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Post-Restoration Larval Lost River Sucker (*Deltistes luxatus*) and Shortnose Sucker (*Chasmistes brevirostris*) use of the Williamson River Delta, Upper Klamath Lake, Oregon.

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The Nature Conservancy

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Introduction

An expansive deltaic marsh at the mouth of the Williamson River, in southcentral Oregon, once existed before the onset of irrigated agriculture in the Upper Klamath Basin. This marsh was historically considered to be one of the most important nursery and rearing habitats for larval and juvenile endangered Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*) (National Research Council 2004). In the 1940s, private landowners finished constructing perimeter and internal levees and converted roughly 6,000 acres of this historic marsh system to cropland and pasture, eliminating connectivity between the wetland ecosystem and the Williamson River, Upper Klamath Lake (UKL), and Agency Lake (AL). The U.S. Fish and Wildlife Service (1993) cited the loss of wetland habitat, specifically larval and juvenile nursery habitat, as one factor that contributed to the decline and subsequent Endangered Species Act listing of these two sucker species. After being identified as a critical site for restoration in the 1990s, The Nature Conservancy (Conservancy) purchased the northern half of the delta in 1996 and the southern portion in 1999. With help from multiple federal, state, and tribal partners, the Conservancy initiated an innovative plan to restore the wetland.

UKL hosts the largest remaining spawning populations of endemic Lost River sucker and shortnose sucker, although remnant spawning populations exist in Clear Lake, California (U.S. Fish and Wildlife Service 1993, Barry et al. 2009). Both species are long-lived, lake dwelling catostomids that make spring spawning migrations in the Williamson River and its largest tributary, the Sprague River, and also spawn at springs along the eastern shore of UKL (Buettner and Scoppetton 1990, Janey et al. 2008). Larval suckers hatched in the Williamson and Sprague rivers emerge from spawning gravels and immediately begin a downstream, passive, nocturnal out-migration towards UKL (Cooperman and Markle 2003). It is believed that historically larvae would use the wetland ecosystem at the mouth of the Williamson River for rearing before it was diked and drained. Wetland habitat and the associated macrophytic vegetation, which was created when the functionality of the marsh system was restored, provide ample growing and feeding opportunities (Crandall et al. 2008), warmer water temperatures during the out-migration period than UKL (Wong et al. 2010), the ability to retain larvae from the clock-wise gyre that dominates surface water currents (Cheng et al. 2005, Markle et al. 2009), and protection from non-native fathead minnow (*Pimephales promelas*) by providing cover and refuge (Markle and Dunsmoor 2007).

In order to gauge the response of larval suckers to wetland restoration at the delta, connectivity to UKL and the Williamson River was restored at two small-scale (< 100 acres) sites at the delta in 2000 and 2003. Larval sucker monitoring from 2000 to 2005 indicated that larvae were extensively using these pilot restoration projects, Riverbend and South Marsh, and the restored habitat provided ample growing and feeding opportunities for sucker larvae (Crandall et al. 2008; Figure 1). To stimulate re-establishment of wetland habitat throughout the remaining area of the delta, the Conservancy removed sections of perimeter and internal levees in the northern half of the delta, Tulana, in 2007 through explosive and mechanical means. The southern half of the delta, Goose Bay, was reconnected to the Williamson River and UKL in 2008 by mechanically removing sections of levee. For a detailed account of the restoration project, see the final construction report (Conservancy 2009). Currently, approximately 2,500 acres of emergent wetland habitat are available for larval and juvenile sucker rearing, with an additional 3,000 acres of open water habitat, similar to conditions in UKL and AL. The two primary goals of wetland restoration at the delta are to improve larval and juvenile sucker rearing habitat and facilitate improvements in water quality in UKL and AL by reducing agriculture return flows from the property and reestablishing natural wetland processes.

With pre-project data already collected at the delta, post-implementation monitoring of larval suckers provides a critical step in understanding the impacts the project has had on the target species and can assist in supplying valuable feedback necessary for adaptive management. The scope of work covered in this report is a continuation of a monitoring program that has been established since 2006. Specific objectives of the program are to:

1. Determine the distribution, abundance, and habitat use of endangered larval suckers at the Williamson River Delta, with a focus on the Tulana and Goose Bay portions of the delta;
2. Determine if other species (native and non-native) are using the restored wetlands;
3. Describe and characterize fish condition (age, size, growth, gut fullness) of larval suckers;
4. Determine how restoration at the delta changes the distribution and patterns of habitat use by larval suckers along Upper Klamath Lake (UKL) shorelines and in South Marsh; and,
5. Build collaborative relationships with scientists and managers across the Upper Klamath Basin to share information and better understand sucker life history dynamics.

This report presents results from the past two years of larval sucker monitoring at the delta, from May 2010 to July 2011. And the results were positive: larval suckers frequent the shallow areas of the restored delta and were more likely to be captured in the restored wetlands than the lakeshore fringe wetlands, which have not undergone any restoration.

Study Area

The Williamson River Delta straddles the last four miles of the Williamson River before it empties into UKL, in southcentral Oregon. Given its proximity to UKL and AL, the delta's hydrology is influenced by the lake's surface elevation, which is regulated by the U.S. Bureau of Reclamation and typically fluctuates between approximately 4,143 feet in the spring and 4,138 feet in the fall. Williamson River flow and wind also dictate how water moves throughout the delta and interact in various combinations that can lead to different replacement rates of water in Tulana and Goose Bay (Wood, in press).

Four restored areas within the delta (Riverbend, Tulana, Goose Bay, and South Marsh) and two lakeshore fringe wetlands along the southern shoreline of Goose Bay (Goose Bay West and Goose Bay East) were sampled in 2010 and 2011 (Figure 1). Because monitoring has been ongoing since 2000 at the two pilot restoration areas and along the Goose Bay shoreline, our post-restoration monitoring focused mainly on quantitatively and qualitatively understanding how larval suckers responded to reconnecting Tulana and Goose Bay to the river and lakes. As a result, descriptions of Tulana and Goose Bay are included below; for detailed descriptions of the habitat available in Riverbend and South Marsh, as well as the areas along the Goose Bay shoreline, see Crandall et al (2008).

At low water levels (~4138-4140 ft), UKL and AL are connected to Tulana via four half-mile openings located around the perimeter. While there are three breaches along the Williamson River on the Tulana side of the Delta, only one serves as a significant pathway for flow at low lake elevations. Substantial soil subsidence due to farming practices has occurred on the western portion of Tulana, resulting in elevations in this area that are as much as eight feet below average lake levels (David Evans and Associates, Inc. 2005). As a result, the western portion of Tulana is now inundated year round and closely resembles the open water conditions of UKL and AL. However, species such as water smartweed (*Polygonum amphibium*) and hardstem bulrush (*Schoenoplectus acutus*) have been documented in this open water portion of the delta. With higher elevations and seasonal management as a wetland prior to restoration, the eastern portion of Tulana currently provides habitat typical of a seasonally flooded wetland, with large patches of hardstem bulrush, intermixed with a mosaic of other emergent wetland species including dock (*Rumex spp.*), Norwegian cinquefoil (*Potentilla norvegica*), and a variety of rush species (*Eleocharis spp.*).

The Conservancy breached the southern perimeter of Goose Bay in 2008 at three places ranging in length from 1,000 to 3,000 feet, allowing hydrologic connectivity to UKL during seasonally high water levels. Additionally, three breaches along the Williamson River allow hydrologic mixing between the river and Goose Bay. Unlike Tulana, Goose Bay did not experience significant subsidence, mainly due to differences in soil composition, and was not managed as a wetland prior to restoration. This resulted in significantly less wetland vegetation available for larval and juvenile suckers in 2009. During the first year after flooding, much of the vegetative habitat available consisted of remnant crop stubble from former agricultural fields. In 2010, after a year of seasonal flooding, wetland plant species began to colonize Goose Bay (Elseroad et al. 2010). Significant emergent and riparian vegetation establishment occurred in 2011, with large patches of hardstem bulrush, giant stem bur-reed (*Sparganium eurycarpum*), broadleaf cattail (*Typha latifolia*), and other emergent wetland species covering areas of Goose Bay. As the delta matures, riparian and emergent wetlands are expected to recolonize much of the sparsely covered areas in Goose Bay and the shallower areas of Tulana, and post-restoration monitoring is in place to track changes in vegetation at the delta (Elseroad et al. 2010).

Methods

Sampling Design

The sampling protocol used in 2010 and 2011 followed established protocols that have been employed by Conservancy staff to document larval sucker use of the delta since 2006. Sampling was conducted weekly from 10 May to 15 July in 2010, and 9 May to 14 July in 2011, for a sampling period of ten weeks each year. Sampling was conducted at six areas within or in close proximity to the delta in both 2010 and 2011: Riverbend, Tulana, Goose Bay, Goose Bay West, Goose Bay East, and South Marsh (see Figure 1). In each of the six locations, pop nets were used to capture larval suckers in areas with cover (> 25% emergent or submerged aquatic vegetation) and in open water (0% macrophyte cover), replicated at a variety of shallow water depths (range 0.10 meter to 1.0 meter deep).

Pop nets consisted of two, 1-inch diameter PVC frames (approximately 2.56 square meters), one weighed down with rebar to serve as the lead line and the other wrapped in foam core to act as a float. One-meter wide, fine mesh material (mosquito netting) connected the two frames to form a cube. The nets lacked a bottom and top, allowing them to be set in vegetation. To set the nets, both frames were submerged and secured underwater with cinderblocks. Each cinderblock had a long line attached enabling the bricks to be pulled away from the net without disturbing the sampling area and allowing the upper frame, wrapped in foam, to "pop" up, enclosing the section of water. Each net was set for a minimum of 30 minutes prior to sampling to ensure each site had recovered from disturbances resulting from setting the net. After the net was "popped" we measured water depth, wind speed, UTM coordinate information, water temperature, dissolved oxygen, pH, and conductivity (Hydrolab Quanta®) at the site.

Additionally, each net was given a simple qualitative vegetation rating of 0-5, where a 0 represented no vegetation in the net and a 5 indicated that dense vegetation existed throughout the entire net (Figures 2, A-F). Small aquarium dip nets were used to collect the fish enclosed in the net, and each net was swept at least five times after the last fish was caught to ensure that no larvae were missed. Samples were immediately stored in 95 percent ethanol. Stalks of vegetation in the nets were sometimes removed in order to more effectively capture fish.

Pop nets were set at both random and fixed points in 2010 and 2011. Each year, random sampling points were generated for the six areas prior to the start of sampling using Hawth's Tools version 3.27 (Beyer 2004) in ArcMap, and were visited once. Two fixed points in both Tulana and Goose Bay were visited weekly to support a larval modeling project (see Figure 1; Wood et al., in review). Four points were visited weekly in both Tulana and Goose Bay (two fixed, two random), while two were visited each week in Riverbend, South Marsh, Goose Bay West, and Goose Bay East (two random). More sampling effort was allocated to Tulana and Goose Bay because the focus of the monitoring project was to understand the impact of the most recent restoration activities on larval suckers. Two nets were set at each point, ideally with one in vegetation and one in an area of open water; however, at certain sites in Goose Bay and along the Goose Bay shoreline, vegetation did not exist at the point and thus both nets were set in open water. If a random point was too deep for our sampling gear (~ > 1.0 m deep), the nets were set in the closest area of shallower water. Nets were set in both the morning and afternoon in order to avoid possible diel influences on larval catches.

Fish Identification, Condition, and Aging

Immediately after collection, we transferred all larvae (suckers and non-suckers) to 50 milliliter (mL) jars containing ~20 mL of 95 percent ethanol. All fish larvae were later identified to species, measured to the nearest 0.5 millimeter (mm) standard length (SL), and assessed for gut fullness using a variable-powered (7-30X) dissecting microscope. Preserved larval fish were identified using dorsal and lateral melanophore patterns and morphological characteristics (D. Simon, Oregon State University, written comm. 2004). Due to similarities in pigmentation patterns between shortnose sucker and Klamath largescale (*Catostomus snyderi*) sucker larvae (Markle et al. 2005), we were unable to positively differentiate between the two species. For data analysis, all larvae identified as either shortnose sucker or Klamath largescale sucker were grouped together and designated as shortnose/Klamath largescale (SNS/KLS). All sucker larvae over 15 mm were grouped as unknown due to difficulties in distinguishing between all three sucker species when larger than 15 mm without the use of x-rays or gill raker counts. Larval suckers were qualitatively assigned to one of five gut fullness levels based on a visual estimation: 0 percent full, 25 percent full, 50 percent full, 75 percent full, and 100 percent full (Cooperman and Markle 2003).

A portion of the captured sucker larvae (222 individuals) from 2010 were sent to Mark Terwilliger at Oregon State University to be aged by counting the daily growth increments on extracted otoliths. The average precision estimate of otolith aging measurements was ± 2.15 percent (M. Terwilliger, Oregon State University, personal comm. 2011). Age data will allow us to examine potential differences in growth rates throughout the six different sampling areas and to gain insight into the retention abilities of the restored wetlands throughout the delta. Furthermore, age data from our sampling could be used in the future in conjunction with data collected from other areas of the delta and the surrounding lake by researchers from Oregon State University and the U.S. Geological Survey.

Data Analysis

Mean catch per unit effort (CPUE), expressed as the number of fish per net, was used to compare fish captures across the six sampling areas and two sampling years. A significant portion of our sampling effort was focused on the two newly restored areas, Tulana and Goose Bay, and CPUE allows characterization of catches across sites despite uneven sampling effort. Nets set in water depths less than 0.5 meters (m) were classified as shallow nets, while nets set in depths greater than 0.5 m but less than 1.0 m were classified as deep nets for analysis purposes. Nets with more than 25 percent vegetation were categorized as vegetation nets, while nets set in open water areas were grouped as no-vegetation nets. This allowed us to analyze larval sucker habitat preferences in four different habitat types: deep-vegetation, deep-no vegetation, shallow-vegetation, and shallow-no vegetation.

Wind data for 2010 and 2011 was obtained from the Williamson River West Meteorological Station (U.S. Geological Survey Station No. 422807121572500). Upper Klamath Lake levels and Williamson River flows were obtained from Upper Klamath Lake gauging station at Rocky Point (U.S. Geological Survey Station No. 11505800) and Williamson River gauging station at river kilometer 16.6 (U.S. Geological Survey Station No. 11502500), respectively.

