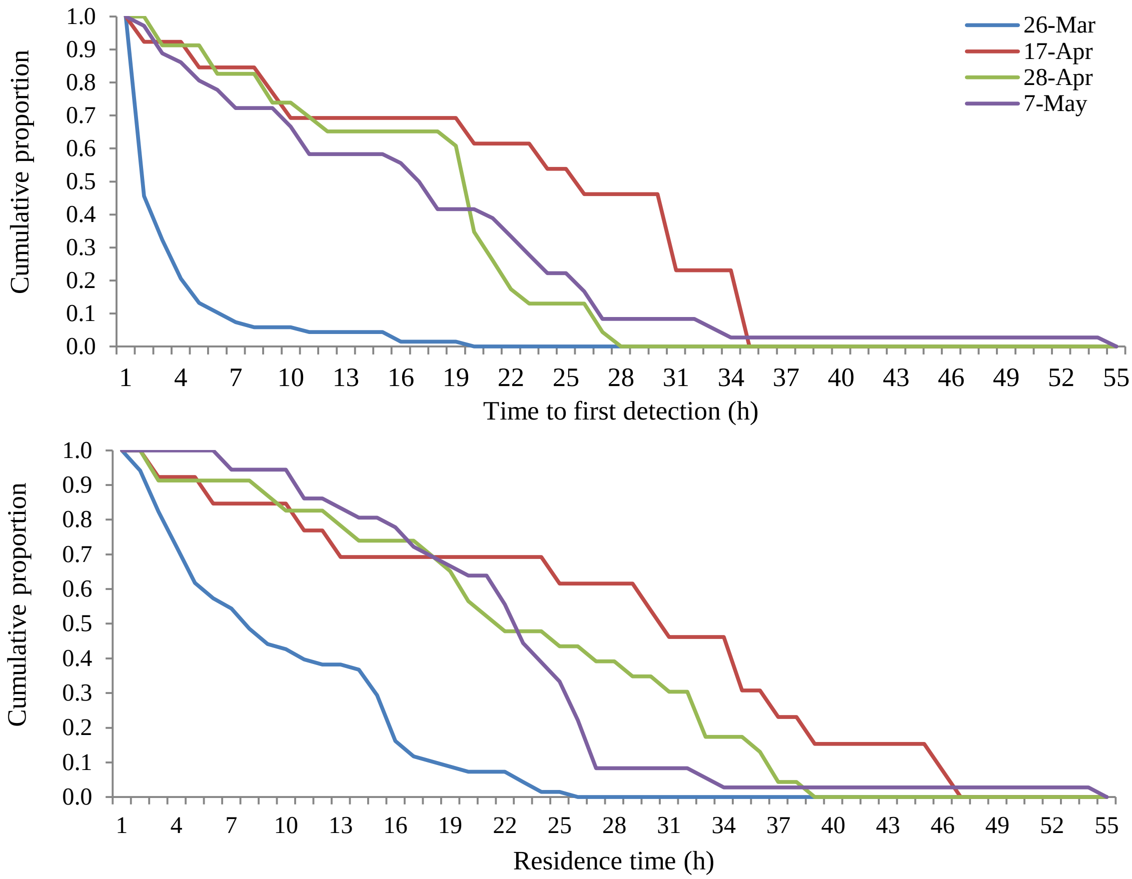


Figure 38. Time-to-first detection (upper panel) and residence time (lower panel) of juvenile salmon from group releases in the south outlet channel on 26 March vs. those released to the south pond on 17 April, 28 April, and 7 May, 2014. Residence time includes data for fish that exited to Multnomah Channel and fish that were detected upstream of the south water control structure, but never passed.

The group released on 26 March had the longest residence time, with a median of 7.2 d in the south outlet channel. Each subsequent release group spent successively less time in the south outlet channel, with groups released on 17 and 28 April having median residence times of 7.6 h and 47.5 minutes, respectively. The group released on 7 May had a residence time of only 40.3 minutes.

Inter-array transit time (elapsed time between the last detection at the SWCS array and first detection at the SOC array) was measured for 32 fish released to the south pond and detected on both the SWCS and SOC arrays. Transit time ranged from -2.3 to 12.6 d. Negative transit times are a result of fish moving upstream to the SWCS array after having been detected at the SOC array.

Respective mean transit times were 3.6 h, 1.8 h, and 34.7 minutes for groups released on 17 April, 28 April, and 7 May. Fish released in the south outlet channel on 26 March had a wider range of inter-array transit times: -6.8-17.0 d. Median transit time for this group was 1.3 d.

Passage Rates and Timing 2015—Numbers of tagged salmon released and detected, with 2015 release dates and locations are shown in Table 39, along with numbers detected on each array or recaptured in traps. Overall, of the 191 juvenile salmon tagged and released into the south pond in 2015, 37% were detected on the SWCS array. Yet only two of these fish successfully passed the south water control structure, despite active management of the surface-oriented fish passage slot. However, of the tagged juvenile salmon released to the north pond, 43% successfully negotiated the north water control structure and exited to Multnomah Channel (Figure 39).

Table 39. Date of release, release site, species, and number of juvenile salmon PIT-tagged and detected or recaptured in 2015. See Figure 10 for location of release sites and PIT arrays.

				Detection or recapture (n)			
Date/source	Release site	Salmon species	Number released	SWCS array	SOC array	NWCS array	Recaptured by Oneida trap (n)
14 April/bag seine	A	Chinook	37				
	A	Coho	1	9			
	B	Chinook	44	11			
	B	Coho	1				
	D	Chinook	27			7	
	E	Chinook	44			19	1
	E	Coho	1			1	1
29 April/bag seine	A	Chinook	44	24			1
	B	Chinook	45	24			
	D	Chinook	42			24	1
	E	Chinook	43			20	1
1 May/hatchery	C	Chinook	23				
15 May/bag seine	A	Chinook	19	3			
	D	Chinook	18			5	

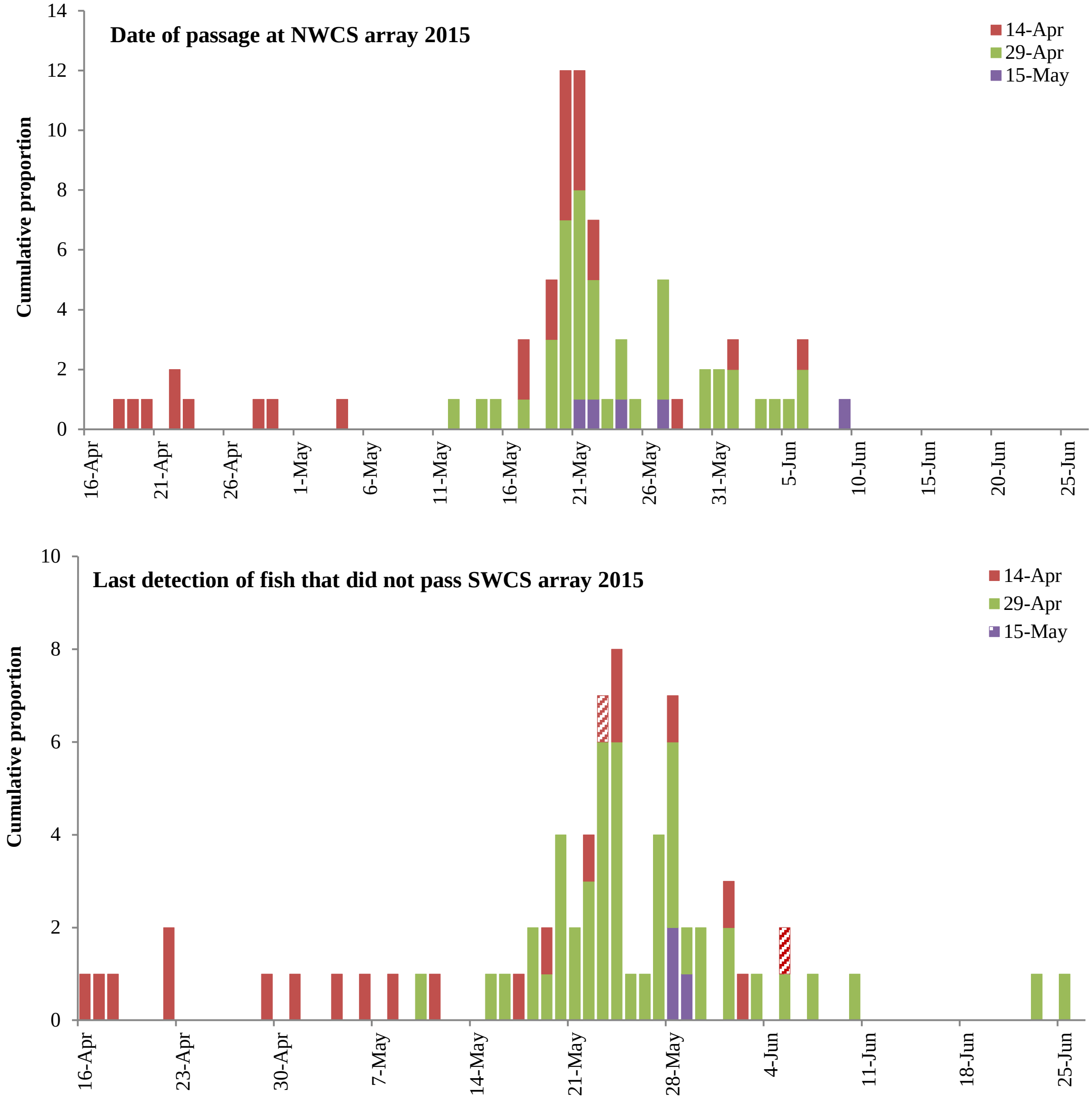


Figure 39. Passage dates for 76 juvenile salmon that exited the north pond (NWCS array; upper panel). Lower panel: last date of detection for 70 juveniles that were never detected passing the south water control structure (SWCS array). On lower panel, striped bars indicate two fish that successfully passed the south water control structure on 23 May and 5 June 2015.

Passage Conditions 2015— In 2015 we monitored and adjusted riser boards of the fishway to provide constant water flow through the fish slot. However, only two fish passed the south water control structure. In contrast, at the north water control structure, juvenile salmon passed throughout the study period, with a large pulse of fish passing around 21 May (Figure 40).

