Larval Lost River and Shortnose Sucker Response to Large Scale Wetland Restoration at the Williamson River Delta Preserve

2010 Annual Data Summary

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Introduction

Wetland ecosystems provide many unique and beneficial ecological functions including water quality improvement through removing and retaining nutrients and processing waste (Mitsch 1992), habitat qualities that promote a high degree of biodiversity (Zedler and Kercher 2005), and flood reduction (Hey and Philippi 1995). However, despite these important ecosystem services, wetland destruction since the 1780s in the U.S. alone is estimated at 53%, with the main loss being freshwater wetlands (Moser et al. 1996). With these sharp declines and a greater understanding of wetland ecology, restoring hydrologic connectivity to degraded wetland systems has become an important strategy for the recovery of certain species (U.S. Fish and Wildlife Service 1993, Mitsch and Gooselink 2000, Brumbaugh et al. 2006).

In Upper Klamath Lake, Oregon wetland habitat had decreased to only 7,000 hectares (ha) by 1968, a reduction of roughly 65% (National Research Council 2004). Providing substantial habitat for both waterfowl and fish, a large marsh ecosystem historically occupied the interface of the Williamson River and Upper Klamath and Agency lakes. However, the conversion of this deltaic habitat, the Williamson River Delta, to agriculture land in the 1940s has been cited as a principal reason for the decline in populations of two federally endangered fish species endemic to the Upper Klamath River Basin in southern Oregon and northern California, the Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris* (U.S. Fish and Wildlife Service 1993). For larval and juvenile suckers, habitat complexity within littoral wetlands is important for protection from non-native fish species (Markle and Dunsmoor 2007), provides ample growing and feeding opportunities (Crandall et al. 2008), and helps retain larvae from the clockwise gyre that dominates surface currents in Upper Klamath Lake (Markle et al. 2009).

The Hatfield Upper Klamath Basin Working Group identified large scale restoration at the Williamson River Delta as an opportunity to provide an increase in nursery habitat for larval and juvenile Lost River sucker and shortnose suckers, improve water quality conditions at the Williamson River and Upper Klamath Lake boundary, and facilitate other ecosystem functions normally associated with healthy wetland habitat. In 1996, The Nature Conservancy and numerous state, federal, and tribal partners began an innovative wetland restoration project to restore this once important habitat.

The Nature Conservancy purchased the northern portion of the Williamson River Delta in 1996 (formerly called Tulana Farms and referred to as Tulana) and the southern portion in 1999 (formerly called Goose Bay Farms and referred to as Goose Bay) to create the Williamson River Delta Preserve (WRDP, referred to as the Delta). Three small scale restoration projects were completed at the Delta in 1999 and 2003. Fish monitoring results from 2001 through 2007 in these areas indicated that larval and juvenile suckers were using the Riverbend and South Marsh wetlands, with few fish captured at the Campfields restoration site (Crandall et al. 2008).

After the success of these small scale projects, an innovative restoration plan throughout the larger Tulana and Goose Bay portions of the Delta was completed. In October 2007, roughly 3,000 meters (m) of levee was removed, flooding 2,500 ha of old agricultural fields on the Delta. In November 2008 levees along the Goose Bay portion of the Delta were mechanically breached, including a historic oxbow channel. With the subsequent flooding of Goose Bay, an additional 1,000 ha of emergent habitat are now available for larval and juvenile suckers. In 2010 we continued with larval sucker monitoring in the restored wetlands of Riverbend, Tulana, Goose Bay, South Marsh, and at lakeshore wetlands along the Goose Bay shore.

The objective of this ongoing monitoring project is to assess the response of larval suckers to wetland restoration at the Delta by determining: 1) the distribution, abundance, and habitat use of endangered larval suckers, 2) if other native and non-native species are using the Delta, 3) the response in fish condition (size, gut fullness) to the most recent restoration projects, and 4) compare data collected from the Delta with data collected during previous years and outside project sites. Additionally, data collected is one component of a long-term research and monitoring collaboration with the U.S. Geological Survey, Oregon State University, and the Bureau of Reclamation aimed at evaluating the effect of restoration at the Delta and hydrodynamic processes on larval and juvenile Lost River and shortnose suckers.

Post restoration monitoring offers a unique opportunity to develop an essential understanding of how larval suckers respond to the developing habitats throughout the Delta and provides a baseline from which to document changes over time. Larval sucker monitoring at the Delta is also imperative for assessing wetland restoration as a means of aiding in the recovery of Lost River sucker and shortnose sucker in Upper Klamath Lake. We sampled at random points to monitor an array of shallow water (<1 meter deep) habitat types across the Delta and at fixed points to determine temporal changes throughout the course of the larval outmigration period. Results from 2010 are included in this report.

Methods

Sampling Design

Our 2010 sampling program mimicked the protocol used at the Delta since 2006, designed to answer specific questions regarding larval sucker use of the newly restored Tulana and Goose Bay portions of the Delta and comparing current use with trends seen prior to restoration. The main objective was to assess the effect of different water depths, structure (vegetation), wetland types (restored vs. lakeshore fringe), and water quality on sucker abundance and condition in these restored areas.

In 2010 we conducted larval sampling at six locations throughout the Delta: four restored wetlands (Riverbend, South Marsh, Tulana, and Goose Bay) and two areas of existing lakeshore fringe wetlands along the lake margin of Goose Bay—Goose Bay west (GBW) and Goose Bay east (GBE; Figure 1). In each of the six locations we set nets in areas with cover (>25% emergent or submerged aquatic vegetation) and in open water (0% macrophyte cover), replicated at both shallow (mean depth = 0.28 m ± 0.0057 SE) and deep (mean depth = 0.59 m ± 0.0059 SE) water depths. This sampling design allows us to model larval sucker distribution in four habitat types: deep water with vegetation, deep water without vegetation, shallow water with vegetation, and shallow water without vegetation.

Random sampling sites were generated for each of the six areas prior to sampling using Hawth's Tools version 3.27 in ArcMap and were only visited once per season. Additionally, two fixed sites in both Tulana and Goose Bay were visited weekly to support a larval modeling project (see Figure 1). Four sampling sites were visited weekly in both Tulana and Goose Bay (two fixed, two random), while two sites were visited each week in Riverbend, South Marsh, GBE, and GBW (two random). More sampling effort was allocated to Tulana and Goose Bay compared to the other four areas because these areas are significantly larger and we wanted to ensure a fairly representative spatial coverage of these areas. Ideally, at each site one net was set in vegetation and one in an area devoid of vegetation; however, at certain sites in Goose Bay and along the Goose Bay shoreline vegetation did not exist at the site and thus both nets were set in open water. If a random point was too deep for our sampling gear, the nets were moved to the closest area of shallower water. Deep and shallow nets, as well as un-vegetated and vegetated nets, were set in both the morning and afternoon in order to avoid possible diel influences on larval catches.

The nets consisted of two 1" diameter PVC frames (approximately 2.56 m square), 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 of the net 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, and 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% ethanol. Stalks of vegetation in the nets were sometimes removed in order to more effectively capture fish. This schedule was repeated every week from May 10 – July 15.

Fish Identification, Condition, and Ageing

Immediately after collection, we transferred all larvae (suckers and nonsuckers) to 50 milliliter (mL) jars containing ~20 mL of 95% ethanol. All fish larvae were 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% full, 25% full, 50% full, 75% full, and 100% full (Cooperman and Markle 2003; Hendrixson 2008).

A portion of the captured sucker larvae (222 individuals) 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% (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 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 larval suckers per net, was used to compare larval captures across sampling areas and sampling years. Because a significant portion of our sampling effort is focused on the two newly restored areas, Tulana and Goose Bay, CPUE allows characterization of catches across sites despite uneven sampling effort. Wind data for 2009 and 2010 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

General Trends

Larval suckers began recruiting to our nets on 10 May 2010, and we ceased sampling on 15 July when we stopped catching larvae, for a sampling period of ten weeks. A total of 1536 suckers were captured in 320 nets, resulting in a mean catch per unit effort of 4.8 ± 1.40 SE suckers per net. 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. Four habitat types were sampled: 81 nets were set in deep water with no vegetation, 77 were set in deep water with vegetation, 82 were set in shallow water with no vegetation, and 80 nets were set in shallow water with vegetation present. Our sampling effort in 2010 (n = 320 nets) represented the greatest annual effort since this sampling methodology was adopted in 2006.

Similar to past years' efforts, catches of larval suckers were variable in 2010, with 40% of the nets set in 2010 capturing at least one sucker, compared to 52% in 2009 and 57% in 2008. Forty one nets (13%) caught at least five suckers, 21 nets (7%) captured at least 10 suckers, and the highest single net capture of suckers was 304 on 29 June in Riverbend. Of the 1536 suckers captured in 2010, 99 were identified as LRS, 1032 as SNS/KLS, and 405 suckers were ≥ 15 mm, were not identified to species and were thus labeled as unknown, representing 7%, 67%, and 26% of the total sucker catch, respectively. This species composition, with SNS/KLS representing the majority and LRS representing the minority of suckers captured, is similar to the species composition observed during past years' sampling efforts.

Peak cumulative larval sucker catches occurred during the week of 28 June, substantially later than the peaks witnessed in 2008 and 2009, 9 June and 1 June, respectively (Figure 3). The three highest net catches occurred in Riverbend on 29 June (two nets) and 7 July with 304, 226, and 201 suckers captures in each. These three nets accounted for roughly 48% of the total larval sucker catch in 2010. Comparing weekly catch curves from each of the six sampling areas, some differences in weekly peaks were prevalent. Catches of suckers along the Goose Bay shoreline (Goose Bay west and east) and South Marsh were low throughout the entire sampling period with no significant peaks. However, catches in Goose Bay peaked during the week of 14 June, while catches in Tulana peaked the following week, 21 June, and Riverbend catches peaked during the week of 28 June (Figure 4).

Catches of larval suckers were roughly 10 times greater in Riverbend compared to the next highest sampling area. 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. Larval suckers were captured more frequently in nets set in restored areas (Riverbend, Tulana, Goose Bay, South Marsh) compared to nets set in the lakeshore fringe wetlands along the Goose Bay shoreline (Goose Bay west and east), with CPUEs of 6.1 ± 1.9 SE and 0.9 ± 0.2 SE suckers per net.