Results

Catch Trends

In 2010, larval suckers began recruiting to nets on 10 May and we ceased sampling on 15 July, when larval suckers were no longer recruiting to our nets. The following year, larval suckers recruited to our nets beginning on 10 May 2011 and we ceased sampling on 14 July 2011. Forty nets were set in Riverbend, 80 in Tulana, 80 in Goose Bay, 40 in Goose Bay West, 40 in Goose Bay East, and 40 in South Marsh each season, and the sampling period lasted ten weeks during each year. Three hundred and twenty nets were set each year, with 32 nets being set each week. In 2010, 1,536 larval suckers were captured, resulting in a mean CPUE of 4.8 ± 1.40 standard error (SE) suckers per net. Fewer suckers, a total of 945, were captured in 2011, leading to a CPUE of 2.96 ± 0.63 SE. Catch per unit effort in 2011 was the lowest since these sampling protocols were first implemented in 2006. Mean catch per unit effort was 14.87 ± 3.62 SE in 2006, 8.96 ±1.31 SE in 2007, 8.26 ± 1.81 SE in 2008, and 3.53 ± 1.19 SE in 2009.

Some similar patterns of larval sucker catches emerged in 2010 and 2011. The number of nets that contained at least one, five, or ten suckers was similar amongst the two years. Forty percent of nets set in 2010 captured at least one sucker, while 38 percent of nets captured at least one sucker in 2011. In 2010, 41 nets (13 percent) caught at least five suckers, 21 nets (7 percent) captured at least 10 suckers, and the highest single net capture of suckers was 304 on 29 June in Riverbend. Forty nets (12.5 percent) captured at least five suckers in 2011, 21 nets (7 percent) captured at least 10 suckers, and the highest single net capture was 127 suckers on 20 June in Tulana.

Weekly mean catch per unit effort of larval suckers in 2010 peaked during the week of 28 June, roughly one week later than peak catches in 2011 (Figure 3). Both of these peaks were substantially later than the peaks witnessed in 2008 and 2009, 9 June and 1 June, respectively. Peak catches occurred during the same weeks in both 2010 and 2011 in each of the individual restored areas (Riverbend, Tulana, Goose Bay, and South Marsh; Figure 4). This did not occur in the two sites along the Goose Bay shoreline. In Goose Bay west in 2010, mean catch per unit effort peaked five weeks later than it did in 2011. Likewise, mean catch per unit effort in Goose Bay East peaked later in 2010 than in 2011 (see Figure 4).

Larval sucker species composition was fairly similar in 2010 and 2011, with low catches of Lost River suckers. Of the 1,536 suckers captured in 2010, 99 were identified as Lost River sucker, 1,032 as shortnose/Klamath largescale sucker, and 405 suckers were ≥ 15 mm, were not identified to species, and were thus labeled as unknown, representing 7 percent, 67 percent, and 25 percent of the total sucker catch, respectively. In 2011, of the 945 suckers captured, 72 (8 percent) were identified as Lost River sucker, 405 (43 percent) as shortnose/Klamath largescale sucker, and 468 (49 percent) were 15 mm or larger and were labeled as unknown. This species composition, with low catches of Lost River suckers, was witnessed in years prior to 2010. Numbers and mean catch per unit effort of suckers and other native and non-native fish species captured in 2010 and 2011 are provided in Table 1.

In 2010, catches of larval suckers were substantially higher in Riverbend than the other five sampling areas. Cumulative mean catch per unit effort was 25.3 ± 10.5 SE suckers per net in Riverbend while only 2.6 ± 1.0 SE in Goose Bay, 2.5 ± 0.6 SE in Tulana, 1.1 ± 0.4 SE in Goose Bay West, 1.0 ± 0.3 SE in South Marsh, and 0.8 ± 0.3 SE in Goose Bay East. This was the first year in which catches of larval suckers were highest in Riverbend since the sampling protocols were adopted in 2006. Mean catch per unit effort of larval suckers was greatest in Tulana in 2011 (4.3 ± 1.8 SE), followed by South Marsh (3.60 ± 1.75 SE), Goose Bay East (3.60 ± 2.67 SE), Goose Bay (2.56 ± 0.63 SE), Riverbend (1.75 ± 0.77 SE), and Goose Bay West (0.88 ± 0.38). Captures of larval suckers were higher in the restored areas of the Delta than in the areas along the Goose Bay shoreline during both years (Figure 5). This trend has been witnessed in each of the three sampling seasons (2009, 2010, 2011) since the Goose Bay portion of the Delta was restored in the fall of 2008. However, sucker catches along the Goose Bay shoreline in 2011 (mean CPUE = 2.24 ± 1.35 SE) were greater than in 2009 (mean CPUE = 0.92 ± 0.50 SE) and 2010 (mean CPUE = 0.93 ± 0.23 SE). The numbers and mean catch per unit effort of larval suckers in each of the six sampling areas from 2010 and 2011 are located in Table 2.

Larval Sucker Habitat Use

Larval suckers were captured more frequently in pop nets set in vegetation in 2010 and 2011. Mean catch per unit effort of larval suckers in nets set in vegetation in 2010 was 4.9 ± 1.9 SE, while only 4.7 ± 2.1 SE suckers per net were captured in nets with no vegetation. In 2011, the difference between vegetated nets and open water nets was greater, with 3.4 ± 1.1 SE suckers per net captured in nets set in vegetation and 2.5 ± 0.6 SE suckers per net captured in nets with no vegetation present. When analyzing habitat associations with depth, differences existed amongst the two years. In 2010, mean catch per unit effort of suckers in deep nets (0.5 m – 1.0 m deep) was 6.8 ± 2.8 SE while only 2.8 ± 0.6 SE in shallow nets (< 0.5 m deep). However, in 2011, deep nets captured only 2.3 ± 0.8 SE suckers per net while shallow nets captured 3.6 ± 0.9 SE suckers per net.

When the two habitat variables are combined for analysis, catches in 2010 were highest in deep-vegetation nets compared to deep-no vegetation, shallow-no vegetation, and shallow-vegetation nets—mean catch per unit efforts of 7.0 ± 4.1 SE, 6.6 ± 3.7 SE, 3.3 ± 1.0 SE, and 2.4 ± 0.7 SE, respectively. In 2011, catches of larval suckers in the four habitat types differed from 2010. Suckers were captured more frequently in shallow-vegetation nets compared to the other three habitat types in 2011. Mean catch per unit effort in shallow-vegetation nets was 4.2 ± 1.8 SE, while 3.0 ± 0.8 in shallow-no vegetation nets, 2.6 ± 1.4 SE in deep-vegetation nets, and 2.0 ± 0.9 SE in deep-no vegetation nets.

No significant patterns emerged when analyzing the relationship between the density of vegetation in each net and the number of suckers captured in the net in 2010. Larval suckers were caught in similarly high numbers in nets set in both sparse vegetation (vegetation class 1) and dense vegetation (vegetation class 4; Figures 2A and 2B). Nets with a vegetation class rating of 3 or 4 (medium density of vegetation; see Figure 2) were more likely to capture larval suckers in 2011 than nets with other densities of vegetation. During both sampling years, larval suckers were captured in a variety of both native and non-native wetland plant species, including hardstem bulrush, curly dock (*Rumex crispus*), rush species, reed-canary grass (*Phalaris arundinacea*), cattail, simple-stem bur reed, water smartweed, broad-leaf arrowhead (*Sagittaria latifolia*), and a variety of dead, submerged upland vegetation remaining from when the land was in agriculture production. Mean catch per unit effort was highest in both years in nets set in rush species (n = 37 nets in both years), with 13.9 ± 8.5 SE suckers per net captured in 2010 and 5.5 ± 3.0 SE in 2011. Table 3 shows the mean catch per unit effort and standard error of larval suckers captured in different wetland plant species in 2010 and 2011.

Fish Condition

Mean standard length (SL) of larval suckers captured in 2011 was 0.7 mm larger than the mean SL of suckers captured in 2010. Mean SL of suckers captured in 2010 was 14.3 ± 0.04 mm, with a range from 10 mm to 27 mm, while mean SL of suckers captured in 2011 was 15.1 ± 0.06 mm, with a range from 11.5 mm to 31 mm. Of the larvae identified to species in 2010, suckers identified as shortnose/Klamath largescale were on average 0.4 mm larger than fish identified as Lost River sucker ($mean_{SNS/KLS}$ = 13.6 ± 0.02 mm; $mean_{LRS}$ = 13.2 ± 0.07 mm). Mean standard length of unidentified suckers (≥ 15 mm SL) was 16.5 ± 0.1 mm. Mean standard length of suckers identified as Lost River sucker in 2011 was 13.5 mm ± 0.06 mm, compared to 13.8 mm ± 0.03 SE for fish identified as shortnose/Klamath largescale, and 16.4 mm ± 0.09 mm for suckers greater than 15 mm in length.

Differences existed in the mean standard lengths of suckers captured in the two wetland types between 2010 and 2011. In 2010, suckers occupying the habitat in the restored wetlands of the delta (Riverbend, Tulana, Goose Bay, and South Marsh) were generally smaller (mean SL = 14.3 ± 0.04 mm) than suckers inhabiting the fringe wetlands along the Goose Bay shoreline (Goose Bay West and Eeast; mean SL = 15.3 ± 0.2 mm). In 2011, however, suckers captured in the restored wetlands were on average larger than suckers captured along the Goose Bay shoreline (mean $SL_{restored}$ = 15.2 ± 0.07 mm, mean SL_{fringe} = 14.5 mm ± 0.08 mm).

Comparisons of standard lengths amongst the six sampling areas were inconsistent between 2010 and 2011. Larval suckers captured in South Marsh during 2010 were on average larger than fish trapped in the other five sampling areas; mean standard length in South Marsh was 15.8 ± 0.3 mm, followed by Goose Bay East (mean SL = 15.7 ± 0.5 mm), Tulana (mean SL = 15.6 ± 0.2 mm), Goose Bay West (mean SL = 15.1 ± 0.2 mm), Goose Bay (mean SL = 14.8 ± 0.1 mm), and Riverbend (mean SL = 13.9 ± 0.04 mm). In 2011, pop nets set in Riverbend captured the largest suckers (15.9 ± 0.39 mm), followed by Goose Bay (15.5 ± 0.14 mm), Tulana (15.1 ± 0.09 mm), South Marsh (14.8 ± 0.17 mm), Goose Bay East (14.6 ± 0.08 mm), and Goose Bay West (14.2 ± 0.22 mm). This marked the first time that suckers captured in South Marsh were not the largest since these sampling protocols were adopted in 2006.

Size trends among the four habitat types were similar during both years. In 2010 and 2011, larval suckers captured in shallow-vegetation pop nets were on average larger than suckers captured in the other three habitat types, followed by fish captured in shallow-no vegetation nets, deep-vegetation nets, and deep-no vegetation nets. Fish captured in water smartweed, curly dock, and simple-stem bur reed in 2010 were larger than fish captured in other vegetation species, with mean standard lengths of 16.0 ± 0.25 mm, 15.4 ± 0.27 mm, and 15.4 ± 0.23 mm, respectively. In 2011, mean standard length of larvae captured in pondweed species (*Potamogeton spp.*) and simple-stem bur reed were greater than in other wetland plant species, with mean SLs of 15.8 ± 0.17 mm and 15.7 ± 0.41 mm, respectively.

Of the 1,536 suckers captured in 2010, gut fullness levels could be determined for 87 percent (n = 1332) of the fish, while gut fullness could be determine for 788 of the 945 suckers (83 percent) captured in 2011. Gut fullness trends were similar in 2010 and 2011. During both years, larval suckers captured in the restored wetlands of the delta had a higher percentage of fish with at least 50 percent gut fullness compared to larvae captured along the Goose Bay shoreline. Additionally, larvae captured in Riverbend had the lowest proportion of fish with empty guts and fewer larvae with empty guts were captured in Tulana compared to Goose Bay. Larvae captured in Goose Bay west during both years had the highest proportion of fish captured with 25 percent or 0 percent gut fullness (Figures 6 and 7). A higher proportion of fish with 25 percent or 0 percent gut fullness was captured in shallow-vegetation nets in 2010, while in 2011 larvae captured in deep-no vegetation nets had a higher proportional of 25 percent or 0 percent gut fullness levels.

Researchers at Oregon State University aged 222 larval suckers from the 2010 sampling cohort. Of those, 25 five were Lost River sucker, 76 were shortnose/Klamath largescale sucker, and 121 were greater than 15 mm and labeled as unknown. The mean age (± standard deviation) of Lost River sucker larvae was 18.5 ± 3.7 days, while the mean age of shortnose/Klamath largescale larvae was 20.3 ± 3.6 days. Unknown larvae were an average of 32.1 ± 6.2 days old. The youngest fish aged, identified as a Lost River sucker, was 13 days old and captured on 28 June in Tulana, while the oldest fish was an unknown sucker 50 days old and captured in Riverbend. The earliest hatch date from our aged samples was 11 April, roughly two months earlier than the last larval hatch date from the sample, 25 June. The earliest and latest Lost River suckers hatched on 25 April and 21 June, respectively. Of the 25 Lost River suckers that were aged, one was hatched in April, 15 were hatched in May, and 9 were hatched in June. The earliest and latest shortnose/Klamath largescale suckers hatched on 1 May and 25 June, respectively. Of the 76 shortnose/Klamath largescale sucker, zero fish were hatched in April, 37 were hatched in May, and 39 were hatched in June. Of the 121 unknown suckers, 15 were hatched in April (earliest 11 April), 77 were hatched in May, and 29 were hatched in June (latest 20 June). Of the 222 aged fish, 62 suckers (28%) were hatched between 19 May and 29 May. Figure 8 shows a graph of fish age and standard length. Sucker larvae captured in South Marsh (mean age = 28.8 ± 7.7 days) were older than fish captured in the other five sampling areas, while fish captured in Goose Bay east were on average the youngest (mean age = 25.0 ± 5.1 days; Figure 9). No sucker specimens were aged from 2011.

Larval Sucker Dispersion Modeling

In a collaborative effort with researchers from Oregon State University and the U.S. Geological Survey, a 2-demensional hydrodynamic model is being used to understand the impact that restoration at the delta has on the dispersion of larval suckers into UKL and AL (Wood et al., in press). Catch data from larval sucker monitoring programs led by TNC, Oregon State University, and the U.S. Geological Survey were used to calibrate the model. In order to gather data for this model, we collected weekly data at two fixed sites within Tulana (point A and point B) and two sites within Goose Bay (point C and point D) during 2010 and 2011 (Figure 1). All nets set at these sites were placed within the same 100 m X 100 m area each week to ensure that all habitat types were sampled. Nets were set in shallow water at points A and C and deep water at points B and D. In 2010 and 2011, 20 nets were set at each site over the ten week sampling period.

At fixed points during both years, highest mean catch per unit effort occurred at a point located in shallow water. In 2010, mean cumulative catch per unit effort was highest at point C in Goose Bay (6.7 ± 3.8 SE), followed by point B (mean CPUE = 3.2 ± 1.2 SE), point A (mean CPUE = 2.8 ± 1.0 SE), and point D (mean CPUE = 1.0 ± 0.5 SE). However, mean cumulative catch per unit effort was greatest at point A in Tulana in 2011 (11.15 ± 6.5 SE), followed by point C in Goose Bay (3.7 ± 1.7 SE), point B (1.6 ±0.8 SE), and point D (0.9 ± 0.3 SE).