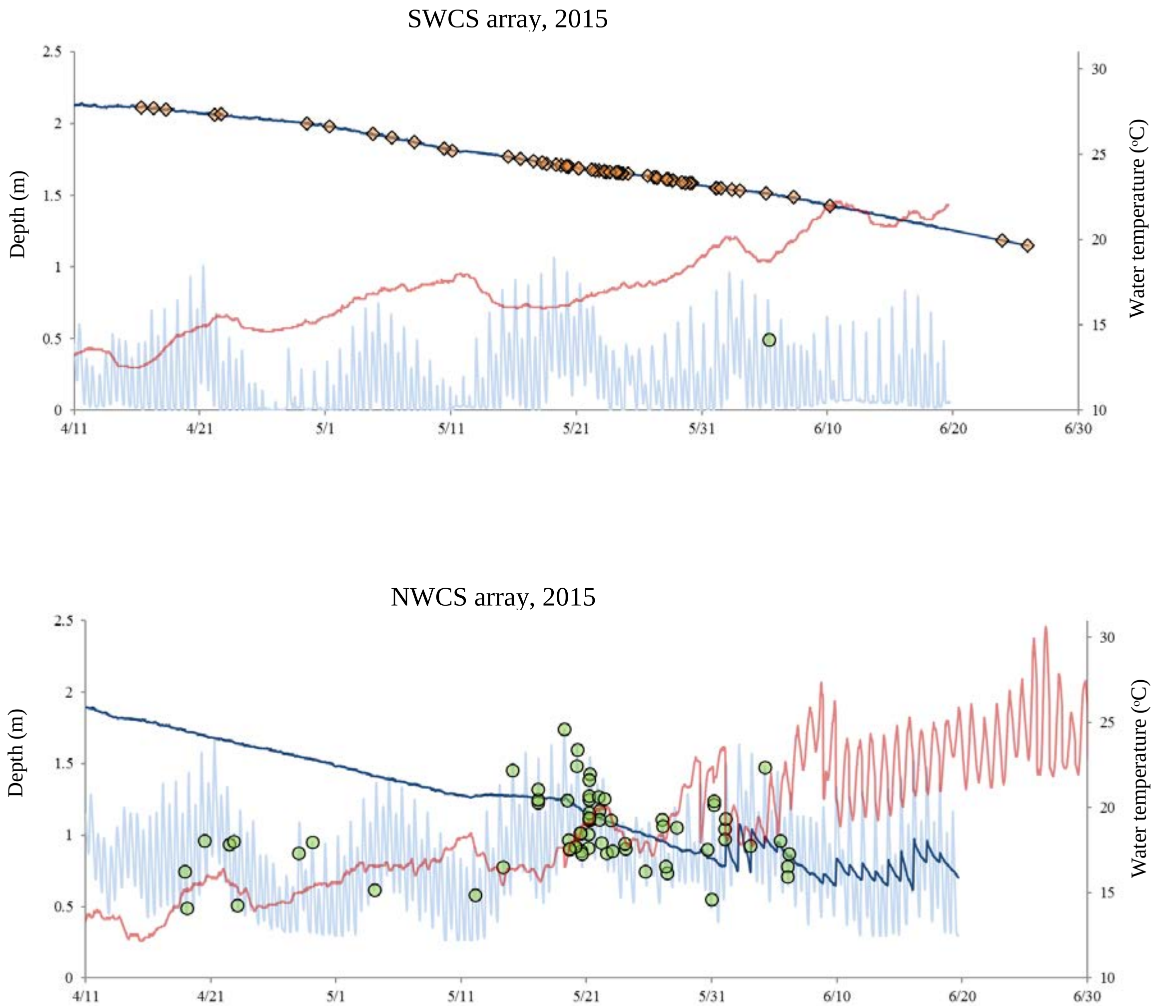


Figure 40. Passage and attempted passage vs. water level and temperature at the south (upper panel) and north (lower panel) water control structure arrays in 2015. Green circles indicate successful passage events; orange diamonds indicate unsuccessful attempts. The NWCS array was located downstream of the water control structure; thus, all detections were of fish that successfully passed the structure. Dark blue lines indicate water levels upstream of water control structures, while light blue lines indicate water levels immediately downstream. Red line indicates temperature.

Residence Time 2015—In 2015 there was no unifying pattern for time to first detection. Residence timing was most protracted for the first release group on 14 April, and shorted with each of the following release groups (Figure 41). Difference in timing between north and south pond release groups was substantial for the first release but similar for subsequent groups (compare dashed vs. solid lines, Figure 41, upper panel).

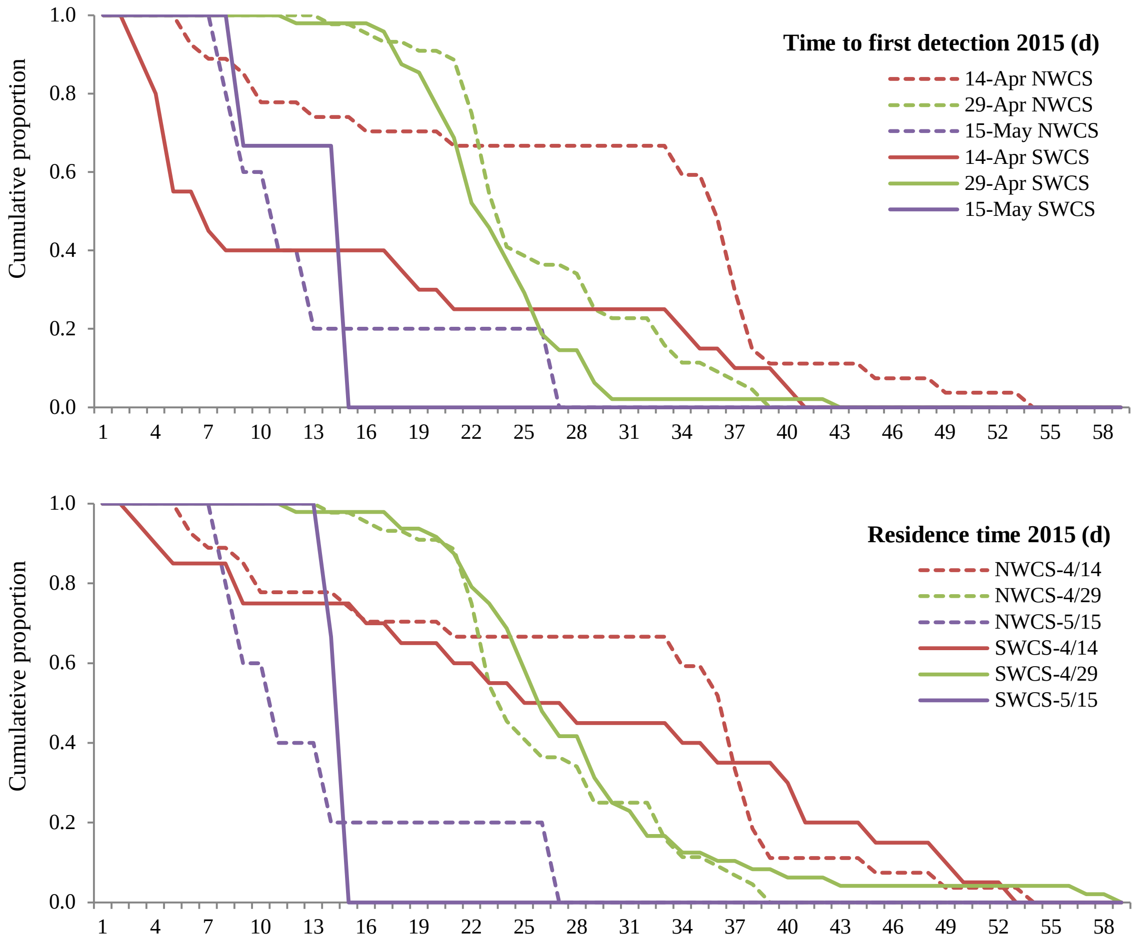


Figure 41. Time to first detection (upper panel) and residence time (lower panel) for tagged juvenile salmon released to the north (dashed lines) and south ponds (solid lines) on three dates in 2015. Detections on the NWCS array downstream of the water control structure were fish that exited the marsh ponds. Residence time for fish released in the south pond includes data for one fish known to have exited the marsh. All others were detected upstream from the south water control structure, but never passed.

For fish released to the north pond, the difference between time to first detection and residence time was minimal (dashed lines in Figure 41). By the time these fish were detected on the NWCS array, they had already negotiated the water control structure and were about to exit to Multnomah Channel. The distance between the channel and NWCS array was short (~20 m), and juvenile salmon did not linger near this array.

For fish released to the south pond, the greater distance from the water control structure to Multnomah Channel provided the opportunity for longer residence within the south outlet channel. Therefore, residence time for south pond releases was on average 2-10 d longer than time of first detection.

Residence time was longest for the first release group and shortest for the third release group to the south pond (Figure 40, lower panel), except for two fish from the second release group that remained in the south pond for over 50 d. Median residence time was 25 d for the first and second release groups and 13 d for the third group. However, only two fish were detected passing the south water control structure in 2105. Thus, these measurements actually reflect time spent within the south pond or south outlet channel upstream of the water control structure. Fish that remained in these areas until they were no longer being detected were presumed to have perished.

In contrast, residence times for fish released in the north pond accurately reflect residence time within the north pond, since the NWCS array was located downstream of the water control structure. Median residence time for the first, second, and third release groups in the north pond was 35, 23, 9 d, respectively.

For fish released to the south pond, summary measures of residence time were not possible in 2015 because only one of the two salmon that passed the south water control structure was also detected on the SOC array. This individual moved from the SWCS array to the SOC array within 19 minutes.

Passage Rates and Timing 2016—Numbers of salmon tagged, dates and locations of release, and numbers detected on each array or recaptured in traps are listed in Table 40. Overall, 24% of the 100 juvenile Chinook salmon PIT-tagged and released into the south pond during 2016; 24 were detected on the SWCS array.

None of these fish successfully passed the south water control structure, despite another year of monitoring and adjusting the surface-oriented fish passage slot. However, 57% of PIT-tagged juvenile salmon released in the north pond in 2016 successfully negotiated the north water control structure and exited to Multnomah Channel (Figures 42-43).

Table 40. Date of release, release site, species, and number of juvenile salmon PIT-tagged and detected or recaptured in 2016. See Figure 10 for location of release sites and PIT arrays.

Hatchery releases on 11 April 2016					
		Number released	Number detected (n)		Recaptured by
Release site	Salmon species	(n)	SWCS array	NWCS array	Oneida traps (n)
A	Chinook	50	11		1
B	Chinook	50	13		1
D	Chinook	57		31	
E	Chinook	58		35	

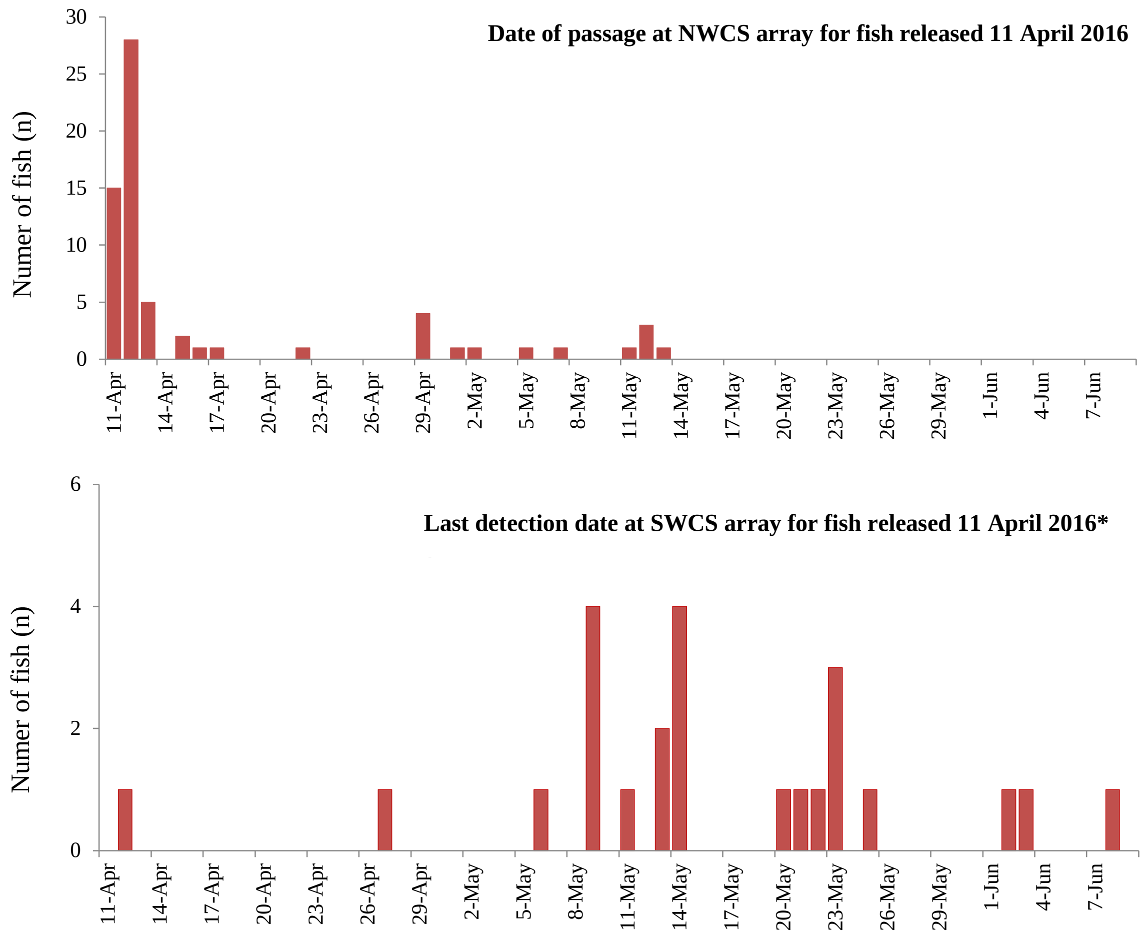


Figure 42. Date of passage at the NWCS array and date of last detection at the SWCS array for hatchery juvenile salmon released on 11 April 2016. Top panel shows the date of passage for 66 salmon that exited the north pond. Bottom panel shows the last date of detection for 24 salmon that did not pass the south water control structure.