Larval Sucker Habitat Use

Larval suckers were caught more frequently in nets set in deep water (>0.5 m deep, <1.0 m deep) than in shallow water (<0.5 m deep). Mean catch per unit effort of suckers in deep nets was 6.8 ± 2.8 SE fish per net while only 2.8 ± 0.6 SE in nets set in shallow water. Catch differences were not large between nets set in vegetation and nets lacking vegetation, with mean catch per unit effort of 4.9 ± 1.9 SE suckers in vegetated nets and 4.7 ± 2.1 SE suckers in nets without vegetation. With the two habitat variables combined for analysis, catches were higher in deep water nets set in vegetation compared to deep water nets without vegetation, shallow water nets without vegetation, and shallow nets with vegetation—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.

When analyzing the relationship between the amount of vegetation in a net versus the number of suckers captured in the net, no patterns emerged as larval suckers were caught in similarly high densities in nets set in both sparse vegetation (vegetation class 1) and dense vegetation (vegetation class 4; Figure 5A and 5B). We captured larval suckers in a variety of both native and non-native wetland plant species, including *Schoenoplectus ssp.*, *Eleocharis spp.*, *Typha latifolia*, *Polygonum spp.*, *Potamogeton spp.*, *Phalaris arundinacea*, *Rumex spp.*, and a variety of dead, submerged vegetation remaining from when the land was in agriculture production. Mean catch per unit effort was highest in nets set in *Eleocharis spp.* (n=37 nets), with 13.9 ± 8.5 SE suckers per net captured.

Fish Condition

Mean standard length (SL) of suckers captured in 2010 was 14.3 mm ± .04 SE, with a range from 10 mm to 27 mm. Of the larvae identified to species, suckers identified as SNS/KLS were on average 0.4 mm larger than fish identified as LRS ($mean_{SNS/KLS}$ = 13.6 mm ± 0.02 SE; $mean_{LRS}$ = 13.2 mm ± 0.07 SE). Mean standard length of unidentified suckers (≥ 15 mm SL) was 16.5 mm ± 0.1 SE. Larval suckers captured in South Marsh were on average larger than fish trapped in the other five sampling areas; mean standard length in South Marsh was 15.8 mm ± 0.3 SE, followed by Goose Bay east (mean SL = 15.7 mm ± 0.5 SE), Tulana (mean SL = 15.6 mm ± 0.2 SE), Goose Bay west (mean SL = 15.1 mm ± 0.2 SE), Goose Bay (mean SL = 14.8 mm ± 0.1 SE), and Riverbend (mean SL = 13.9 mm ± 0.04 SE). Cumulative percent length frequency diagrams suggest that there was a wider distribution of suckers of different lengths in the restored wetlands than in the lakeshore fringe wetlands along the Goose Bay shoreline (Figure 6).

Suckers occupying habitat in the restored wetlands of the Delta (Riverbend, Tulana, Goose Bay, and South Marsh) were generally smaller (mean SL = 14.3 mm ± 0.04 SE) than suckers inhabiting the wetlands along the Goose Bay shoreline (Goose Bay west and east; mean SL = 15.3 mm ± 0.2 SE). However, only two fish 20 mm or greater in SL were captured along the Goose Bay shoreline while 30 suckers 20 mm or greater in SL were caught in the restored wetlands (see Figure 6). Larger suckers tended to occupy shallow water habitat more frequently, as these fish were on average 1.4 mm larger than fish captured in deep water nets (mean $SL_{shallow}$ = 15.3 mm ± 0.1 SE, mean SL_{deep} = 13.9 mm ± 0.04 SE). However, size differences amongst suckers captured in nets with vegetation versus nets without vegetation were not as substantial, as the mean SL of suckers in nets with vegetation was 14.4 mm ± 0.07 SE compared to 14.3 mm ± 0.05 SE in nets without vegetation. When the depth and vegetation habitat variables are combined, mean standard length of suckers captured in shallow nets with vegetation (mean SL = 15.6 mm ± 0.2 SE) was greater than the other habitat combinations: mean $SL_{shallow\ no\ veg}$ = 15.1 mm ± 0.1 SE, mean $SL_{deep\ veg}$ = 14.01 mm ± 0.06 SE, mean $SL_{deep\ no\ veg}$ = 13.9 mm ± 0.05 SE.

Two hundred and twenty two larval suckers were aged by researchers at Oregon State University, of which 25 were LRS, 76 were identified as SNS/KLS, and 121 were unknown. The mean (± SD) age of Lost River sucker larvae was 18.5 ± 3.7 days, while the mean (± SD) age of SNS/KLS larvae was 20.3 ± 3.6 days. Of the suckers aged, the youngest fish was 13 days old, captured on 28 June in Tulana, while the oldest fish was 50 days old, captured on 22 June in Riverbend. The earliest hatch date of a larval sucker from our aged sample was 11 April, roughly two months earlier than the last larval hatch date from our sample, 25 June. There was a strong relationship between the length and age of larval suckers (R^2 = 0.80, P < 0.001; Figure 7). 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 8).

Of the 1536 suckers captured in 2010, gut fullness levels could be determined for 87% (n=1332) of the fish. Larval suckers captured in the four restored wetlands had higher mean gut fullness levels and had a higher percentage of fish with at least 50% gut fullness compared to larvae captured along the Goose Bay shoreline (Figure 9). More importantly, only 2% of larvae captured in the restored wetlands had 0% gut fullness compared to 13% in the existing wetlands along the Goose Bay shoreline. Fish captured in nets without vegetation in both shallow and deep water had fuller guts than fish captured in nets with vegetation set in both depth categories. Sucker larvae captured in shallow nets without vegetation had the greatest mean gut fullness at 68.5% ± 1.8 SE. Fish identified as SNS/KLS had a greater mean gut fullness (64.9% ± 0.7) than fish identified as LRS (37.9% ± 2.5); however, because larger larvae are likely to have fuller guts, this disparity is logical as larvae identified as SNS/KLS were larger on average than larvae identified as LRS.

Fixed Points

Two sampling sites within Tulana (point A and point B) and two sites within Goose Bay (point C and point D) were visited weekly in order to gain data to validate a larval sucker drift model for the Delta and Upper Klamath Lake (see Figure 1; Tammy Wood, U.S. Geological Survey, personal comm. 2011). The Tulana fixed points remained at the same location as in 2008 and 2009 while the Goose Bay sites remained in the same locations as in 2009. All nets set at these four fixed 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 while points B and D were deep sites. A total of 20 nets were set at each site in 2010.

Mean 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). Weekly mean catch curves for the fixed points in Tulana and Goose Bay are shown in Figures 10 and 11, respectively. Looking at the habitat (i.e. vegetation) associations of sucker larvae at the fixed points, fish were captured at varying rates in vegetation and open water at the Tulana points but at similar rates in vegetation and open water nets at the two Goose Bay points. At the shallow point in Tulana (point A), larval suckers were captured at higher rates in nets without vegetation (mean CPUE = 4.6 ± 1.8 SE) compared to nets with vegetation (mean CPUE = 1.0 ± 0.3 SE). Alternately, at the deep point in Tulana (point B), suckers were captured more frequently in nets set in vegetation (mean CPUE = 4.7 ± 2.2 SE) compared to nets without vegetation (mean CPUE = 1.7 ± 0.7 SE). At both points in Goose Bay, larval suckers were captured at similar rates in both habitat types, with slightly higher catches in nets without vegetation at point C (mean $CPUE_{no\ veg}$ = 7.0 ± 6.6 SE and mean $CPUE_{veg}$ = 6.4 ± 4.2 SE) and slightly higher catches in nets with vegetation at point D (mean $CPUE_{veg}$ = 1.0 ± 0.9 SE and mean $CPUE_{no\ veg}$ = 0.9 ± 0.4 SE).

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. This discrepancy in size between the fish at the Tulana and Goose Bay fixed points is rational as cumulative mean standard length of all suckers captured in Tulana was greater than the mean standard length of fish captured in Goose Bay in 2010.

Water Quality Conditions

High stress threshold conditions are defined by Loftus (2001) as conditions potentially threatening to the health of larval and juvenile suckers in Upper Klamath Lake, based on temperature, DO concentration, 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, recorded in each net with a Hydrolab Quanta®, indicated shallow sites were on average about 3^{o}C warmer than deep nets and no difference existed between the mean temperature of both vegetated and open water sites (mean = 18.1 ^{o}C). Average 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). Twelve nets recorded a temperature greater than 28 ^{o}C, all after 28 June and located in Tulana, Goose Bay, or Riverbend. Interestingly, a total of five suckers were captured in two of these 12 nets.

Mean instantaneous dissolved oxygen concentrations were greatest in Riverbend (mean = 9.0 mg/L ± 0.16 SE), followed by Goose Bay (mean = 8.7 mg/L ± 0.17 SE), Goose Bay west (mean = 8.6 mg/L ± .15 SE), Goose Bay east (mean = 8.4 mg/L ± 0.16 SE), South Marsh (mean = 7.9 mg/L ± 0.29 SE), and Tulana (mean = 7.8 mg/L ± 0.18). Only six nets 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 on 12 and 13 July. Only one sucker was captured in a net with an instantaneous dissolved oxygen concentration of 4.0 mg/L or less.

The highest mean seasonal pH was measured in Goose Bay west (mean pH = 8.4 ± .010 SE), followed by Goose Bay east (mean pH = 8.3 ± 0.08 SE), South Marsh (mean pH = 8.2 ± 0.11 SE), Riverbend (mean pH = 8.1 ± 0.07 Se), Goose Bay (mean pH = 8.1 ± 0.06 SE), and Tulana (mean pH = 8.0 ± 0.05 SE). Only one net, set along the Goose Bay west shoreline, registered a pH greater than 9.7 with a measured pH of 9.72. No suckers were captured in this net.

Water quality conditions differed between the two wetland types. Mean instantaneous water temperature was roughly 2 ^{o}C higher in the restored wetlands than in the lakeshore fringe wetlands. Mean dissolved oxygen concentrations were similar in the two wetland types: mean $DO_{restored}$ = 8.2 mg/L ± 0.11 SE and mean $DO_{existing}$ = 8.5 mg/L ± 0.11 SE.