At fixed points in 2010, vegetation associations were inconsistent. At the Tulana shallow point (point A), larval suckers were captured at higher rates in nets without vegetation compared to nets with vegetation (4.6 ± 1.8 SE vs. 1.0 ± 0.3 SE, respectively), while at the Tulana deep point (point B) larvae were captured more frequently in nets set in vegetation than nets without vegetation (4.7 ± 2.2 SE vs. 1.7 ± 0.7 SE, respectively). While differences were less substantial at the Goose Bay points, larval suckers were captured at slightly higher rates in nets without vegetation at point C than with vegetation (mean $CPUE_{no\ veg}$ = 7.0 ± 6.6 SE and mean $CPUE_{veg}$ = 6.4 ± 4.2 SE) and slightly higher rates in nets with vegetation compared to nets without at point D (mean $CPUE_{veg}$ = 1.0 ± 0.9 SE and mean $_{CPUEno\ veg}$ = 0.9 ± 0.4 SE). In the two areas, larvae captured at deep fixed points were captured more frequently in vegetation while larvae captured at shallow fixed points were more likely to be captured in nets without vegetation. In 2011, catches at fixed points were more consistent with respect to the presence or absence of vegetation. At shallow and deep points in Tulana and Goose Bay, sucker larvae were captured more frequently in nets set in vegetation. At point A in Tulana, mean catch per unit effort in vegetation was 13.8 ± 12.6 SE while 8.5 ± 4.1 SE in open water. At point B, mean catch per unit effort in vegetation was 2.7 ± 1.5 SE while only 0.4 ± 0.2 SE in open water. Likewise, mean catch per unit effort in vegetation at point C in Goose Bay was 4.3 ± 3.2 SE while only 3.0 ± 1.1 SE in open water. Mean catch per unit effort in vegetation at point D in Goose Bay was 1.2 ± .5 SE, while only 0.6 ± 0.3 SE in open water.

Weekly mean catch curves for the fixed points in Tulana and Goose Bay are shown in Figures 9 and 10, respectively. During both years at the Tulana fixed points, catches were generally higher during the first seven weeks of the sampling period at the shallow point (point A). However, beginning in week 8 during both years, catches at point B began to increase and were greater than catches at point A. In Goose Bay, catches of larvae at shallow point C were greater than catches at point D during the first part of the sampling season. Like Tulana, catches of larvae at the deep point began to increase towards the end of the sampling season and were greater during the last three weeks in 2010 and last week in 2011 than at the shallow point (point C).

In 2010, larger suckers on average were captured at point B in Tulana compared to the size of fish captured at the other fixed points. Mean standard length of suckers at fixed point B was 15.6 mm ± 0.3 SE, compared to 14.9 mm ± 0.3 SE at point A, 14.9 mm ± 0.2 SE at point C, and 14.8 mm ± 0.3 SE at point D. Unlike in 2010, mean standard length of larval suckers was greatest at a shallow fixed point in 2011. Mean standard length at point C in Goose Bay was 15.3 ± 0.2 SE, 15.2 ± 0.1 SE at point A, 14.9 ± 0.5 SE at point D, and 14.3 ± 0.3 SE at point B.

Water Quality Conditions during 2010 and 2011

High stress threshold conditions are defined by Loftus (2001) as conditions potentially threatening to the health of larval and juvenile suckers in UKL, based on temperature, dissolved oxygen concentration (DO), and pH. These thresholds are characterized by temperature > 28 ^{o}C, DO < 4.0 milligrams/liter (mg/L), and pH > 9.7.

Instantaneous water temperature data in 2010, recorded in each net with a Hydrolab Quanta©, indicated shallow sites were on average about 3^{o}C warmer than deep sites, and no difference existed between the mean temperature of both vegetated and non-vegetated sites (mean = 18.1^{o}C). This trend was witnessed in 2011 as well, with mean water temperature in shallow nets about 3^{o}C higher than in deep nets ($mean_{shallow}$ = 18.3^{o}C, $mean_{deep}$ = 15.8^{o}C). Mean temperature in 2011 was similar amongst nets with vegetation and nets without vegetation, as the mean temperature in vegetated nets was 17.2^{o}C, compared to 17.0^{o}C in open water nets. During both years, mean instantaneous water temperatures were the highest in Riverbend and Tulana and lowest along the Goose Bay shoreline, Goose Bay West and Goose Bay East. In 2010, mean instantaneous water temperatures were greatest in Riverbend (mean = 19.1 ^{o}C ± 0.85 SE), followed by Tulana (mean = 19.0 ^{o}C ± 0.67 SE), Goose Bay (mean = 18.3 ^{o}C ± 0.65 SE), South Marsh (mean = 17.3 ^{o}C ± 0.69 SE), Goose Bay East (mean = 17.2 ^{o}C ± 0.79 SE), and Goose Bay West (mean = 16.6 ^{o}C ± 0.74 SE). In 2011, mean instantaneous water temperatures were greatest in Tulana (17.8 ± 0.62 ^{o}C), followed by Riverbend (17.6 ± 0.74 ^{o}C), Goose Bay (17.2 ± 0.51 ^{o}C), South Marsh (16.6 ± 0.73 ^{o}C), Goose Bay East (16.5 ± .85 ^{o}C), and Goose Bay West (15.9 ± 0.82 ^{o}C). Mean water temperatures appear to be higher in the restored areas of the delta than in the areas along the Goose Bay shoreline.

Twelve nets recorded a temperature greater than 28^{o}C in 2010, all after 28 June and located in Tulana, Goose Bay, or Riverbend. All of these nets were set in shallow water. Interestingly, a total of five suckers were captured in two of these 12 nets. In 2011, only three nets exceed the 28^{o}C threshold identified by Loftus (2001) as potentially harmful to larval suckers. These nets were all set in shallow water in Tulana on 5 July and did not capture any larval suckers.

Only six nets in 2010 recorded a dissolved oxygen concentration of 4.0 mg/L or less, four set in Tulana and two set in South Marsh. These nets were set in Tulana on 12 July and in South Marsh on 13 July, during the last week of sampling. All four nets in Tulana were deep nets, while the nets in South Marsh were shallow nets. Only one sucker, in South Marsh, was captured in a net with an instantaneous dissolved oxygen concentration of 4.0 mg/L or less. In 2011, three nets set in South Marsh recorded a DO concentration of 4.0 mg/L or less. One net, in shallow water, was set on 28 June, and the other two, set in deep water, were set on 12 July. Like 2010, only one sucker was captured in a net with a DO concentration of 4.0 mg/L or less. Dissolved oxygen concentrations were not recorded in 16 nets in 2010 and eight nets in 2011 due to equipment malfunction.

Loftus (2001) also identified pH concentrations greater than 9.7 as potentially lethal to larval suckers. Only one net in 2010, set along the Goose Bay West shoreline, registered a pH greater than 9.7 with a measured pH of 9.72. This was a shallow-no vegetation net set on 15 July. No suckers were captured in this net. Two nets set in Goose Bay in 2011 recorded a pH greater than 9.7. These nets were set on 14 July in shallow water and did not capture any suckers. However, a deep-vegetation net set in Goose Bay on 14 July with a pH of 9.68 captured two suckers.

While temperatures differed between the restored wetlands of the delta and the fringe wetlands along the Goose Bay shoreline, dissolved oxygen concentrations were similar. Mean instantaneous water temperature was roughly 2°C higher in the restored wetlands in 2010 than the lakeshore fringe wetlands. Mean dissolved oxygen concentrations were similar in the two wetland types: mean $DO_{restored}$ = 8.2 ± 0.11 mg/L and mean DO_{fringe} = 8.5 ± 0.11 mg/L. Mean water temperature in 2011 in the restored areas was roughly 1°C higher than in areas along the Goose Bay shoreline. Mean dissolved oxygen concentrations were similar between the two wetland types in 2011: mean $DO_{restored}$ = 8.4 ± 0.11 mg/L and mean DO_{fringe} = 8.4 ± 0.10 mg/L.

Non-Sucker Species

Due to the nature of pop nets, our sampling methods were not exclusive to larval suckers—several other fish species were caught in 2010 and 2011, including tui chub *Gila bicolor*, blue chub *G. coerulea*, fathead minor *Pimephales promelas*, yellow perch *Perca flavescens*, bullhead *Ameiurus spp.*, sculpin *Cottus spp.*, and largemouth bass *Micropterus salmoides*. A total of 1,687 non-sucker larvae were captured in 2010, resulting in a mean catch per unit effort of 5.3 ± 0.9 non-suckers per net: 343 tui chubs (CPUE = 1.1 ± 0.24 SE), 554 blue chubs (CPUE = 1.7 ± 0.31 SE), 731 fathead minnows (CPUE = 2.3 ± 0.55 SE), 51 yellow perch (CPUE = 0.2 ± 0.07 SE), 6 bullhead (CPUE = 0.02 ± 0.02 SE), and 2 sculpin (CPUE = 0.01 ± 0.004 SE). Catches of non-suckers were lower in 2011, with a mean catch per unit effort of 1.9 ± 0.31 non-suckers per net: 68 tui chubs (0.21 ± 0.05 SE), 27 blue chubs (0.08 ± 0.03 SE), 483 fathead minnows (1.51 ± 0.30 SE), 7 yellow perch (0.02 ± 0.01), 7 sculpin (0.02 ± 0.01), and 1 largemouth bass (0.003 ± 0.00 SE).

While catches of non-suckers were similar in the two wetland types (restored, lakeshore fringe; mean CPUE = 5.3 non-suckers per net) in 2010, catches of non-suckers were greater in the lakeshore fringe wetlands compared to the restored wetlands in 2011 (mean $CPUE_{fringe}$ = 2.4 ± 0.7 SE, mean $CPUE_{restored}$ = 1.8 ± 0.4 SE). The catch per unit effort for each species in each of the six sampling areas during both years is shown in Figure 11. In 2010, non-suckers were captured at similar rates in the four different habitat types, but most frequently in deep-vegetation nets (6.2 ± 1.56 SE), followed by shallow-no vegetation nets (5.4 ± 1.47 SE), deep-no vegetation nets (4.9 ± 1.74 SE), and shallow-vegetation nets (4.8 ± 1.05 SE). Non-sucker larvae were captured more frequently in shallow-vegetation nets in 2011 than the other three habitat types. Mean catch per unit effort in shallow-vegetation nets was 2.1 ± 0.73 SE, compared to 1.9 ± 0.82 SE in deep-vegetation nets, 1.8 ± 0.42 SE in shallow-no vegetation nets, and 1.7 ± 0.73 SE in deep-no vegetation nets in 2011.

Yellow perch, bullhead, largemouth bass, and fathead minnow are the four non-sucker species most likely to prey on larval or juvenile suckers. Larval yellow perch, bullhead, and largemouth bass were captured in low densities in 2010 and 2011. In 2010, larval yellow perch were captured in all sampling areas except South Marsh, with Goose Bay West having the highest CPUE. Larval bullheads were only captured in two nets in Tulana during the last week of sampling, 15 July. In 2011, yellow perch larvae were captured in Riverbend, Goose Bay, Goose Bay East, and South Marsh, while one larval largemouth bass was captured in Tulana. Fathead minnow larvae were the most abundant non-sucker species in both 2010 and 2011. In 2010, fathead minnow comprised of 23 percent of the annual sucker and non-sucker cumulative catch, and roughly 30 percent in 2011. Catches of fathead minnow in both years were less than in 2009, when roughly 50 percent of the sucker and non-sucker cumulative catch was comprised of fathead minnow. Fathead minnow catches were slightly greater in fringe wetlands compared to the restored wetlands of the delta in 2010 ($CPUE_{fringe}$ = 2.5 ± 0.95 SE, $CPUE_{restored}$ = 2.2 ± 0.66 SE). However, the opposite occurred in 2011, when fathead minnow catches were slightly higher in the restored wetlands of the delta (mean CPUE = 1.67 ± 0.38 SE) than the fringe wetlands along the Goose Bay shoreline (mean CPUE = 1.04 ± 0.38 SE).

Discussion

The Nature Conservancy's larval fish sampling effort in 2010 and 2011 marked the second and third year of monitoring larval sucker use of the completed wetland restoration project at the Williamson River Delta Preserve. The restoration project, supported and funded by numerous state, federal, and tribal partners, is intended to increase larval and juvenile rearing habitat and establish complexity within this habitat. With both the Tulana and Goose Bay portions of the delta now hydrologically connected to the Williamson River, UKL, and AL, roughly 2,500 acres of shallow water habitat are available for larval and juvenile sucker rearing. Results from 2010 and 2011 indicate that larval suckers frequent the shallow areas of the restored delta and were more likely to be captured in the restored wetlands than the lakeshore fringe wetlands along the Goose Bay shoreline.

Catches of larval suckers in 2010 were greater than in 2011, but less than annual catches in each of the three years prior to complete restoration of the delta, 2006, 2007, and 2008. Mean catch per unit effort was 14.9 ± 3.62 SE in 2006, 9.0 ± 1.31 SE in 2007, and 8.3 ± 1.81 SE in 2008. Catches of larval suckers in 2009 were comparable to catches in 2011, with a mean catch per unit effort of 3.53 ± 1.19 SE in 2009. Substantial variability in cumulative annual catches is expected given the spawning ecology and early life history of suckers. Temporal and spatial variation in spawning run timing of suckers, differences in fecundity and larval survival in the Williamson and Sprague rivers, disparities in larval outmigration characteristics, varying meteorological conditions (wind, flow, lake level elevation), or increased dispersal due to the increase in available habitat at the delta could all result in inter-annual catch discrepancies. Most likely, different combinations of these factors result in the disparities we experience in our annual catches of larval suckers. While some of these factors have been researched individually, little is known about how these elements interact to affect the abundance of larvae and larval outmigration dynamics.