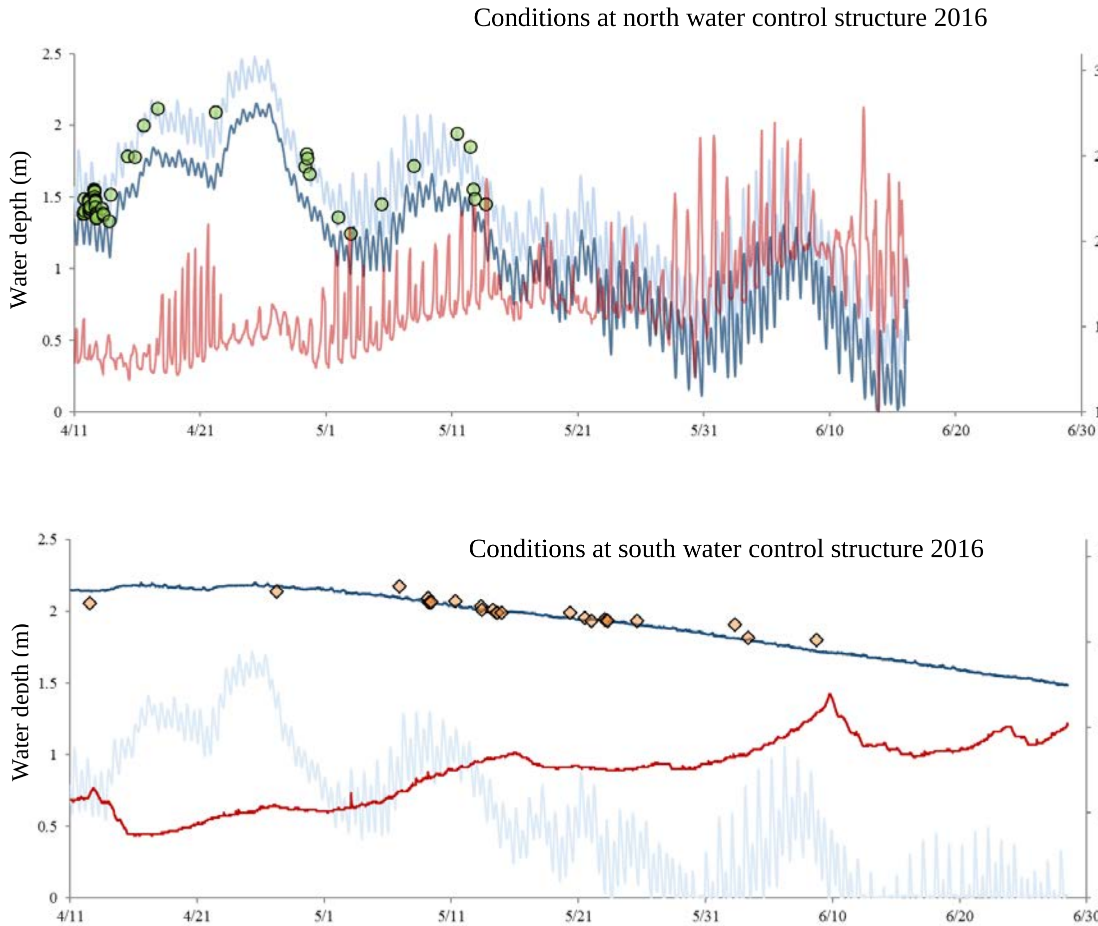


Figure 43. Passage and attempted passage vs. water level and temperature at the north (upper panel) and south (lower panel) water control structure arrays in 2016. Green circles indicate successful passage events; orange diamonds indicate unsuccessful attempts. The NWCS array was located downstream of the water control structure; thus, all detections were of fish that successfully passed the structure. Dark blue lines indicate water levels upstream of water control structures, while light blue lines indicate water levels immediately downstream. Red line indicates temperature.

Residence Time 2016—In 2016 one group of hatchery Chinook salmon was released into the north and south ponds on 11 April. Median time to first detection was 1 d for fish released to the north pond (Figure 44). These fish were more likely to exit the pond quickly because the water control structure remained open and the pond was subject to tidal flooding and ebbing. However, one fish released to the north pond was not detected for 32 d. For north pond releases, median residence time was similar to time to first detection, indicating that fish did not remain in the area once they exited the north pond.

Metrics in the south pond were much different. Median time to first detection in the south pond was 31 d, and maximum time to first detection was 52 d (Figure 44). Median and maximum residence times were 33 and 58 d, respectively. None of these fish passed the south water control structure.

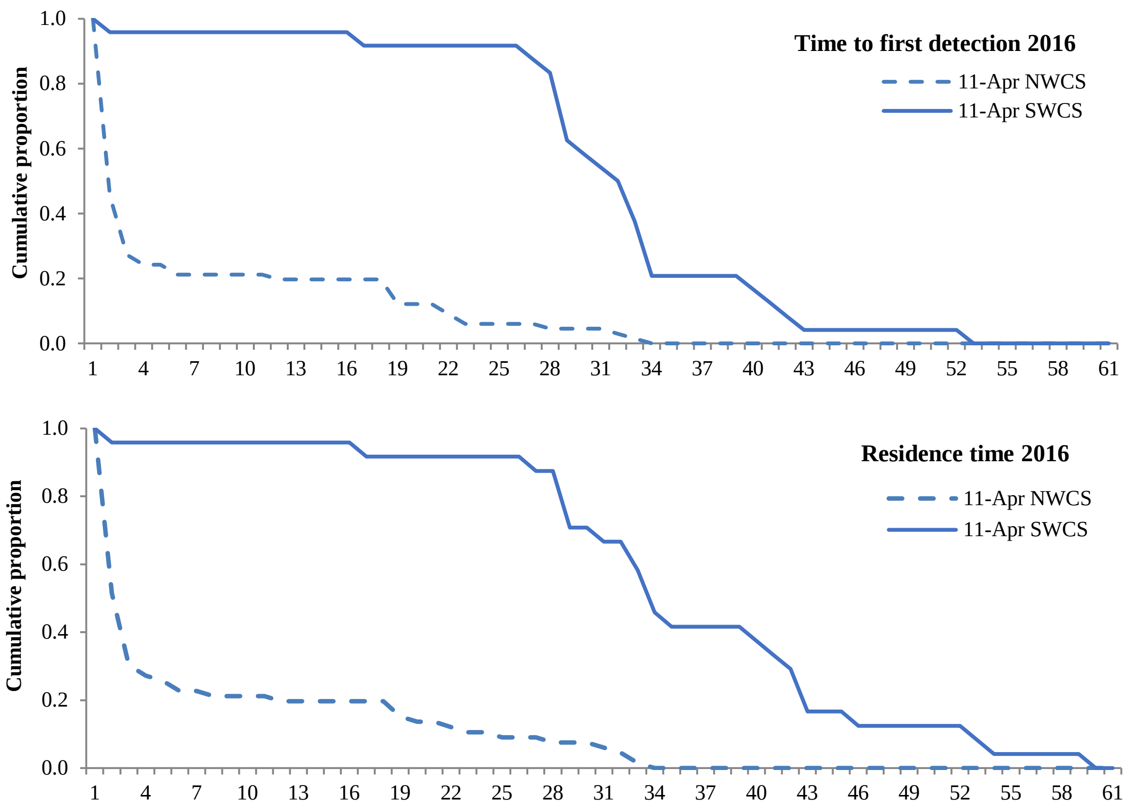


Figure 44. Time to first detection and residence time of hatchery Chinook salmon juveniles released to north and south ponds, 11 April 2016. The north water control structure (NWCS) array was located downstream of the water control structure; thus, all detected fish had exited the marsh. Residence time for fish released in the south pond denotes time from release to time of last detection. None of the fish released to the south pond were detected on the SWCS array.

Group Releases into Multnomah Channel

On two occasions in 2015, we released PIT-tagged hatchery Chinook salmon into Multnomah Channel from the Sauvie Island boat ramp, 3.1 km upstream from the MCM property. On 19 March, we released 492 fish, and on 15 April we released another 500. Fish were PIT-tagged several days prior to release at the Oregon State University Smith Farm Genetics and Performance Lab and transported to the release site in 750-L fiberglass tanks.

We monitored all detections of these fish and measured 1) time to first detection, and 2) residence time, defined as the time between first and last detection on any array. We used first detection instead of release time as the beginning measurement for residence time to account for travel time from release to the marsh property.

Assumptions for analyses were 1) tagging mortality did not affect detection probability; 2) probability of survival within the marsh was equal among all fish released; and 3) detections depicted the behavior of tagged salmon rather than the movement of predators that had consumed tagged fish.

Only 27 fish from the 19 March and 15 April releases were detected on any marsh array (Table 41). Individuals detected at the SOC array had a median time-to-first detection of 1.2 h and median residence time of 0.5 h. Individuals detected only at the NWCS array had median time-to-first detection of 1.8 d and median residence time of 1.0 d.

Three individuals detected on the SOC array moved upstream and were later detected on the downstream line of the SWCS array. These fish had the longest median time-to-first detection, at 5.3 d and longest median residence time, at 14.0 d. Finally, two fish were detected on all three arrays. Their median time-to-first detection and residence time were 3.8 and 12.6 d, respectively.

Table 41. Release dates and detections data for PIT-tagged juvenile Chinook salmon released in Multnomah Channel and detected on marsh arrays in 2015.

		Detected		Detection by array (n)			
Release date	Released (n)	(n)	(%)	SOC	NWCS	SOC & SWCS	SOC, SWCS & NWCS
19 March	492	18	3.7	6	7	3	2
15 April	500	9	1.8	8	1	0	0

Growth Experiments

Net-Pen Trials

Methods

In the south pond, we used temporary holding pens to compare juvenile salmon growth rates in areas comprised of vegetation dominated by either native emergent plants or reed canarygrass. Nets were 1.2-m high and constructed of 0.64-cm Ace knotless netting. Each 1.2 by 3.7-m net was attached to a rectangular frame comprised of metal posts. Lead weights held the sides of each net to the substrate surface.

2014—In 2014, we placed three replicate net-pens in each area (Figure 45). We selected sites where both vegetation types occurred at a similar depth (~1 m) to control for physical differences. On 27 May, we distributed 10 hatchery-reared juvenile Chinook salmon to each of the 6 pens. Fish used in the experiment ranged 92-99 mm FL; however, the size range of groups in each pen varied no more than 2 mm FL.

Size range of fish in reed canarygrass pens was 92-93 mm FL for one group and 94-95 mm FL for the other two. For fish in native vegetation pens, size range was 96-97 mm FL for two groups and 98-99 mm FL for the other one. The growth experiment continued for 13 d, and fish were retrieved from pens using a scoop net constructed of 0.64-cm mesh stretched over a 1.2- by 1.5-m rigid frame.

Figure 45. Net-pen locations in reed canarygrass (solid rectangles) and natural emergent vegetation (open rectangles) at Multnomah Chanel Marsh in 2014.

In October 2014, we conducted surveys during low-water periods after the peak in vegetative biomass, following methods modified from those of Roegner et al. (2009). For analysis, each pen was divided into 12 equal quadrats (0.25 m^2); and three quadrats were randomly selected for evaluation. Evaluations included percent cover estimation by species, including bare ground, and density by stem count. Results from the three quadrats were then averaged to describe vegetation under the net-pen.

