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

2009 Annual Data Summary

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Executive Summary:

This report summarizes results from The Nature Conservancy's first full season of larval fish monitoring at the Williamson River Delta (the Delta) following completion of restoration at the Delta in the fall of 2008. The principal objective of the monitoring program is to quantitatively and qualitatively assess the response of larval endangered Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris* to wetland restoration at the Delta. From May to July 2009, larval fish samples were taken using pop nets set at a variety of shallow water (< 1 m deep) locations throughout the Delta, as well as locations along the Goose Bay shoreline in Upper Klamath Lake.

A significant shift in the spatial distribution of larval suckers throughout the Delta occurred in 2009, with a large reduction of catches along the Goose Bay shoreline compared to data collected in 2006, 2007, and 2008 prior to complete restoration at the Delta. Catches of larval suckers in the restored areas of the Delta were greater than catches at the lakeshore fringe wetlands along the Goose Bay shoreline. Furthermore, larval suckers captured in 2009 at the restored areas of the Delta had a distinct size and gut fullness advantage over larvae captured along the Goose Bay shoreline.

In this data summary, we also present preliminary data suggesting a possible association between water quality conditions, mainly dissolved oxygen concentrations, in the shallow portion of Tulana and Goose Bay and the spatial distribution of larger larval suckers (standard length ≥ 20mm) collected at the Delta. This potential relationship could provide useful information regarding the continued low levels of recruitment for larval and juvenile suckers and one that will be analyzed further.

These results from the first year of monitoring larval sucker response to the completed wetland restoration project at the Delta provide an important baseline for assessing how these endangered fish respond to an increase in emergent marsh habitat at this historic rearing area. Additionally, the pre and post-restoration larval sucker data collected at the Delta since 2006 could offer insightful information important for the management and recovery of these species.

Introduction:

Wetland ecosystems have disappeared at a rapid rate over the last century as marsh habitats throughout the world have been drained and filled for agriculture and development purposes (Zedler and Kercher 2005). The unique hydrology of wetlands creates a natural system that provides numerous important ecological functions including habitat for a rich variety of biota (Mitsch and Gosselink 2000), diverse biogeochemical cycling (Reddy and DeLaune 2009), and flood and sediment control (Hey and Phillipi 2006). Recently, as scientists and managers have become aware of the diverse ecological functions provided by wetlands, restoring hydrologic function to these ecosystems has become a strategy in the recovery of certain endangered or threatened species (U.S. Fish and Wildlife Service 1993).

By 1968 littoral marsh habitat adjacent to Upper Klamath Lake, Oregon had decreased to only 17,000 acres, a reduction of roughly 65% and a loss of habitat that has been cited as a

principal reason for the decline in populations of two 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* (National Research Council 2004). This decrease in wetland habitat has been blamed for high mortality rates of larval and juvenile suckers and the ensuing poor recruitment into adult life stages. Habitat complexity within these 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; Hendrixson 2008; Erdman and Hendrixson 2009), and helps retain sucker larvae from the clock-wise gyre that dominates surface currents in Upper Klamath Lake (Markle et al. 2009).

The Williamson River Delta Restoration Project is a 7,500 acre wetland restoration project located at the interface of the Williamson River and Upper Klamath Lake, an effort initiated by The Nature Conservancy (TNC) in 1996. Prior to the 1940s, the lower four miles of the Williamson River consisted of a complex deltaic wetland, with large stands of emergent marsh habitat connecting the river, Upper Klamath Lake, and Agency Lake. Roughly 22 miles of levees were built around the delta in the 1940s, resulting in the loss of connectivity between this important nursery habitat, the river, and the lake. Restoring wetland complexity with regards to vegetation and hydrology to the Williamson River Delta and the northern portions of Upper Klamath Lake was identified as a high priority for recovering endangered suckers (National Research Council 2004).

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 2005 in those three areas indicated that larval suckers were using the Riverbend and South Marsh wetlands, with few fish captured at the Campfields restoration site (Figure 1).

An innovative restoration plan throughout the larger Tulana portion of the Delta was completed in October 2007 (David Evans and Associates, Inc. 2005). Roughly 100 tons of explosives were used to breach approximately two miles of levees and flood 3,500 acres 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 2,000 acres of emergent habitat (shallow) are now available for larval and juvenile suckers. In 2009 we continued with larval sucker monitoring in Tulana, Riverbend, and South Marsh, at lakeshore wetlands along the Goose Bay shore, and expanded our monitoring efforts to the newly restored Goose Bay portion of the Delta (Figure 2).

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 and if other native and non-native species are using the Delta, 2) the response in fish condition (size, gut fullness, developmental stage) to the most recent restoration projects, and 3) compare data collected from the Delta with data collected during previous years and outside project sites. Monitoring data collected here is also being used in a collaborative project with USGS and OSU to document larval sucker use of the deep water areas of the Delta and in select shoreline habitats in Upper Klamath Lake, to validate a

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hydrodynamic larval drift model for the Delta, and to better understand age 1+ suckers distribution throughout the Delta.

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 determining the success of this wetland restoration project and acquiring useful information that can be used for restoration of other littoral marsh habitats along the shore of Upper Klamath Lake. We used a combination of fixed and random sampling locations to monitor an array of habitat types across the Delta and to determine changes in time at individual locations. Results from 2009 are included in this report.

Methods:

Sampling Design

Our 2009 sampling program was designed to gather data to further strengthen conclusions derived from the previous three years of larval sucker monitoring and answer specific questions regarding larval sucker use of the newly restored Tulana and Goose Bay portions of the Delta. The main objective was to assess the effect of different water depths, structure (vegetation), wetland types, and water quality on sucker abundance and condition in these restored areas. Given the results from 2006, 2007, and 2008, we hypothesized that the restored areas of the Delta would function at least as well as the existing lakeshore wetlands in providing suitable rearing habitat and that larvae in restoration wetlands would be larger and better fed than their counterparts in the lake.

In 2009 we conducted larval sampling in shallow areas (<1m deep) at six locations at 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 east (GBE) and Goose Bay west (GBW) (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 (average 0.27m ± SE 0.0075) and deep (average 0.71m ±SE 0.0108) water depths. This sampling design mimicked the protocol used during the past three sampling seasons 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). Ideally, at each site one net was set in vegetation and one in an area without 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. 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 interactions.

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The nets consisted of two 1" diameter PVC frames (approximately 2.5 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, GPS location, and water temperature, dissolved oxygen, pH, and conductivity (Hydrolab Quanta®) at the site. 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 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 18 – July 9.

Fish Identification, Condition, and Ageing

Preserved fish were counted, measured, identified, and analyzed for gut fullness and developmental stage. Immediately after collection, we transferred all larvae (suckers and nonsuckers) to 50 mL jars containing ~20 mL of 95% ethanol. All fish larvae were identified to species, measured to the nearest 0.5 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 (Simon 2004). Due to similarities in pigmentation patterns between shortnose sucker and Klamath largescale *Catostomus snyderi* sucker larvae (Simon 2004; 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. Larvae that could not be identified were labeled as unknown. Additionally, all sucker larvae over 15mm were grouped as unknown due to difficulties in distinguishing between all three sucker species when larger than 15mm 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: empty, 25% full, 50% full, 75% full, and 100% full (Cooperman and Markle 2003; Hendrixson 2008).

A portion of the captured sucker larvae (128 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 ± 2.93% (M. Terwilliger, Oregon State University, personal comm., 2010). 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 in order to strengthen the larval production estimate (Cooperman et al. 2010).

Analysis

We analyzed data collected in 2009 to examine larval fish distribution, habitat use, and species composition throughout the Delta and to compare this year's data with past years' results. We used catch per unit effort (CPUE), expressed as number of fish per net, because CPUE is an effective way to standardize catch data collected over a period of time, under differing circumstances, and when certain sampling sites or areas are visited more often than others. We tested for differences in mean larval sucker abundance (CPUE) as a function of depth, vegetation presence, and location (wetland type, i.e. restored versus existing). Temporal and spatial distribution of larval fish was also analyzed and the relationship between fish length, gut fullness, and location was explored. We used the nonparametric Wilcoxon and Kruskall-Wallis rank sum tests ($\alpha = 0.05$) in the program JMP 8.0.1 to compare probability distributions of larval sucker catches, fish condition (length, gut fullness), and habitat preferences (depth and vegetation) with respect to the different sampling locations, allowing us to determine if significant statistical differences existed.

Habitat and fish condition data in the following section was summarized with the removal of a single net due to its outlier characteristics. This net, set in Tulana on 2 June, captured 304 larval suckers or 32% of our entire sucker catch in 2009. The *z*-score for this sample is 14.3, and since a *z*-score this large is highly improbable, this data point is most likely an outlier.

For the purpose of investigating the potential relationship between larval sucker spatial distribution and water quality conditions (mainly dissolved oxygen concentrations) in the emergent areas of the Delta, data from The Nature Conservancy's water quality monitoring program was used (Wong et al. 2009, 2010). Continuous (hourly) physical water chemistry data was collected in 2008 and 2009 using multi-probe instruments (YSI 600XLM sondes) placed at numerous locations throughout the Delta. For the purpose of our analysis data from two sites were used: TL9 (in the emergent area of Tulana) and GB4 (in the emergent area of Goose Bay; Wong et al. 2009, 2010).

Results:

We timed the start of sampling to coincide with peak larval sucker drift in the lower Williamson River (Craig Ellsworth, US Geological Survey, personal comm., 2010). Larval suckers recruited to our nets beginning the week of 18 May and we ceased sampling the week of 6 July when larvae were no longer being caught. During our 2009 sampling event we set 244 pop nets: 30 in Riverbend, 62 in Tulana, 64 in Goose Bay, 28 in Goose Bay west, 28 in Goose Bay east, and 32 in South Marsh (Figure 2). Sixty (25%) nets were set in deep water with vegetation, 66 nets (27%) were set in deep water without vegetation, 49 nets (20%) were set in shallow water with vegetation, and 69 nets (28%) were set in shallow water without vegetation.

A total of 963 suckers were captured in 2009, resulting in a mean catch per unit effort (number of larval suckers per net) of 3.95. Larval suckers were captured in 52% of pop nets, compared to 57% in 2008. Suckers were identified to species when possible, yielding a total of 75 LRS, 630 SNS/KLS, and 258 unknown suckers representing 8%, 65%, and 27% of the total sucker catch, respectively. This species composition, with SNS/KLS representing the majority of

larvae caught, is similar to past years' sampling efforts. Numbers and catch per unit effort of suckers and other fish species caught in 2009 are located in Table 1.

Unlike past years where a bimodal seasonal catch curve was witnessed, 2009 cumulative catch per unit effort peaked sharply during the week of 1 June and then abruptly decreased the following week and continued to decline until the end of our sampling season (Figure 3). The three highest net catches occurred in Tulana (two nets on 2 June, one net on 4 June), with 304, 84, and 80 larval suckers captured, respectively. These three nets combined accounted for about 49% of the total 2009 larval sucker catch. The next highest single net catch was in Goose Bay west on 17 June with 32 larvae captured. When analyzing the weekly catch curves in each of the six sampling areas, Tulana catches peaked during the week of 1 June, while catches in Riverbend and South Marsh peaked during the week of 8 June, and catches in Goose Bay west peaked during the week of 15 June (Figure 4). Catches in both Goose Bay and Goose Bay east were relatively stable, with small peaks during the weeks of 22 June and 29 June, respectively (Figure 4).

Mean catch per unit effort was highest in Tulana followed by Riverbend, South Marsh, Goose Bay, Goose Bay west, and Goose Bay east (Figure 5). When examining catches in the restored wetlands of the Delta and the existing lakeshore fringe wetlands along the Goose Bay shoreline, significant differences existed in the number of larval suckers caught per net, with 4.8 larvae captured per net in restored wetlands compared to 1.05 larvae captured per net in the existing wetlands (Wilcoxon test, $\alpha = 0.05$, $P < 0.001$).

Habitat Use by Larval Suckers

Larval suckers were caught slightly more frequently in shallow nets (2.9 larvae per net)) than in nets set in deep water (2.6 larvae per net); however, these differences were not significant (Wilcoxon test, $\alpha = 0.05$, $P = 0.7338$). Higher catches occurred in nets set in vegetation (CPUE = 2.9 larvae per net) than in nets set in open water (2.6 larvae per net), although these differences were also not significant (Wilcoxon test, $\alpha = 0.05$, $P = 0.0568$). With the two variables combined for analysis, larval suckers were captured in greater numbers in nets set in deep water with vegetation, followed by nets set in shallow without vegetation, nets in shallow water with vegetation, and nets in deep water without vegetation, and again, the differences were not significant (Wilcoxon test, $\alpha = 0.05$, $P = 0.2756$).

Larval suckers occupied different habitats within the restored and existing wetlands. In the restored wetlands suckers were captured at higher rates in nets set in shallow water without vegetation and deep water with vegetation (Figure 6). Conversely, in the existing wetlands suckers were found twice as frequently in nets set in deep water without vegetation, followed by deep nets set in vegetation. No fish were captured in shallow nets set in vegetation in existing wetlands (Figure 7).