Non-Sucker Species

Due to the nature of the sampling gear used, our sampling methods were not exclusive to larval suckers—several other larval fish species were caught, including tui chub *Gila bicolor*, blue chub *G. coerulea*, fathead minnow *Pimephales promelas*, yellow perch *Perca flavescens*, bullhead *Ameiurus spp.*, and sculpin *Cottus spp*. A total of 1687 non-sucker larvae were captured in 2010, resulting in a mean catch per unit effort of 5.3 ± 0.9 SE non-suckers per net. In 2010, 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) were captured.

Catches of non-suckers in both the restored and existing wetland types were similar, with a catch per unit effort of 5.3 fish per net in each. Differences in non-sucker catch rates existed between the six sampling areas, with the greatest catch per unit effort in Riverbend (CPUE = 13.5 ± 3.62), followed by Goose Bay east (CPUE = 7.7 ± 2.10 SE), Tulana (CPUE = 5.2 ± 1.15 SE), Goose Bay (CPUE = 3.3 ± 1.17), Goose Bay west (CPUE = 3.0 ± 1.22 SE), and South Marsh (CPUE = 1.8 ± 0.56 SE). The catch per unit effort for each species in each sampling area is shown in Figure 12. Non-suckers were captured at similar rates in the four different habitat types, but most frequently in deep nets set in vegetation (CPUE = 6.2 ± 1.56 SE), followed by shallow nets without vegetation (CPUE = 5.4 ± 1.47 SE), deep nets without vegetation (CPUE = 4.9 ± 1.74 SE), and shallow nets with vegetation (CPUE = 4.8 ± 1.05 SE).

Yellow perch, bullhead, and fathead minnows are the three non-sucker species most likely to prey on larval or juvenile suckers. While yellow perch and bullhead were captured in low densities, fathead minnow larvae were captured in the highest densities of non-sucker species. Yellow perch were captured in all restored areas except South Marsh while bullheads were only captured in two nets in Tulana during the last week of sampling, 15 July. Fathead minnow catches were highest in Riverbend (CPUE = 6.2 ± 2.77), Goose Bay east (CPUE = 4.0 ± 1.44 SE), Tulana (CPUE = 2.1 ± 0.64), South Marsh (CPUE = 1.1 ± 0.34), Goose Bay west (CPUE = 1.1 ± 0.46), and Goose Bay (CPUE = 0.9 ± 0.38 SE).

Discussion

Large scale wetland restoration at the Williamson River Delta was intended to assist in the recovery of endangered populations of Lost River sucker and shortnose sucker in Upper Klamath Lake, Oregon. The reestablishment of hydrologic connectivity between the Delta and the Williamson River and Upper Klamath and Agency lakes provides a substantial increase in the nursery habitat available for the larvae of these two catostomid species during their spring outmigration. With both the Tulana and Goose Bay portions of the Delta now restored, roughly 1,000 ha of shallow water habitat are accessible for larval and juvenile sucker rearing. Annual monitoring of changes in temporal and spatial patterns, physical conditions, and habitat occupancy of larvae in the Delta can provide valuable insight into answering questions regarding future wetland restoration projects in the upper basin and lake level management for Upper Klamath Lake. Results from The Nature Conservancy's sampling in 2010, the second year of post-restoration monitoring, suggest that larval suckers are extensively using the restored wetlands.

Catches of larval suckers in 2010 were higher than in 2009, yet mean annual catch per unit effort was lower than in 2006 (mean CPUE = 14.9 ± 3.62 SE), 2007 (mean CPUE = 9.0 ± 1.31 SE), and 2008 (mean CPUE = 8.3 ± 1.81 SE). The variability in cumulative annual CPUE since 2006 could be a product of temporal variation in the spawning population of adult suckers, differences in egg production or larvae survival in the Williamson and Sprague Rivers, disparities in larval outmigration characteristics resulting from inter-annual deviation in river flow or lake elevation, greater dispersion of larvae after restoration at the Delta, or some other factor. However, while restoration of the Delta has certainly affected the spatial distribution of larvae, it does not seem likely that the reconfiguration of the landscape at the mouth of the Williamson River would result in the variation of cumulative annual catches we have experienced since hydrologic reconnection.

An important trend in our larval catches post-restoration is still manifested despite the discrepancy in inter-annual cumulative larval catches. In 2009 and 2010, after the hydrologic reconnection of Goose Bay, larval sucker catches along the Goose Bay shoreline decreased significantly compared to catches in this location prior to restoration. Prior to flooding of Goose Bay, catch per unit effort along the Goose Bay shoreline was 25.3 ± 7.26 SE in 2006, 13.33 ± 2.23 SE in 2007, and 13.5 ± 5.53 SE in 2008. After restoration however, catch per unit effort of larval suckers was 0.9 ± 0.50 SE in 2009 and 0.9 ± 0.23 SE in 2010. Before wetland restoration, larval suckers 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 with the clockwise gyre that usually dominates lake circulation patterns (Cooperman and Markle 2003, Tammy Wood, U.S. Geological Survey, personal comm. 2011). Because hydrologic reconnection of Tulana and Goose Bay in November 2007 and October 2008, respectively, created numerous pathways for which larvae can now use to enter either the Delta or Upper Klamath and Agency Lakes, sucker larvae are no longer forced to travel along the Goose Bay shoreline. This new landscape at the mouth of the Williamson River and redistribution of suckers into previously unavailable habitats has most likely caused the decrease in our catches in the lakeshore fringe wetlands along the Goose Bay shoreline in 2009 and 2010.

One of the more interesting and puzzling trends witnessed in 2010 was the abundance of larval suckers in Riverbend, especially during the last three weeks of the sampling season. Catch per unit effort in Riverbend in 2010 was 25.3 ± 10.47 SE, compared to 2.9 ± 0.97 SE in 2006, 6.5 ± 2.55 SE in 2007, 5.4 ± 2.40 SE in 2008, and 3.3 ± 0.76 SE in 2009. Roughly four times higher than catches in any previous year, sucker larvae were found in typical numbers (roughly three to six fish per net) during the first seven weeks of the sampling season; however, beginning on 29 June, sucker larvae were densely packed throughout the deeper portions of this wetland. Because the hydrodynamics in this restored wetland are influenced by Upper Klamath Lake levels and Williamson River flows, much of the typically shallower portions of this wetland were dry during this peak in larvae because it occurred when lake levels had begun to decrease rapidly. High densities of sucker larvae were constrained to the deeper channels throughout the wetland (Figure 13). Any conclusions as to the direct cause of this abundance of larvae in Riverbend are speculative; however, Upper Klamath Lake levels, Williamson River flow conditions, and timing of spawning certainly are contributing factors but how each component effects the abundance of larvae in this wetland is entirely unknown.

Larval Sucker Habitat Use

Larval suckers were captured in a variety of open water and vegetated habitats throughout the emergent and riparian wetland zones of the Delta. While suckers were captured with greater frequency in deep nets (>0.5m deep, <1.0m deep) with and without vegetation, catch variability existed in the four different habitats sampled and it's likely that these differences were not statistically significant. Additionally, in 2010 each net was given a vegetation classification as an attempt to gain further insight into the relationship between the amount of vegetation in each net and the number of suckers captured. However, larvae were captured most frequently in nets with sparse vegetation and nets with dense vegetation, further suggesting that sucker larvae occupy a wide variety of microhabitats throughout the Delta.

While actual catch differences amongst the habitat types were variable, analysis of larval sucker condition, i.e. size and gut fullness, suggest that certain habitat types could be more beneficial to larval sucker growth. Larvae captured in shallow water had a distinct size and gut fullness advantage over larvae caught in nets set in deep water. Looking at the entire dataset, no size or gut fullness differences could be identified between fish captured in vegetation and open water nets. However, in Goose Bay and Tulana, fish captured in vegetation in both deep and shallow nets were on average larger than larvae captured in open water nets. Sucker larvae captured in the restored wetlands of the Delta did not maintain a size advantage compared to larvae captured in the lakeshore fringe wetlands along the Goose Bay shoreline; however, larvae captured in the restored areas did have fuller guts. Despite the difference in the condition of larval suckers between the restored and lakeshore fringe wetlands, habitat occupancy patterns were similar with larger fish with fuller guts captured in shallow nets.

Studies have shown that larval suckers show preference towards emergent vegetation, as it is used for protection from predators (Markle and Dunsmoor 2007) and larval survival was partially dependant on the total volume of emergent vegetation in the lake (Cooperman and Markle 2004). The mosaic of habitats throughout the Delta could contribute to improved survival of larval suckers, as wetlands serve as retention areas that slow advection from areas of possible high survival (emergent wetlands) to areas of low survival (Lake Euwana; Markle et al. 2009).

Larval suckers were captured in a variety of emergent wetland vegetation species and dead vegetation remaining from when the fields were in upland production. Larvae did not appear to have any preference for one type of emergent vegetation over another. Data from 2008 and 2009 show the same result. Habitat heterogeneity throughout the shallow areas of the Delta, in terms of cover of vegetation, diversity of wetland species, and patchiness of the vegetation, is probably more important than the presence of a specific emergent marcophyte species.

Larval Sucker Distribution in Relation to Delta Hydrodynamics

Catch per unit effort of larval suckers at point C, a shallow point in Goose Bay, was twice as high as the CPUE at any of the other three fixed sites at the Delta in 2010. In 2008, when fixed points were only sampled in Tulana (Goose Bay was not flooded until fall 2008), CPUE was about six times greater at point A than at point B. Additionally, in 2009, when fixed points in both Tulana and Goose Bay were sampled, catches at point A were about three times higher than catches of larval suckers at any of the three other fixed sites. Two hydrodynamic and meteorological factors could be resulting in the change witnessed in 2010: 1) lake elevation and river flow differences amongst years and 2) wind direction and speed differences amongst years. These two factors both affect the transport of water and rate of replacement of water throughout the Tulana and Goose Bay portions of the Delta (Wood and Buccola, in review). Point A is located roughly 80-120 m southwest of the northern most river breach in Tulana (see Figure 1) and serves as the first entrance to Tulana (furthest upstream)from the Williamson River during low lake elevations. In 2010, Upper Klamath Lake elevation was on average 0.5 m lower during the beginning of larval outmigration than in 2008 and 2009, which could have hindered the ability of larval suckers to enter Tulana at this location and theoretically could have reduced the amount of larvae at this fixed site. However, modeling of larval transport based on 2009 conditions indicated that with a 0.25 m decrease in observed lake elevation in 2009, larvae had a tendency to enter Tulana more frequently (Wood et al., in review).