We assigned trace species a cover of one percent. Surveys were conducted during low-water periods, when some plant species had begun to die back. Therefore, we recorded high levels of bare ground/detritus in some pens, particularly in natural emergent pens.

2015—Net pen structures in 2015 were the same as in 2014. Locations of net pens were slightly altered from 2014 locations to achieve more uniform vegetation composition within each net pen (Figure 46). In 2015, net pens had a maximum depth of ~2 m (6 ft), but the observed depth fluctuated based on the water level in each microhabitat. To prevent predation from birds and mammals, we stretched lightweight bird netting across the top of the pens.

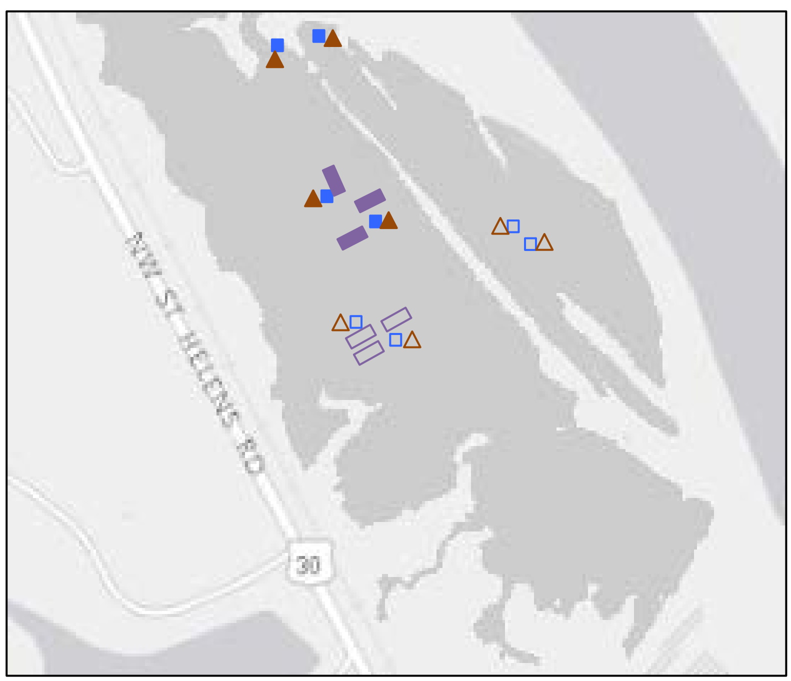


Figure 46. Approximate sampling site for net-pens ( ), emergence traps ( ) and fallout traps ( ) in reed canarygrass (solid) and natural emergent vegetation (open) at Multnomah Chanel Marsh in 2015.

At the start of each experiment, all fish were weighed (g wet weight) and measured (mm FL). Individuals assigned to the same net-pen were selected for similar length (± 1.0 mm FL), allowing for a relatively consistent initial weight. This allowed us to avoid the use of individual tags, which could potentially affect short-term growth rates and helped to control for feeding differences due to size

On each of three dates, we placed 10 hatchery juvenile Chinook salmon (~2.25 fish/m^2) in each net pen and held them for 10 d. A total of three net-pen experiments were conducted in 2015 (3 and 17 April and 1 May). After each 10-d holding period, we sacrificed all individuals by transferring fish from pens to buckets containing tricaine methanesulfonate (50 mg/L). Fish were then measured (mm FL), weighed (g wet weight), and immediately placed on ice. After transport from the field, samples were stored at -80°C for later diet analysis.

We tested two net-pen configurations (open- and closed-bottom) in the first experiment on 3 April. However, only fish from the closed-bottom design, which was used in the reed canarygrass microhabitat, were successfully recovered at the end of the experiment. We therefore used the closed-bottom pen configuration for all subsequent experiments.

Growth was defined as the change in mean length and mean weight of fish within each pen between the beginning and end of the holding period. Results are presented as the average increase in mm or g over the 10-d growth period. For a more extensive comparison of growth see Klopfenstein (2016).

In October 2015 we conducted another vegetation survey to guide the placement of the net pens for the 2016 experiments, in which we would have four net pens in each vegetation type. Vegetation surveys were conducted under each of four net-pens in natural emergent vegetation and in reed canarygrass. As in 2014, each pen was divided into 12 equal quadrats (0.25 m^2), with three quadrats randomly selected for evaluation.

The evaluation included percent cover estimation by plant species, including bare ground, and density by stem count. Results from the three quadrats were again averaged to describe the vegetation under each net-pen. We assigned trace species a cover of one percent. Survey methods were modified from those described by Roegner et al. (2009), and were conducted during low-water levels in October 2015, after the peak vegetative biomass when some species began to die back. Therefore, we recorded high levels of bare ground/detritus in some pens, particularly the natural emergent pens.

2016— For 2016 experiments, pens were relocated from their 2015 positions to improve the differentiation in habitat types (Figure 47). We used the same net pen structures described for the previous two years. The average depth of the net-pens was ~1.2 m in the natural vegetation and ~1.04 m in the reed canarygrass. Net pen trials occurred twice in April 2016.

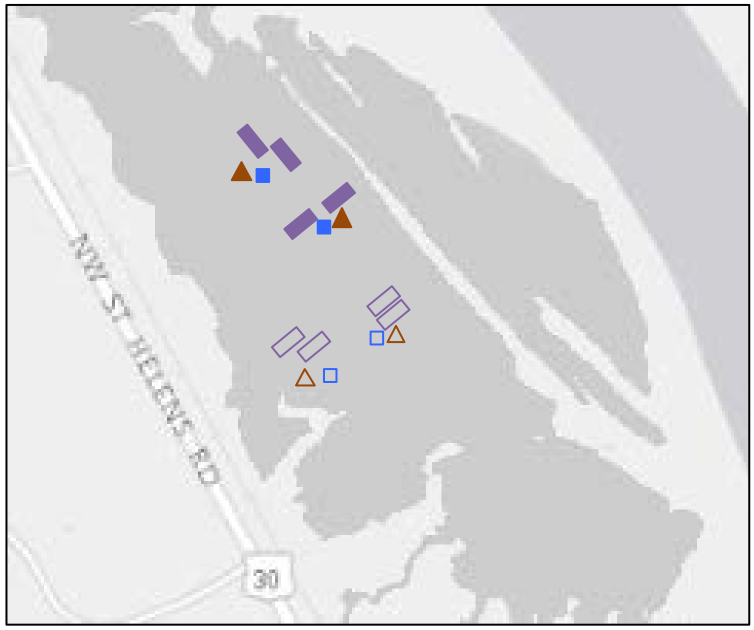


Figure 47. Net-pen ( ), emergence traps ( ) and fallout traps ( ) approximate sampling locations in reed canarygrass (solid) and natural emergent vegetation (open) at Multnomah Chanel Marsh in 2016.

To measure growth, ten hatchery juvenile Chinook salmon (~2.25 fish/m^2) were placed in each net-pen for 10 d. At the start of each experiment, all fish were weighed (g wet weight) and measured (mm FL). Individuals placed in the same net-pen were selected for a similar length (± 1.0 mm FL), which allowed for a relatively consistent initial weight and avoided the need for individual tags that could affect short-term growth rates. Fish were sacrificed after 10 d by transfer into buckets of water containing tricaine methanesulfonate (50 mg/L). We then measured (mm FL), weighed (g wet weight), and immediately placed them on ice. Samples were stored at -80° C for later diet analysis.

For fish recovered from pens, we defined growth as the change in mean length and weight between the initiation and end of the holding period. Results are presented as the average increase in mm or g over the 10-d growth period for fish in each habitat. For a more extensive comparison of growth see Klopfenstein (2016).

Results

2014—Due to delays in construction and delivery of net pens, the growth experiment was conducted later in the year than anticipated. Concerns regarding temperature increases and oxygen level decreases in the south pond proved valid when no live hatchery salmon were recovered at the end of the 13-d experiment.

Results from the October 2014 vegetation survey are presented in the 2015 section because they describe the vegetation composition experienced by fish in the 2015 growth trials.

2015—Net-pens located in native vegetation habitat were dominated by Columbian sedge *Carex aperta*, 15-6% and bare ground, 39-68%. However, reed canarygrass was also present in native pens, contributing an average of 15% to the ground cover (Figure 48). In the non-native vegetation habitat, reed canarygrass was the dominant cover, at 52-67%, followed by bare ground at 23-43%. In the native vegetation habitat, Columbian sedge had the highest density, with reed canarygrass also having a significant presence (Table 42). In the non-native vegetation habitat, reed canarygrass had the highest density in all three pens.

Of the three dates on which net-pen experiments were attempted, two were completed, and a total of 82 fish were collected (Table 43). Fish in the 3 April experiment (reed canarygrass only) grew 3.6 mm and gained 0.7 g on average (n = 24). During the 17 April deployment, average growth over 10 d was 6.5 mm in length and 1.4 g in weight for the natural vegetation (n = 30) vs. 4.8 mm in length and 1.0 g in weight for the reed canarygrass (n = 28). Unusually low water levels and high temperatures in the marsh exceeded the survival tolerances of fish by mid-spring. As a result of these unfavorable conditions, no fish were recovered from the third experiment.

Results from the October 2015 vegetation survey are presented in the 2016 section because they describe the vegetation composition experienced by fish in the 2016 growth trials.

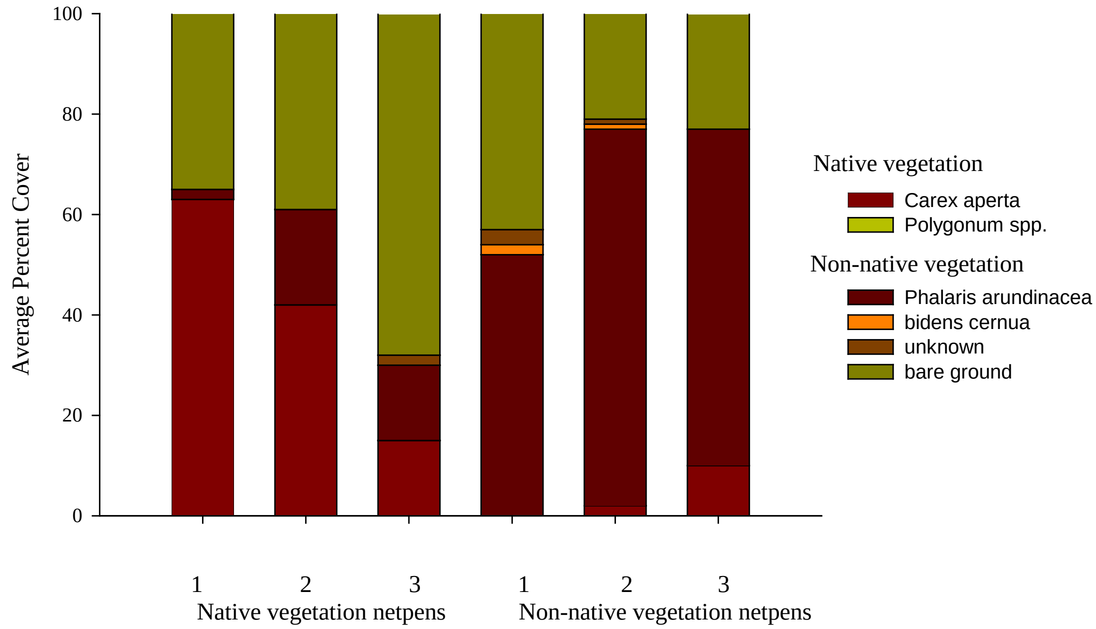


Figure 48. Average percent cover by species for areas beneath the net-pens used for the native vegetation and non-native vegetation growth experiments, 2015.

Table 42. Plant density expressed as stem count/m^2 for net-pens used for growth comparisons in natural emergent vegetation vs. reed canarygrass habitats.