Fish Condition

The average standard length (SL) of larval suckers captured was 14.5 mm, with a range from 11.5 mm to 29.0 mm. Of the larvae identified to species, shortnose/Klamath largescale suckers were on average 0.3 mm larger than Lost River sucker larvae (mean$_{SNS/KLS}$ = 13.4 mm ± 0.04 SE; mean$_{LRS}$ = 13.1 mm ± 0.10 SE). Mean standard length of unidentified suckers (all suckers > 15 mm) was 17.0 mm. Larval sucker lengths were greatest in South Marsh (mean SL =

15.6 mm ± 0.2 SE), followed by Goose Bay (mean SL = 15.5 mm ± 0.2 SE), Goose Bay east (mean SL = 14.8 mm ± 0.5 SE), Riverbend (mean SL = 14.2 mm ± 0.2 SE), Goose Bay west (mean SL = 14.1 mm ± 0.1 SE), and Tulana (mean SL = 13.6 mm ± 0.1 SE), differences that were statistically significant (Kruskal-Wallis test, α = 0.05, P < 0.0001).

Consistent with previous years' results, fish occupying habitat in restored wetlands were on average larger than fish captured in the existing wetland habitat along the Goose Bay shoreline (mean $SL_{restored}$ = 14.5 mm ± 0.1 SE, mean $SL_{existing}$ = 14.3 mm ± 0.2 SE). No larvae larger than 19 mm were captured in the existing lakeshore wetlands, while 24 larvae equal to or larger than 20 mm were captured in the restored wetlands.

Larval suckers captured at shallow, vegetated sites were on average larger than larvae collected in the three other habitat types, and these differences were significant (Figure 8; Kruskal-Wallis test, α = 0.05, P = 0.0162). The length frequency distribution of larval suckers caught in the five sampling locations shows the higher frequency of larger fish in Goose Bay, Riverbend, and South Marsh (Figure 9). Additionally, the length frequency diagram from Tulana shows smaller larvae making up a significant portion of the catch, with 13 mm larvae making up roughly 17% of the cumulative catch in 2009 (see Figure 9).

One hundred and twenty eight larval suckers were aged by researchers at Oregon State University, of which 17 were LRS, 51 were identified as SNS/KLS, and 60 were unknown. The mean (± SD) age of Lost River sucker larvae was 14.2 ± 3.1 days, while the mean (± SD) age of SNS/KLS sucker larvae was 17.3 ± 3.8 days. The earliest hatch date of a larval sucker from our aged sample was 12 April, roughly two months earlier than the last larval hatch date from our sample, 22 June. There was a strong relationship between the length and age of larval suckers (R^2 = 0.80, P < 0.001; Figure 10). Sucker larvae captured in South Marsh (mean age = 27.9 ± 8.3 days) were older than fish captured in the other five sampling areas, while fish captured in Tulana were on average the youngest (mean age = 20.4 ± 7.4 days; Figure 11).

Differences existed in the amount of food present in the stomachs of larvae collected at the six sampling areas. Looking at the proportion of larval suckers captured in each of the five gut fullness bins (0% full, 25% full, 50% full, 75% full, 100% full), a larger portion of suckers with at least 50% gut fullness were captured in the restored wetlands (Figure 12). More importantly, fewer suckers with 0% gut fullness were captured in the restored wetlands (4.2%) compared to suckers captured in the existing wetlands (7.3%).

With regards to differences in the gut fullness of larvae captured in the four different habitat types, fish caught in deep nets without vegetation had fuller guts (64.8% full) compared to fish caught in shallow nets without vegetation (62.8% full), shallow nets with vegetation (61.5% full), and deep nets with vegetation (58.6% full). These differences were also significant (Kruskal-Wallis test, α = 0.05, P = 0.0373). Gut fullness differences also existed amongst the two identifiable sucker species, with shortnose/Klamath largescale suckers having fuller guts on average (60.4% full) than Lost River suckers (51.3% full). Intuitively these results are robust as larger fish tend to have fuller guts, and on average shortnose/Klamath largescale were larger than the Lost River suckers collected.

Our random sampling design enabled us to sample for larval suckers in areas containing numerous native wetland plant species for the "vegetated" habitat type, including *Schoenoplectus ssp.* (n=35), *Eleocharis spp.* (n=29), *Typha latifolia* (n=4), *Polygonum spp.* (n=2), *Potamogeton spp.* (n=1), *Rumex spp.* (n=13), and a variety of dead, submerged vegetation

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remaining from when the land was in agriculture production (n=21). Larval suckers were captured in all wetland plant species except in *Polygonum* and *Potamogeton*, with the greatest catches occurring in the dead agriculture weeds, *Schoenoplectus spp.*, and *Eleocharis spp.* (Figure 13).

Significant size differences existed amongst larvae collected in each of the vegetation types (Kruskal-Wallis test, α = 0.05, P < 0.0001). Larger fish were captured in dead agricultural vegetation while the smallest fish were captured in *Rumex spp.* and *Schoenoplectus spp.* Shortnose suckers were captured at higher rates in *Schoenoplectus spp.* while Lost River suckers were caught more frequently in *Rumex spp.*

Non-Sucker Species

Due to the nature of the sampling gear used, our sampling methods were not exclusive to larval suckers—several other species of fish were caught, including tui chub *Gila bicolor*, blue chub *G. coerulea*, fathead minnow *Pimephales promelas*, yellow perch *Perca flavescens*, and sculpin *Cottus spp*. Mean catch per unit effort of non-suckers was 33.4 fish per net. A total of 1007 (CPUE = 4.1) tui chub, 2757 (CPUE = 11.3) blue chub, 4371 (CPUE = 17.9) fathead minnow, 10 (CPUE = 0.04) yellow perch, and 3 (CPUE = 0.01) sculpin were captured in 2009.

Catches of non-sucker species in the existing lakeshore fringe wetlands along the Goose Bay shoreline were incredibly high in 2009, with a catch per unit effort of 79.8 fish per net, compared to a catch per unit effort of 19.6 in the restored areas. Goose Bay west had the highest catches of non-suckers (CPUE = 114.8 fish per net), followed by Goose Bay east (CPUE = 44.8), South Marsh (CPUE = 36.2), Goose Bay (CPUE = 20.6), Tulana (CPUE = 20.5), and Riverbend (CPUE = 2.4). The catch per unit effort for each species at each sampling area is shown in Figure 14. In deep nets set in vegetation, a mean of 42.4 non-suckers were caught, compared to 37.2 fish per deep net set in open water, 24.5 fish per shallow net set in vegetation, and 15.2 fish per shallow net set in open water.

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 flow model for the Delta (see Figure 1; Tammy Wood, US Geological Survey, personal communications; Wood and Cheng 2006). The Tulana fixed points remained at the same location as in 2008; 2009 was the first year Goose Bay was flooded, so new fixed points were chosen there to compliment the sites in Tulana. 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 16 nets were set at each point in 2009.

Mean catch per unit effort of larval suckers was greatest at point A (mean CPUE = 7.2 ± 5.2 SE), followed by point D (mean CPUE = 2.0 ± 0.7 SE), point B (CPUE = 1.6 ± 0.6 SE), and point C (mean CPUE = 0.7 ± 0.4 SE). The weekly catch per unit effort at the four different points in Tulana and Goose Bay, respectively, are shown in Figures 15 and 16. Interestingly, mean catch per unit effort was higher in nets set in open water at both Tulana fixed points, while mean catch per unit effort was higher in nets set in vegetation at both fixed points in Goose Bay.

Fish captured at point D were on average the largest (mean SL = 15.4 mm), followed by fish captured at point C (mean SL = 14.3 mm), point B (mean SL = 14.0 mm), and point A (mean SL = 13.3 mm). This is consistent with results collected from all nets set within Goose Bay and Tulana, as mean cumulative standard lengths of fish captured in Goose Bay were greater than mean cumulative standard lengths of fish captured in Tulana.

Water Quality

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

Instantaneous water temperature data, recorded in each net with a Hydrolab Quanta®, indicated shallow sites were on average $3.5^{o}C$ warmer than deep water sites and vegetated sites (mean = $20.8^{o}C$) were on average warmer than open water sites (mean = $20.6^{o}C$). Average instantaneous water temperature was highest in South Marsh (mean = $21.5^{o}C$), followed by Riverbend (mean = $21.1^{o}C$), Goose Bay (mean = $21.0^{o}C$), Tulana (mean = $20.5^{o}C$), Goose Bay east (mean = $20.2^{o}C$), and Goose Bay west (mean = $19.4^{o}C$). Mean temperatures throughout the sampling season were roughly $1.0^{o}C$ warmer at sites in restored areas compared to sites in the existing lakeshore fringe wetlands.

Dissolved oxygen (DO) concentrations were on average about 1.0 mg/L higher at shallow sites than in deep water sites. Differences in mean DO concentrations did not differ between sites in vegetation and sites in open water. Mean DO concentrations throughout the sampling area were highest in South Marsh (mean DO = 9.1 mg/L), followed by Goose Bay west (mean DO = 8.5 mg/L), Riverbend (mean DO = 8.4 mg/L), Goose Bay (mean DO = 7.6 mg/L), Goose Bay east (mean DO = 7.6 mg/L), and Tulana (mean DO = 7.3 mg/L). Dissolved oxygen concentrations equal to or below 4.0 mg/L were recorded in 10 nets, nine of which were set in Tulana. Larval sucker threshold stress values for DO were defined by Loftus (2001) as 6.0 mg/L low stress level and 4.0 mg/L high stress level. While larval suckers were not detected at six of these sites, 80 larvae were captured in a net set in Tulana with a measured DO concentration of 3.77 mg/L. This net had the third highest capture of suckers during the 2009 sampling season.

The highest mean seasonal pH levels were measured in Goose Bay west (mean pH = 8.9), South Marsh (mean pH = 8.8), Goose Bay east (mean pH = 8.3), Tulana (mean pH = 8.3), Goose Bay (mean pH = 8.3), and Riverbend (mean pH = 8.0). Eight nets, four in Tulana and four in South Marsh, registered pH levels greater than 9.7, all occurring during the weeks of 8 and 15 June. A total of ten larvae were captured in these nets, including three larvae in the net with the highest pH recorded during 2009, 10.12.

Discussion:

Wetland restoration at the Williamson River Delta Preserve was aimed at enhancing potential larval and juvenile Lost River and shortnose sucker rearing habitat and complexity within this habitat by reestablishing hydrologic connectivity between the Delta, the Williamson River, and Upper Klamath and Agency Lake. With the removal of sections of levee from the

Goose Bay portion of the Delta in the fall of 2008 and the subsequent hydrologic reconnection, roughly 5,500 acres of habitat at the Delta are now accessible to larvae and juvenile suckers for the first time since the 1940s. The 2009 sampling effort served as the first year of complete post-restoration data collection and the fourth season that the same methods have been used to monitor the response of larvae to restoration at the Delta. 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.

Catches of larval suckers in 2009 were much lower, in terms of actual numbers of fish captured and catch per unit effort, than the previous three years in which a similar sampling protocol was used. Cumulative catch per unit effort was highest in 2006 (CPUE = 14.18), similar in both 2007 and 2008 (CPUE = 8.96 and 8.27, respectively), and significantly lower in 2009 (CPUE = 3.94). Other researchers experienced high larval catches in 2006 (D. Markle, Oregon State University, personal communication; Ellsworth et al. 2009), suggesting that higher catches in 2006 were not simply an effect of our sampling design or an aberration. The high larval production in 2006 could be attributed to a greater percentage of the adult population spawning, better egg and larvae survival, or differences in larval drift characteristics in the Williamson and Sprague Rivers as a result of river flow or lake elevation. Lower catches in 2009 could be an indication of these potentially limiting spawning and larvae production factors, and do not imply a negative effect of wetland restoration at the Delta on larval abundance and production. Furthermore, due to the fact that there are now thousands of additional acres available to larvae at the Delta, it is possible that the random points sampled in 2009 might not have captured the full extent of the spatial variability in sucker distribution and thus possibly failed to capture a representative subset of the larval sucker population in 2009. However, we do not believe this is the case, as other researchers experienced low catches in 2009 (D. Markle, Oregon State University, personal communication).

Changes in Larval Sucker Distribution

Despite lower cumulative catches of larvae in 2009, significantly more fish were captured in the restored wetlands than in the existing wetlands along the southern shoreline of Goose Bay. This result differs from the trend witnessed during the previous three years in which catches in existing wetlands have been much greater than combined catches in the restored wetlands (Figure 17). Lower catches in the existing wetlands along the Goose Bay shoreline in 2009 were most likely a result of the restoration of the Goose Bay portion of the Delta. With the removal of sections of levee along the Williamson River and Upper Klamath Lake, larvae are no longer forced out the mouth of the river and swept along the shoreline of Goose Bay by the dominant clockwise lake current. Larvae now have access to the interior portions of the Delta at numerous points, creating a much different distribution of larvae throughout the Delta and along the Goose Bay shoreline (Figure 18). Larvae captured in the restored wetlands were on average larger and had fuller guts than fish captured in the existing wetlands, a possible result of a greater presence of wetland vegetation, an increase in prey availability for larvae, or stronger advection properties of the restored wetlands leading to longer retention of larvae. It appears that these restored areas provide high quality habitat for larval suckers.