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). Wind rose data indicates that mean wind speed was greater in 2010 than in 2009 (Figures 14A and 14B). In 2010 roughly 53% of wind from the west, southwest, or northwest reached speeds of 4-8 m/second compared to only 38% in 2009. Greater prevailing wind speeds in 2010 could have pushed aggregations of sucker larvae into Goose Bay instead of Tulana and thus could explain our lower catches at point A and greater catches at point C in 2010 compared to 2008 and 2009.

Non-sucker catches

Catches of non-sucker species were roughly six times lower in 2010 than in 2009, possibly a result of the cooler than normal spring in the Upper Klamath Basin in 2010. Figure 15, a graph of the mean daily instantaneous water temperature (^{o}C) recorded in each net with a Hydrolab Quanta®, from 2009 and 2010, shows the cooler water temperatures experienced during the first month of sampling in 2010. These lower water temperatures could have delayed the spawning of some non-sucker species, thus possibly resulting in the decrease in non-sucker catches. Fathead minnow generally begin spawning once water temperatures have reached 18 ^{o}C (Dobie et al. 1956). In 2010, mean daily instantaneous water temperature did not exceed 18 ^{o}C until 7 June. Fathead minnow abundance was especially low in 2010 compared to 2009. Catch per unit effort of fathead minnow in 2009 was 17.95 ± 2.94 SE, while only 2.3 ± 0.55 SE in 2010. Habitat preference overlapped between fathead minnows and larval suckers, as both groups of fish were captured more frequently in deep nets set in vegetation. Because the fathead minnow that we catch are larvae the risk of predation is minimal; however, in a laboratory setting adult fathead minnow preyed on larval suckers, so it is assumed that fathead minnow consume larval suckers in the Delta (Markle and Dunsmoor 2007). Additionally, high densities of larval and adult fathead minnow in Upper Klamath Lake occupy the same nursery habitat as larval suckers (Buettner and Scoppettone 1990, Markle and Dunsmoor 2007; Erdman and Hendrixson 2009) and the larvae could be competing with sucker larvae for food resources and cover opportunities. 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% 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.

Summary

Three trends observed in 2010 were different from trends witnessed during past years' pop-netting efforts at the Delta: 1) sucker larvae captured in the restored wetlands of the Delta had smaller mean standards lengths than sucker larvae captured in the lakeshore fringe wetland habitats along the Goose Bay shoreline, 2) catches at fixed point A in Tulana were lower than catches at other fixed points, and 3) abundance of larval suckers in Riverbend was four times as high as catches in this restored wetland during any other sampling year. At the start of our sampling season in 2010, Upper Klamath Lake level was at the lowest it had been at the beginning of any season since these sampling protocols were adopted in 2006. At this time and without further analysis, we are unsure of the effect that this lower than average lake level during the beginning of larval outmigration had on our catches. Understanding the effect of lower lake elevations on the distribution of sucker throughout the Delta and the effects on larval abundance in certain areas is extremely important to the recovery of these species.

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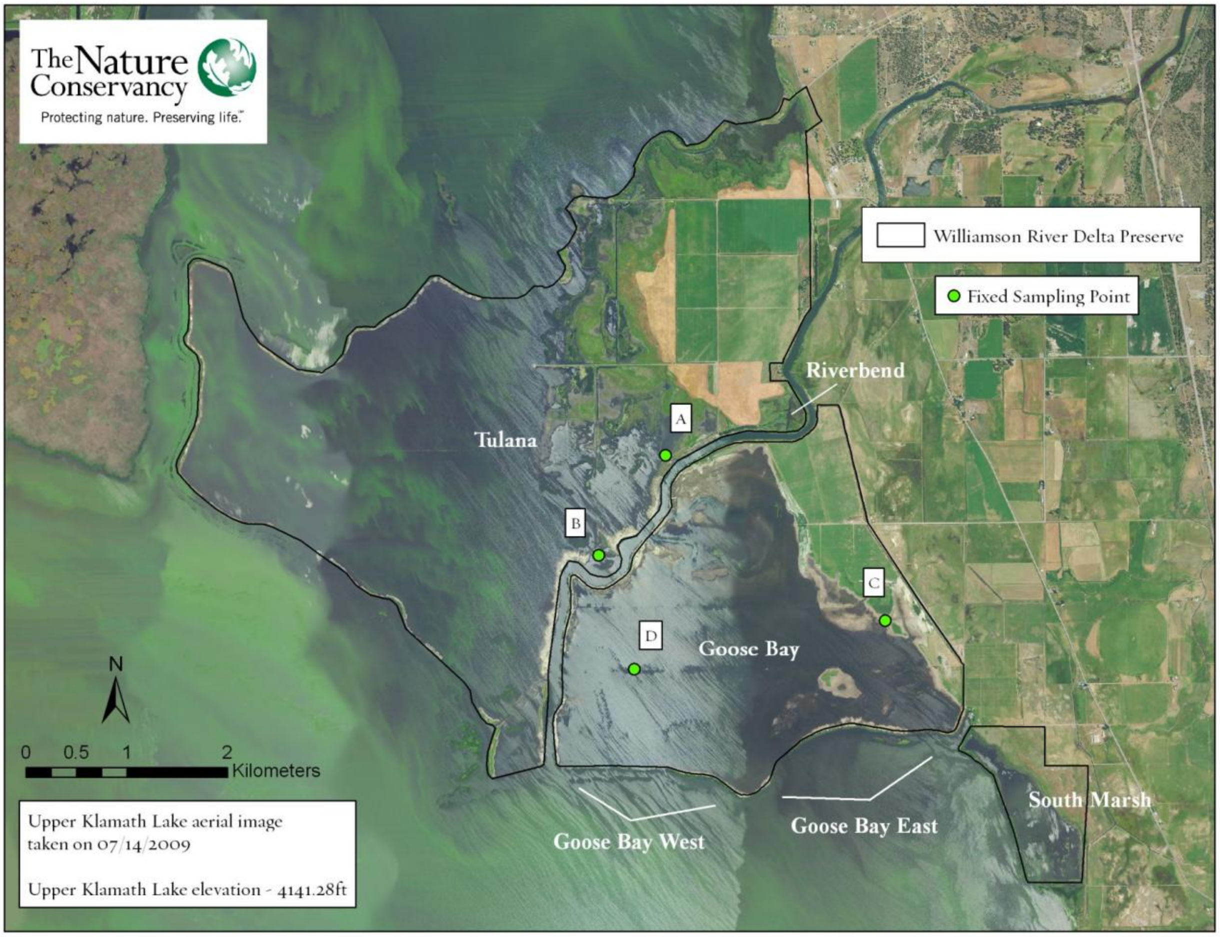


Figure 1. Map of the Williamson River Delta Preserve showing six sampling locations, Riverbend, Tulana, Goose Bay, Goose Bay west, Goose Bay east, South Marsh, and four fixed sites sampled for larval Lost River and shortnose suckers, Upper Klamath Lake, Oregon, 2010.

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, 2010.

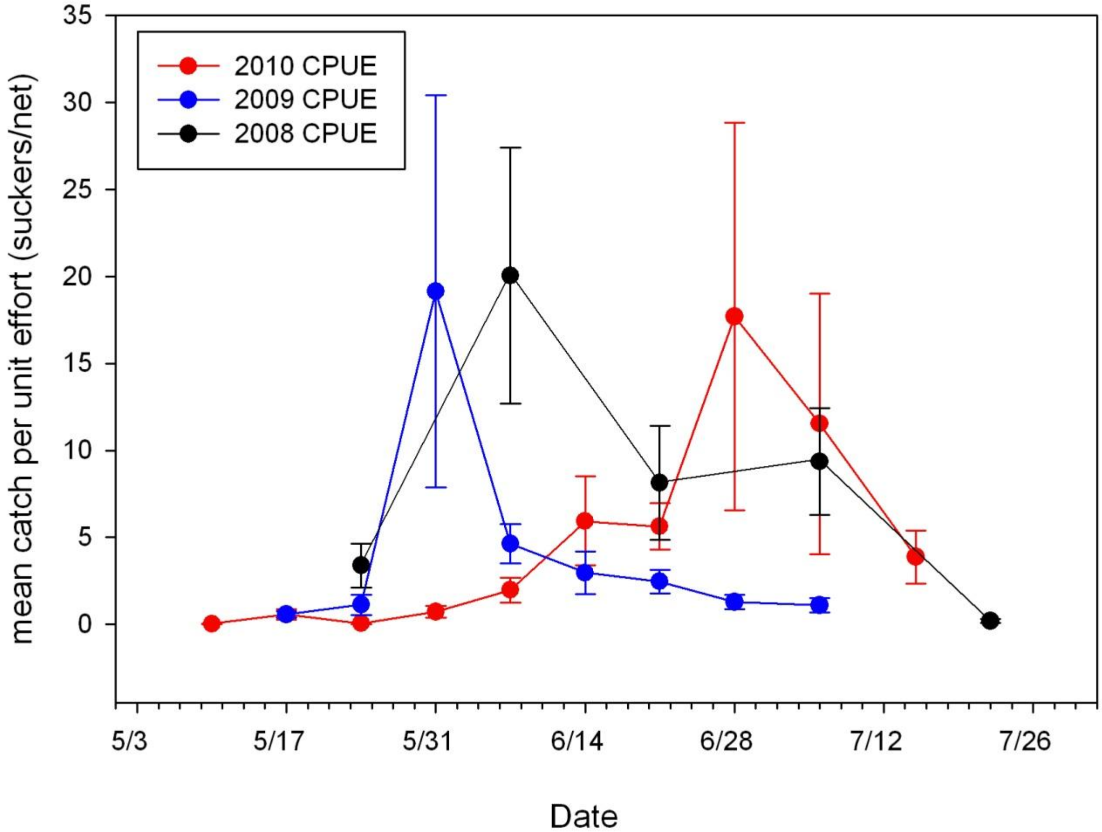


Figure 3. Larval Lost river and shortnose sucker weekly and bi-weekly cumulative catch per unit effort (suckers/net) with standard error bars from 2008, 2009, and 2010, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.