	Plant density 2015					
	Native plant (stem/m^2)			Non-native plant (stem/m^2)		
Plant species	Pen 1	Pen 2	Pen 3	Pen 1	Pen 2	Pen 3
Native						
Carex aperta	648	520	296	--	72	148
Non-native						
Phalaris arundinacea	20	248	220	640	568	408
Bidens cernua	--	--	--	8	3	--
misc. unknown	--	--	4	108	1	--

Table 43. Initial and final measurements of fork length (FL), and weight for fish deployed during the growth experiments at Multnomah Channel Marsh in natural emergent vegetation and reed canarygrass in 2015.

			Fish growth 2015					
			Natural emergent vegetation					
			Pen 1		Pen 2		Pen 3	
Date of net pen deployment (2015)		n	Fork length (mm)	Weight (g)	Fork length (mm)	Weight (g)	Fork length (mm)	Weight (g)
3 Apr	Initial	30	60.5	2.0	60.7	2.0	60.5	1.9
	Final	0	–	–	–	–	–	–
17 Apr	Initial	30	65.8	2.4	65.0	2.4	64.0	2.3
	Final	30	72.7	4.0	71.1	3.7	70.5	3.5
1 May	Initial	30	72.5	3.4	73.0	3.6	70.0	3.2
	Final	0	–	–	–	–	–	–
			Reed canarygrass					
			Pen 1		Pen 2		Pen 3	
		n	Fork length (mm)	Weight (g)	Fork length (mm)	Weight (g)	Fork length (mm)	Weight (g)
3 Apr	Initial	30	62.5	2.2	62.2	2.1	63.4	2.3
	Final	24	66.3	2.8	65.6	2.8	67.0	3.0
17 Apr	Initial	30	67.1	2.7	66.0	2.6	67.5	2.7
	Final	28	71.6	3.7	71.3	3.6	71.8	3.6
1 May	Initial	30	68.4	2.9	72.0	3.4	71.0	3.3
	Final	0	–	–	–	–	–	–

2016—Native vegetation cover was dominated by Columbian sedge (5-45%), an unknown knotweed *Polygonum* spp. (1-41%), and bare ground (35-78%). Non-native cover consisted almost entirely of reed canarygrass (70-88%) and bare ground (12-30%; Figure 49). Native habitat was more diverse and contained no reed canarygrass. However, some unknown species were likely non-native, and these comprised a high proportion of the overall plant density in two of the four pen locations (Table 44).

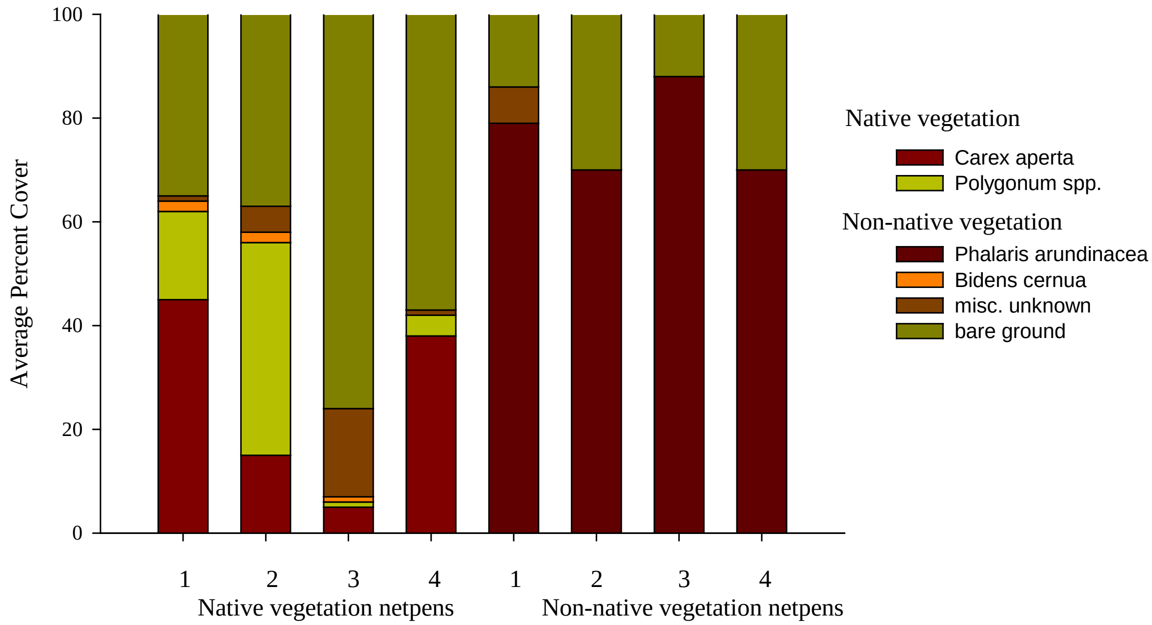


Figure 49. Average percent cover by species for areas beneath the net-pens used for the native and non-native vegetation growth experiments, 2016.

Table 44. Plant density expressed as stem count/m^2 for net-pens located in native and non-native vegetation habitats and used for growth experiments, 2016.

	Plant density 2016							
	Native vegetation (stem/m^2)				Non-native vegetation (stem/m^2)			
Plant species	Pen 1	Pen 2	Pen 3	Pen 4	Pen 1	Pen 2	Pen 3	Pen 4
Native								
Carex aperta	712	200	48	1,060				
Polygonum spp.	248	664	1.2	56				
Non-native								
Phalaris arundinacea					636	840	1,308	972
Bidens cernua	1.2	28	4					
misc. unknown	176	736	308	32	320			

Of the two net-pen experiments attempted, one was successfully completed, and a total of 81 fish were recovered (Table 45). We successfully recovered fish (n = 77) from both microhabitats during the 28 March deployment. Juvenile Chinook salmon grew an average 9.2 mm and 1.5 g in the natural emergent vegetation (n = 38) and 7.5 mm and 1.1 g in reed canarygrass (n = 39). Unusually low water levels and high temperatures in the marsh exceeded the survival tolerances of the fish by early spring. As a result of these unfavorable conditions, only 4 of 80 fish were recovered from the 11 April deployment.

Table 45. Initial and final counts, fork length (FL), and weight of fish deployed during growth experiments at Multnomah Channel Marsh in natural emergent vegetation and reed canarygrass in 2016.

	Fish growth 2016									
	Natural emergent vegetation									
Date of net pen deployment		Pen 1		Pen 2		Pen 3		Pen 4		
	N	FL (mm)	Wt (g)	FL (mm)	Wt (g)	FL (mm)	Wt (g)	FL (mm)	Wt (g)	
28 Mar										
Initial	40	63.0	2.4	64.0	2.6	64.0	2.5	65.0	2.7	
Final	38	72.1	3.8	72.8	3.9	73.3	4.1	74.7	4.4	
11 Apr										
Initial	40	65.0	2.6	63.0	2.3	64.0	2.5	66.0	2.7	
Final	2	–	–	65.0	2.7	–	–	–	–	
	Reed canarygrass									
		Pen 5		Pen 6		Pen 7		Pen 8		
	N	FL (mm)	Wt (g)	FL (mm)	Wt (g)	FL (mm)	Wt (g)	FL (mm)	Wt (g)	
28 Mar										
Initial	40	65.0	2.7	64.0	2.5	66.0	2.8	65.0	2.7	
Final	39	72.5	3.8	72.1	3.7	73.9	4.1	71.7	3.7	
11 Apr	40	65.0	2.6	63.0	2.4	64.0	2.6	64.7	2.6	
Initial	2	66.0	2.7	–	–	–	–	68.0	3.6	
Final										

Prey Resources

Methods

In 2015 and 2016, we used a combination of fallout and emergence traps to compare prey composition and density associated with natural emergent vegetation vs. reed canarygrass. We deployed four fallout traps in areas dominated by natural vegetation and five in areas dominated by reed canarygrass in the south pond (Figure 36).

In natural vegetation, we placed two fallout traps in representative deep-water habitat (~0.5–2 m) near net-pens in the main pond and two near the south pond breach site. In reed canarygrass habitats, we placed two replicate traps in deep water near the pens and three in shallow water (<0.5 m) near the edge of the pond. Two emergence traps were deployed adjacent to fallout traps in each of the deep-water natural vegetation sites and in the deep-water and shallow-water reed canarygrass habitats.

Fallout traps consisted of plastic floating bins (58.4 × 41.3 cm) filled with a few centimeters of water and biodegradable soap to capture terrestrial invertebrates, adult insects, and other prey items that may fall into the traps (Gray et al. 2002). We sampled fallout traps twice per month from late March through June. Emergence traps were placed on the surface of the pond next to the fallout traps to sample emerging invertebrates (e.g., Chironomidae). Emergence traps, enclosing a basal area of approximately 0.25 m^2, collect invertebrates as they emerged from the aquatic to terrestrial environment (Brown 2009).

We sampled emergence traps twice per month from April through June in both years. Each fallout and emergence trap was deployed for approximately 48 h. Upon retrieval, we sieved the samples (#250; 0.063 mm) and stored the contents in non-denatured ethanol (95% ethanol) for future laboratory analysis. A dissecting microscope was used to identify invertebrates to the lowest taxonomic level feasible, typically family.

Invertebrate fallout and emergence-trap counts were converted to densities/m^2 over 48 h. Taxa found in less than 5% of all samples were removed from analysis. We log-transformed data to reduce variation prior to producing a resemblance matrix and using a Bray-Curtis coefficient to determine similarity between species in the samples (Clarke and Warwick 2001). We then used the analysis of similarity (ANOSIM) to test the invertebrate assemblage differences throughout the sampling season and between microhabitats. To test total insect density and density of specific prey groups between reed canarygrass and natural emergent vegetation, we used the nonparametric Kruskal-Wallis test ($\alpha = 0.05$).

In both years, we sorted invertebrates into the following taxonomic groups for analysis: Arachnida, Chironomidae, Collembola, Coleoptera, Diptera, Hemiptera, Hymenoptera, and Other Insects. The Diptera category included a number of juvenile Chinook salmon prey, such as Ceratopogonidae, Ephydridae and Psychodidae, with Ephydridae being the most abundant.

Results

2015—A total of 53 fallout and 47 emergence trap samples were collected in 2015. Due to high wind and rain, a few fallout traps were flooded and could not be used. From those retrieved, we collected a total of 42 insect and other invertebrate taxa (Table 46).

Individuals from the order Thysanoptera were not identified to family. Additional non-insect prey resources were collected from three orders: Collembola (springtails), Malacostraca (amphipods and isopods), and Arachnida (spiders and mites). The most dominant taxa from both trap types included Chironomidae and other Diptera (Figure 50). Fallout traps collected a higher abundance and diversity of flying and terrestrial insects. Invertebrate densities generally increased through the sampling season, peaking in late April-June and dropping to lowest levels in March (Figure 51).

For invertebrates captured in emergence traps, average total density was 156 ±20/m^2 for natural vegetation and 221 ±41/m^2 for reed canarygrass habitats. For invertebrates captured in fallout traps average total density was 649 ±115 and 641 ±73/m^2 for natural vegetation and reed canarygrass habitats, respectively (Table 47).

Results showed little to no variation between habitats, but did exhibit significant seasonal differences. In fallout traps, the largest contributors to dissimilarity between reed canarygrass and natural emergent vegetation were Collembola and Chironomidae, as well as Ephydridae and Acari (ticks and mites). Differences in density between habitats were greater among invertebrates caught in fallout traps than emergence traps, particularly in natural vegetation, where very high Chironomidae densities were observed in April and May.

For specific taxa, statistically significant differences between habitats were observed from fallout trap deployments on 22 April, 6 May, 22 May, and 5 June. From fallout traps deployed on 22 April, average Chironomidae density was 740 ±245/m^2 in the natural vegetation and 382 ±83/m^2 in the reed canarygrass habitat (Kruskal-Wallis P = 0.03). Additionally, the total density of invertebrates collected in fallout traps on 22 April was significantly higher in the natural vegetation (Kruskal-Wallis P = 0.03).