Larval Sucker Habitat Use

Larval suckers were captured in a variety of habitats throughout the emergent and riparian areas of both the Tulana and Goose Bay portions of the Delta, including in a range of emergent wetland plant species, in dead vegetation remaining from when the flooded areas were dominated by upland weeds, in nets set in open water with no vegetation within close proximity, and in nets set in open water directly adjacent to patches of emergent vegetation. Although slight differences in catches of larvae in the four habitat types used for analysis existed and larvae were caught more frequently in vegetation than in open water, these disparities were not statistically significant. This suggests that the patchwork of habitats available throughout the Delta is providing conditions suitable for larval rearing.

Studies have shown that larval suckers show preference towards emergent vegetation, as it is used for protection from predators (Markle and Dunsmoor 2007), and that larval survival was partially dependant on the total volume of emergent vegetation in the lake (Cooperman and Markle 2004). The increase in emergent macrophytes associated with restoration of deltaic wetlands and complexity within this habitat 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). Increased survival of larval suckers could translate into greater recruitment into the adult spawning population; poor recruitment has been identified as a limiting factor for sucker recovery in Upper Klamath Lake (National Research Council 2004).

Data collected regarding larval condition suggests that areas of shallow water and the presence of emergent macrophytes could be advantageous for larval suckers. Larger fish were captured in shallow, vegetated sites more frequently compared to the three other habitat types. Emergent macrophytes have been shown to be an important component for freshwater macroinvertebrate abundance (Parsons and Matthews 1995) and larval suckers feed primarily on surface macroinvertebrates, mainly adult Chironomidae (Markle and Clauson 2006). Additionally, high densities of Chironomidae have been found at the Delta (Kuwabara et al. 2010). The addition of emergent wetland habitat at the Williamson River Delta could positively affect early larval sucker survival by providing a significant size and energetic benefit.

Larval suckers were captured in a variety of emergent wetland vegetation species and dead vegetation remaining from when the fields were in upland production. While larger fish were captured more frequently in dead upland vegetation, *Typha latifolia*, and *Eleocharis spp.*, larvae did not appear to have any preference for one type of emergent vegetation over another. Data from 2008 showed the same result. Habitat heterogeneity throughout the shallow areas of the Delta, in terms of cover of vegetation, diversity of wetland species, and access to vegetation patches, is probably more important than the presence of a specific emergent marcophyte species.

Fathead Minnow Abundance and Distribution

Another important difference between the restored areas of the Delta and the existing wetlands along the Goose Bay shoreline was the high number of non-sucker species captured along the Goose Bay shoreline. Catches of non-sucker species in 2009 were much higher than in past years, especially catches of fathead minnows, which can prey on larval suckers (Markle and Dunsmoor 2007). The timing of peak larval sucker and fathead minnow catches did not

overlap—while sucker catches peaked sharply during the first week of June, fathead catches did not peak until the week of 22 June. It is possible that the high production of fathead minnows in areas adjacent to the Delta could have limited larval sucker survival in 2009, as the abundance of adult fathead minnows along the shoreline of Upper Klamath Lake has been shown to have a negative relationship with annual larval sucker survival (Markle and Dunsmoor 2007).

Larvae Distribution Related to Delta Hydrodynamics

Catches at Tulana fixed points were highest at point A, a shallow site, while catches in Goose Bay were greatest at point D, a deep water site (see Figure 1). At point A, larvae were captured more frequently in open water and at point D larval suckers were captured in vegetation more regularly. In addition, mean catch per unit effort at both Tulana fixed sites was higher in nets set in open water, while mean catch per unit effort was higher in nets set in vegetation at both fixed points in Goose Bay. Numerous factors could be influencing these results: 1) the spatial location of points related to the hydrologic pathways throughout the Delta, 2) the location of points relative to access points to the Delta from the Williamson River, 3) possible habitat and water quality differences between the two restored areas, and 4) most likely a combination of all these factors.

Since both points in Tulana were located directly adjacent to breaches along the Williamson River, it is possible that larvae at these two locations were simply using the area as temporary stopovers before arriving at the more protected areas in the interior of the eastern side of Tulana and thus would most likely avoid vegetation at these locations. On the other hand, with both points in Goose Bay located in the interior, larvae could potentially be using the vegetation for rearing purposes. Without the ability to track individual sucker larvae, the explanations for these differences are purely hypothetical; however, the hydrodynamic model should give insight into these and other larval distribution uncertainties.

The vegetation at the fixed points differed between the two restored areas. At point A in Tulana, *Rumex spp.* dominated the wetland plant community. Some *Schoenoplectus spp.* and *Typha latifolia* were present at point B, and the vegetation at both points C and D in Goose Bay was dominated by dead vegetation remaining from when the fields were upland and not flooded. Larvae were captured in all types of vegetation, but as mentioned earlier, mean catch per unit effort was higher in vegetation in Goose Bay. With almost no emergent macrophyte vegetation the first year after flooding in Goose Bay, larvae potentially sought out the only available habitat. As emergent macrophytes become established in Goose Bay during the next five years, these trends will be especially interesting to follow.

Temporal distribution of larvae at the fixed points in Goose Bay followed similar patterns, with peaks during the week of 8 June at both points (Figure 16). Temporal patterns at the Tulana points followed patterns similar to ones observed in 2008, in which catches at point A were higher earlier in the sampling season and then decreased, while an opposite trend was witnessed at point B (Figure 19). Again, the hydrodynamic model will help determine if this is mainly an effect of lower lake elevations later in the sampling season, decreased flows in the Williamson River, or possibly some other factor.

Larval Distribution and Water Quality

Although we captured larvae in 2009 in numerous nets when larval sucker stress threshold conditions were exceeded, no significant conclusions regarding fish distribution and water quality conditions throughout the Delta can be made. However, several interactions between distribution and water quality could be occurring at the Delta. Each sampling season numerous suckers greater than or equal to 20 mm in SL are captured, with the majority caught in the last three to four weeks of the season (late June and early July). This is an important cohort to analyze due to the recruitment problems currently facing the sucker populations in Upper Klamath Lake (National Research Council 2004), as these fish have survived the larval stage (the larval stage ends approximately 45–55 days posthatch, at about 22 mm SL; Cooperman 2004).

In 2009, 2 suckers greater than or equal to 20 mm SL were captured in Tulana and 13 in Goose Bay. In comparison, 29 suckers greater than or equal to 20 mm SL were captured in Tulana in 2008, representing 50% of all fish greater than or equal to 20 mm SL. Studies on age-1 and age-2 suckers indicate changes in habitat use coincide with changes in water quality throughout the lake and suckers will actively avoid areas of low DO concentration (Burdick and VanderKooi 2010). Dissolved oxygen concentrations in the emergent area in Tulana were approximately 1.72 mg/L lower in 2009 than in 2008 during the last three weeks of the sampling season (Figure 20), which could explain why fewer large fish were captured in Tulana in 2009. Likewise, greater catches of larger age-0 fish in Goose Bay compared to Tulana in 2009 could be explained by the better water quality conditions in Goose Bay as the larval season progressed (Figure 21). Understanding this possible relationship is important for future management of lake levels in Upper Klamath Lake, as water quality within the Delta is affected by lake level elevation, Williamson River flow, and meteorological conditions.

Summary:

Data collected during 2009 suggests that larval Lost River and shortnose suckers are extensively using the restored Tulana and Goose Bay portions of the Delta for rearing. While larval production seemed to be relatively low in 2009, the establishment of emergent wetlands at the Delta should help increase larval survival. Emergent wetlands have been shown to provide feeding and growing opportunities for larval suckers (Crandall et al. 2008), protection from piscivorous predators (Markle and Dunsmoor 2007), and retention areas that reduce emigration from Upper Klamath Lake (Markle et al. 2009), as well as warm water refugia associated with increased larval development rates (Vondracek et al. 1980; Bestgen 2008). Data collected and presented here also show a food and growth advantage in wetlands as evidenced by fuller guts and larger sizes. Completion of the hydrodynamic model of the Delta remains critical in understanding larvae distribution and the effects of high and low lake elevations on the availability of emergent wetland habitat within the Delta. Continued monitoring of larval suckers at the Delta will help gauge the successfulness of the restoration project as well as provide possible insight into questions regarding lake level management, the affects of wind and river discharge on larvae distribution throughout the Delta, and a greater understanding of larvae behavior in response to wetland establishment.

Citations

Bestgen, K.R. 2008. Effects of water temperature on growth of Razorback Sucker larvae. Western North American Naturalist 68:15-20.

Burdick, S.M, and Vanderkooi, S.P. 2010, Temporal and spatial distribution of endangered juvenile Lost River and shortnose suckers in relation to environmental variables in Upper Klamath Lake, Oregon: 2008 annual data summary: U.S. Geological Survey Open-File Report 2010-1051, 36 p.

Cooperman, M.S., and D.F. Markle. 2003. Rapid out-migration of Lost River and shortnose sucker larvae from in-river spawning beds to in-lake rearing grounds. Transactions of the American Fisheries Society 132:1138-1153.

Cooperman, M.S., and D.F. Markle. 2004. Abundance, size, and feeding success of larval shortnose suckers and Lost River suckers from different habitats of the littoral zone of Upper Klamath Lake. Environ. Biol. Fishes, 71(4): 365–377.

Cooperman, M.S., D.F. Markle, M. Terrwilliger, and D.C. Simon. 2010. A production estimate approach to analyze habitat and weather effects on recruitment of two endangered freshwater fish. Canadian Journal of Fisheries and Aquatic Science. 67:28-41.

Crandall, J.C., L.B. Bach, N. Rudd, M. Stern, and M. Barry. 2008. Response of larval Lost River and shortnose suckers to wetland restoration at the Williamson River Delta, Oregon. Transactions of the American Fisheries Society 137:402-416.

David Evans and Associates, Inc. 2005. Final Williamson River Delta Restoration Environmental Impact Statement. Prepared for Natural Resources Conservation Service, The Nature Conservancy of Oregon, and Bureau of Reclemation.

Ellsworth, C.M. Personal Communication. U.S. Geological Survey. 2010

Ellsworth, C.M., Tyler, T.J., VanderKooi, S.P., and Markle, D.F.. 2009. Patterns of larval sucker emigration from the Sprague and lower Williamson Rivers of the Upper Klamath Basin, Oregon, prior to the removal of Chiloquin Dam—2006 annual report: U.S. Geological Survey Open-File Report 2009-1027, 32 p.

Erdman, C.S. and H.A. Hendrixson. Larval Shortnose and Lost River Sucker Response to Large Scale Wetland Restoration of the North Half of the Williamson River Delta Preserve, Oregon. The Nature Conservancy. 2009.

Hendrixson, H. 2008. Non-native fish species and Lost River and shortnose suckers use of restoration and undisturbed wetlands at the Williamson River Delta: Final report for activities conducted in 2006 and 2007. Submitted to USFWS Ecosystem Restoration Office, 2008.

Hey, D.L. and N.S. Phillippi. 1995. Commentary Flood Reduction through Wetland Restoration: The Upper Mississippi River Basin as a Case History. Restoration Ecology. 3: 4-17.

Henning, J.A., R.E. Gresswell, and I.A. Fleming. 2006. Juvenile Salmonid Use of Freshwater Emergent Wetlands in the Floodplain and Its Implications for Conservation Management. North American Journal of Fisheries Management. 26: 367-376.

Kuwabara, J.S., B.R. Topping, J.L. Carter, F. Parchaso, J.R. Asbill, J.M. Cameron, S.V. Fend, J.H. Duff, and A.C. Engelstad. 2010. The transition of benthic nutrient sources after planned levee breaches adjacent to Upper Klamath and Agency Lakes, Oregon: U.S. Geological Survey Open-File Report 2010-1062, 27 p. [http://pubs.usgs.gov/of/2010/1062/].

Loftus, M.E. 2001. Assessment of potential water quality stress to fish. Report by R2 Resources Consultants to Bureau of Indian Affairs, Portland, Oregon.

Markle, D.F. Personal Communication. Oregon State University. April 2010.

Markle, D.F., and K. Clauson. 2006. Ontogenetic and habitat-related changes in diet of late larval and juvenile suckers (Catostomidae) in Upper Klamath Lake, Oregon. Western North American Naturalist 66:492-501.

Markle, D.F., and L.K. Dunsmoor. 2007. Effects of habitat volume and fathead minnow introduction on larval survival of two endangered sucker species in Upper Klamath Lake, Oregon. Transactions of the American Fisheries Society 136:567-579.

Markle, D.F., M.R. Cavalluzzi, and D.C. Simon. 2005. Morphology and taxonomy of Klamath Basin suckers (Catostomidae). Western North American Naturalist 65:473-489.

Markle, D.F., S. A. Reithel, J. Crandall, T. Wood, T.J. Tyler, M. Terwilliger, and D.C. Simon. 2009. Larval fish transport and retention and the importance of location for juvenile fish recruitment in Upper Klamath Lake, Oregon. Transactions of the American Fisheries Society 138:328-347.