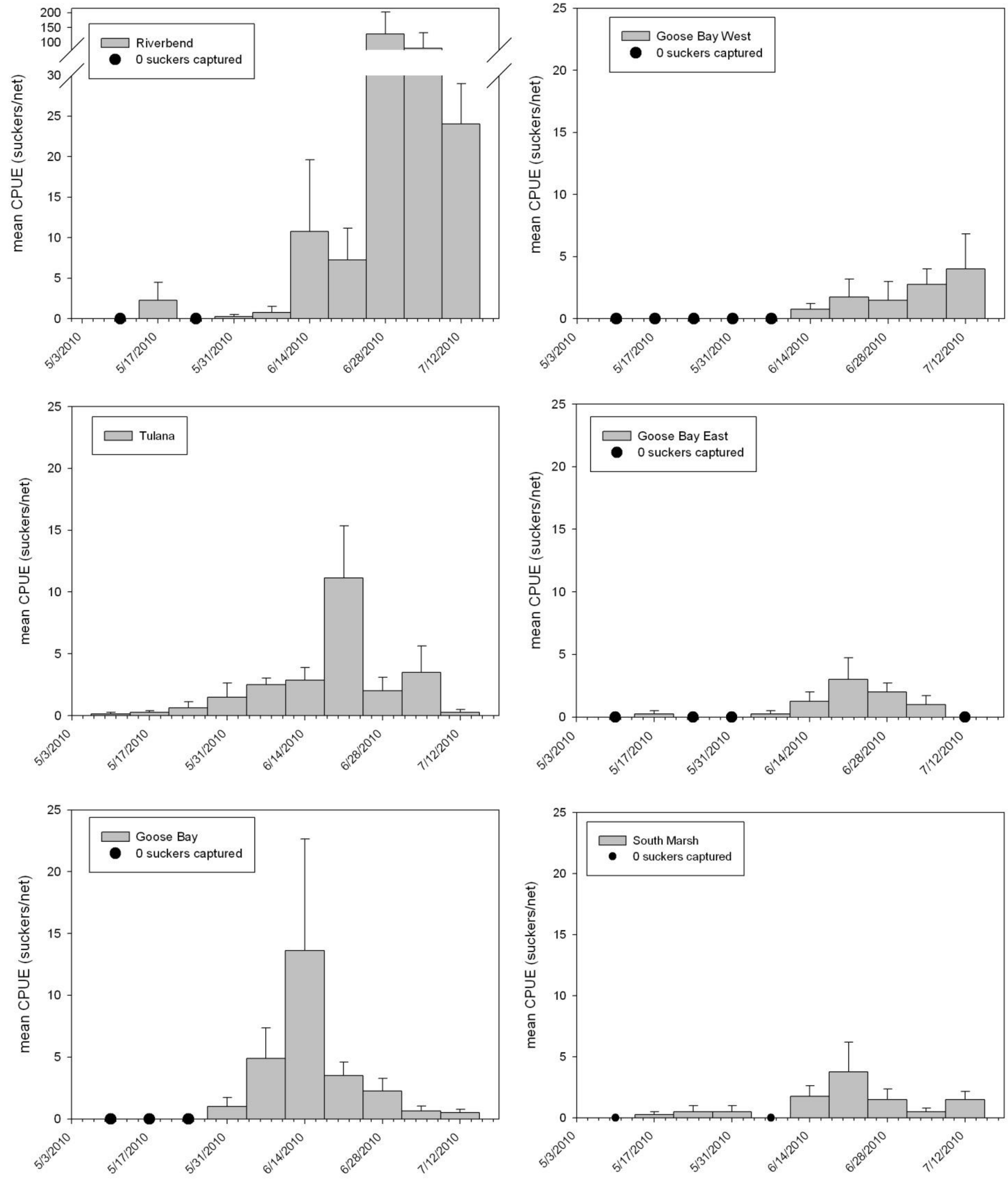
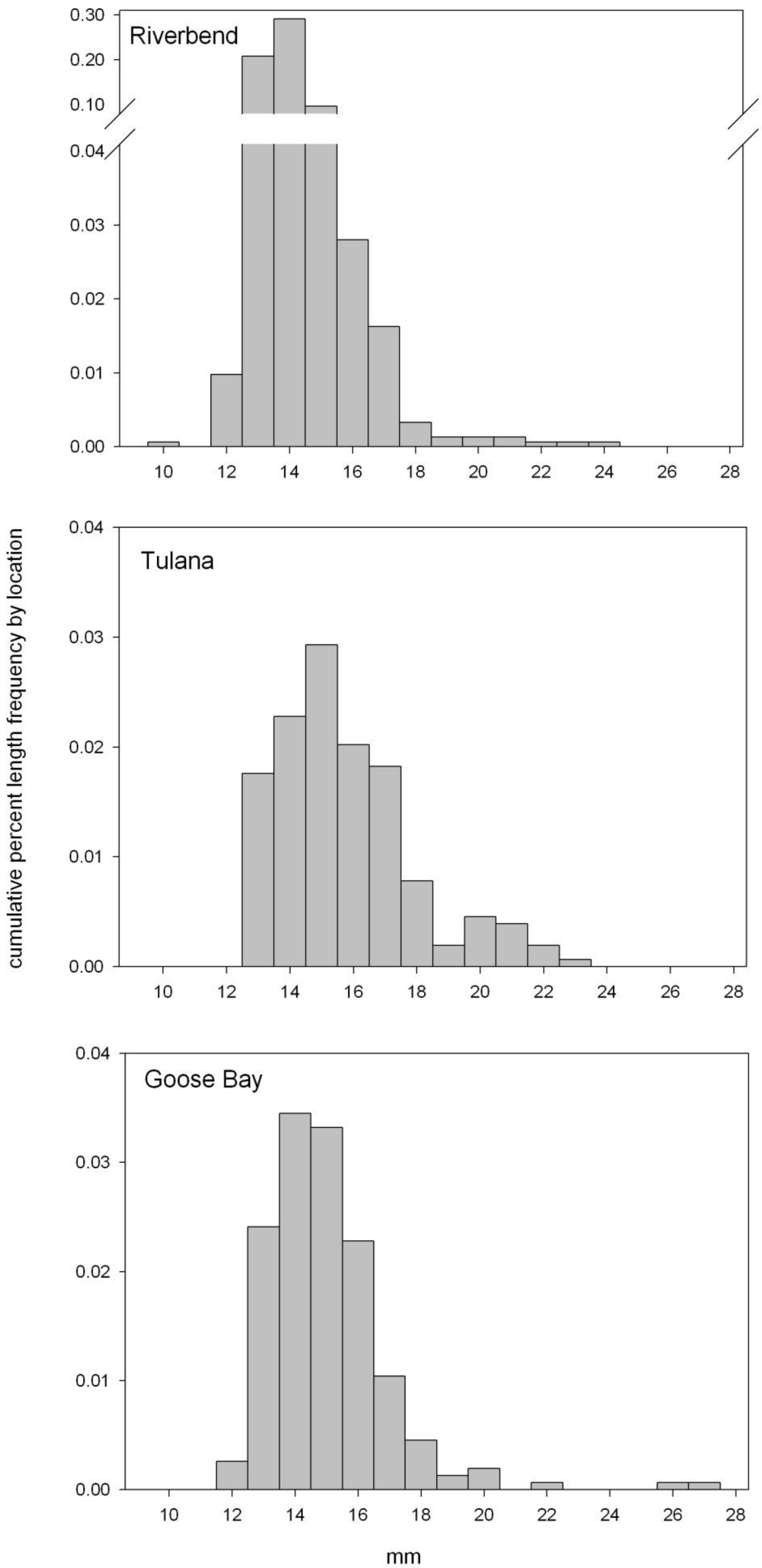


Figure 4. Weekly mean (± SE) catch per unit effort (CPUE; suckers per net) in Riverbend, Tulana, Goose Bay, Goose Bay West, Goose Bay East, and South Marsh, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010.

Figure 5. Pictures showing pop-nets set in vegetation class 1 (A) and vegetation class 4 (B), Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010.



Riverbend
0.30
0.20
0.10
0.04
0.03
0.02
0.01
0.00
10
12
14
16
18
20
22
24
26
28
Tulana
Goose Bay
cumulative percent length frequency by location
mm