Table 46. Invertebrate taxa collected in 2015 from the fallout traps, emergence traps, and stomach contents at Multnomah Channel Marsh and prey grouping for the invertebrate and diet analysis.

Subclass	Order	Family/superfamily	Invertebrate trap grouped taxa	PSIRI grouped taxa
Class Arachnida				
	Araneae		Arachnida	Other
Acari			Arachnida	Other
Class Branchipoda				
	Cladocera		–	Copepoda/ Cladocera
Class Collembola				
	Entomobryo-morpha		Collembola	Other
	Symphypleona		Collembola	Other
Class Insect				
Pterygota	Coleoptera	Carabidae	Coleoptera	Other Insect
		Chrysomelidae	Coleoptera	–
		Coccinellidae	Coleoptera	–
		Curculionidae	Coleoptera	–
		Hydraenidae	Coleoptera	–
		Hydrophilidae	Coleoptera	–
		Staphylinidae	Coleoptera	–
	Diptera	Cecidomyiidae	Diptera	–
		Ceratopogonidae	Diptera	Diptera
		Ceratopogonidae Pupa	–	–
		Chironomidae	Chironomid	Chironomid
		Chironomidae Pupa	–	Chironomid Pupa
		Chironomidae Larvae	–	Chironomid Larvae
		Chloropidae	Diptera	–
		Culicidae	Diptera	–
		Dolichopodidae	Diptera	–
		Drosophilidae	Diptera	–
		Ephydridae	Diptera	Ephydridae
		Psychodidae	Diptera	–
		Sarcophagidae	Diptera	–
		Scathophagidae	Diptera	–
		Sciaridae	Diptera	Diptera
		Sciomyzidae	Diptera	–
		Sepsidae	Diptera	–
		Sphaeroceridae	Diptera	–
		Tachinidae	Diptera	–
		Tipulidae	Diptera	–
	Hemiptera/ Homoptera	Aphidoidea (superfamily)	Hemiptera	Other Insect
		Belostomatidae	Hemiptera	–
		Cicadellidae	Hemiptera	–
		Corixidae	Hemiptera	Other Insect
		Delphacidae	Hemiptera	–
		Hydrometridae	Hemiptera	–
	Hymenoptera	Braconidae	Hymenoptera	Other Insect
		Chalcididae	Hymenoptera	–
		Eulophidae	Hymenoptera	–
		Formicidae	Hymenoptera	Other Insect
		Mymaridae	Hymenoptera	Other Insect
	Odonata	Coenagrionidae	Other	–
	Thysanoptera		Other	Other Insect
	Trichoptera	Limnephilidae	Other	Other Insect
Eumalacostraca	Amphipoda		–	Other
	Isopoda		–	Other

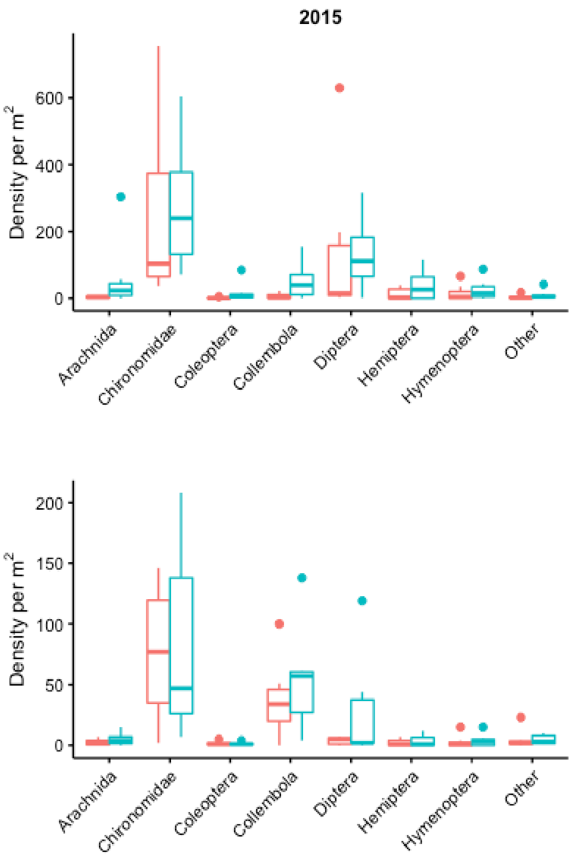


Figure 50. Average trap densities (per m^2) for grouped taxa collected at Multnomah Channel Marsh over 48 hours from fallout traps (top) and emergence traps (bottom) in natural emergent vegetation (pink) and in reed canarygrass (blue). Ephydridae were the most abundant Diptera collected.

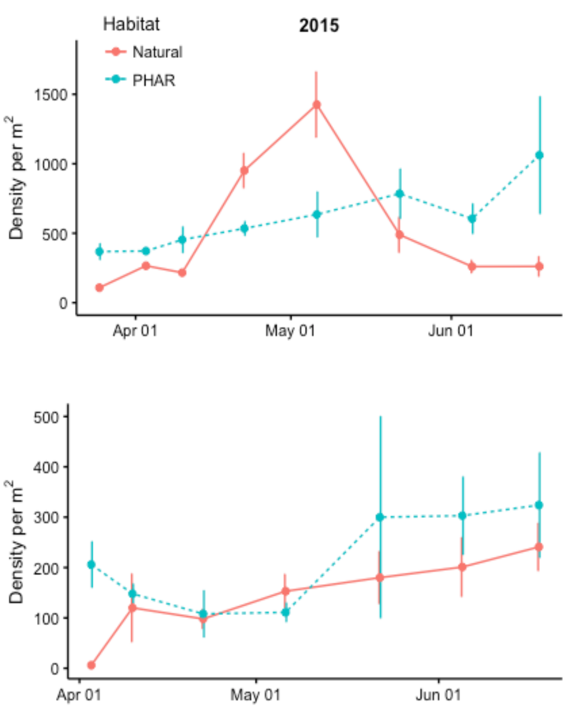


Figure 51. Average total densities (per m^2) of invertebrates collected from fallout (top) and emergence traps (bottom) set for 48 h in both natural emergent vegetation and reed canarygrass (PHAR) habitats of the Multnomah Channel Marsh south pond. Standard error bars are not included for dates that only included one sample.

Conversely, in the May and June samples, there was a significantly greater density of Chironomidae and Diptera in reed canarygrass samples (Kruskal-Wallis $P = 0.05$). The density of Collembola was significantly greater for fallout traps in reed canarygrass than for those in natural emergent vegetation in (Kruskal-Wallis $P = 0.02$), but few differences were detected for other taxa.

Table 47. Average density of grouped taxa and the total invertebrates collected in fallout and emergence traps at Multnomah Channel Marsh from 2015 in both reed canarygrass (PHAR) and natural emergent vegetation. Ephydridae were the most common Diptera collected. SD = standard deviation; SE = standard error.

Habitat/trap	Arachnid	Chironomid	Collembola	Coleoptera	Diptera	Hemiptera	Hymenoptera	Other	Total
Reed canarygrass (PHAR)									
Fallout	35	272	54	20	161	52	30	17	641
SD	52	186	108	50	176	76	33	30	408
SE	9	33	19	9	32	14	6	5	73
Emergence PHAR	6	98	62	1	33	4	5	10	221
SD	9	130	79	2	82	7	7	17	201
SE	2	27	16	0	17	1	1	4	41
Natural emergent vegetation									
Fallout	6	389	10	2	193	19	24	7	649
SD	5	334	14	3	283	26	39	9	525
SE	1	73	3	1	62	6	8	2	115
Emergence	3	89	44	2	4	3	4	7	156
SD	5	70	47	3	6	6	7	12	100
SE	1	14	10	1	1	1	1	2	20

2016—Twelve samples of each trap type were collected in 2016. A total of 27 insect and other invertebrate taxa were collected (Table 48). Individuals from Thysanoptera were not identified to family. Non-insect prey resources were collected from three orders: Collembola, Malacostraca, and Arachnida. The most dominant taxa from the traps included Chironomidae and other Diptera, primarily Ephydridae (Figure 52). Fallout traps collected a higher abundance and diversity of flying and terrestrial insects.

Invertebrate density generally increased throughout the sampling season, with peaks in late April/early May and the lowest abundance in April (Figure 53). The average total density of invertebrates in the natural emergent vegetation and in reed canarygrass was 145 ±37 m^2 and 242 ±45 m^2, respectively, and for the fallout traps was 719 ±158 m^2 and 521 ±115 m^2, respectively (Table 49).

Although, little or no variation in invertebrate density was observed between habitats, densities differed for some taxa. The largest contributors to dissimilarity were Collembola and Chironomidae, as well as Ephydridae and Acari in the fallout traps. The density of Collembola was significantly greater in emergence traps in reed canarygrass (Kruskal-Wallis $P = 0.02$). Additionally, fallout traps in reed canarygrass had a slightly greater, though not statistically different, density of Hymenoptera compared to those in the natural vegetation.

Table 48. Invertebrate taxa collected in 2016 from fallout traps and emergence traps with stomach contents at Multnomah Channel Marsh and prey grouping for invertebrate and diet analyses.

Class	Subclass	Order	Family/ Superfamily	Invertebrate Trap Grouped Taxa	PSIRI Grouped Taxa
Arachnida					–
		Araneae		Arachnida	
	Acari			Arachnida	–
Branchipoda					
		Cladocera		–	Copepoda/ Cladocera
Collembola					
		Entomobryo-morpha		Collembola	–
		Symphypleona		Collembola	–
Insect					
	Pterygota	Coleoptera	Carabidae	Coleoptera	Other insect
			Curculionidae	Coleoptera	–
			Hydrophilidae	Coleoptera	–
			Staphylinidae	Coleoptera	–
		Diptera	Cecidomyiidae	Diptera	–
			Ceratopogonidae	Diptera	–
			Chironomidae	Chironomid	–
			Chironomidae pupa	–	Chironomid pupa
			Chironomidae larvae	–	Chironomid larvae
			Dolichopodidae	Diptera	–
			Ephydridae	Diptera	Ephydridae
			Psychodidae	Diptera	–
			Sciaridae	Diptera	–
			Sphaeroceridae	Diptera	–
			Tipulidae	Diptera	–
		Hemiptera/ Homoptera	Aphidoidea (superfamily)	Hemiptera	–
			Cicadellidae	Hemiptera	–
			Delphacidae	Hemiptera	–
		Hymenoptera	Braconidae	Hymenoptera	Other Insect
			Chalcididae	Hymenoptera	–
			Eulophidae	Hymenoptera	–
			Mymaridae	Hymenoptera	Other Insect
		Odonata	Coenagrionidae	Other	–
		Thysanoptera		Other	–
		Trichoptera	Limnephilidae	Other	–
Malacostraca					
	Eumalacostraca	Amphipoda		–	Other
		Isopoda		–	Other

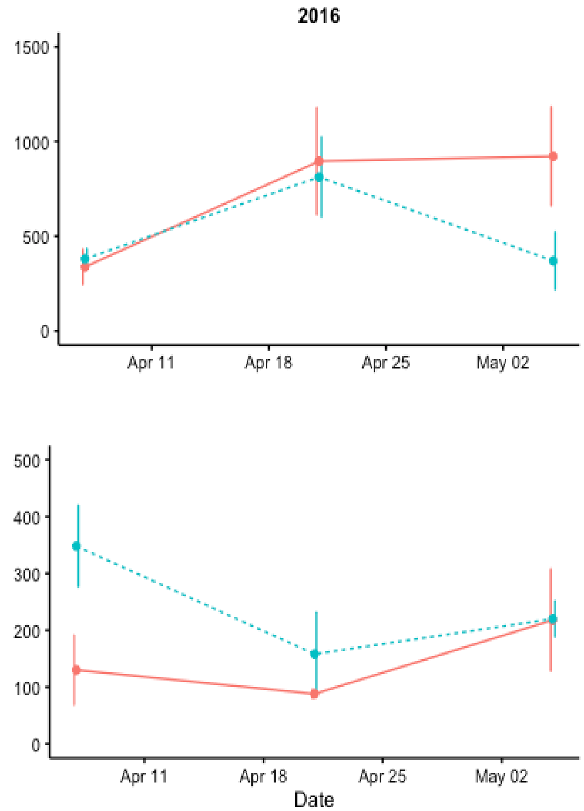


Figure 52. Average trap densities (per m^2) for grouped taxa collected at Multnomah Channel Marsh over 48 h from fallout traps (top) and in emergence traps (bottom) in natural emergent vegetation and in reed canarygrass (PHAR). Ephydridae were the most abundant Diptera collected.