Mitsch, W.J. and J.G. Gosselink. 2000. Wetlands. Wiley & Sons, Inc. New York. 920 pp.

Modde, T., R.T. Muth, and G.B. Haines. 2001. Floodplain Wetland Suitability, Access, and Potential Use by Juvenile Razorback Suckers in the Middle Green River, Utah. Transactions of the American Fisheries Society. 130:1095-1105.

National Research Council (NRC). 2004. Endangered and threatened fishes in the Klamath River Basin. The National Academics Press, Washington, DC.

Parsons, J.K., and R. A. Matthews. 1995. Analysis of the associations between macroinvertebrates and macrophytes in a freshwater pond. Northwest Science 69:265-275.

Reddy, K.R. and R.D. DeLaune. 2008. Biogeochemistry of Wetlands: Science and Applications. Taylor & Francis Group. Florida. 774 pp.

Simon, D.C. 2004. A Workshop to Aid and Assist in Identifying Selected Larval and Juvenile Fishes in the Klamath Basin. Department of Fisheries and Wildlife: Oregon State University. 12 March 2004.

Terwilliger, M. Personal Communication. Oregon State University. 2010.

U.S. Fish and Wildlife Service. 1993. Lost River (Deltistes luxatus) and Shortnose (Chasmistes brevirostris) Sucker Recovery Plan. Portland, Oregon. 108 pp.

Vondracek, B., J. J. Cech Jr., and R. K. Buddington. 1980. Environmental Biology of Fishes Vol:151-156.

Wong, S., C. Doehring, and H.A. Hendrixson. 2009. Water Quality Conditions on the Williamson River Delta, Oregon: One Year Post-Restoration. The Nature Conservancy.

Wong, S., C. Doehring, and H.A. Hendrixson. 2010. 2009 Water Quality Conditions on the Williamson River Delta, Oregon: Two Years Post-Restoration. The Nature Conservancy.

Wood, T.M. Personal Communication. US Geological Survey, Biological Resources Division. December 2009.

Wood, T.M. and R.T. Cheng, 2006. Use of UnTRIM to investigate transport and water quality in Upper Klamath Lake, presented to the Seventh International Conference on Hydroscience and Engineering, Philadelphia, PA, Sept. 11-13, 2006.

Zedler, J.B. and S. Kercher. 2005. Wetland resources: status, trends, ecosystem services, and restorability. Annual Review of Environment and Resources 30:39-74.

Tables

Table 1. Number and catch per unit effort (fish/net) of each species captured using pop-nets during 2009 sampling, Williamson River Delta Preserve, Upper Klamath Lake, OR, 2009.

Species	n	Catch Per Unit Effort (fish/net)	
		mean	± SE
Lost River Sucker	75	0.31	0.09
Shortnose/Klamath Largescale Sucker	629	2.58	1.05
Unknown Sucker spp.	259	1.06	0.25
Tui Chub	1011	4.14	1.25
Blue Chub	2764	11.33	3.20
Fathead Minnow	4381	17.95	2.94
Sculpin spp.	4	0.02	0.01
Yellow Perch	10	0.04	0.22
Total	9143	37.47	6.93

Figures
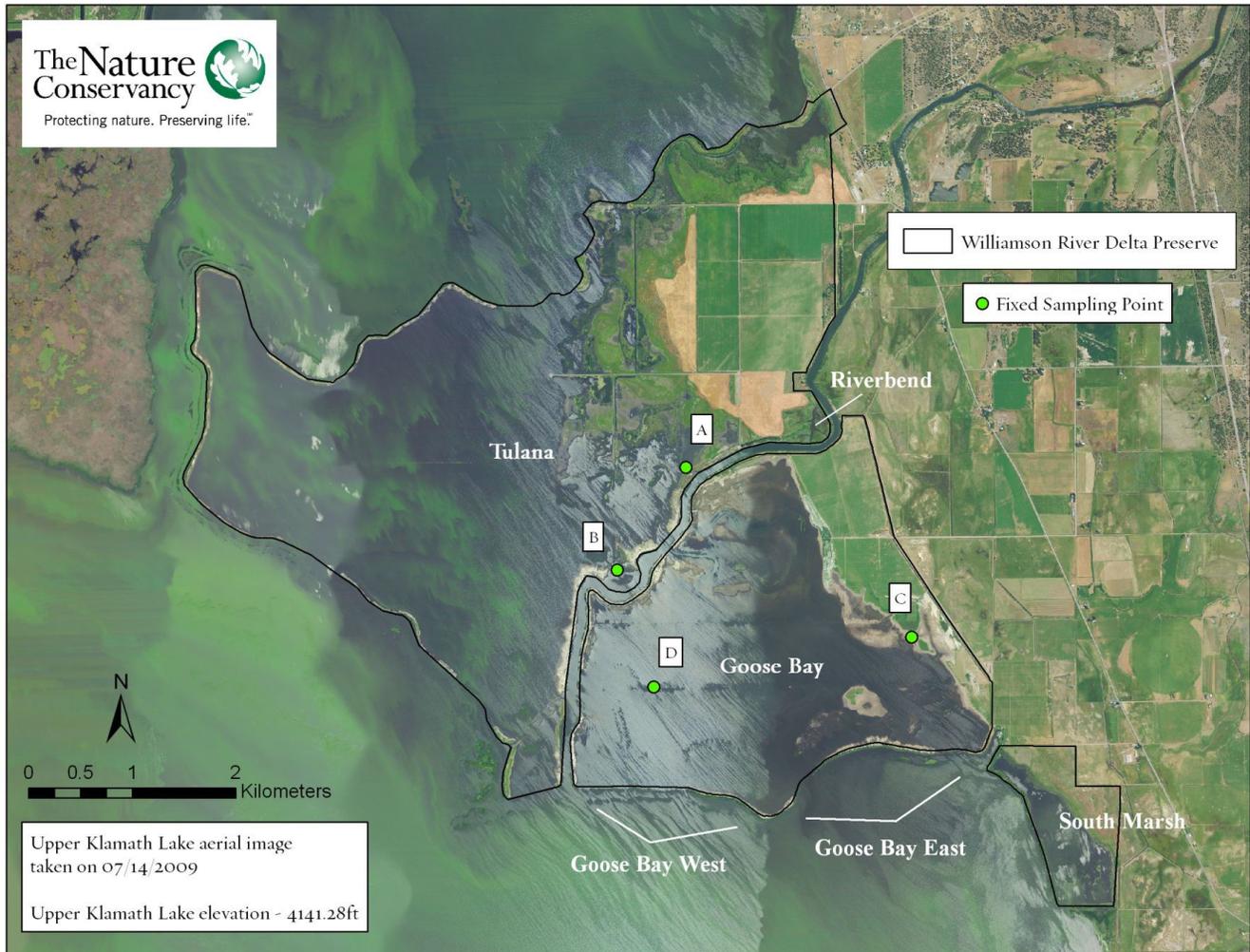
Figure 1. Map of the Williamson River Delta Preserve showing six sampling locations and four fixed sites sampled for larval Lost River and shortnose suckers, Upper Klamath Lake, Oregon, 2009.
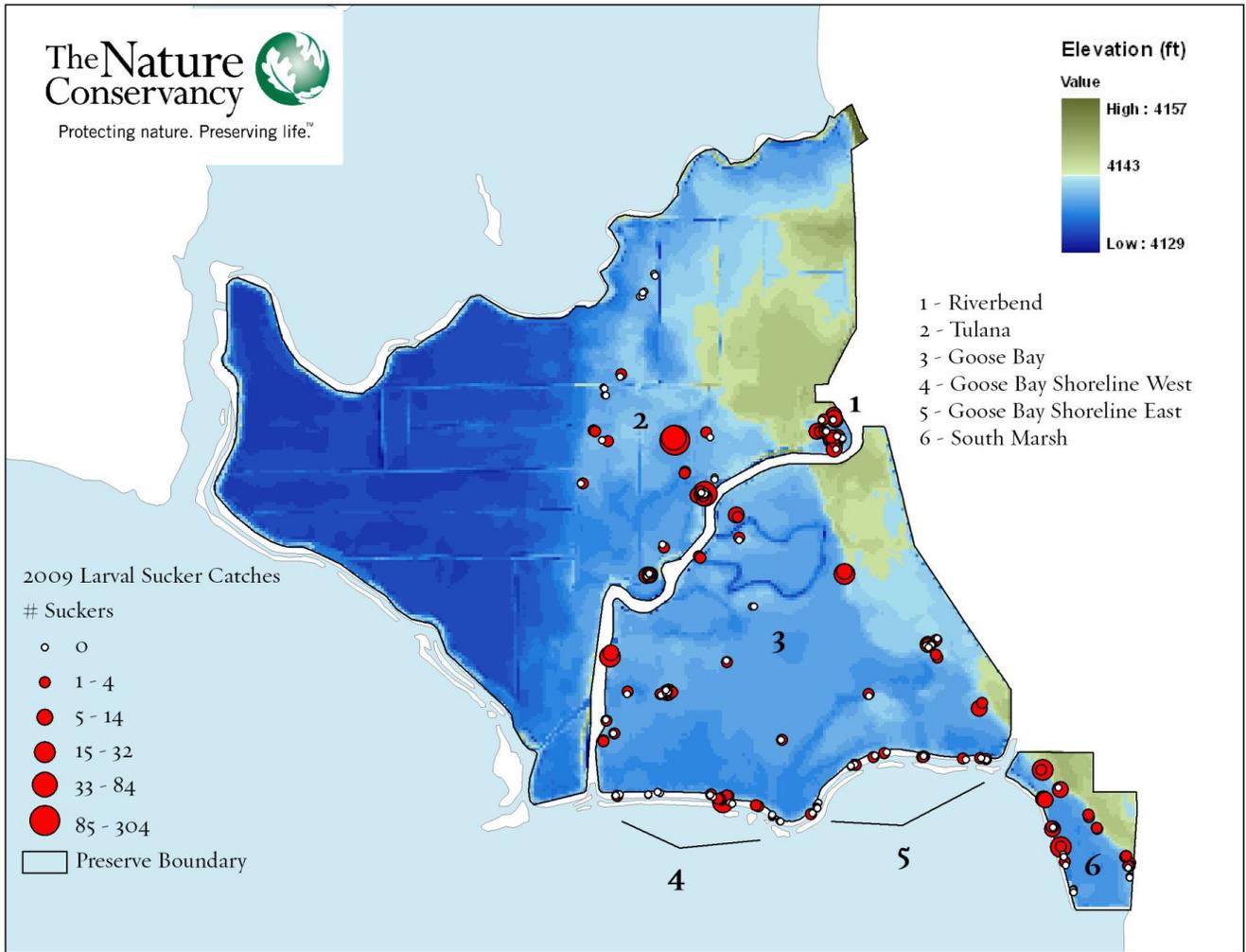
Figure 2. Map showing location of each pop net set and number of larval suckers captured in each net, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
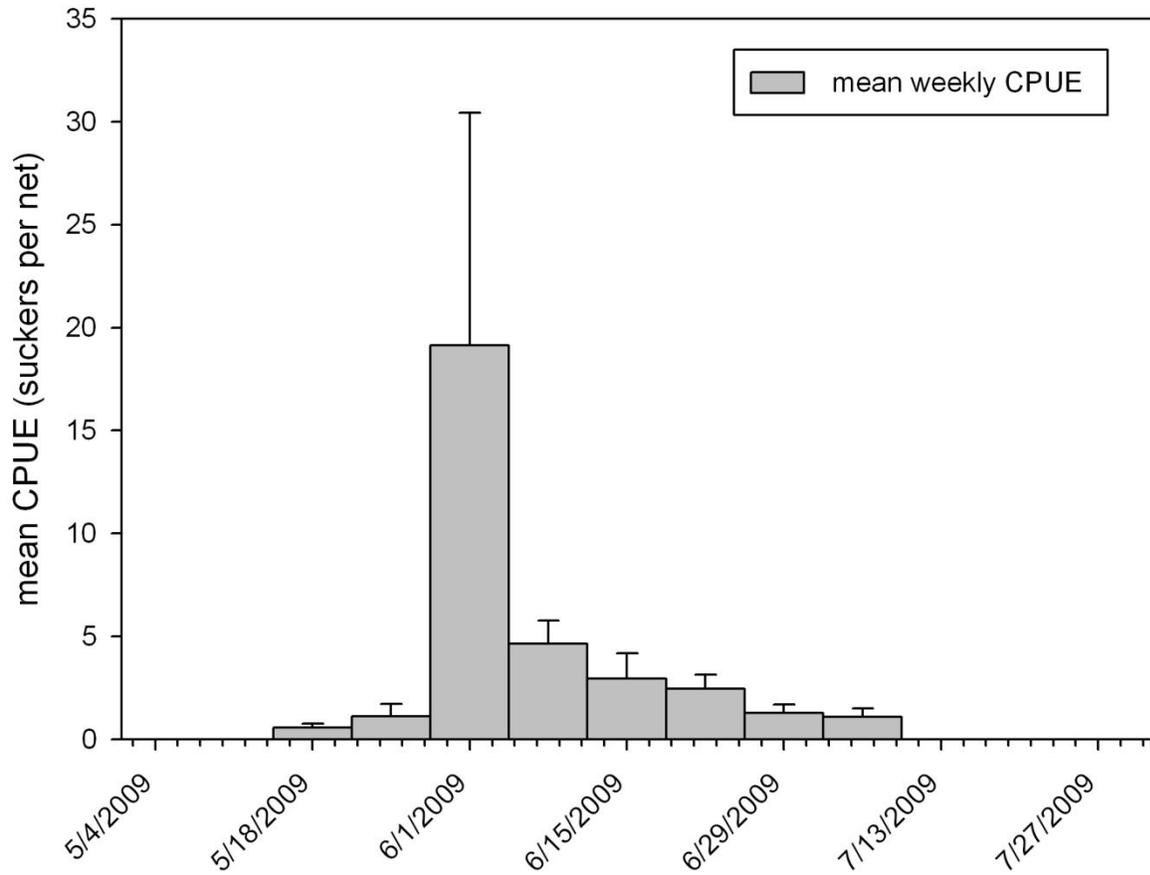
Figure 3. Weekly mean (±SE) cumulative 2009 larval sucker catch per unit effort (CPUE; suckers per net) at Riverbend, Tulana, Goose Bay, Goose Bay West and East, and South Marsh, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
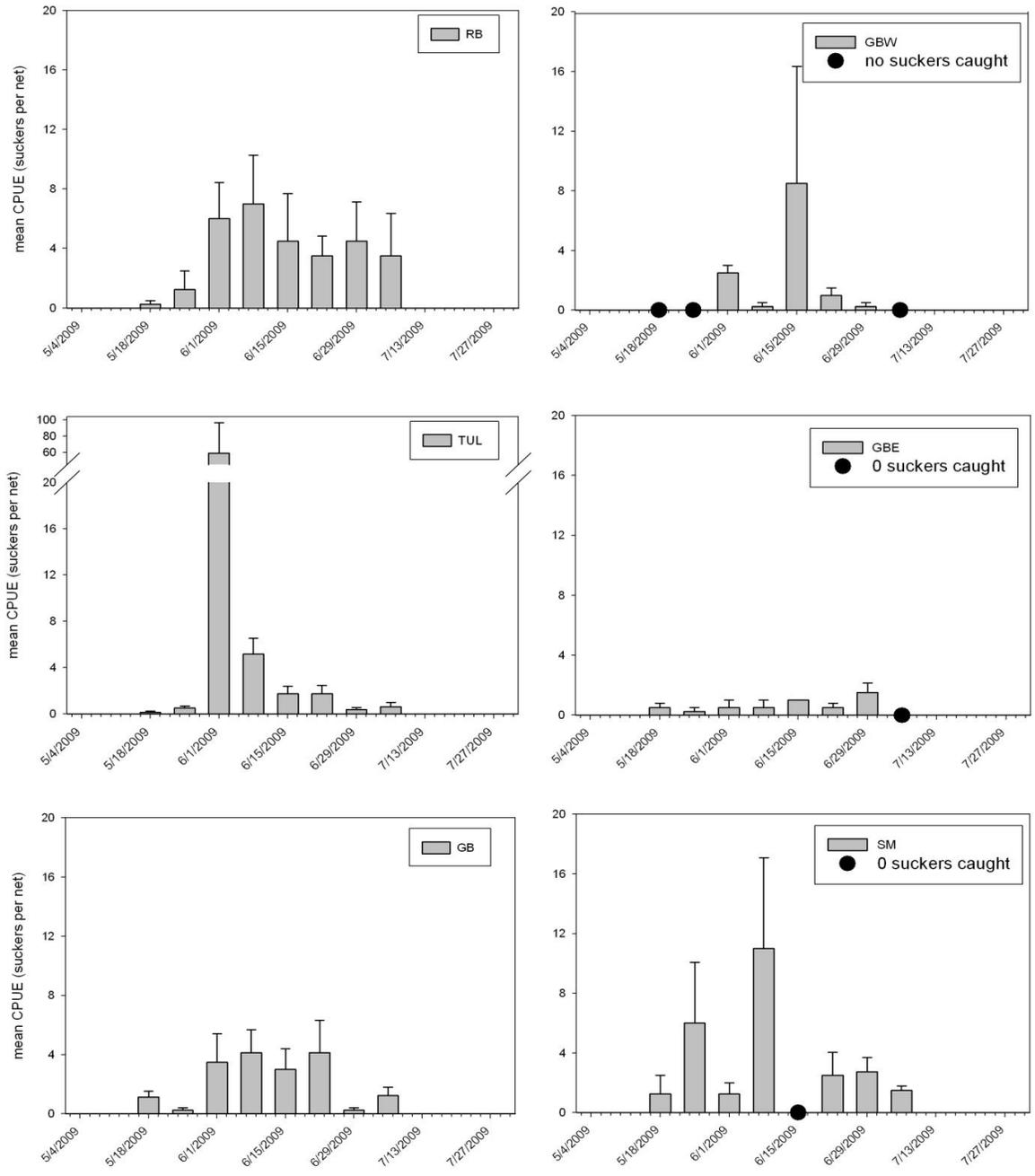
Figure 4. Weekly mean (± SE) catch per unit effort (CPUE; suckers per net) in Riverbend (RB), Tulana (TUL), Goose Bay (GB), Goose Bay West (GBW), Goose Bay East (GBE), and South Marsh (SM), Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.