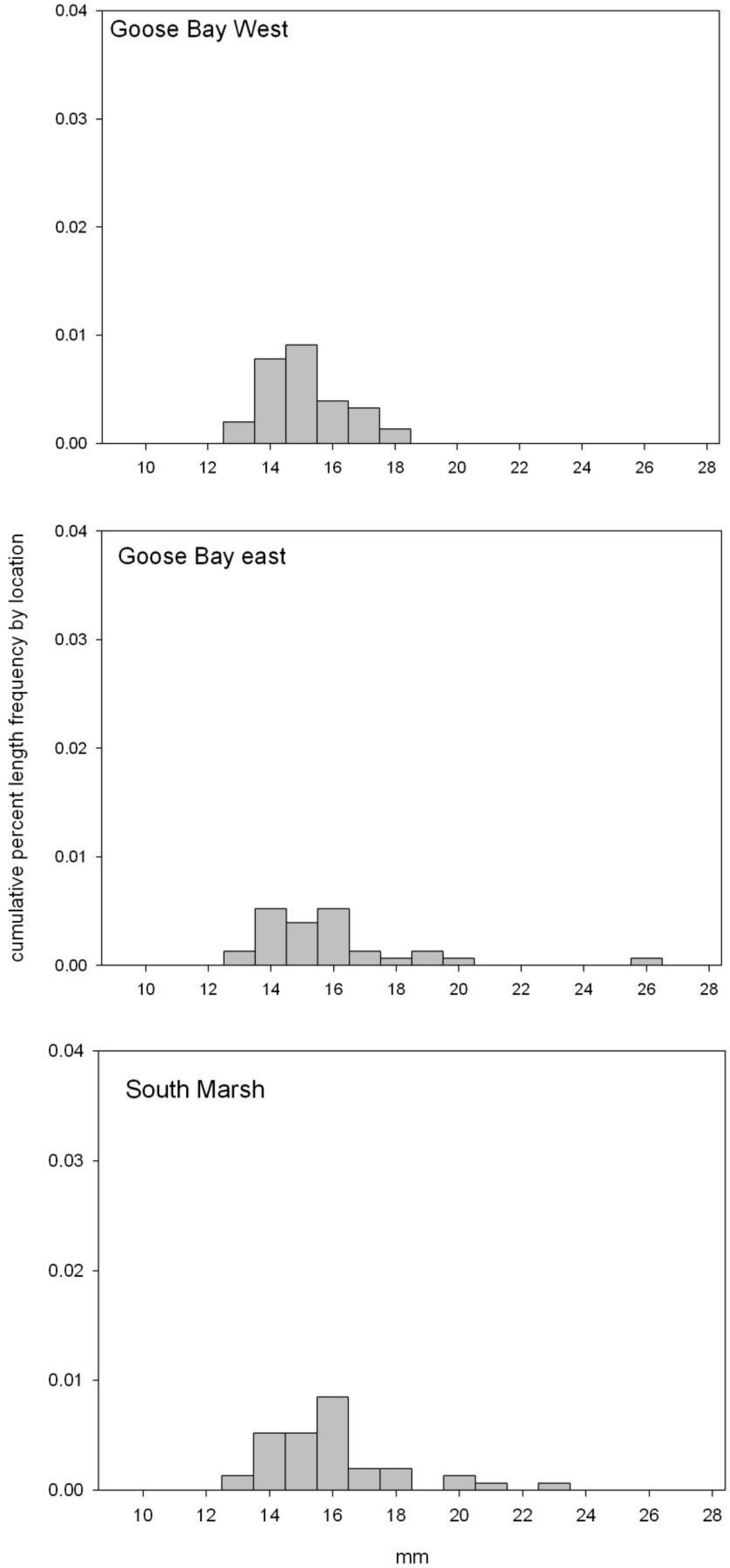


Figure 6. Cumulative percent length frequency distribution of larval suckers captured in pop-nets at six locations at the Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010.

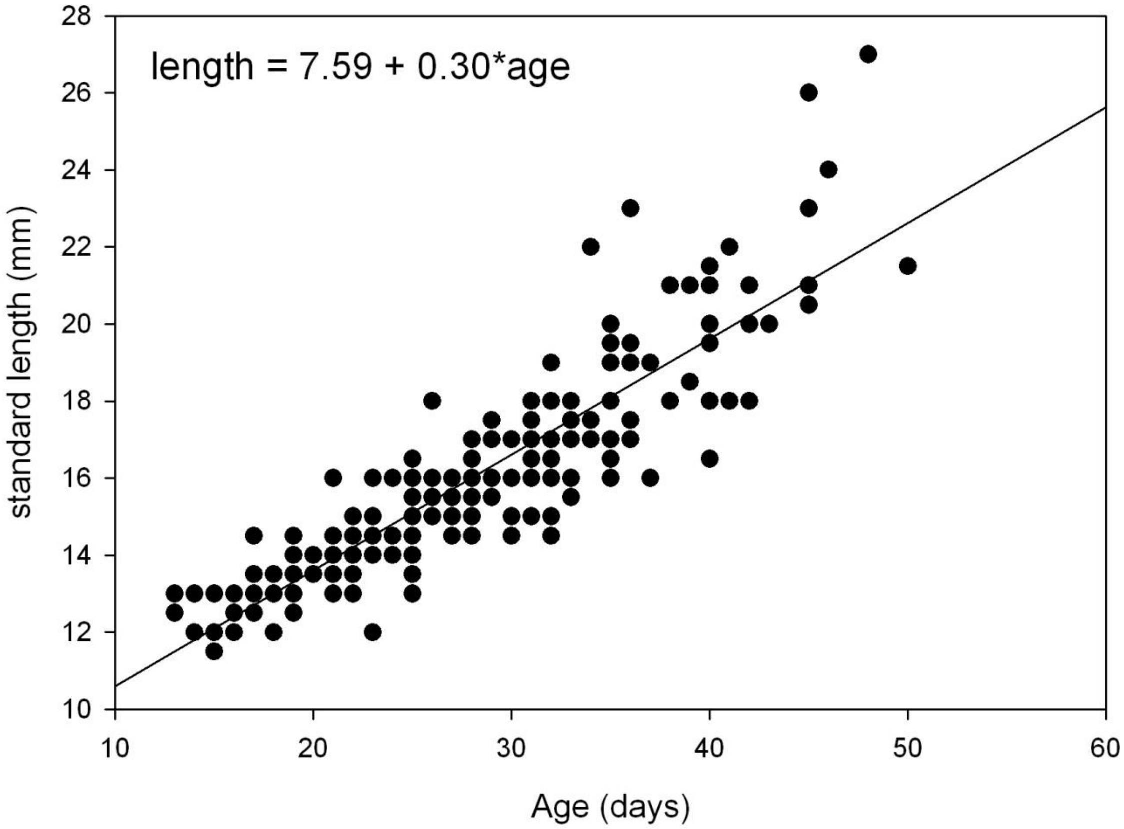


Figure 7. Length to age comparison for sucker larvae collected in 2010 at the Williamson River Delta, Upper Klamath Lake, Oregon. Age estimates were based on median lapilli otolith ring counts read three times by Oregon State University researchers (M. Terwilliger, Oregon State University, personal comm. 2011). The linear relationship between length and age for larval suckers is shown by the line and regression equation (R^2 = 0.80).

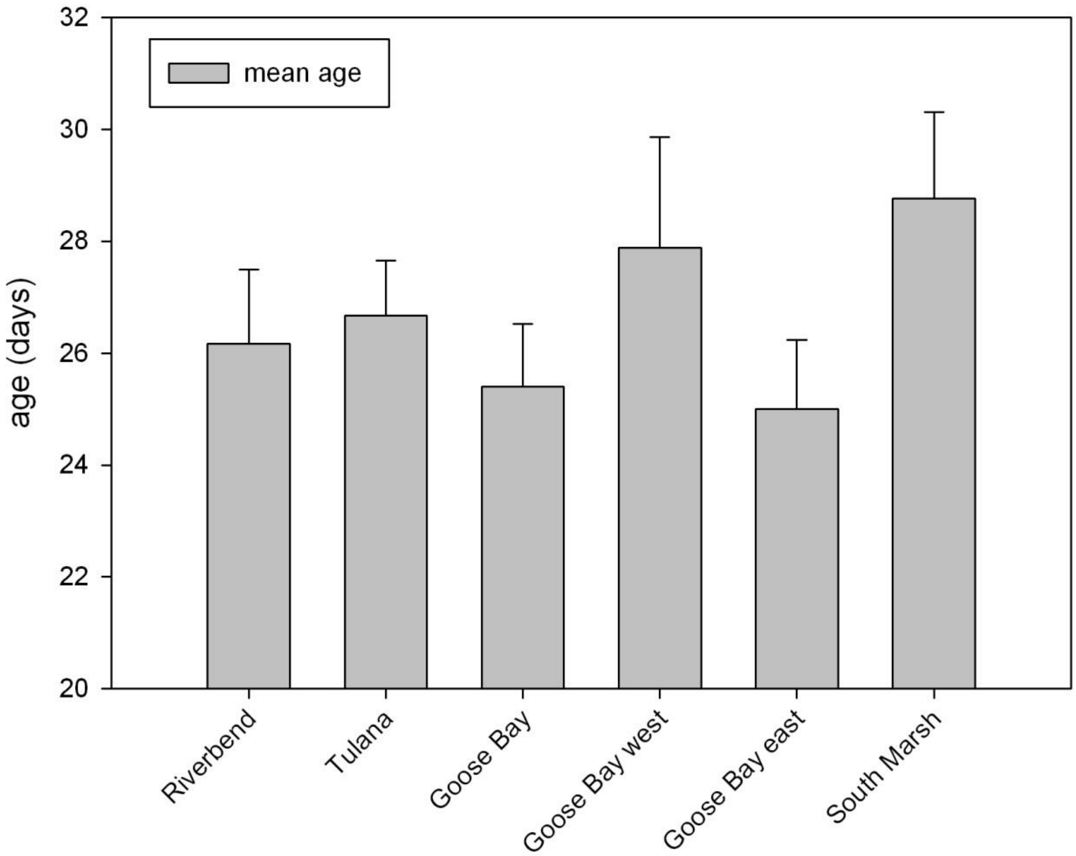


Figure 8. Mean (±SE) age of larval suckers captured in six sampling areas at the Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010. Age estimates were based on median lapilli otolith ring counts read three times by Oregon State University researchers (M. Terwilliger, Oregon State University, personal comm. 2011).