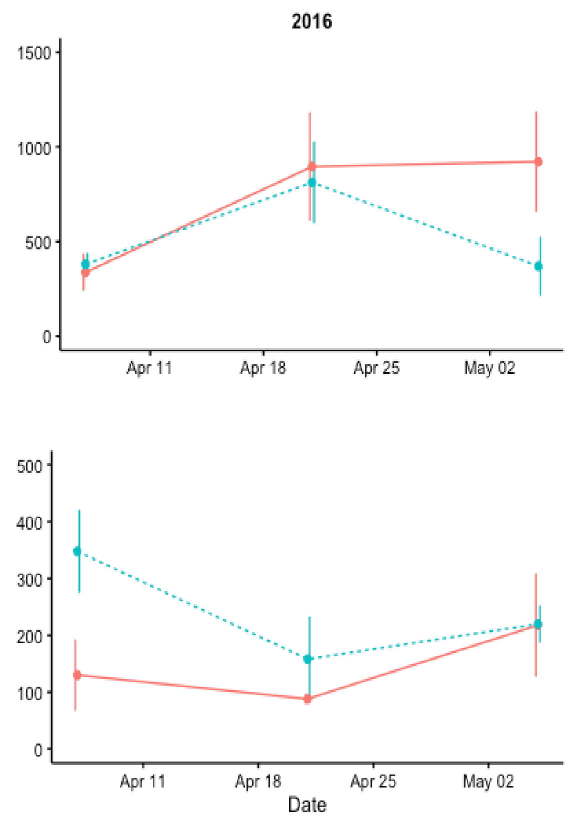


Figure 53. Average total densities (per m^2) of invertebrates collected from fallout traps (top) and in emergence traps (bottom) over 48 h in natural emergent vegetation (solid pink) and in reed canarygrass (dotted blue) at Multnomah Channel Marsh. Standard error bars are not included for dates that only included one sample.

Table 49. Average density of grouped taxa and the total invertebrates collected in fallout and emergence traps at Multnomah Channel Marsh from 2016 in both reed canarygrass (PHAR) and natural emergent vegetation. Ephydridae were the most common Diptera collected. SD = standard deviation; SE = standard error.

Trap	Arachnid	Chironomid	Collembola	Coleoptera	Diptera	Hemiptera	Hymenoptera	Other	Total
				Reed canarygrass (PHAR)					
Fallout	1	370	9	4	129	1	6	2	521
SD	2	140	5	4	142	2	2	3	282
SE	1	57	2	2	58	1	1	1	115
Emergence	3	12	210	3	3	3	1	7	242
SD	5	12	94	5	5	5	2	9	110
SE	2	5	39	2	2	2	1	4	45
				Natural emergent vegetation					
Fallout	2	477	12	2	205	7	3	12	719
SD	3	189	16	3	208	9	3	22	388
SE	1	77	6	1	85	4	1	9	158
Emergence	2	23	61	1	43	9	0	7	145
SD	2	30	44	2	75	13	0	7	91
SE	1	12	18	1	31	6	0	3	37

Salmon Diets

Methods

Fish samples for stomach content analyses were available from net-pen experiments in 2015 and 2016 only, since no fish survived net-pen holding in 2014. For fish retrieved from net-pens in both years, we removed partially thawed stomachs in the lab and placed them in a 10% buffered formalin solution for 2-3 weeks. Stomachs were then transferred into non-denatured ethanol (95%). For dissection, we removed stomach contents and identified prey to the lowest possible taxonomic level using a dissecting microscope. After sorting and counting, the blotted wet weight (mass to nearest 0.0001 g) was recorded for each prey taxa.

All taxa were sorted into the following taxonomic groups for analysis: Amphipoda, Arachnida, Chironomidae Larvae, Chironomidae Pupa, Chironomidae Adult, Diptera (e.g., Ceratopogonidae), Ephydridae, Hemiptera, Hymenoptera, Other Insects, and Copepoda/Cladocera. Diets were compared using the nonparametric Kruskal-Wallis test ($\alpha = 0.05$), ANOSIM, and the prey specific index of relative importance (%PSIRI). This index identifies the relative importance of different prey taxa found in diets and is based on frequency of occurrence and percent numerical and gravimetric composition (Cortes 1997; Brown et al. 2012):

$$\%\text{PSIRIi} = \frac{\%\text{FOi} \times (\%\text{PNi} + \%\text{PWi})}{2},$$

where %FOi is percent frequency of occurrence of each prey taxa, %PNi is prey-specific numeric proportion of each prey, and %PWi is prey-specific gravimetric proportion of each prey. The calculated value for each taxon represents the percentage of the total PSIRI for all prey. Instantaneous ration (*I*) was calculated for each sample collected (David et al. 2014), as a measure of stomach fullness.

$$I = \frac{\text{stomach content mass}}{\text{total body mass} - \text{stomach content mass}} \times 100$$

We used the Kruskal-Wallis test to compare stomach fullness between fish in the microhabitats each year.

Results

2015—In 2015, diets of juvenile salmon recovered from net-pen experiments contained prey from 21 insect and other invertebrate taxa (n = 80; 2 empty). Copepoda/Cladocera were most frequently consumed, with %FO ranging 61-100% (Table 50). Chironomidae adults and Ephydridae were the next most frequently consumed prey taxa, with respective %FOs ranging 18-74 and 22-73%.

Table 50. Frequency of occurrence (%FO), numeric proportion of prey (%PNi), gravimetric proportion of prey (%PWi), and prey-specific index of relative importance (%PSIRI) for grouped taxa found in the diets of juvenile Chinook salmon reared in natural emergent vegetation and in reed canarygrass (PHAR) during the 2015 net-pen experiments at Multnomah Channel Marsh.

		Juvenile Chinook diets, 2015			
N	Grouping	%FO	%PNi	%PWi	%PSIRI
	Reed canarygrass 13 April 2015				
23	Other	17.4	7.4	5.5	1.1
	Chironomidae larvae	47.8	5.5	1.9	1.8
	Chironomidae pupa	60.9	20.4	53.2	22.4
	Chironomidae	73.9	32.6	37.8	26.0
	Diptera (other)	26.1	16.3	11.4	3.6
	Ephydridae	73.9	20.7	28.8	18.3
	Copepoda/Cladocera	60.9	63.3	15.9	24.1
	Other Insect	13.0	11.8	29.8	2.7
	Natural emergent vegetation 27 April 2015				
30	Other	6.7	0.9	10.9	0.4
	Chironomidae larvae	3.3	1.4	2.5	0.1
	Chironomidae pupa	10.0	2.2	11.7	0.7
	Chironomidae adult	46.7	5.1	8.7	3.2
	Dipteran (other)	3.3	0.0	14.0	0.2
	Ephydridae	53.3	26.5	47.8	19.8
	Copepoda/Cladocera	93.3	87.0	65.9	71.3
	Other Insect	16.7	11.3	39.0	4.2
	Reed canarygrass 27 April 2015				
27	Other	7.4	1.9	7.7	0.4
(1 empty)	Chironomidae larvae	14.8	1.2	0.7	0.1
	Chironomidae pupa	7.4	1.3	12.8	0.5
	Chironomidae adult	18.5	2.3	2.8	0.5
	Diptera (other)	7.4	4.9	7.9	0.5
	Ephydridae	22.2	9.2	32.6	4.6
	Copepoda/Cladocera	100.0	96.3	84.5	90.4
	Other Insect	18.5	2.5	29.6	3.0

For all other taxa, the prey specific index of relative importance (PSIRI) ranged from <1 to 22%. The highest diversity and abundance of important prey, namely Chironomidae, Ephydridae, and Diptera, were found during the first experiment in reed canarygrass only. Temperatures, prey availability, growth, and stomach fullness were lower for fish retrieved from the first deployment than for those retrieved from the later deployment.

Some differences by habitat were observed between fish recovered from reed canarygrass vs. natural vegetation on 27 April 2015. From this deployment, fish reared in reed canarygrass consumed significantly more Copepoda/Cladocera (Kruskal-Wallis P = 0.003), but significantly less Chironomidae (Kruskal-Wallis P = 0.02) and Ephydridae (Kruskal-Wallis P = 0.01).

2016—In 2016, diets of juvenile Chinook salmon collected from net-pens contained prey from 10 insect and other invertebrate taxa (n = 78; 3 empty). Copepoda/Cladocera were most frequently consumed, with an average %FO of 99% for the combined habitat types (Table 51). For all other taxa, %PSIRI ranged from <1 to 3%.

Table 51. Frequency of occurrence (FO), numeric proportion of prey (PNi), gravimetric proportion of prey (PWi), and prey specific index of relative importantce (PSIRI) for grouped taxa found in the diets of juvenile Chinook salmon. Fish were reared in natural emergent vegetation and in reed canarygrass (PHAR) and sampled on 7 April 2016 from net-pens in Multnomah Channel Marsh.

	Juvenile Chinook diets, 2016			
Grouping	%FO	%PNi	%PWi	%PSIRI
Reed canarygrass (n = 37)				
Other	8.1	44.8	85.0	5.3
Chironomidae larvae	10.8	3.2	1.7	0.3
Chironomidae pupa	8.1	9.9	26.8	1.5
Chironomidae adult	0.0	0.0	0.0	0.0
Diptera (other)	0.0	0.0	0.0	0.0
Ephydridae	0.0	0.0	0.0	0.0
Cladocera/Copepoda	97.3	95.2	90.1	90.1
Other Insects	10.8	24.1	28.8	2.9
Natural emergent vegetation (n = 37)				
Other	5.4	2.7	21.8	0.7
Chironomidae larvae	0.0	0.0	0.0	0.0
Chironomidae pupa	8.1	2.3	4.9	0.3
Chironomidae adult	0.0	0.0	0.0	0.0
Diptera (other)	0.0	0.0	0.0	0.0
Ephydridae	0.0	0.0	0.0	0.0
Cladocera/Copepoda	100.0	99.5	97.5	98.5
Other Insects	2.7	5.0	33.3	0.5

Diet composition varied slightly between habitats, primarily due to Copepoda/Cladocera and Ephydridae. In reed canarygrass, fish consumed significantly more Chironomidae larvae (Kruskal-Wallis $P = 0.04$) and less Copepoda/Cladocera, but diets did not contain a variety of prey. The four fish collected on 21 April 2016 contained significantly more Amphipoda than the samples from the previous date (Kruskal-Wallis $P < 0.001$), but contained fewer other taxa.

Discussion

Results of this study and of other studies (Baker 2008; Teel et al. 2009) support the conclusion that floodplain wetlands in the tidal-fluvial Columbia River can provide highly productive off-channel rearing habitat for juvenile salmon. Yet few salmon realized such benefits for the flow conditions that occurred during this study, despite efforts to improve connectivity to the floodplain and between the north and south ponds.

Water control structures are used to artificially inundate these wetlands to control reed canarygrass. However, these structures also restricted salmon access to and from the marsh and severely reduced water quality during spring. They also created habitat conditions most conducive to the production of non-native, predatory fish species.

Our captive rearing experiments suggested that control of reed canarygrass and improved production of native wetland vegetation could enhance floodplain-wetland capacity to rear juvenile salmon, particularly in early spring. However, after water control structures are closed, their benefit in controlling reed canarygrass is outweighed by the loss of passage routes for fish to access marsh ponds and by the decline in water quality conditions beyond thresholds where fish could survive in these ponds.