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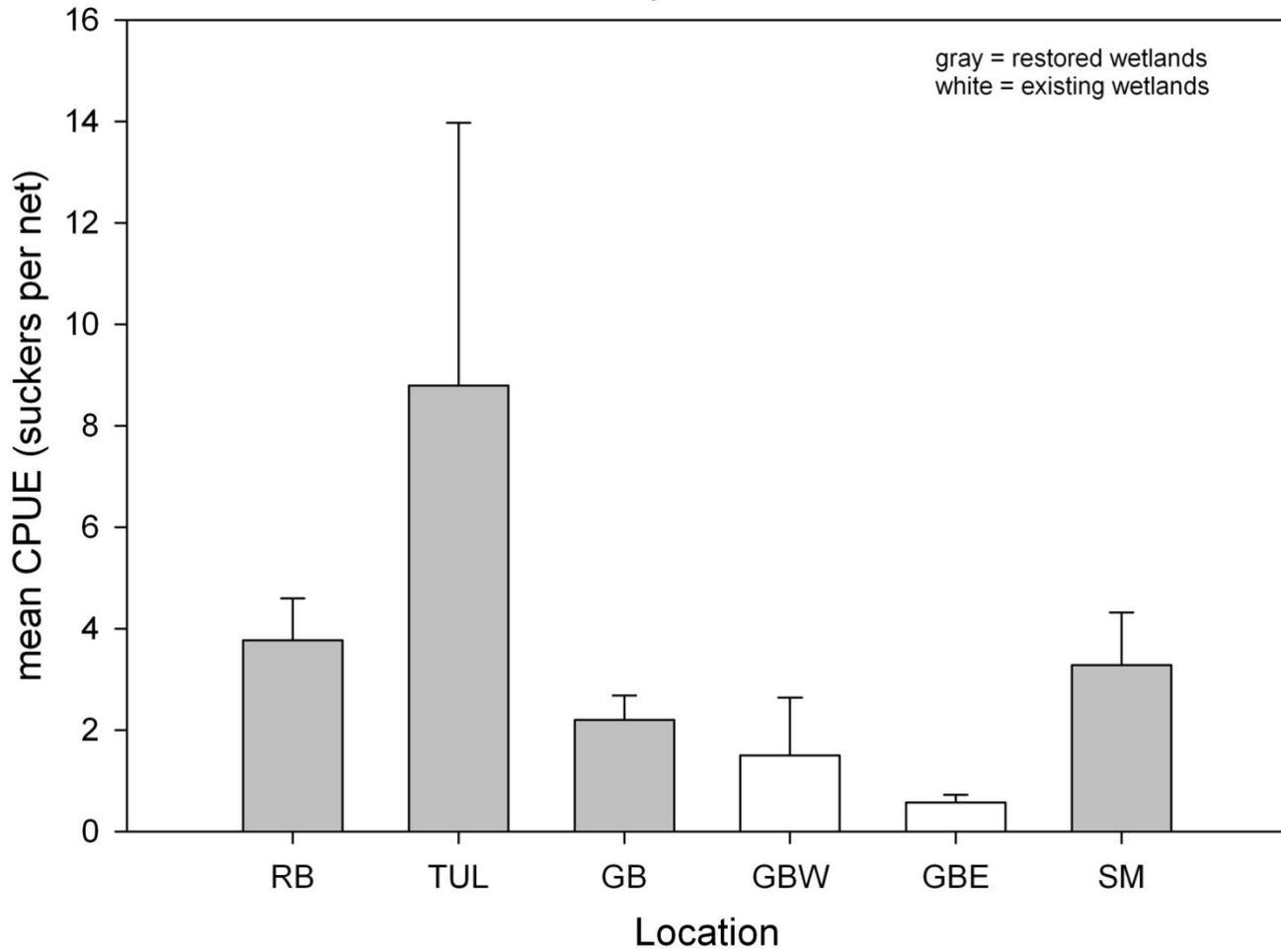
Figure 5. Mean (±SE) larval sucker catch per unit effort (CPUE; suckers per net) in Riverbend (RB), Tulana (TUL), Goose Bay (GB), Goose Bay West (GBW), Goose Bay East (GBE), and South Marsh (SM), Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009. Shaded bars indicate restored wetlands (RB, TUL, GB, SM), and open bars represent existing wetlands (GBW, GBE).
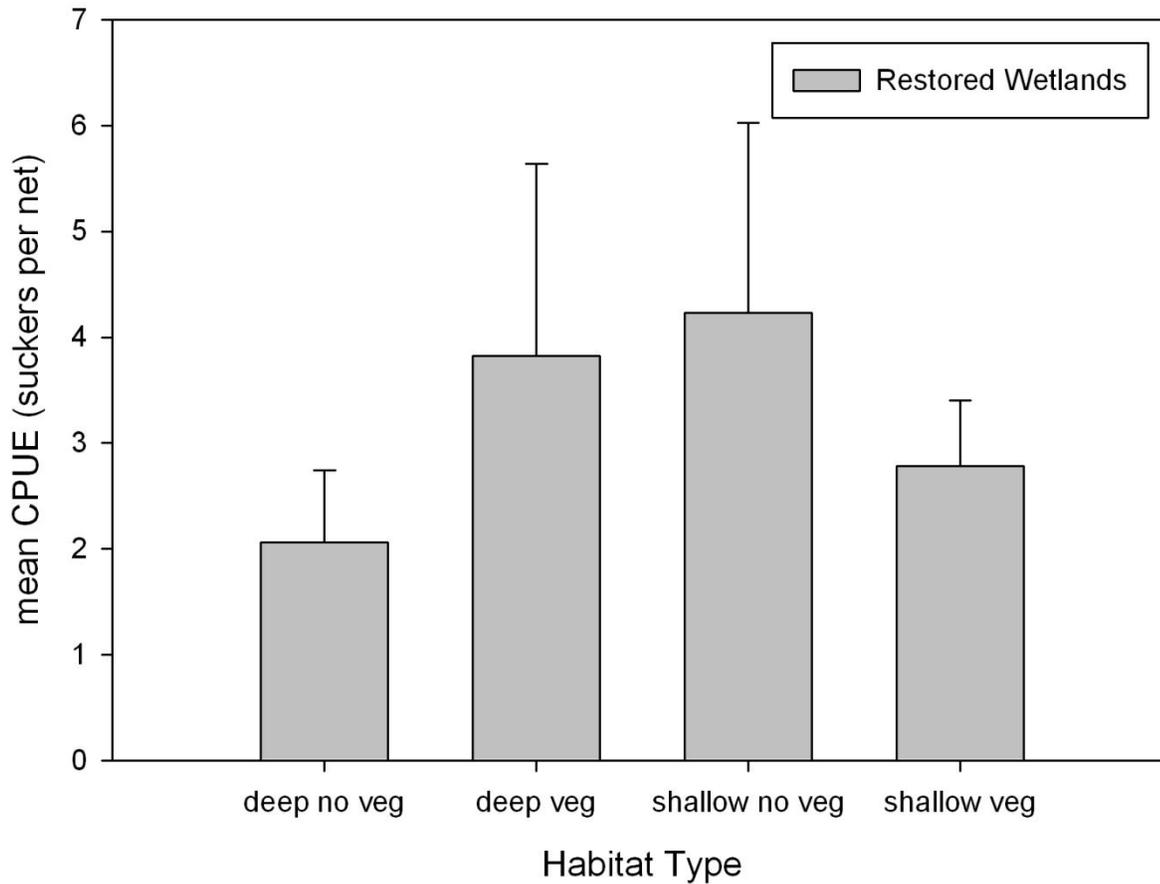
Figure 6. Mean (±SE) larval sucker catch per unit (CPUE; suckers per net) in four different habitat types—deep-no vegetation, deep-vegetated, shallow-no vegetation, and shallow-vegetated—in the four restored wetlands (Riverbend, Tulana, Goose Bay, and South Marsh), Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009. Deep sites are between 0.5m and 1m deep, while shallow sites are defined as less than 0.5m water depth.
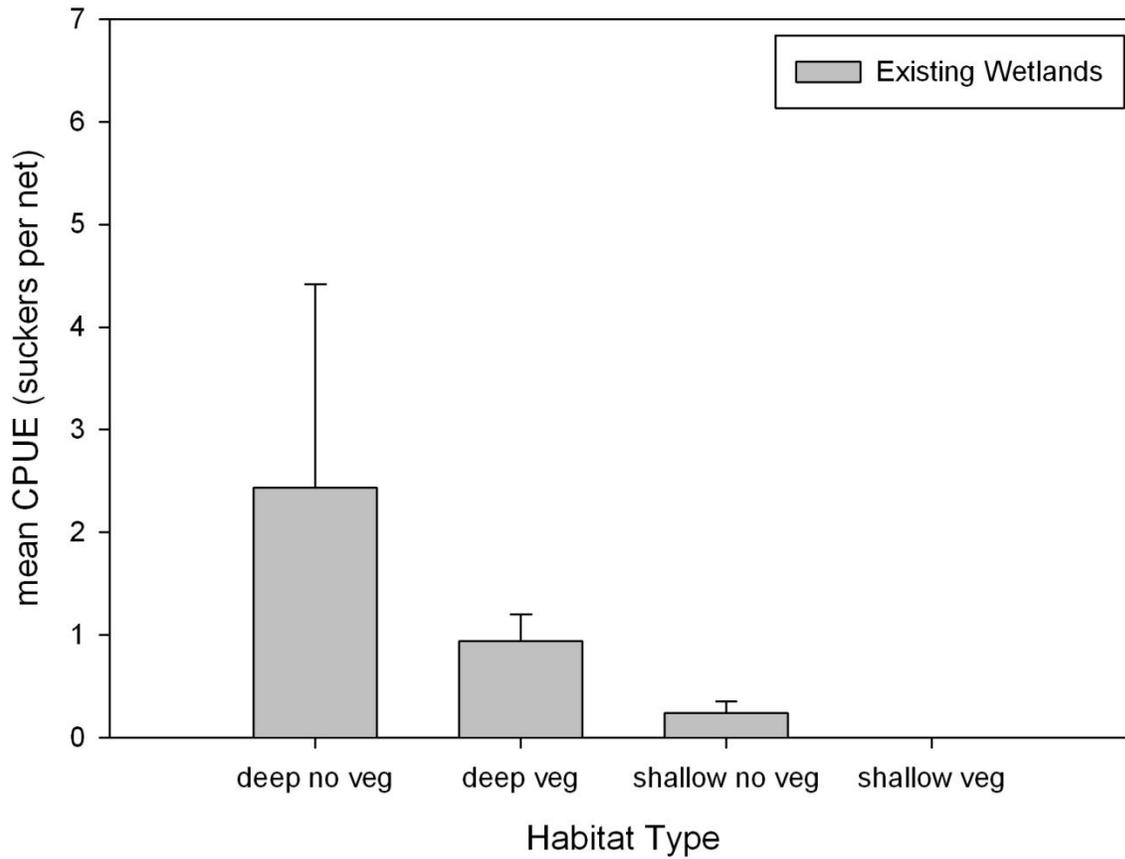
Figure 7. Mean (±SE) larval sucker catch per unit (CPUE; suckers per net) in four different habitat types—deep-no vegetation, deep-vegetated, shallow-no vegetation, and shallow-vegetated—in the two existing wetlands (Goose Bay West and Goose Bay East), Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009. Deep sites are between 0.5m and 1m deep, while shallow sites are defined as less than 0.5m water depth.
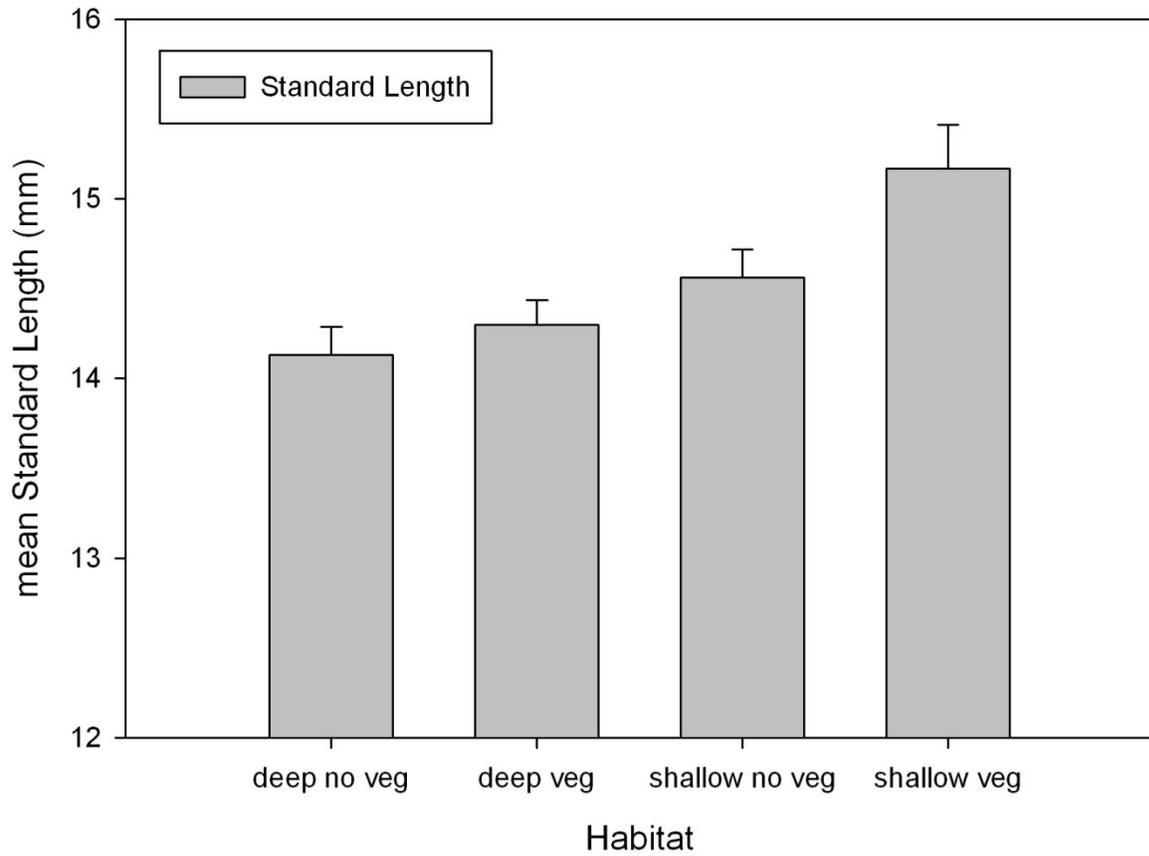
Figure 8. Mean (±SE) standard length of larval suckers captured in four habitat types—deep-no vegetation, deep-vegetated, shallow-no vegetation, and shallow-vegetated, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.