Despite inconsistencies of annual catch data, certain trends existed over the two sampling periods. The most significant trend was the decrease in larval catches along the Goose Bay shoreline compared to pre-restoration catches. Prior to reconnecting Goose Bay, cumulative annual catches were dominated by captures of larval suckers along the Goose Bay shoreline, in Goose Bay West and East. Mean catch per unit effort along the Goose Bay shoreline in 2006 was 25.3 ± 7.26 SE (81 percent of total catch), 13.33 ± 2.23 SE in 2007 (69 percent of total catch), and 13.5 ± 5.33 SE in 2008 (39 percent of total catch). Since restoration, mean catch per unit effort along the Goose Bay shoreline was 0.9 ± 0.50 SE in 2009 (65 percent of total catch), 0.9 ± 0.23 SE in 2010 (5 percent of total catch), and 2.24 ± 1.35 SE in 2011 (19% of total catch). While mean CPUE was higher in 2011 along the Goose Bay shoreline than in 2009 and 2010, it is still significantly lower than catches prior to restoration in this area. The difference in pre and post-restoration catches along the Goose Bay shoreline can be explained by the changes in shoreline configuration and its impact on larval dispersal and outmigration (Erdman et al. 2011). Before wetland restoration of the delta, larvae were constrained by the Williamson River channel, only exited this outmigration corridor at the mouth, and then were generally swept along the Goose Bay shoreline by the clockwise gyre that generally dominates lake circulation patterns (Cooperman and Markle 2003, Wood et al., in press). Larvae would migrate from natal grounds to UKL in as little as a day, most of them in a pre-flexion developmental stage and lacking caudal fin development (Cooperman and Markle 2003). With the change in shoreline configuration post restoration, numerous pathways now exist for larvae to enter UKL and larvae are no longer constrained to one migration corridor. Instead, larval suckers can take an infinite number of complex pathways to enter UKL or AL, as illustrated through larval dispersal modeling by Wood et al (in press). Lower catches along the Goose Bay shoreline since hydrologic reconnection of Goose Bay in 2008 were most likely caused by the reconfigured landscape at the mouth of the Williamson River, rather than disparities in inter-annual larval sucker production (Erdman et al. 2011).

While catches of larval suckers along the Goose Bay shoreline remained relatively similar during 2010 and 2011, larval suckers were found at varying rates in Riverbend, Tulana, and South Marsh during the two years. The most significant catch difference among the six sampling areas between 2010 and 2011 occurred in Riverbend. In 2010, catch per unit effort of larval suckers was 25.3 ± 10.47 SE while only 1.8 ± .77 SE in 2011. Larval catches in Riverbend in 2011 were substantially closer to catches in 2006 (2.9 ± 0.97 SE), 2007 (6.5 ± 2.55 SE), 2008 (5.4 ± 2.40 SE), and 2009 (3.3 ± 0.76 SE) than catches in 2010. Of the suckers captured in Riverbend in 2010, 92 percent (n = 927) were caught during the last three weeks of the sampling season, 28 June, 5 July, and 12 July, and a large portion of these fish (n = 885, 96 percent) were captured in nets set in deep water. A number of possible explanations for this increase exist: 1) a unique combination of UKL elevation and Williamson River flow flushed more larvae into the wetland; 2) peak larval outmigration was delayed in 2010 and occurred when water levels were lower in the wetland, equaling less dispersal of larvae in the wetland; 3) our nets were simply set in the right places at the right times; or 4) a significant pulse of fish entered Riverbend at the end of June and then did not exit the wetland as quickly as larvae in past years.

Water level in this restored wetland is mainly influenced by UKL level, with backwater effects extending beyond Modoc Point Road bridge at lake elevations as low as 4,139.5 ft (Gearheart et al. 1995). However, Williamson River flow does have a limited effect on water level and flow throughout the wetland. In 2010, much of the typically shallower portions of this wetland were dry or had only a few centimeters of standing water during peak larval catches because the peak occurred later than in past years and at a time when water levels were lower (Figure 12). Given the lower water levels, the habitat available in Riverbend was limited to a deep channel that bisects the wetland east-to-west, two smaller and shallower channels that connect the main channel to the river, and some limited shallower areas (Figure 13). At UKL full pool (~4143 ft), approximately 25 acres of wetland habitat are available for larval suckers in Riverbend; however, with a lake elevation of 4,141 ft, only roughly eight acres of wetland habitat are available for larval suckers (see Figure 13). In 2010, UKL elevation was 4,141.31 ft during the week of 28 June at U.S. Geological Survey Station No. 11505800, and continued to drop during the remainder of the sampling season. With a later than usual peak in cumulative sucker catches in 2010 and lower than normal lake level elevations, the high densities we experienced in 2010 in Riverbend could have simply resulted from a similar abundance of larvae as past years, but less area for these larvae to occupy within the wetland. Pulse size and timing of outmigration are other factors that could have led to the high catches in 2010. Figure 14 shows the location of each net set in Riverbend in 2010 and the number of suckers captured in each net and illustrates that the high density nets during the last three weeks of the sampling season were set adjacent to or in the deeper channel that bisects the wetland. Additionally, it appears that access to Riverbend does not vary greatly with different lake elevations. With both high and low lake elevations, access to Riverbend remains the same—through the four breach openings, which were lowered to elevations of 4,138 ft (see Figure 13). Thus, while low lake levels in 2010 certainly affected the amount of wetland habitat available in Riverbend, it did not appear to alter the ability of larval suckers to access the habitat.

Larval sucker catches also differed in Tulana between the two sampling years. Catch per unit effort of sucker larvae in Tulana in 2011 was roughly two times greater than the catch per unit effort in Tulana in 2010. Additionally, at fixed point A, located directly south and roughly 200 m from breach 11, catch per unit effort was roughly four times less in 2010 than in 2011. One explanation for the lower catches in 2010 could be the effect of lower lake elevations during the peak larval outmigration period in 2010. On the Tulana side of the delta, three breaches along the river serve as the first and primary access points to the wetlands inside Tulana (Figure 15) and were lowered to an elevation of 4,138 ft (breach 11), 4,139 ft (breach 12), and 4,140 ft (levee behind breach 13). During the construction phase of the restoration, the levees along the north bank of the Williamson River were lowered to 4,142 ft and provide access when lake elevations are at or near full pool (~4,143 ft). Water levels at these breaches are affected mainly by UKL elevations, with Williamson River flow and wind conditions also impacting the accessibility of Tulana from the river. At lake elevations near full pool, hydrologic connection between the Williamson River and Tulana is not restricted to the breaches; however, as lake elevations decline and become less than 4,142 ft, hydrologic mixing between the river and Tulana is restricted to only the three breaches along the river. During normal water years, UKL elevation is usually greater than 4,142 ft until the middle of June, past the typical peak of larval outmigration. With lower lake levels during the outmigration period in 2010 during which UKL elevation peaked at 4,141.5 ft (see Figure 12), access to the wetlands in Tulana from the Williamson River was restricted to only the three breaches, thus possibly resulting in the lower catches observed in 2010 compared to 2011. Modeling of larval transport based on 2009 conditions indicated that with a 0.25 m decrease in observed lake elevation, larvae had a tendency to enter Tulana more frequently (Wood et al., in review). However, the decrease in lake elevation in 2010 did not result in high catches in Tulana.

The modeling also suggests that under particularly strong prevailing wind conditions in Upper Klamath Lake (winds from the west, southwest, or northwest), the majority of larvae will tend to move into Goose Bay from the river rather then enter Tulana (Wood et al, in review). If wind speeds from the prevailing direction were stronger in 2010 than 2011, it could account for the variability in catches in Tulana between the two years. However, data indicate that mean wind speed was only slightly greater in 2010 (3.61 m/second) than in 2011 (3.49 m/second). During both years, roughly 30 percent of wind from the west, southwest, or northwest reached speeds of 4-8 m/second. Since differences are negligible between 2010 and 2011, it does not appear that wind speed, direction, or duration caused the low catches in Tulana in 2010 compared to 2011.

Unlike Tulana and Riverbend, larval catches in Goose Bay were consistent during both years, with about 2.6 suckers captured per net. Additionally, catches in Goose Bay in 2009 were similar when 2.0 ± 0.4 SE suckers were captured per net. Differences in restoration construction on the southern (Goose Bay) river levee, compared to the northern (Tulana) levee, could explain the similarities in catches between the years, despite varying lake elevations between the two years. Three main breaches along the river in Goose Bay provide access for larval suckers even during low lake elevations: two oxbow breaches and breach 20 (see Figure 15). Unlike the northern bank of the river, the southern levee along the river's edge was not lowered. Instead, a riparian bench was created behind the willows on the river's edge and lowered to 4,139 ft. Figure 16 provides an illustration of the difference between the two river levees post construction. Breach 2, lowered to only 4,142 ft, only provides access during high lake elevation and is relatively small compared to the other breaches. The two oxbow breaches in Goose Bay were removed to 4,136 ft elevation, suggesting that greater water transfer is available during low lake elevations at these breaches than breaches along the river in Tulana. Breach 20 was lowered to 4,138 ft elevation, the same elevation of the deepest breach along the river in Tulana, breach 11. While other factors could be contributing to the similar catch rates in Goose Bay during 2010 and 2011, mainly wind direction and speed, the ability for larval suckers to access the wetlands in Goose Bay does not seem to vary much despite fluctuating lake levels.

Regardless of accessibility, the wetlands at the delta appear to provide a wide variety of microhabitats for larval sucker rearing and complexity within this habitat, in terms of vegetative cover, diversity of wetland species, and patchiness of vegetation. The presence of vegetation appears to be a good predictor of larval sucker habitat, as larval suckers were captured more frequently in nets with vegetation compared to nets without vegetation during both 2010 and 2011. However, when analyzing the relationship between density of vegetation in each net and the number of suckers captured in the net, no significant patterns emerged during 2010 and 2011. In 2010, suckers were captured at similar rates in both nets with sparse vegetation and nets with dense vegetation, while in 2011, suckers were captured more frequently in nets with medium densities of vegetation. Of suckers captured in 2010 and 2011, 98 percent and 95 percent, respectively, were caught in nets set in areas on the edge of large patches of vegetation, or in smaller, more isolated patches of wetland vegetation, or in isolated pockets of open water within ~1 m of wetland vegetation, following habitat associations described by Reiser et al. (2001; Figure 17 A,B,C). Interestingly, mean catch per unit effort was highest during both years in rush species *Eleocharis* spp. Other studies have demonstrated the importance of a vegetative component in larval rearing habitat, whether for providing refugia from non-native fathead minnows (Markle and Dunsmoor 2007), increasing retention time in Upper Klamath Lake (Markle et al. 2009), or promoting increased growing and feeding opportunities (Crandall et al. 2008). Our data suggests that vegetative complexity is a more important component of larval sucker habitat than a certain density of vegetation. Depth appears to be a less important factor in larval habitat as suckers were captured more frequently in deep nets in 2010 while more frequently in shallow nets in 2011.

The benefit of vegetation as a component of larval sucker rearing habitat is manifested through increased larval sucker lengths. In both 2010 and 2011, larval suckers captured in nets with vegetation were on average larger than suckers captured in nets devoid of vegetation, although these differences were small (0.2 mm in 2010 and 0.1 mm in 2011). When the habitat variables were combined (water depth and vegetation/no vegetation), larvae captured in shallow-vegetation nets were on average larger than suckers captured in nets set in the three other habitat types. While the explanation for the association between larger larvae and vegetation is unclear, one possibility could be an increased availability in food resources within vegetation patches at the delta. Despite Markle and Clauson's (2006) suggestion that the association of larval suckers with emergent macrophytes was unlikely a result of better feeding opportunities since larvae were feeding primarily on surface or planktonic prey which are widely available throughout the lake (Bond et al. 1968), prey could accumulate in or near vegetation under certain conditions. This could explain the association between larger larvae and vegetation; however, if food availability was the sole cause for the relationship between larger larvae and vegetation, we'd expect sucker larvae captured in nets with vegetation to have a gut fullness advantage (i.e. more food in their stomachs) over suckers captured in nets without vegetation. This was witnessed in 2011, when 67 percent of sucker larvae captured in nets with vegetation had guts that were either 75 percent or 100 percent full, compared to only 55 percent in nets without vegetation. Conversely, in 2010 only 58 percent of larvae in vegetation nets had guts that were 75 percent or 100 percent full, compared to 65 percent in nets without vegetation. The association between larval suckers and vegetation seems to be partly explained by increased feeding success for larvae within vegetation, but it appears that other factors might be involved as well.

With larger suckers associated with wetland vegetation and the substantial increase in wetland vegetation accompanying restoration at the delta, this newly created habitat could lead to an increase in larval sucker survival. Small differences in individual sizes or foraging success can have substantial effects on larval survival (Miller et al. 1988), suggesting that even the slightest size advantage that results from the presence of wetland vegetation could aid in recovery. Additionally, the restored wetlands of the delta provided warmer water temperatures for sucker rearing than the wetlands along the Goose Bay shoreline. Temperatures in the restored wetland were on average 1.5^{o}C warmer than the fringe wetlands during both 2010 and 2011, and nets set in shallow water were on average 3.0^{o}C warmer during both years than nets set in deep water. Restoration at the delta significantly increased the amount of shallow water habitat available for larval suckers. Warmer water temperatures generally increase the metabolic rate of fish, which corresponds to increased growth rates (Jobling 1994). The rearing habitat at the delta appears to be providing physiological elements essential for larval sucker growth and survival.

Mean standard lengths of larval suckers varied amongst the two years between the restored wetlands and the lakeshore fringe wetlands. In 2010, mean standard length of suckers occupying the habitat in the restored wetlands of the delta was smaller than the mean standard length of larvae captured in the fringe wetlands along the Goose Bay shoreline. This marked the first year since these sampling protocols were adopted in 2006 that larvae captured along the Goose Bay shoreline were on average larger than suckers captured in the restored wetlands. However, results in 2011 were more consistent with past years' results as larvae were on average larger in the restored wetlands. The exact cause for larger fish on average in the lakeshore fringe wetlands in 2010 is unknown but could be attributed to varying outmigration patterns with the new shoreline configuration post-restoration. Many of the larvae captured along the Goose Bay shoreline in 2010 could have been retained in the restored wetlands prior to being captured. An ontogenetic transition in Lost River and shortnose sucker feeding occurs between 20 mm and 30 mm (Markle and Clauson 2006), a shift that could be associated with a migration to more lacustrine habitats. Therefore, larger fish along the Goose Bay shoreline could be a manifestation of the migration of suckers that were retained in the restored wetlands to UKL during this ontogenetic shift. Modeling work (Wood et al., in press) suggests that larvae take numerous paths to enter UKL, many of which travel through the wetlands of the delta first. The small sample size of fish captured in 2010 along the shoreline (n = 74) could also cause this discrepancy and might not reflect the length composition of larvae at this site. Regardless, either explanation is speculative as to the cause of smaller larvae in the restored wetlands compared to the lakeshore fringe wetlands in 2010.

While average lengths of suckers between the two wetland types differed from 2010 and 2011, gut fullness levels were consistently greater in larvae captured in the restored wetlands compared to the fringe wetlands. A higher percentage of larvae from the restored wetlands had gut fullness levels of 50 percent or greater in both 2010 and 2011 than larvae from the wetlands along the Goose Bay shoreline. Larvae captured in Riverbend during both years had the lowest proportion of fish with empty guts, possibly correlated to the significant amount of wetland habitat available at this restoration site. Compared to the other sampling sites, Riverbend has more wetland habitat available per acre and has numerous backwater and slow velocity areas, which could result in increased feeding and rearing success.