Rearing opportunities in these wetland ponds may be somewhat greater during winter, particularly for juvenile coho salmon, provided river flows are sufficient. Fish can enter through the north and south pond outlets before water control structures are closed or through the recently constructed breaches in the barrier berm. However, additional management strategies for the MCM will be needed if the objective is to both control reed canarygrass and provide off-channel rearing habitat during the peak spring migration of Columbia River salmon.

In 2015 the region experienced an historic low-flow year. Springtime water elevations in Multnomah Channel never reached sufficient levels to overtop the new breaches in the barrier berm. However, during December 2015 there was a rain-driven high water event that provided brief hydrologic connection between the Multnomah Channel and marsh. During this time, we observed increased numbers of juvenile coho salmon in the marsh. These observations suggested that juvenile coho salmon had accessed the site via the breaches, although water control structures were open at the time and could not be ruled out as the access point.

We continued sampling in 2016 to determine if high water during the main migration season would provide access for juvenile Chinook salmon, but the river height remained below the 10.7 ft inundation threshold. We also collected water quality data and other data helpful in determining whether the ponds provide suitable rearing habitat for juvenile salmon, should natural flows rise sufficiently to inundate the floodplain.

Fish communities in the marsh ponds remained generally the same during all three study years. Of fish species caught, the most common by far were native threespine stickleback and non-native brown bullhead. Cyprinidae and Centrarchidae were the most common families. We also caught many non-native fishes, such as largemouth bass, that likely prey on or compete with native fishes.

The greatest diversity and evenness of native species occurred during February or March, based on population structure indices. Each year, we observed declines in the community structure of the native species as water quality deteriorated in the spring and early summer. Most fish species caught in ponds were pollution tolerant. The overall percentage of native species in our catch was somewhat higher in 2015 and 2016 than in 2014. However, the restoration work did not seem to affect the resident fish community in the ponds.

Abundance of salmonids in the ponds was consistently low throughout the study period. We observed some differences in the numbers of juvenile Chinook and coho salmon caught from year to year. This study and other previous work at the site demonstrates that juvenile salmonids from other areas will enter these ponds for rearing, before they migrate as smolts. Our sampling in December 2015, found juvenile coho salmon will enter the ponds through the breaches to access rearing habitat. Unfortunately, water levels in the river were too low to fully evaluate passage after the restoration work was complete.

The wetland tributaries provided good aquatic habitat used almost exclusively by native species. An apparently self-sustaining population of native cutthroat trout was present in these streams year round. The few non-native fishes caught were downstream of the Highway 30 culvert close to the ponds, although this part of Patterson Creek still supported many native species, including cutthroat trout. Patterson Creek has some spawning habitat suitable for coho salmon, if fish passage can be improved. In addition, some cutthroat trout may migrate from the tributaries to the estuary seasonally, if passage is available.

Columbia River and Multnomah Channel had very similar fish communities during the three years of this study and compared to previous studies in the vicinity (Teel et al. 2014). Native fish species (e.g., Chinook salmon, threespine stickleback) were most common in the Columbia River and moved from the area in the spring and as temperatures increased. Non-native fish species were always present in Multnomah

Channel and remained abundant when temperatures were high. The north and south ponds were almost entirely composed of non-native fish, some of which appeared to successfully produce new recruits. The predatory nature of these non-native fish species combined with the warm water temperatures likely prevents fish such as salmon from successfully using the ponds as safe habitat.

PIT-tag detection data from groups of tagged Chinook salmon released into the north and south ponds demonstrate that the water control structures impede egress from the MCM and prevent juveniles from completing their seaward migration. The surface-oriented fish passageway of the south water control structure was especially problematic, even when the riser boards were monitored and adjusted to provide constant flow for fish passage. The fish passageway at the north water control structure, which is at a depth of six to eight feet depending on water levels, was seemingly more efficient at passing juvenile Chinook salmon.

The water control structures also limit the exchange of water with Multnomah Channel, limiting water quality within the ponds. Poor exchange could also impede the export of prey and organic matter from the MCM, which might otherwise benefit fish production in Multnomah Channel or other areas of the tidal-fluvial estuary (e.g., Eaton 2010; Klopfenstein 2016). Beginning in mid-May, water temperatures were consistently above 19°C, a threshold at which juvenile Chinook salmon will avoid shallow-water habitat (Bottom et al. 2011), and by late March, dissolved oxygen began to drop to lethal levels.

Water quality of the ponds was so severe that in both 2015 and 2016 Chinook salmon used in growth trials that began in mid-April or later died as a result of exposure to the conditions in the south pond. It is also likely that poor water quality contributed to the low detection rate and poor passage of juvenile salmon through the water control structures. If river levels rise sufficiently to sustain a wetland connection between Multnomah Channel and the MCM, the water quality may improve with the influx of fresh water, but if levels drop thereafter, many salmon could be trapped, especially in the south pond.

While the MCM ponds may not provide usable habitat for juvenile salmon during peak migration, access to the habitat is beneficial other times of the year. During the late-fall through early winter, juvenile coho salmon entered through the open WCSs and overwintered in the ponds. During February and March 2014 and 2015, Willamette River spring Chinook salmon were detected on the PIT arrays in the pond outlets. However, closure of the WCSs prevented the Willamette stock from accessing the wetland.

Likewise, closing the south WCS in 2016 prevented most of the coho salmon that overwintered from continuing their migration. In the south pond, most tagged coho salmon (83%) attempted to pass the south WCS but only a select few (17%) actually passed and exited to Multnomah Channel. Because the north water control structure remained open for the season, most (77%) coho salmon tagged in the north pond successfully exited to Multnomah Channel.

We measured a high abundance of invertebrate prey and documented active feeding and positive growth by captive Chinook salmon, regardless of vegetation type, indicating that even wetlands dominated by reed canarygrass may provide some foraging opportunities for juvenile salmon. However, experimental trials in April 2015 and March-April 2016 demonstrated growth rates were higher for salmon confined in native emergent vegetation compared with salmon held in areas dominated by reed canarygrass. This growth discrepancy was consistent despite little difference in total abundance and diversity of invertebrate prey supported by each vegetation type. Further analysis of growth data indicate a significant difference in growth between the two habitat types (Klopfenstein 2016).

A number of qualitative differences between vegetation types may account for the observed salmon growth discrepancy. During early spring months, more rapid vegetative growth may have reduced the effective rearing volume for captive salmon confined in beds of reed canarygrass compared with fish held in the more sparsely vegetated areas dominated by native wetland plants. Moreover, the energy densities of available prey taxa varied seasonally by vegetation type.

In April 2015, fish diets in the native vegetation had a higher proportion of Chironomidae, a preferred salmon prey taxa with an energy density ~2.7 times greater than that of Copepoda/Cladocera, the dominant prey of salmon held at the reed canarygrass sites (Klopfenstein 2016). Although this and other studies (Hanson et al. 2016) suggest that reed canarygrass is a good producer of Collembola (relative to native wetland vegetation), this taxon is not an important prey resource for juvenile Chinook salmon (Bieber 2005). Overall, spring-migrating salmon in the Columbia River may not fully benefit from floodplain wetlands dominated by reed canarygrass if the seasonal peak in prey production coincides with stressful water conditions and if the prey produced earlier in the spring are of lesser quality for salmon foraging and growth.

Conclusions and Recommendations

Endangered species such as juvenile salmon need access to high-quality habitat where they can rear, forage and seek refuge from predators and adverse conditions such as high flow events. This study shows that at present, the MCM provides foraging opportunities for salmon, but only if they have access to the site. When closed, the water control structures limit access to habitat, promote non-native predatory fish species, and lead to poor water quality.

Restoration breaches have provided improved access to the site during high flow events, and once salmon have entered the site they have access to highly productive habitat. However, salmon within the MCM are also exposed to predatory fish, low dissolved oxygen, and high water temperatures, and without a feasible return route to Multnomah Channel. At a minimum, changes are needed to the operation of water control structures to improve the usefulness of the MCM for salmon. Complete hydrologic reconnection of the MCM to Multnomah Channel through removal of WCSs remains the best option for restoring wetland function and supporting juvenile salmon.

Present management of water control structures encourages non-native predatory fish species, fosters poor water quality, and blocks salmon egress. These outcomes effectively negate any advantage derived from foraging and rearing opportunities. With best management practices for salmon in mind, we offer several alternative management strategies below.

Remove Water Control Structures

The most effective way to support the foraging, rearing, and refuge needs of juvenile salmon is to return the habitat to its natural state so that it can function more like a wetland. Restored hydrologic connectivity with Multnomah Channel through removal of water control structures will improve water quality, reduce habitat favorable to non-native predatory fish, afford salmon increased access to highly productive foraging and rearing grounds, allow the export of organic materials to support external food webs, and enable juvenile salmon to continue their seaward migration. Allowing the MCM to function as a natural wetland is the most enduring mechanism to support the needs of migrating juvenile salmon.

Deepen and Broaden the Restoration Breaches

Increased hydrologic connectivity with Multnomah Channel will improve conditions for salmon within the MCM. Lowering the breaches to elevations that allow more frequent inundation during peak the peak migration periods of juvenile salmon will improve water quality and increase the opportunity for access to productive habitat. However, water control structures would still provide habitat for non-native predatory fish, contribute to poor water quality, and impede juvenile salmon migration. We recommend lowered breach elevations in conjunction with one of the alternative management options for WCSs listed below.

Alternative Management of Water Control Structures

Realizing that complete removal of water control structures would require additional planning, design, and construction costs, we offer these options for WCS management.

Open Both Water Control Structures Year-Round

This option would improve the hydrologic connection between Multnomah Channel and Marsh, increase salmon access to the marsh, improve water quality, reduce habitat for non-native fish species, and allow juvenile salmon to exit the marsh. However, these improvements may not be as substantial as improvements realized from removing water control structures. With WCSs remaining in place, water exchange will still be limited and fish passage delayed.

Open the South WCS Year-Round and Close the North WCS Seasonally

If one water control structure must be closed to provide habitat for amphibians or to control for reed canarygrass, close the north WCS and leave the south WCS open. Juvenile salmon were better able to pass the north WCS under the flow regimes observed in this study.

Conditional Opening of Water Control Structures

If both WCSs are closed seasonally (current management practice) and water from Multnomah Channel flows into the marsh through breaches, then water quality should be monitored in both the north and south MCM ponds twice per week, once waters recede below breach elevations. Once water quality starts to decline (DO $\leq$ 6 mg/L and/or water temperature $\geq$ 19°C) open the WCSs to provide an exit for salmon that have moved into the MCM via breaches.

In hand with these three WCS management strategies, we recommend that portions of the wetland elevation be lowered to expand the area of the MCM that is conducive to recruitment of native vegetation and deters recruitment of reed canarygrass. Recent restoration efforts in the "North Unit" (lower Sauvie Island) have shown some success in modifying site elevations through "scrape down" to create conditions for natural re-establishment of native vegetation. This approach might eliminate the need for water control structures.

Acknowledgments

Funding for this project was provided by Metro. We appreciate the efforts of Sara Akins, Eric Bailey, Alan Gillette, Kersten Schnurle, and Kevin Stertz of the ODFW, who conducted the extensive fish and amphibian surveys in the ponds and streams. We thank the O'Meara family at Wildwood Golf Course for providing access to Crabapple and Patterson Creeks. Thanks also to Kim Jones (ODFW-retired), as well as George McCabe, Jr. and Gordon Rose of Ocean Associates and A. Michelle Wargo-Rub and Jen Zamon of NOAA Fisheries for assistance with fish collections in Multnomah Channel and the mainstem Columbia River. Justin Cooley, Nathaniel Marquiss, Justin Takkunen, and Ariel Whitacre of Metro assisted with the installation and removal of the SWCS and NWCS array. A special thank you to Rick Scrivens (Metro-retired) who helped move gear and get us unstuck with the trusty tractor, and to JoAnne Butzerin who provided a thorough review and edit of this report. References to trade names do not constitute endorsement by NOAA Fisheries, ODFW, or Metro. Curt Zonick of Metro administered the project and provided guidance.

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