cummulative percent length frequency by location

Riverbend

Tulana

Goose Bay

mm
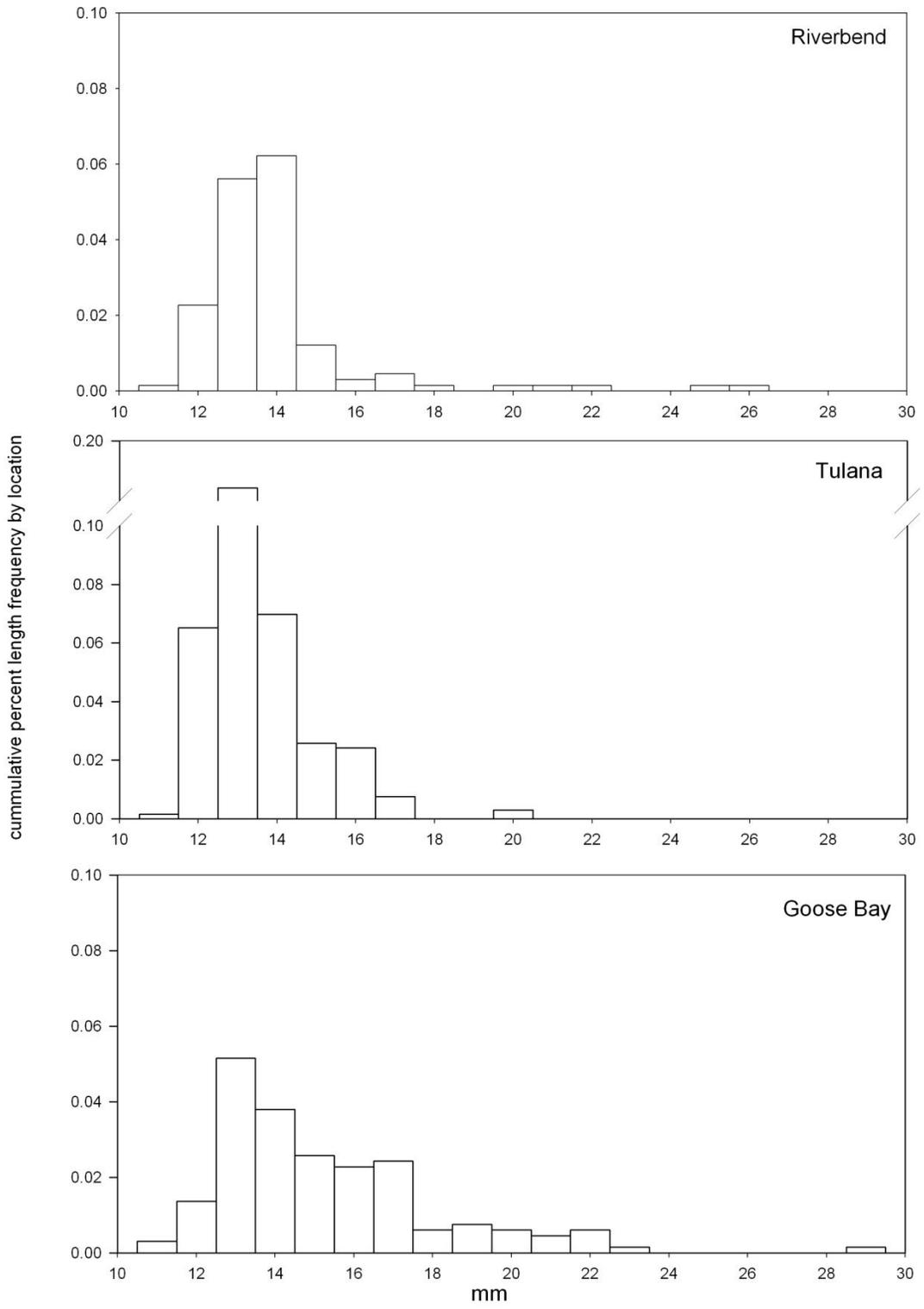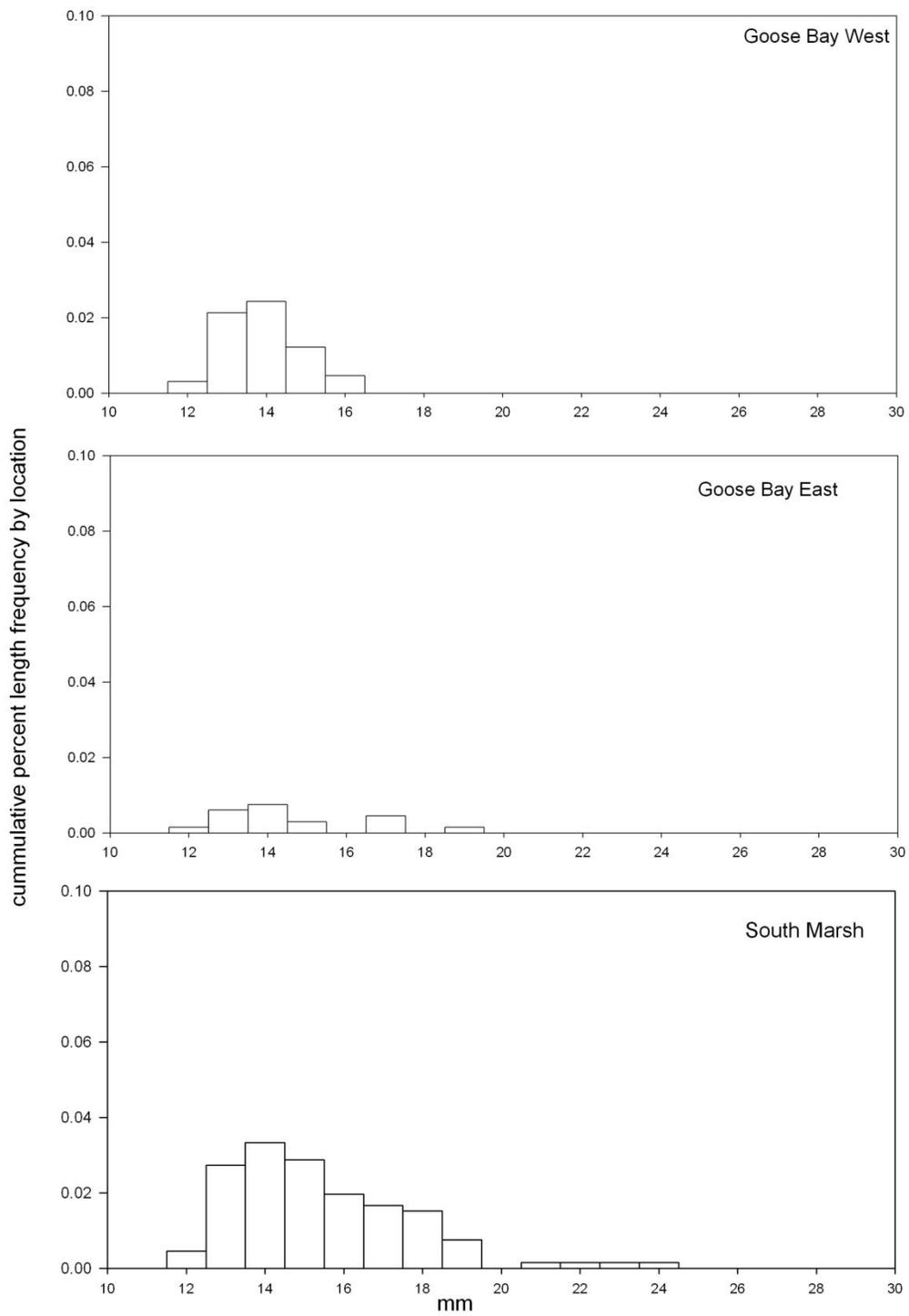
Figure 9. Cumulative percent length frequency distribution of larval suckers captured in pop nets at six locations at the Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
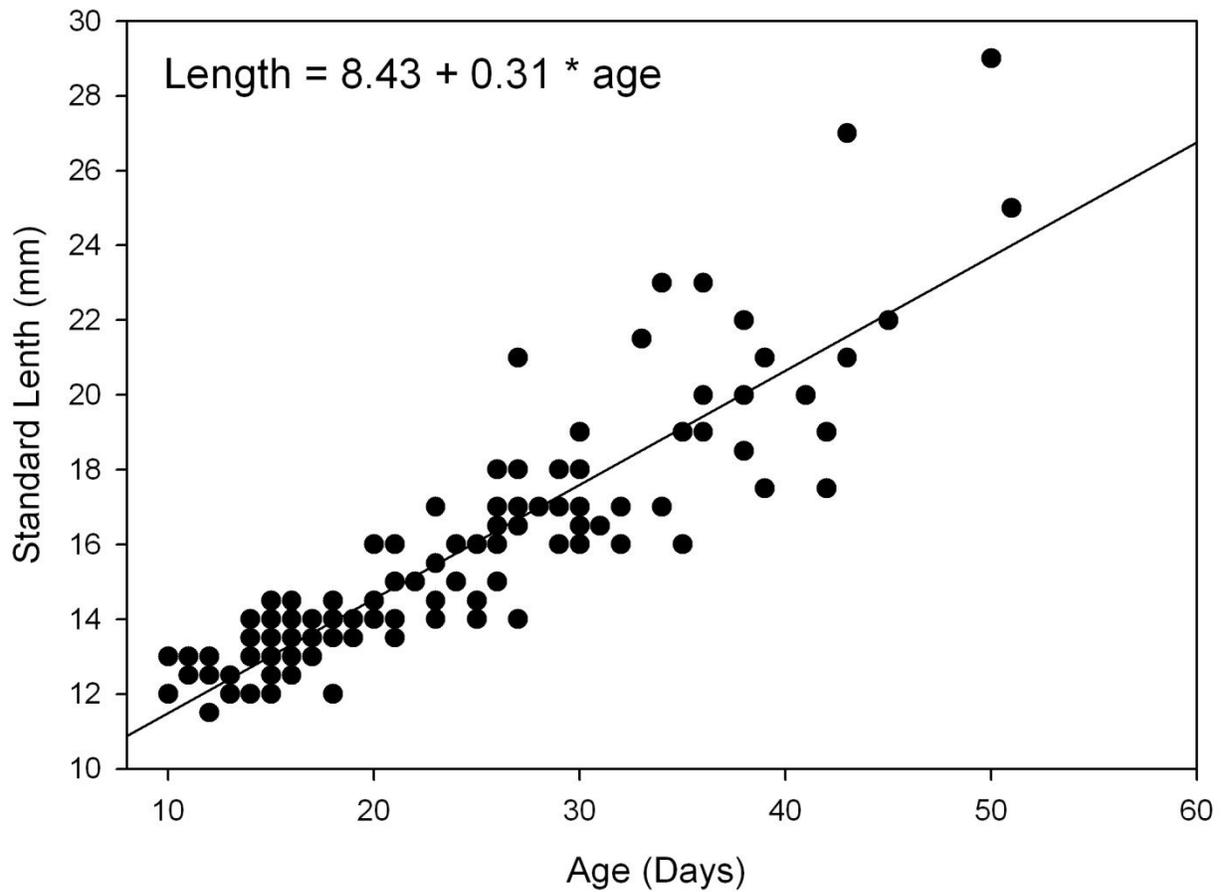
Figure 10. Length to age comparison for sucker larvae collected in 2009 at the Williamson River Delta, Upper Klamath Lake, Oregon. Age estimates were based on median lapilli otolith ring counts read three times by Oregon State University researchers (M. Terwilliger, Oregon State University, personal comm., 2010). The linear relationship between length and age for larval suckers is shown by the line and regression equation (R^2 = 0.80).
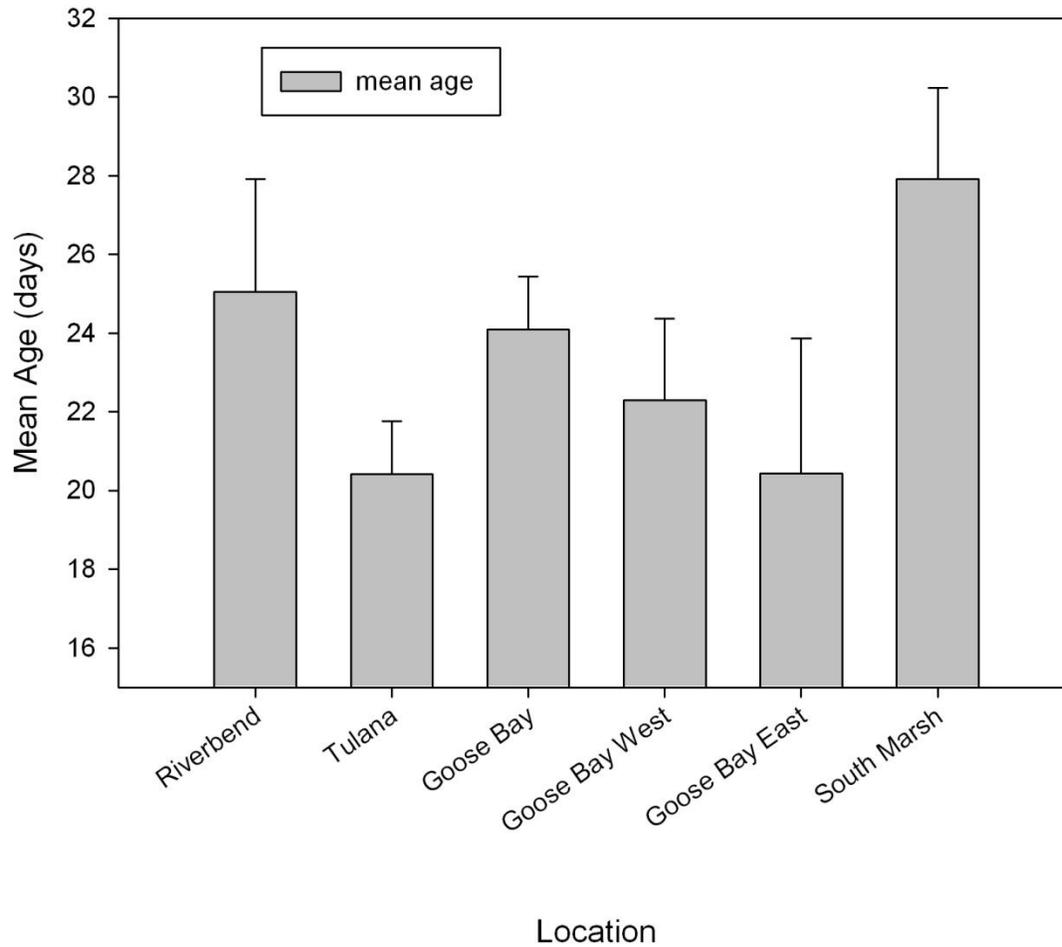
Figure 11. Mean (±SE) age of larval suckers captured in six sampling areas at the Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009. Age estimates were based on median lapilli otolith ring counts read three times by Oregon State University researchers (M. Terwilliger, Oregon State University, personal comm., 2010).