One of the more interesting trends regarding larval sucker size occurred in 2011 when larvae captured in South Marsh were on average smaller than suckers captured in the other three restored areas. In the five years prior to 2011 during which the same sampling protocols were used, larvae captured in South Marsh were the largest on average each year. Because South Marsh is the furthest 'downstream' site and it could potentially take suckers longer to travel to this site, it is logical that larvae there would be larger than fish captured in other areas. In 2011, suckers captured in Riverbend were larger than suckers captured in the other five sampling areas. Riverbend is the furthest 'upstream' site and is the first of the six sites that larval suckers have access to while outmigrating from the Williamson River, suggesting that larvae would potentially be smaller at this site than the other five sites. In 2010, smaller sucker larvae were captured in Riverbend than the other five sampling sites, corroborating the idea that larvae in the most 'upstream' site will be smaller than larvae at sites 'downstream'. The explanation for the results in 2011 is unknown, but could be caused by a combination of meteorological conditions, UKL elevations, Williamson River flows, and the ability of restored wetlands to retain larvae.

Water quality conditions were generally suitable for larval sucker rearing during the 2010 and 2011 sampling periods and usually below the high stress threshold conditions for larval suckers defined by Loftus (2001). During the last two weeks of each sampling season, water quality conditions begin to deteriorate at localized areas throughout the delta. Water quality conditions in the shallow areas of Tulana appear to approach high stress threshold conditions for larval suckers before other areas of the delta or along the Goose Bay shoreline. Regardless, seven suckers were captured in nets that exceeded the high stress threshold conditions for dissolved oxygen, temperature, and pH. During both 2010 and 2011, water temperatures were cooler during the larvae sampling period than in past years, which could have led to the relatively suitable water quality conditions during the larval outmigration period (Figure 18). However, usually beginning in mid-July, threshold exceedance levels begin to occur throughout the delta for portions of each day (Wong and Hendrixson 2011). While exceedance levels exist at times throughout the delta, juvenile suckers might have the ability to migrate from areas of poor water quality to areas of better water quality, as other fish species have been shown in both field and laboratory studies to avoid areas of lethal dissolved oxygen and temperature levels (Schurmann et al. 1998). Regardless, water quality was not a limiting factor for larval suckers in 2010 and 2011 during our sampling period.

Catches of non-sucker species were significantly lower in 2010 and 2011 than in prior years. Catches were roughly six times lower in 2010 than in 2009 and 15 times lower in 2011 than in 2009. This could be a result of cooler than normal water temperatures in 2010 and 2011. Figure 18, a graph of the mean daily instantaneous water temperature (^{o}C) recorded in each net with a Hydrolab Quanta©, from 2009, 2010, and 2011, shows the cooler water temperatures experienced during the first month of sampling during both years. With lower water temperatures, spawning of some non-sucker species could have been delayed and resulted in the lower abundance experienced during the two sampling periods. Fathead minnow generally begin spawning once water temperatures have reached 18^{o}C (Dobie et al. 1956). Figure 18 shows the delay in water temperatures reaching at least 18^{o}C in 2010 and 2011, compared to 2009.

Catches of fathead minnow were low in 2010 and 2011. Catch per unit effort of fathead minnow in 2009 was 17.95 ± 2.94 SE, while only 2.3 ± 0.55 SE in 2010, and 1.51 ± 0.30 SE in 2011. While fathead minnow abundance was especially low during both years, it continues to be the most abundant non-sucker in our catches. Habitat preference between fathead minnow larvae and sucker larvae appears to overlap, as both species were captured more frequently in vegetation during 2010 and 2011. Other studies have witnessed high densities of larval and adult fathead minnow occupying the same nursery habitat as larval suckers (Buettner and Scoppetton 1990, Cooperman and Markle 2004, Markle and Dunsmoor 2007), and fathead minnow preying on larval suckers (Markle and Dunsmoor 2007). The fathead minnow we capture are larvae and pose no immediate predation threat to larval suckers, but could compete with sucker larvae for food and cover resources, and the spawning adults could prey upon larval suckers during the spawning period. Gram for gram, larvae have the potential to exert greater impacts on prey populations than adults in wetland ecosystems since mass-specific consumption rates are inversely related to fish size (Post 1990, Herwig and Zimmer 2007). Herwig and Zimmer (2007) found that larval and juvenile fathead minnow consumed more than adult fatheads and accounted for

83 percent of total prey consumption in a prairie wetland in Minnesota. While Markle and Clauson (2006) suggest that prey abundance in Upper Klamath Lake may not be a limiting factor for larval and juvenile suckers, little is known about the potential food-web interactions between larval and juvenile fathead minnow and larval suckers. In 2010, fathead minnow were captured more frequently along the Goose Bay shoreline than in the restored areas, although the difference was small. Conversely, fathead minnows were captured at higher rates in the restored areas in 2011, but again the difference was small.

Conclusion

Results from monitoring larval sucker use of the Williamson River Delta Preserve in 2010 and 2011 indicate that larval suckers are extensively using the shallow areas of the delta for rearing. Our larval catches are no longer dominated by catches along the Goose Bay shoreline, suggesting that the restoration of Goose Bay has greatly altered the pathways that larvae take to enter UKL and AL. With the association between vegetation and greater larval sucker lengths, the substantial increase in wetland vegetation associated with restoration at the delta will aid in increasing sucker survival. As the wetlands mature, habitat complexity will develop and increase, which appears to be more beneficial for larvae than a certain plant-specific feature. Low lake levels during the larval outmigration period in 2010 certainly affected the ability of larvae to access the wetlands in the delta; however, the exact extent of this effect, besides possibly leading to decreased catches in Tulana in 2010, is unknown. Low lake levels could have also led to the significantly high catches in Riverbend in 2010, but again the exact cause is unknown. While this monitoring helped answer questions about larval sucker demographics and gain a greater understanding of larval sucker use of the delta, certain important questions still exist and answering these questions remains critical to the full recovery of the species.

Acknowledgements

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Tables

Table 1. Number and catch per unit effort (fish/net) of each species captured using pop nets during 2010 and 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

	2010			2011		
		Catch Per Unit Effort (fish/net)			Catch Per Unit Effort (fish/net)	
Species	n	mean	±SE	n	mean	±SE
Unknown Sucker	405	1.27	0.21	468	2.92	1.5
Lost River Sucker	99	0.31	0.09	72	0.45	0.23
Shortnose/Klamath Largescale Sucker	1032	3.23	1.25	405	2.52	1.29
Fathead Minnow	731	2.28	0.55	483	1.51	0.3
Blue Chub	554	1.73	0.31	27	0.08	0.03
Tui Chub	343	1.07	0.24	68	0.21	0.05
Sculpin spp.	2	0.01	0	7	0.02	0.01
Bullhead spp.	6	0.02	0.02	0	0	0
Largemouth Bass	0	0	0	1	0.003	0
Yellow Perch	51	0.16	0.07	7	0.02	0.01
Total	3223	10.07	1.81	1538	4.82	0.72

Table 2. Numbers and catch per unit effort of larval suckers captured at each sample area in 2010 and 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

	2010			2011		
		Catch Per Unit Effort (fish/net)			Catch Per Unit Effort (fish/net)	
Location	n	mean	± SE	n	mean	± SE
Riverbend	1012	25.3	10.47	70	1.75	0.77
Tulana	193	2.4	0.6	347	4.34	1.78
Goose Bay	211	2.6	1	205	2.56	0.63
Goose Bay west	48	1.2	0.4	35	0.88	0.38
Goose Bay east	31	0.8	0.25	144	3.6	2.67
South Marsh	41	1	0.31	144	3.6	1.75
Total	1536	4.8	1.4	945	2.96	0.63

Table 3. Numbers and catch per unit effort of larval suckers captured in a variety of wetland plant species in 2010 and 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

	2010			2011		
		Catch Per Unit Effort (fish/net)			Catch Per Unit Effort (fish/net)	
Vegetation Type	n	mean	± SE	n	mean	± SE
Eleocharis spp.	37	13.89	8.50	37	5.49	2.94
Tripleurospermum maritimum	2	0.50	0.50	0	0.00	0.00
none	163	4.93	1.91	167	2.53	0.62
old upland vegetation	3	0.00	0.00	9	0.11	0.11
Phalaris arundinacea	1	0.00	0.00	4	1.75	1.75
Polygonum amphibium	19	3.95	1.35	16	2.13	0.97
Potamogeten spp.	2	0.00	0.00	4	33.00	31.34
Rumex crispus	37	2.57	1.17	6	0.67	0.67
Sagittaria latifolia	2	0.00	0.00	10	3.20	2.03
Schoenoplectus spp.	44	0.55	0.23	24	2.54	1.39
Sparganium emersum	6	3.83	1.87	25	1.36	0.65
Typha latifolia	3	0.00	0.00	9	0.33	0.17
unknown	1	0.00	0.00	0	0.00	0.00

Figures

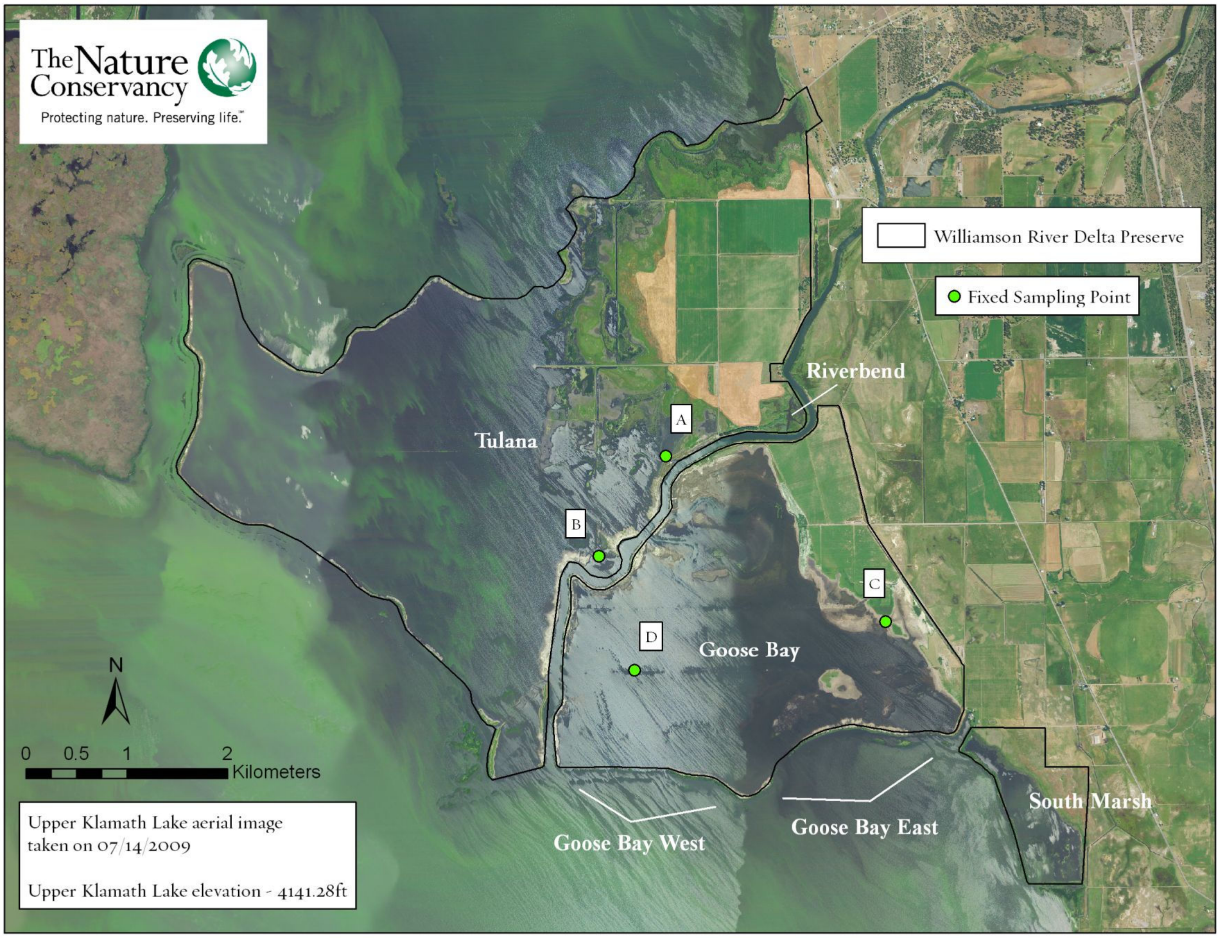


Figure 1. Map of the Williamson River Delta Preserve showing six sampling locations, Riverbend, Tulana, Goose Bay, Goose Bay west, Goose Bay east, South Marsh, and four fixed sites sampled for larval Lost River sucker and shortnose sucker in 2010 and 2011, Upper Klamath Lake, Oregon.

Figure 2. Each pop net was given a qualitative vegetation class rating based on the amount of vegetation in each net. The above images show an example net from each of the six ratings, 0-5, where 0 represents no vegetation in the pop-net and 5 represents high densities of vegetation in the net. A = veg class 0, B = veg class 1, C = veg class 2, D= veg class 3, E = veg class 4, F = veg class 5. Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

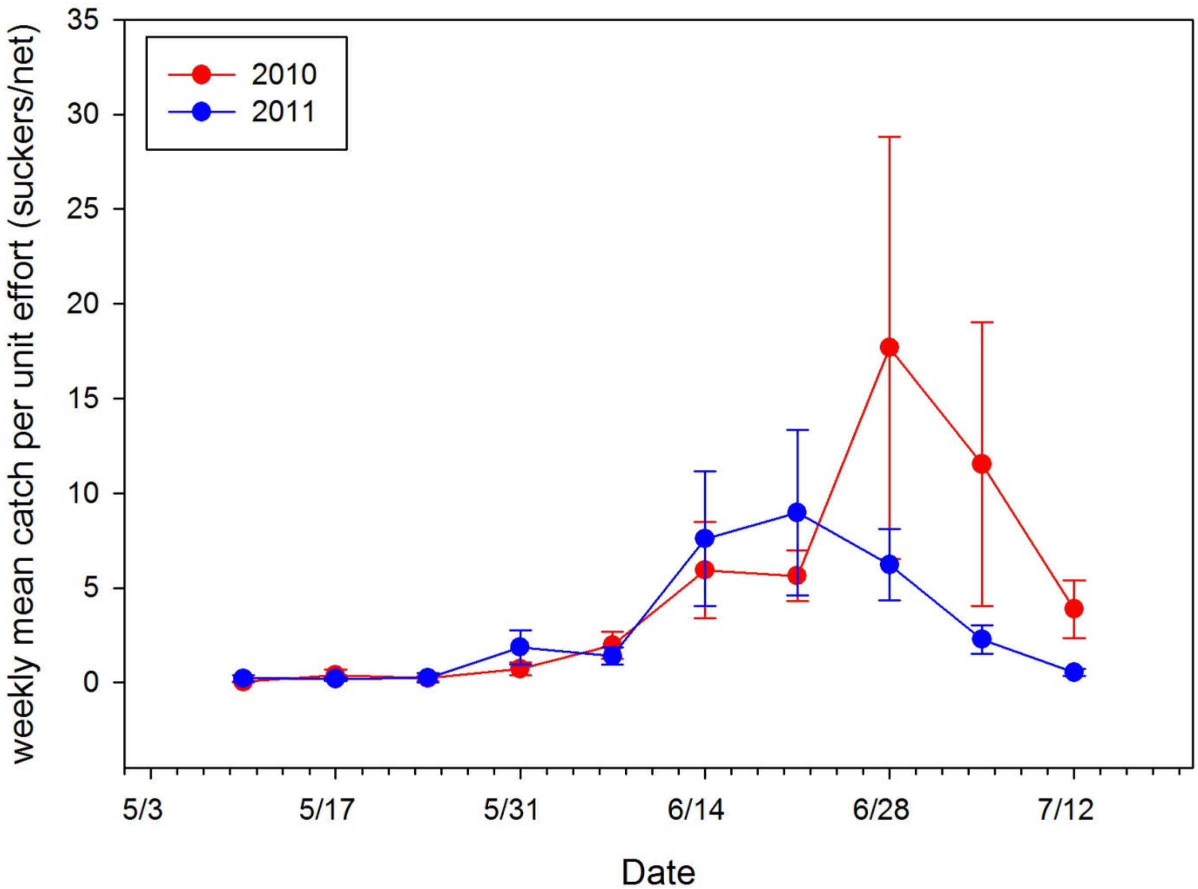


Figure 3. Larval Lost River sucker and shortnose sucker mean weekly catch per unit effort (suckers/net) with standard error bars from 2010 and 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