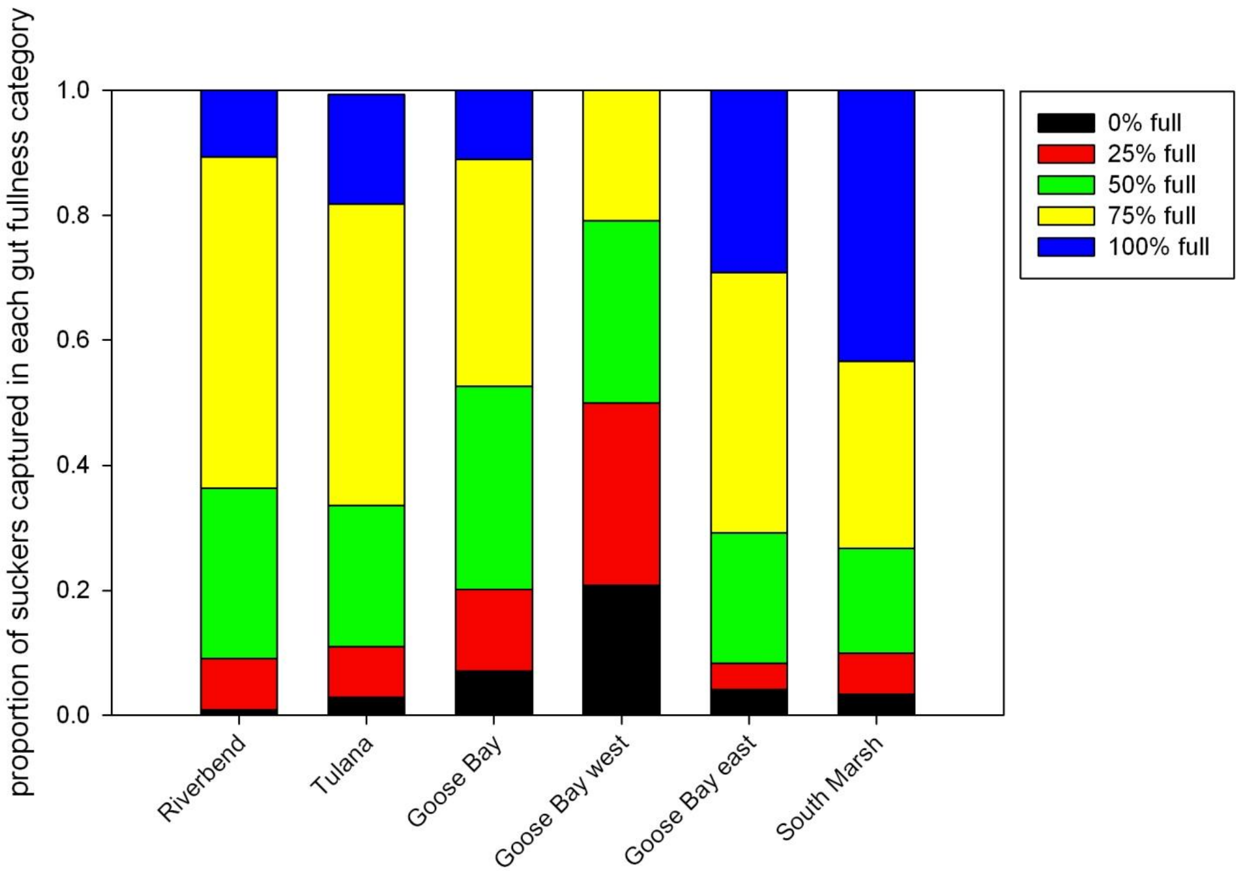


Figure 9. The proportion of larval suckers in each of the five gut fullness categories (0% full, 25% full, 50% full, 75% full, 100% full) captured at each location, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010.

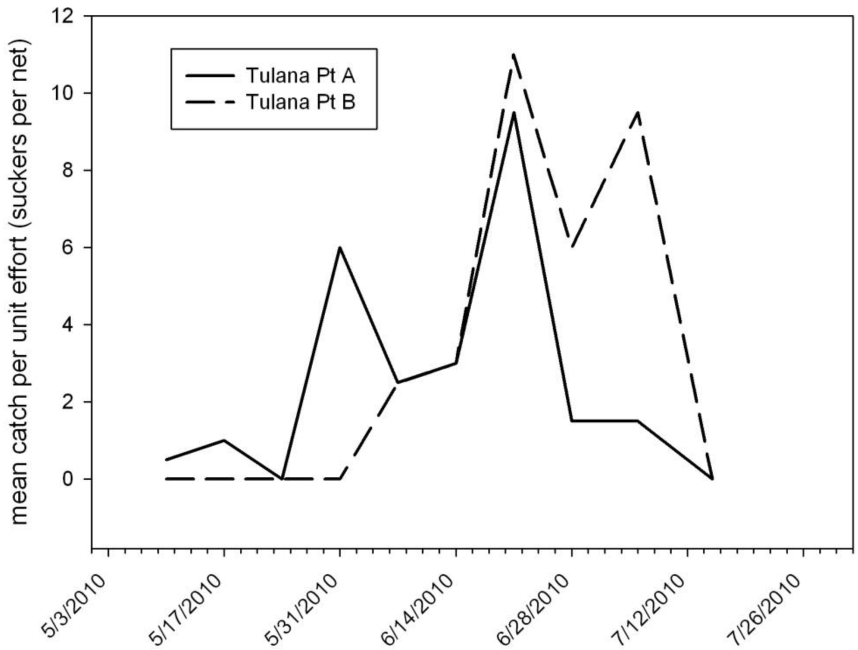


Figure 10. Weekly catch per unit effort (CPUE; suckers per net) at two fixed sampling points (point A and B) in Tulana, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010.

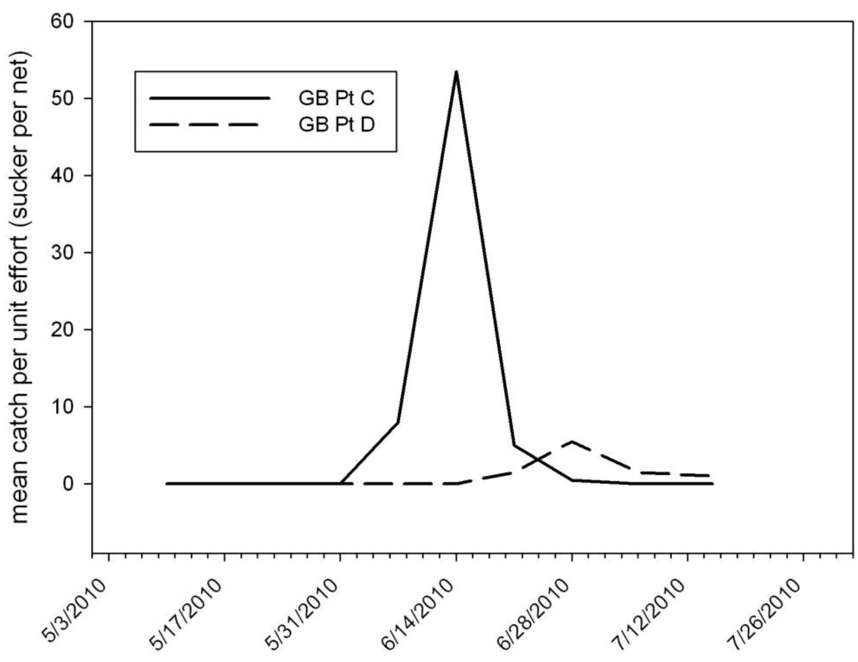


Figure 11. Weekly catch per unit effort (CPUE; suckers per net) at two fixed sampling points (point C and D) in Goose Bay, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010.

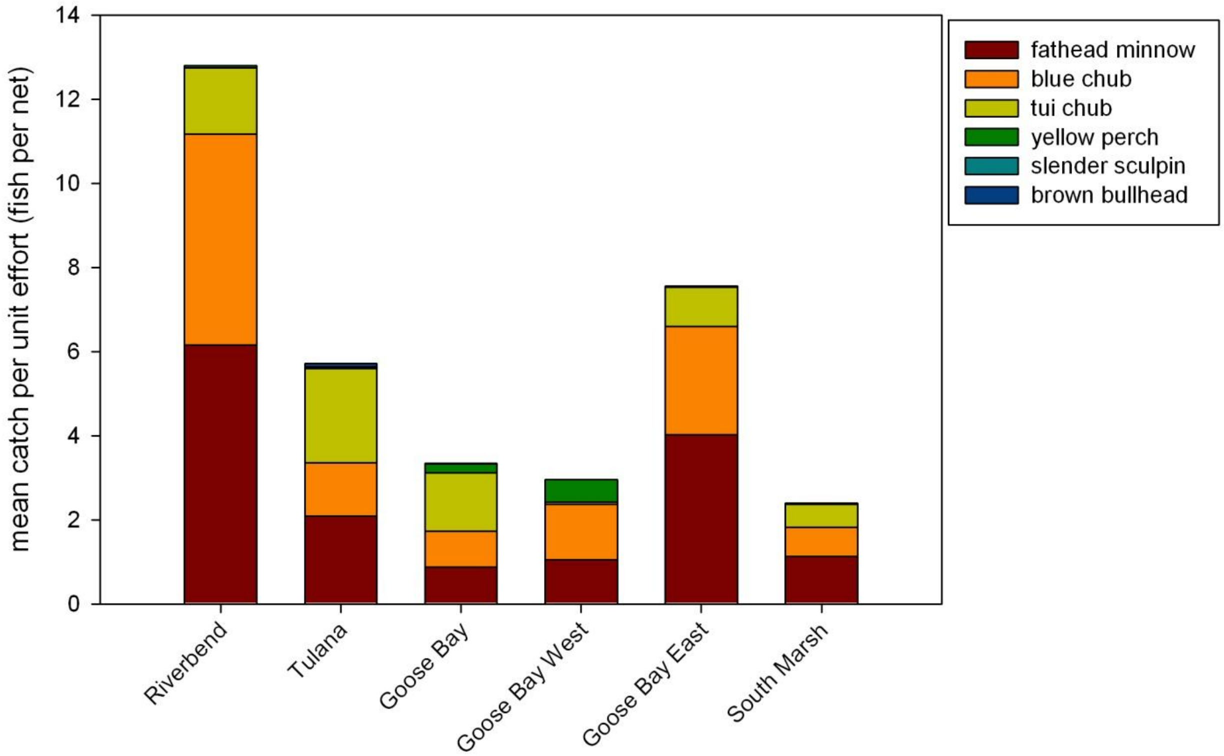


Figure 12. Non-sucker catch per unit effort (fish per net) during weekly sampling at six sampling locations at the Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2010.