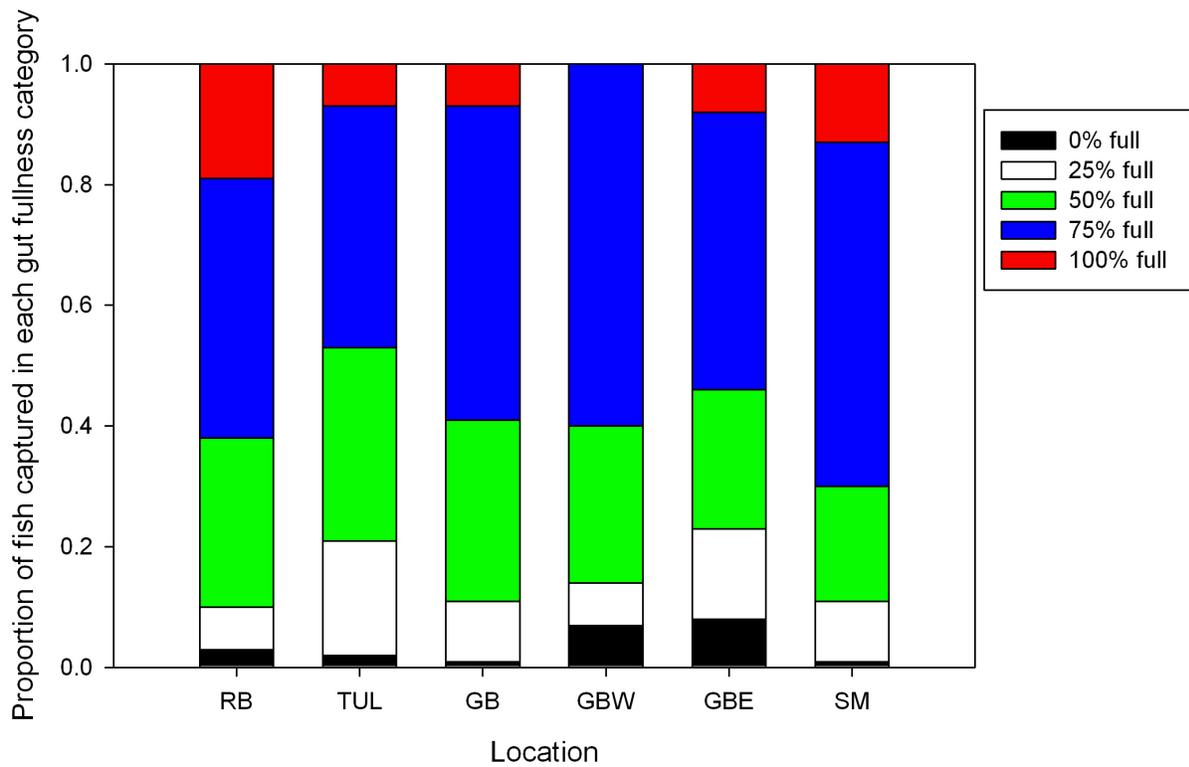
Figure 12. The proportion of larval suckers in each of the five gut fullness categories (0% full, 25% full, 50% full, 75% full, 100% full) captured at each location, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
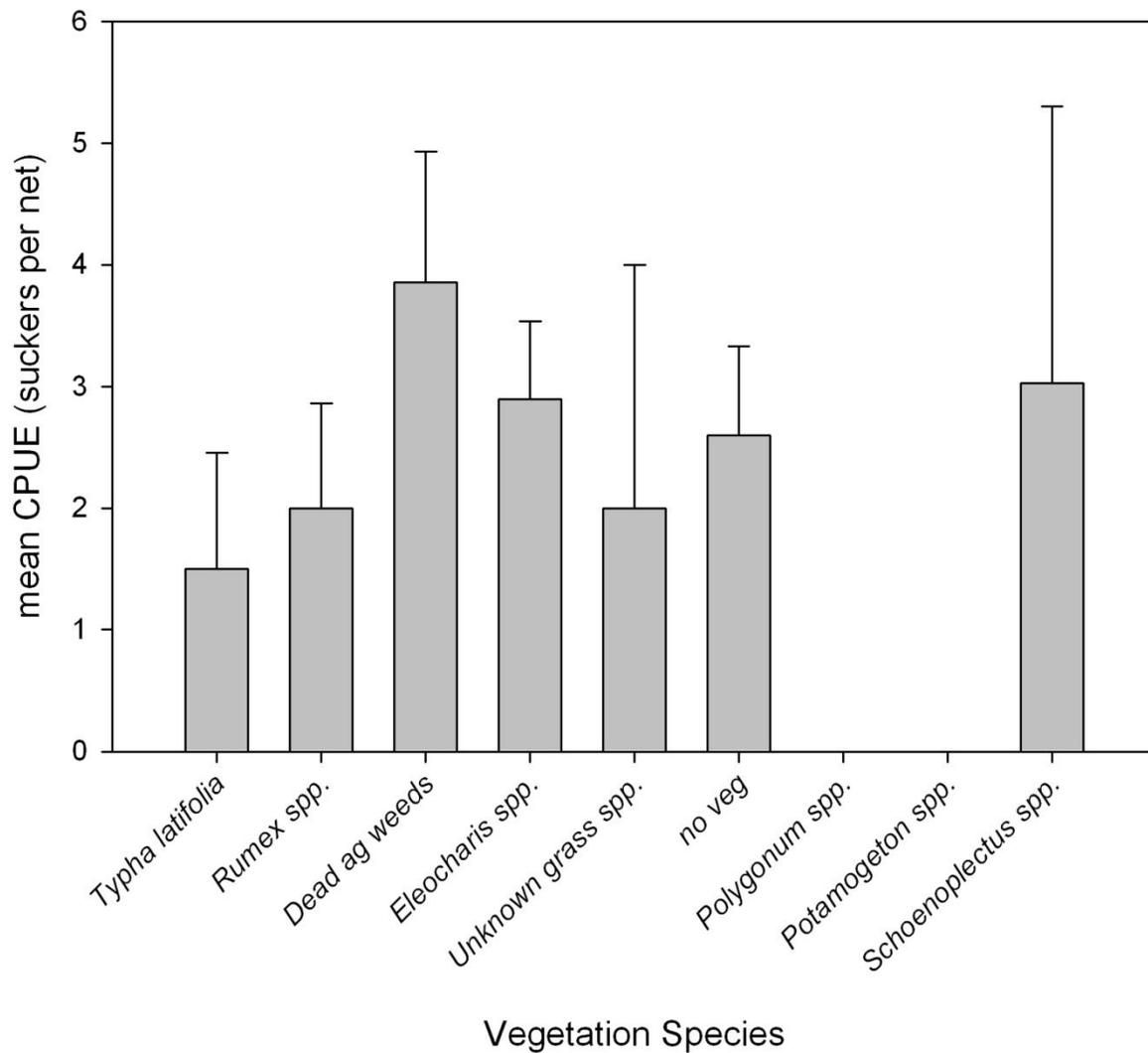
Figure 13. Mean (±SE) larval sucker catch per unit effort (CPUE; suckers per net) in a variety of plant species, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
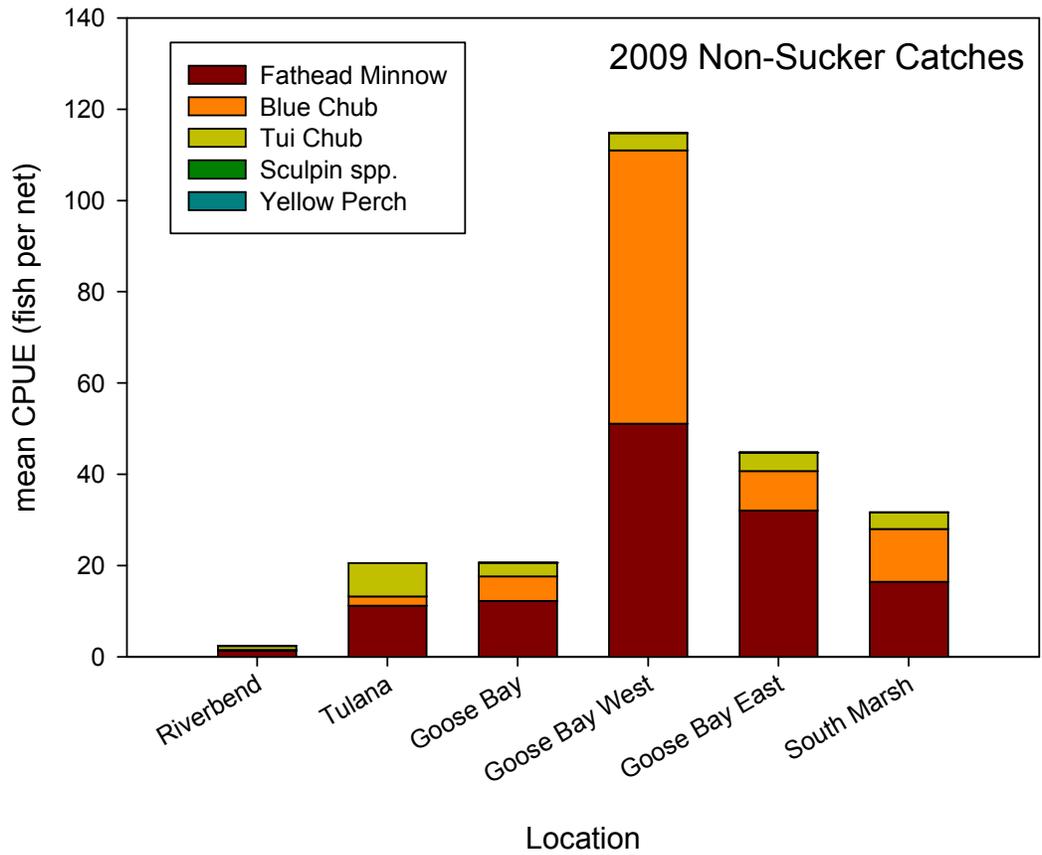
Figure 14. Non-sucker catch per unit effort (CPUE; fish per net) during weekly sampling at six sampling locations in Upper Klamath Lake, Oregon, 2009.
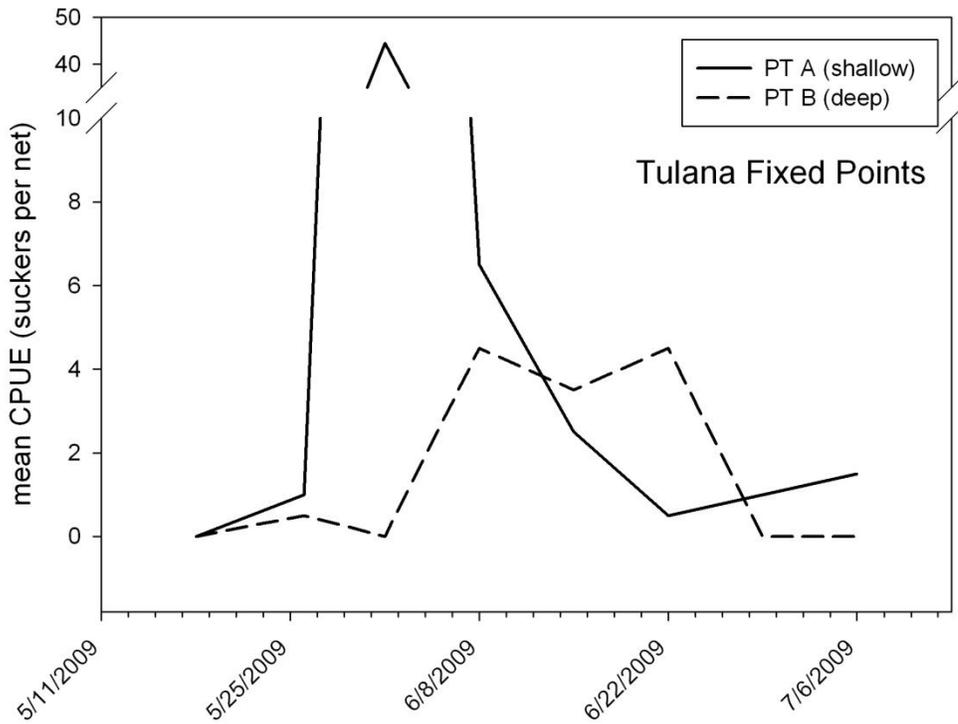
Figure 15. Weekly catch per unit effort (CPUE; suckers per net) at two fixed sampling points (point A and B) in Tulana, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
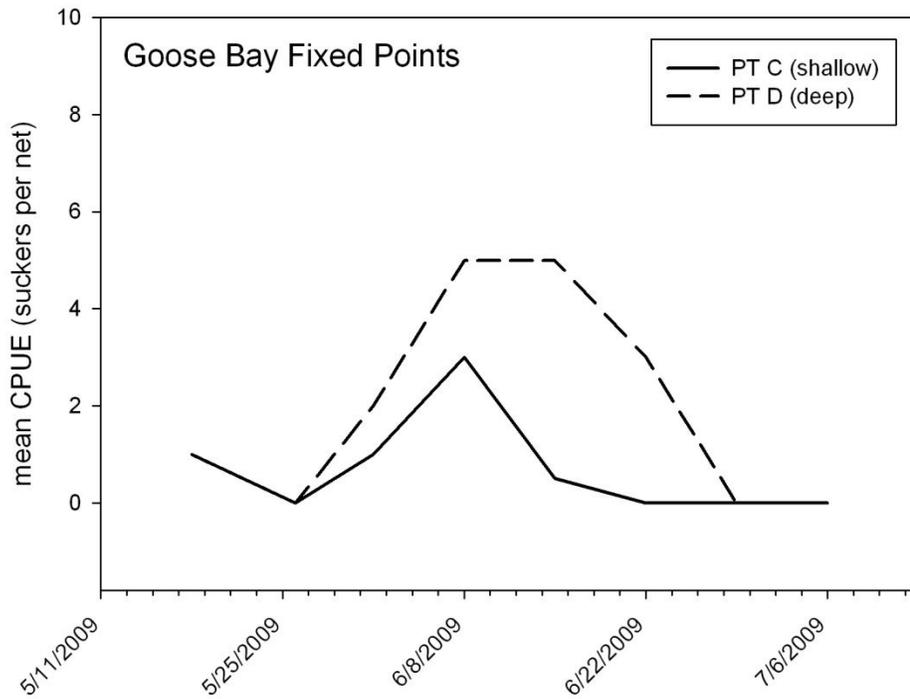
Figure 16. Weekly catch per unit effort (CPUE; suckers per net) at two fixed sampling points (point C and D) in Goose Bay, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.