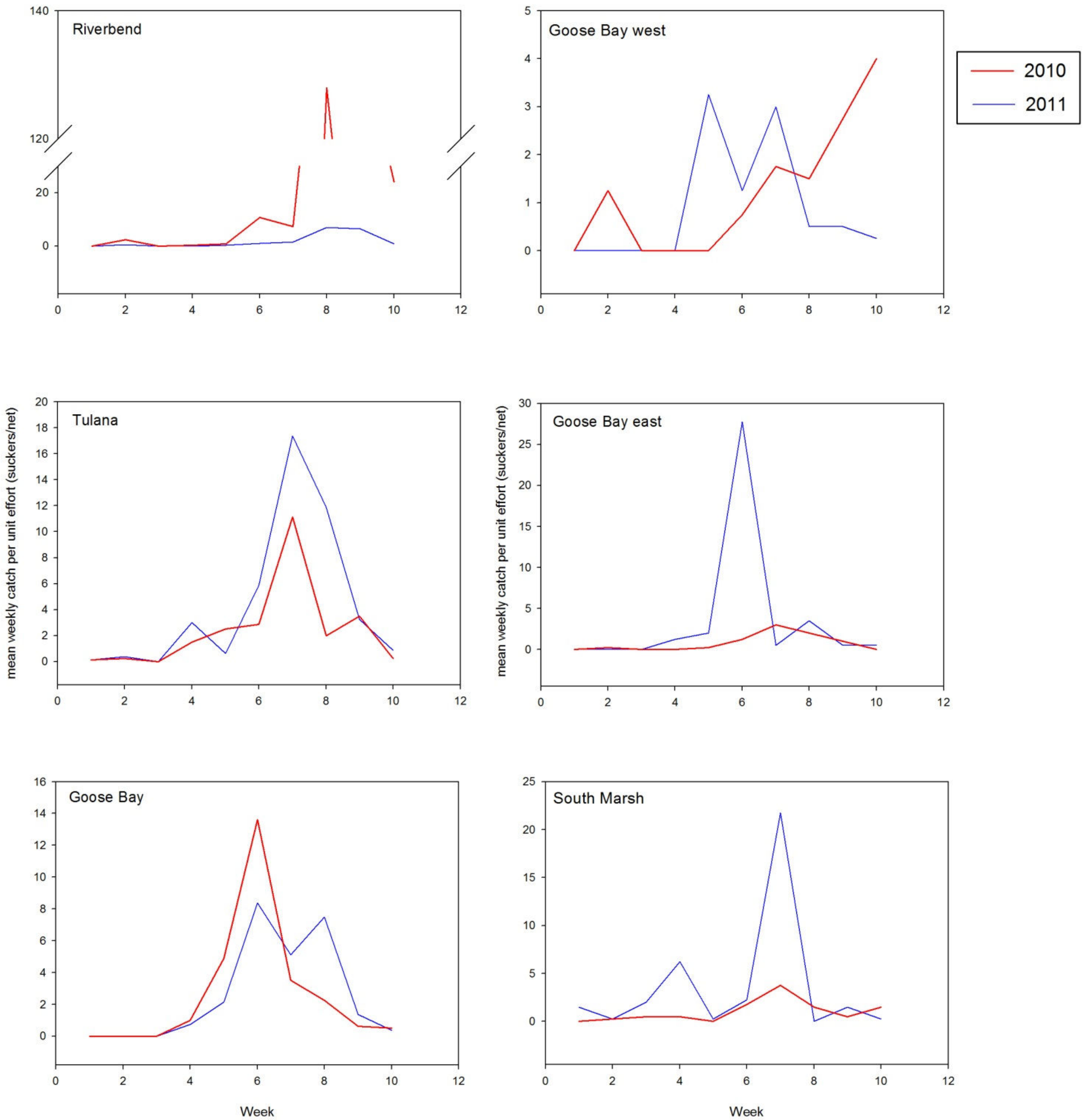


Figure 4. Larval Lost River and shortnose sucker weekly mean catch per unit effort (sucker/net) in each of the six sampling areas in 2010 (red) and 2011 (blue), Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

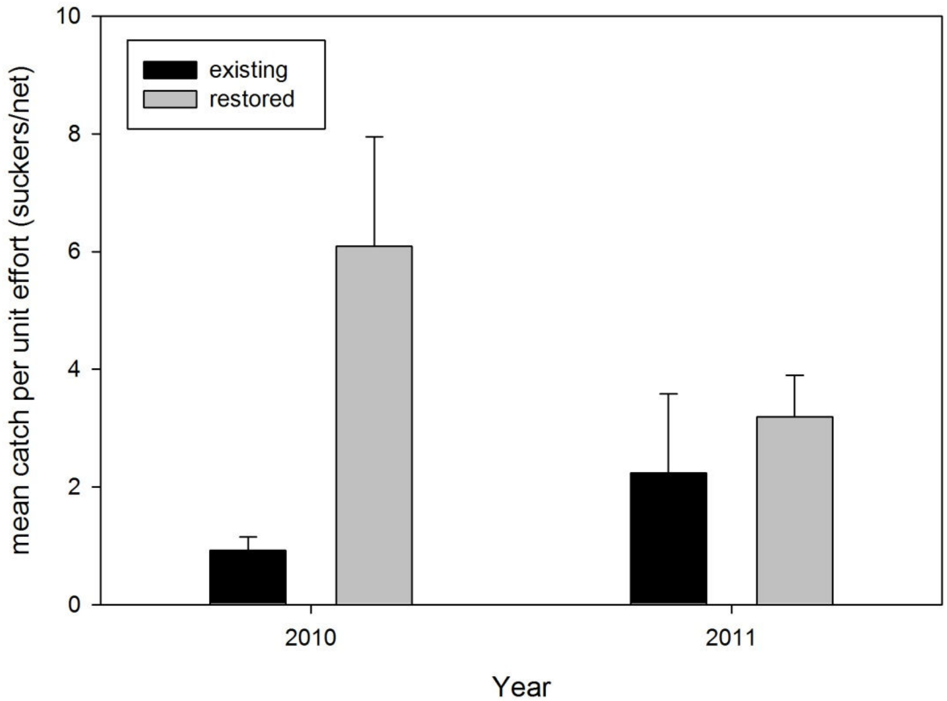


Figure 5. Mean catch per unit effort (suckers/net) in the two wetlands types in 2010 and 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

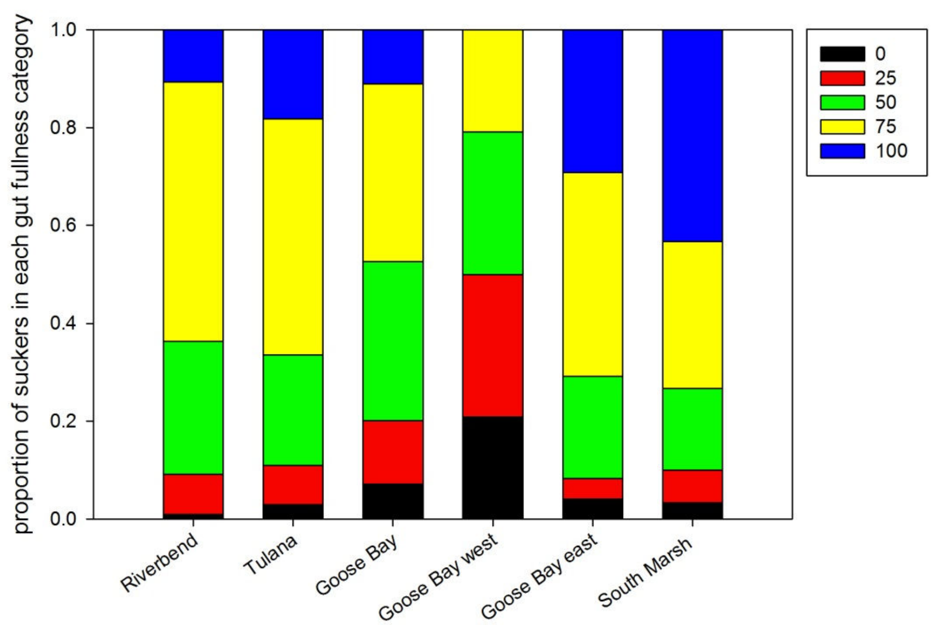


Figure 6. The proportion of larval suckers in each of the five gut fullness categories (0%, 25%, 50%, 75%, or 100% full) captured at each sampling location in 2010, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

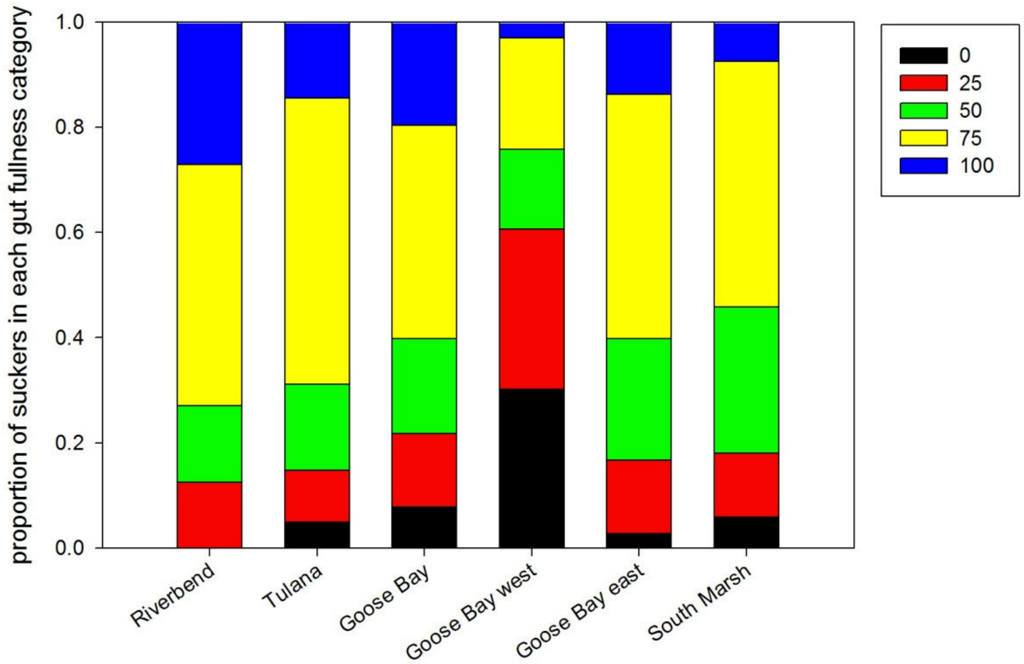


Figure 7. The proportion of larval suckers in each of the five gut fullness categories (0%, 25%, 50%, 75%, or 100% full) captured at each sampling location in 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

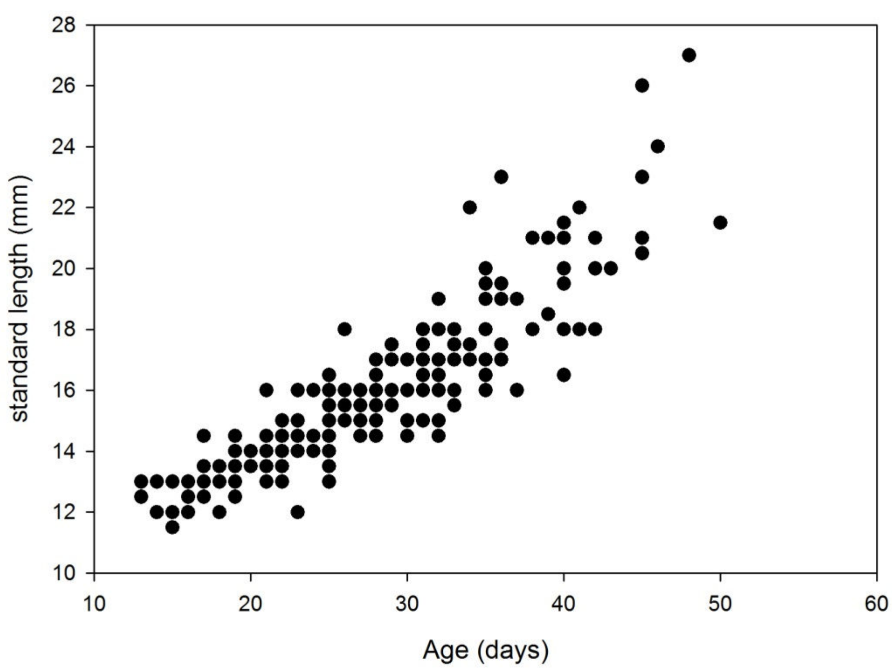


Figure 8. Length to age comparison for sucker larvae collected in 2010 at the Williamson River Delta, Upper Klamath Lake, Oregon. Age estimates were based on median lapilli otolith ring counts read three times by Oregon State University researchers (M. Terwilliger, Oregon State University, personal comm. 2011)..