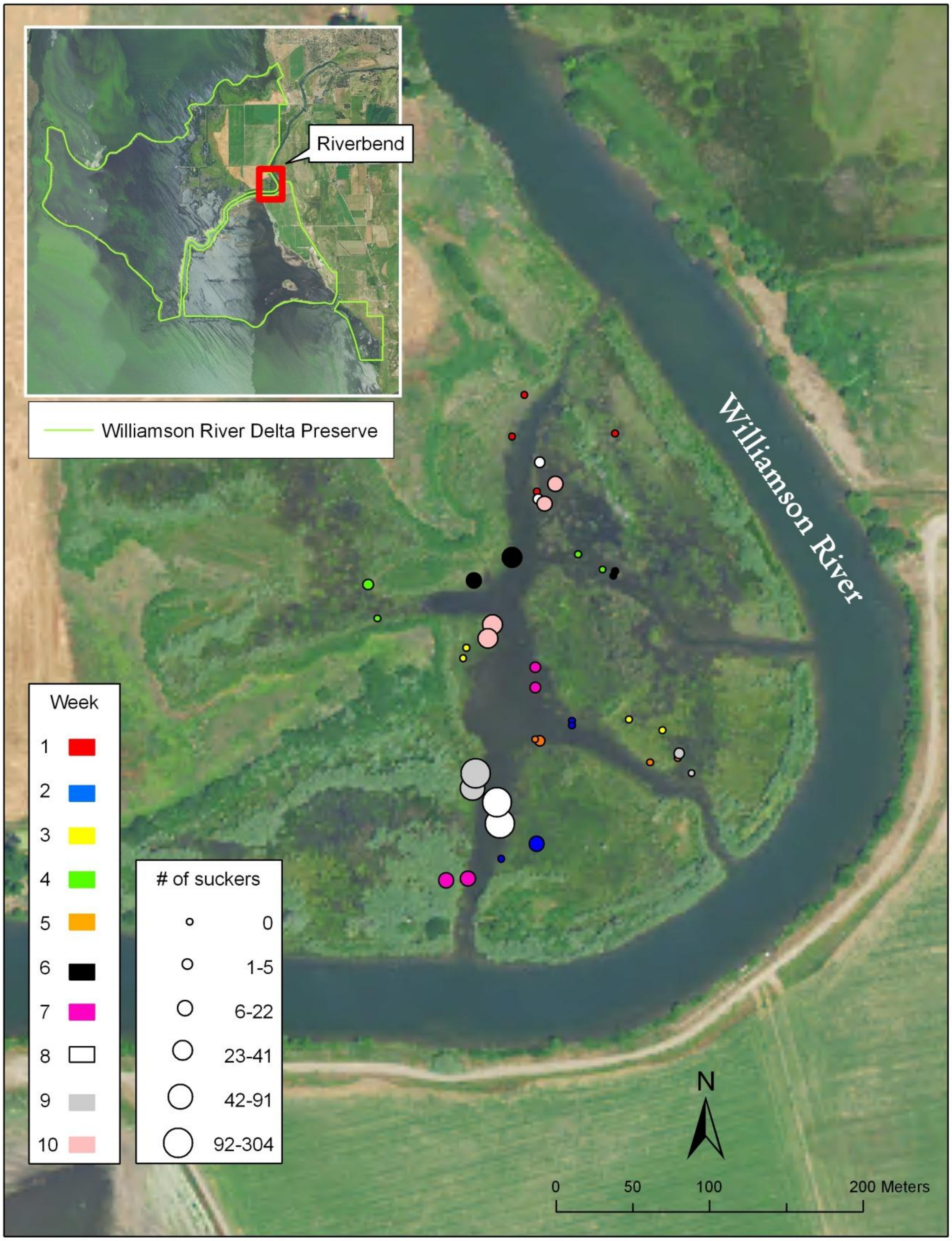


Figure 13. Map showing location of catches of larval Lost River and shortnose suckers in Riverbend, Upper Klamath Lake, Oregon, 2010. Note the high number of larvae captured in the main channels of the restored wetland at the end of the sampling season (weeks 8, 9, and 10).

A

B

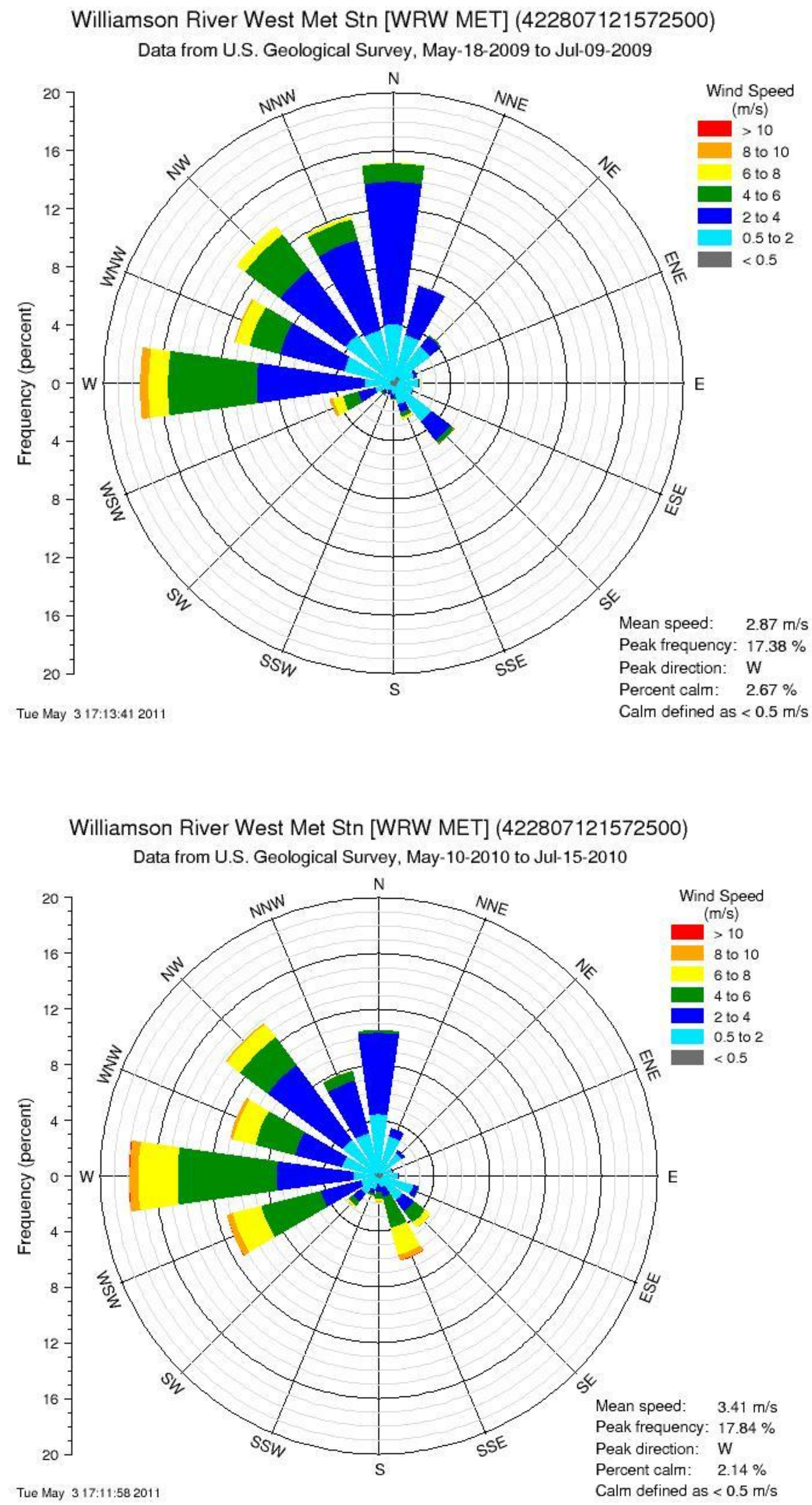


Figure 14. Wind rose graphs for 2009 (A) and 2010 (B), Williamson River, Upper Klamath Lake, Oregon. Wind data for 2009 and 2010 was obtained from the Williamson River West Meteorological Station (U.S. Geological Survey Station No. 422807121572500).

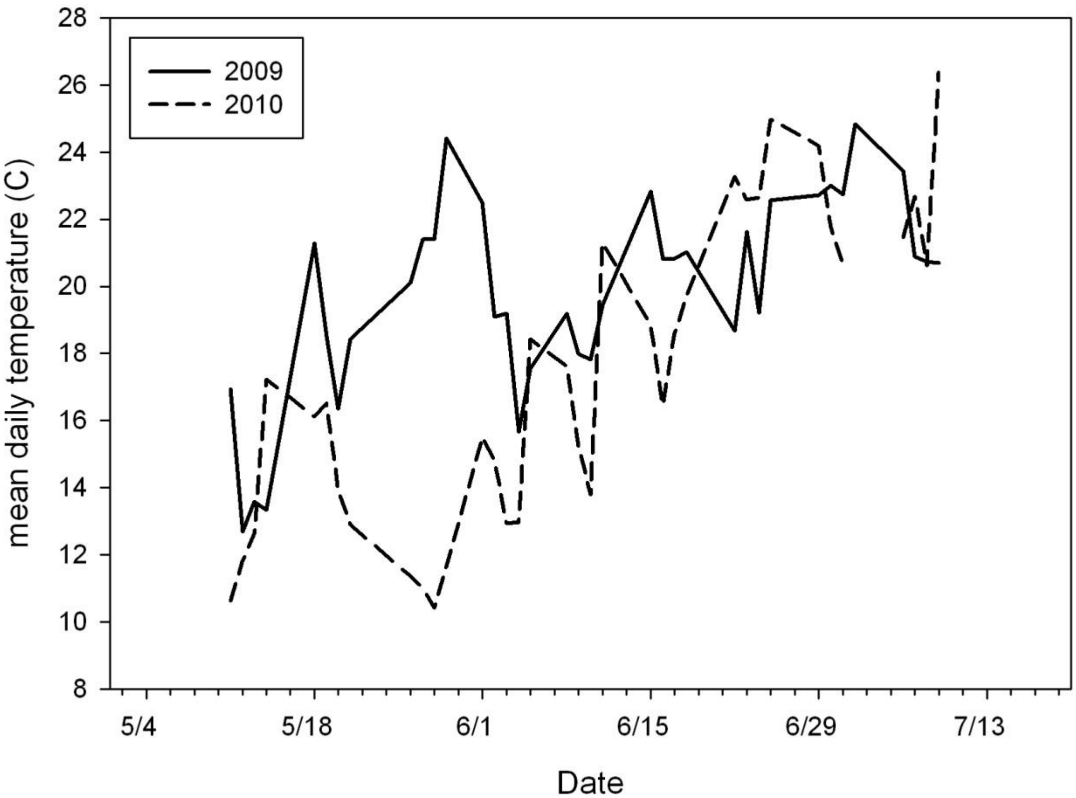


Figure 15. Mean daily instantaneous water temperature (°C) recorded during the 2009 and 2010 larval sampling periods, Williamson River Delta Preserve, Upper Klamath Lake, Oregon.