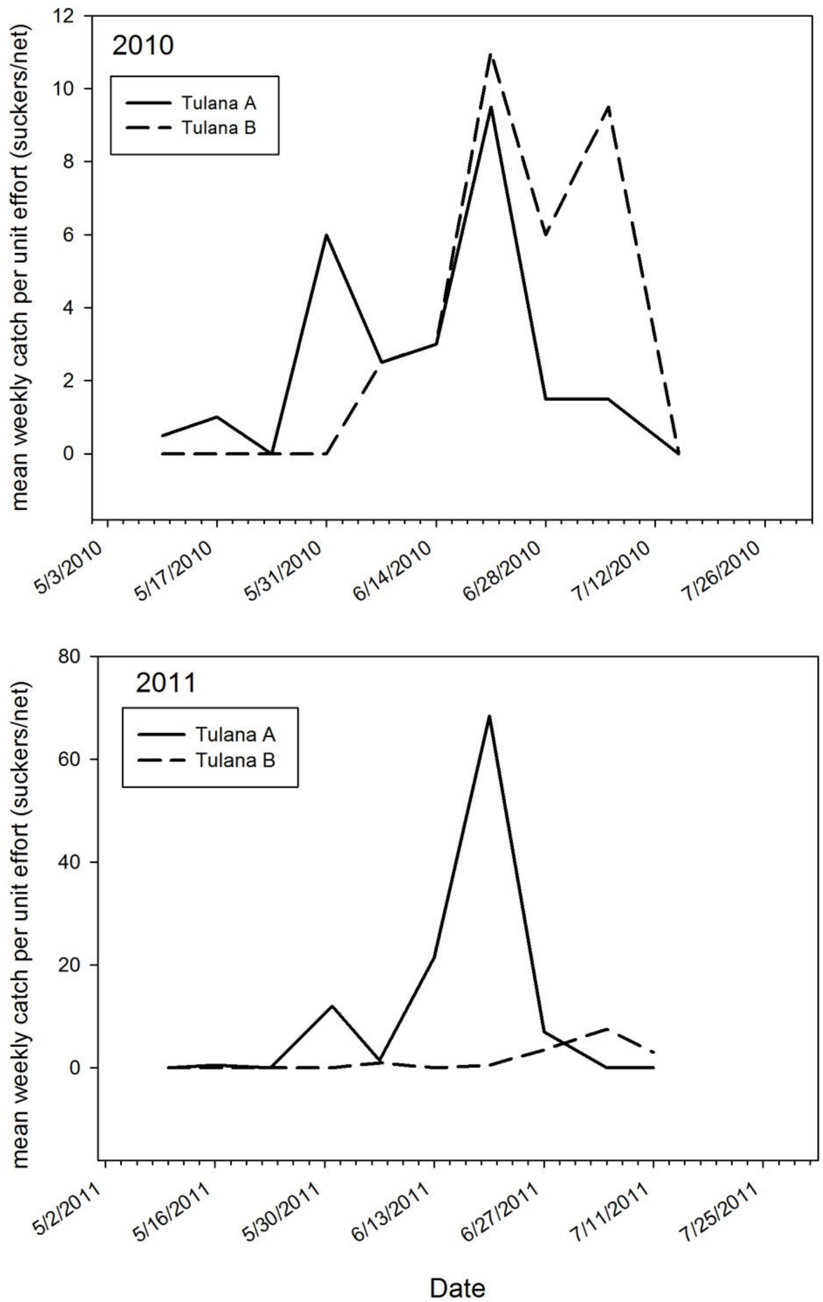
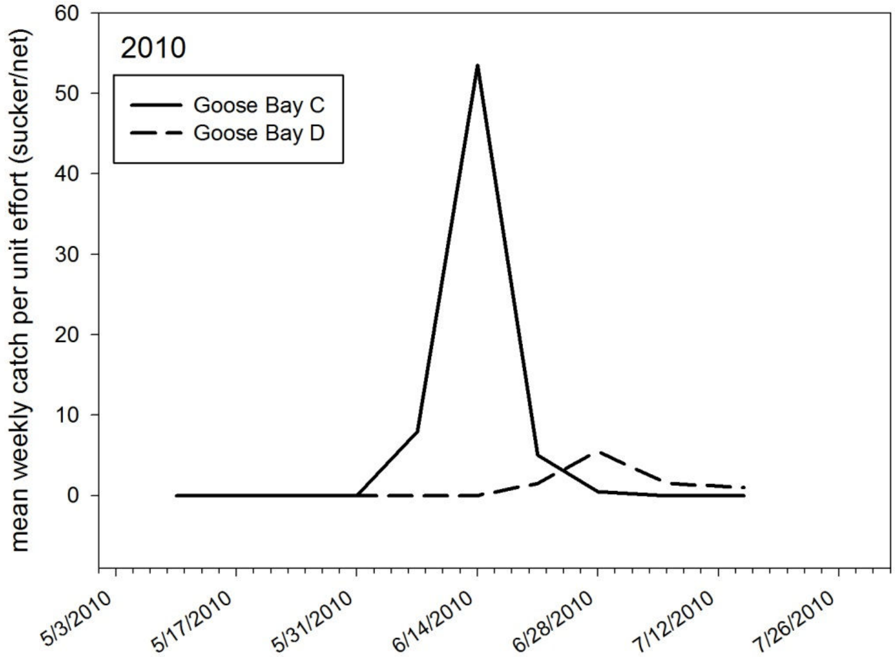


Figure 9. Larval Lost River sucker and shortnose sucker weekly mean catch per unit effort at two fixed points in Tulana in 2010 and 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.



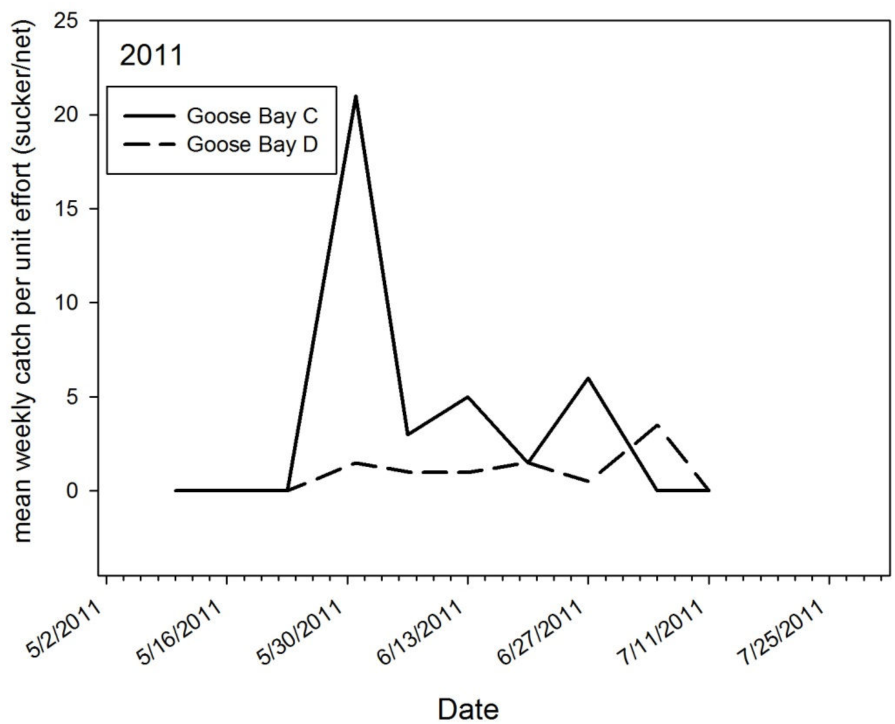


Figure 10. Larval Lost River sucker and shortnose sucker weekly mean catch per unit effort at two fixed points in Goose Bay in 2010 and 2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

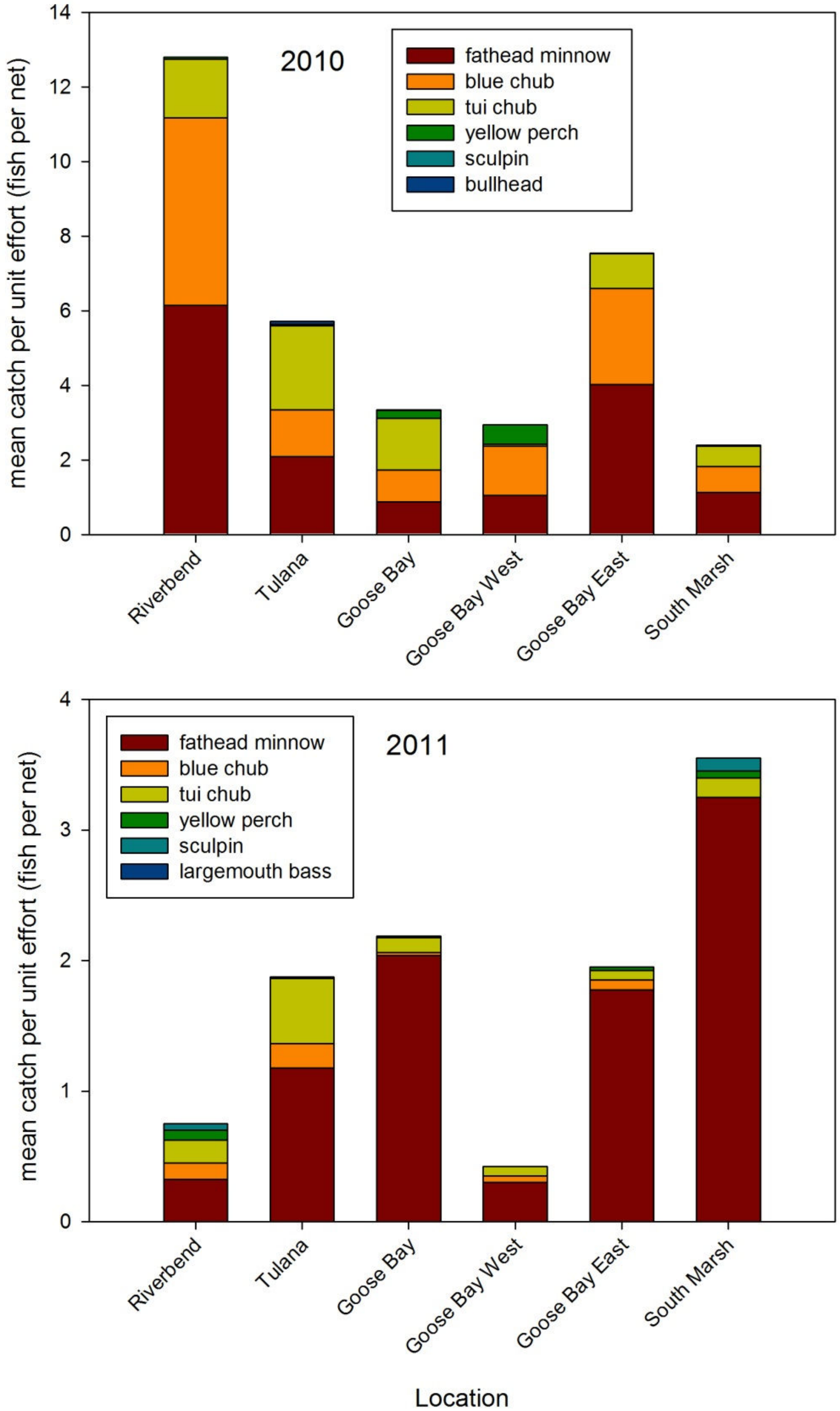


Figure 11. Non-sucker catch per unit effort (fish per net) during weekly sampling at six sampling locations at the Williamson River Delta Preserve in 2010 and 2011, Upper Klamath Lake, Oregon.

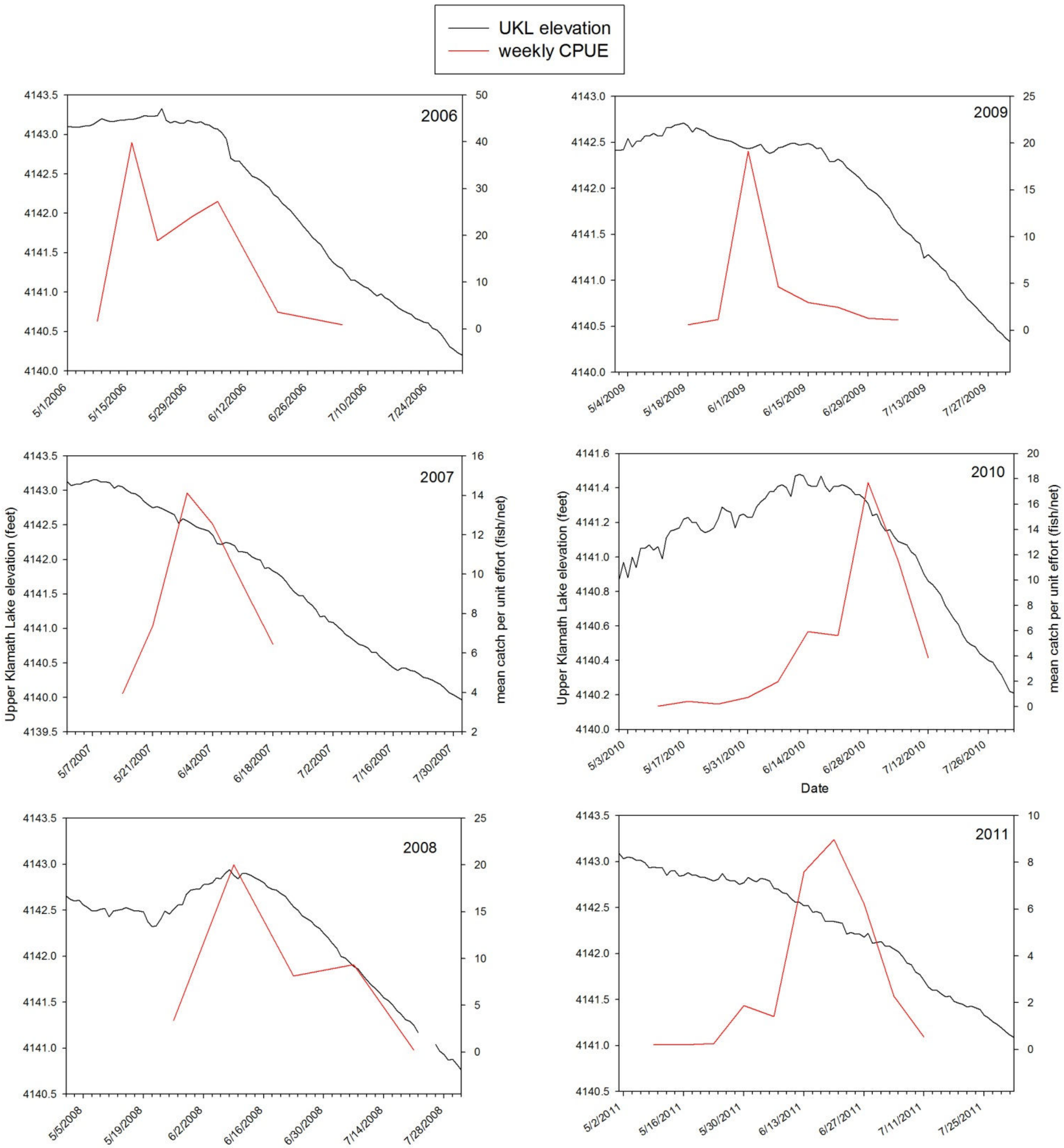


Figure 12. Upper Klamath Lake elevations (feet; black) and weekly mean catch per unit effort curves (CPUE; red) during the larval sampling period from 2006-2011, Williamson River Delta Preserve, Upper Klamath Lake, Oregon. Note the late peak in larval catches and lower lake elevations in 2010.

Figure 13. Map of Riverbend showing wetland habitat available for larval suckers at different Upper Klamath Lake elevations, 4143 ft (shaded in red) and 4141.2 ft (shaded in green), Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

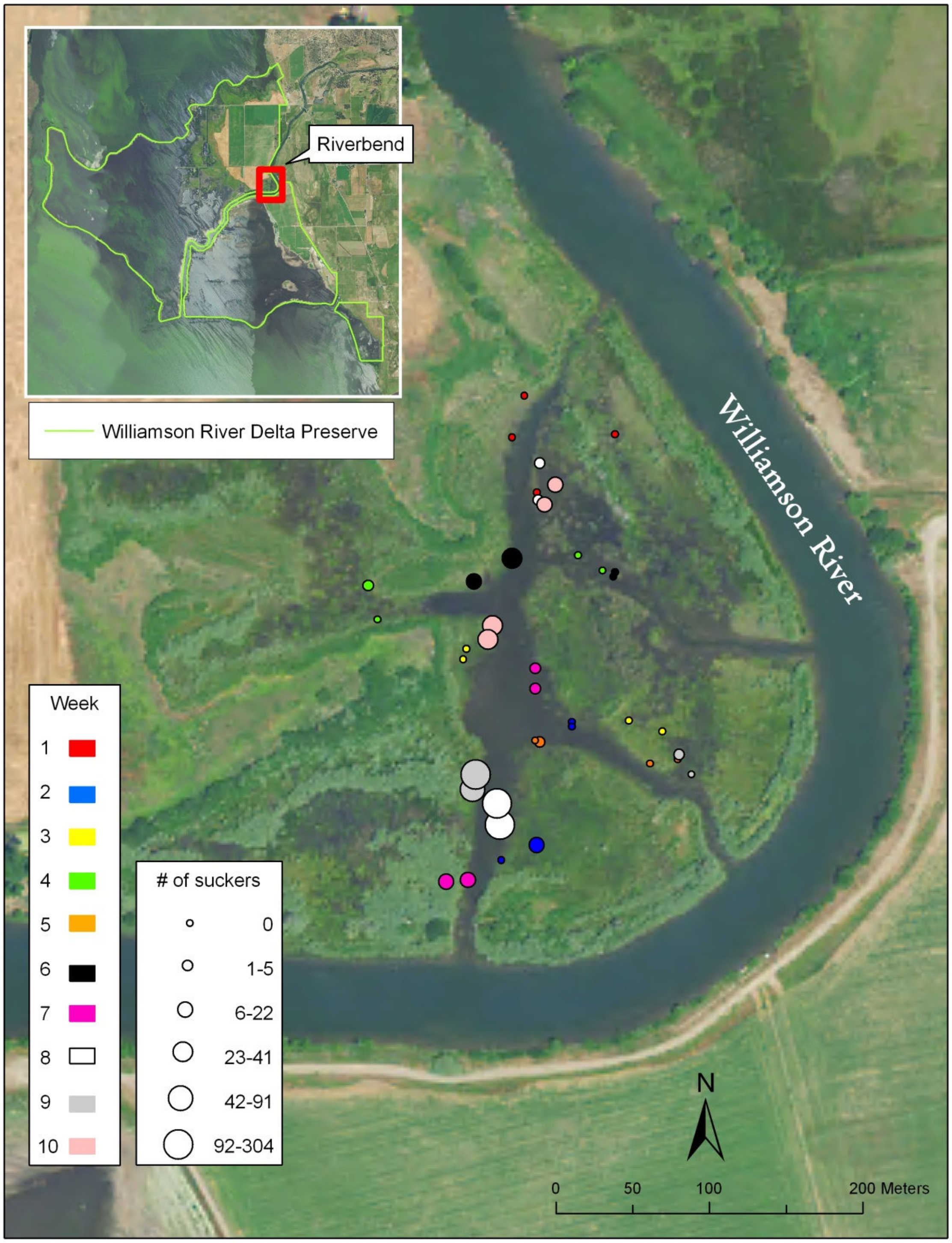


Figure 14. Map showing location of catches of larval Lost River and shortnose suckers in Riverbend, Upper Klamath Lake, Oregon, 2010. Note the high number of larvae captured in the main channels of the restored wetland at the end of the sampling season (weeks 8, 9, and 10).

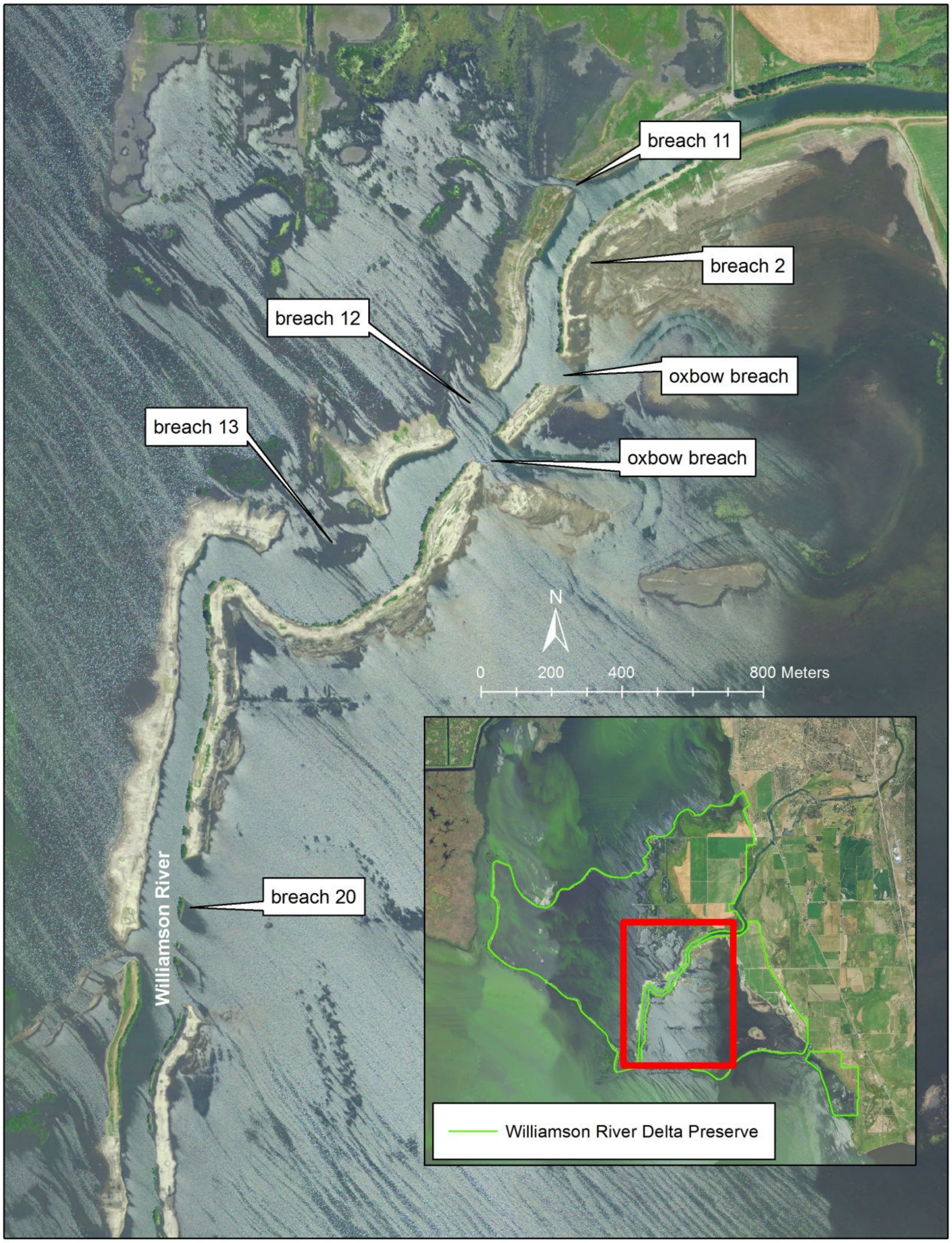


Figure 15. Location of breaches along the Williamson River in both Tulana and Goose Bay, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

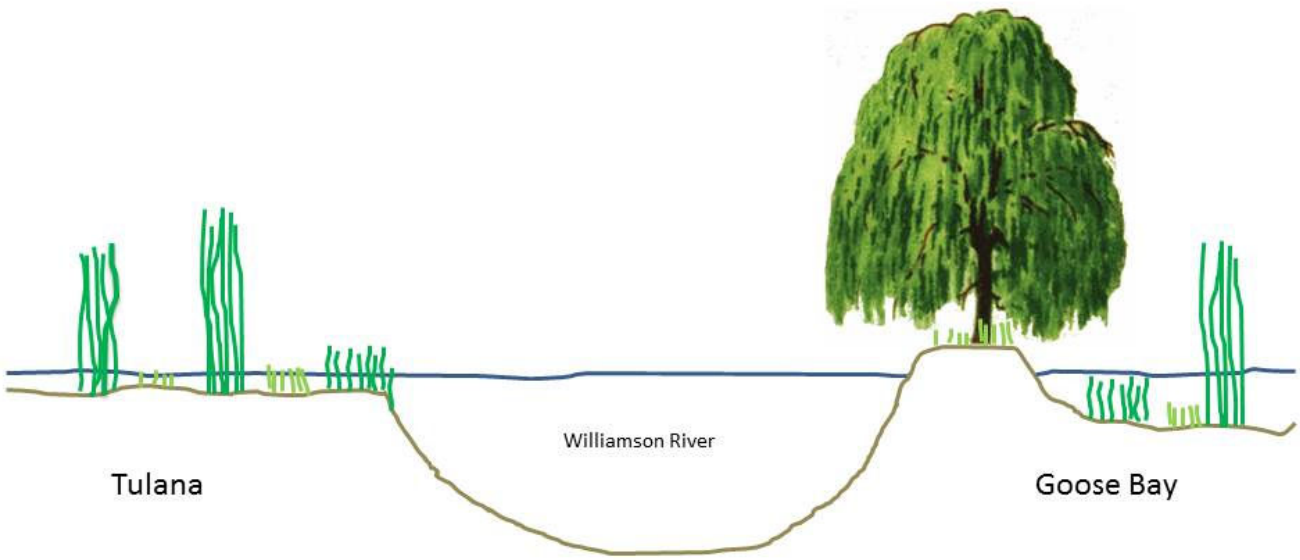


Figure 16. Cross section of post restoration levees along the Williamson River in Tulana and Goose Bay, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

Figure 17. Pop nets set in 2011 on the edge of large *Polygonum amphibium* patch in the Tulana (A), in isolated patch of *Schoenoplectus acutus* in Goose Bay (B), and in open water surrounded by *Schoenoplectus acutus* and *Sparganium emersum* in Goose Bay west (C). Fifteen suckers were captured in net A, four in net B, and one in net C. Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

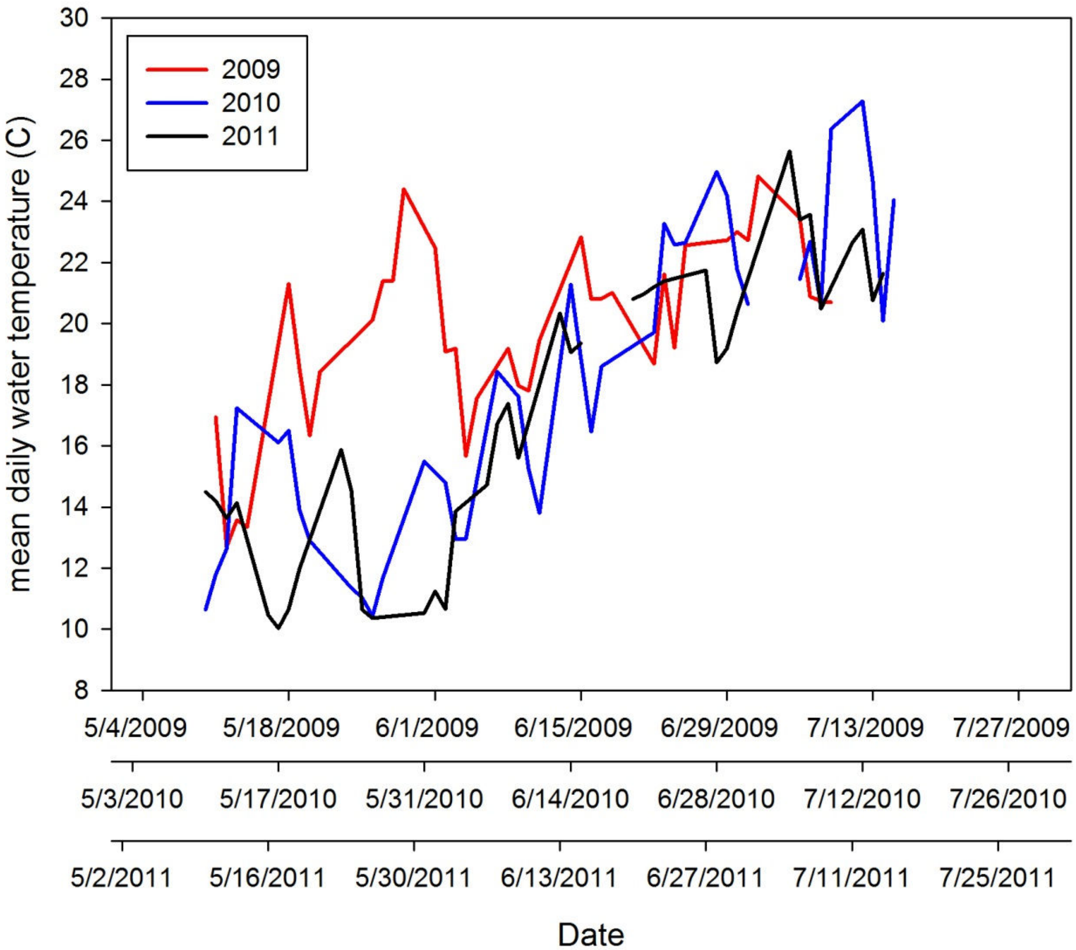


Figure 18. Mean daily instantaneous water temperature (^oC) recorded during the 2009, 2010, and 2011 larval sampling periods, Williamson River Delta Preserve, Upper Klamath Lake, Oregon. Breaks represent gaps in data due to equipment failure.