Figure 17. Annual larval sucker catches in restored (Riverbend, Tulana, Goose Bay, South Marsh) and existing wetlands (Goose Bay west, Goose Bay east), Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
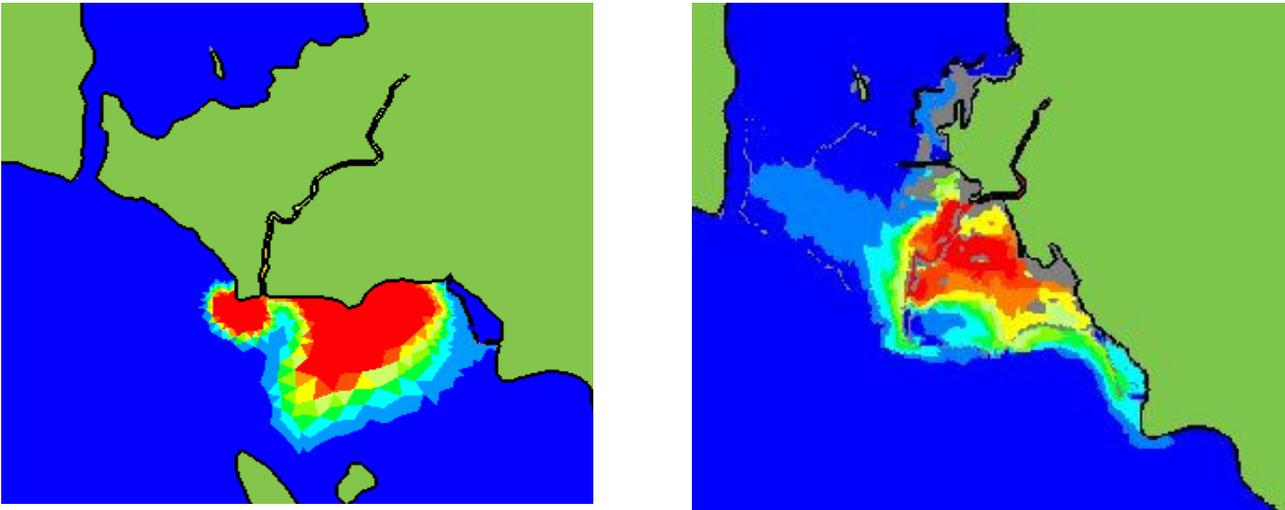
Figure 18. Examples of results generated from a concentration experiment developed using the UN-TRIM hydrodynamic model grid with and without restoration of the Williamson River Delta, Upper Klamath Lake, Oregon. Red indicates the highest predicted concentration of larval suckers (Tammy Wood, personal comm. 2009).
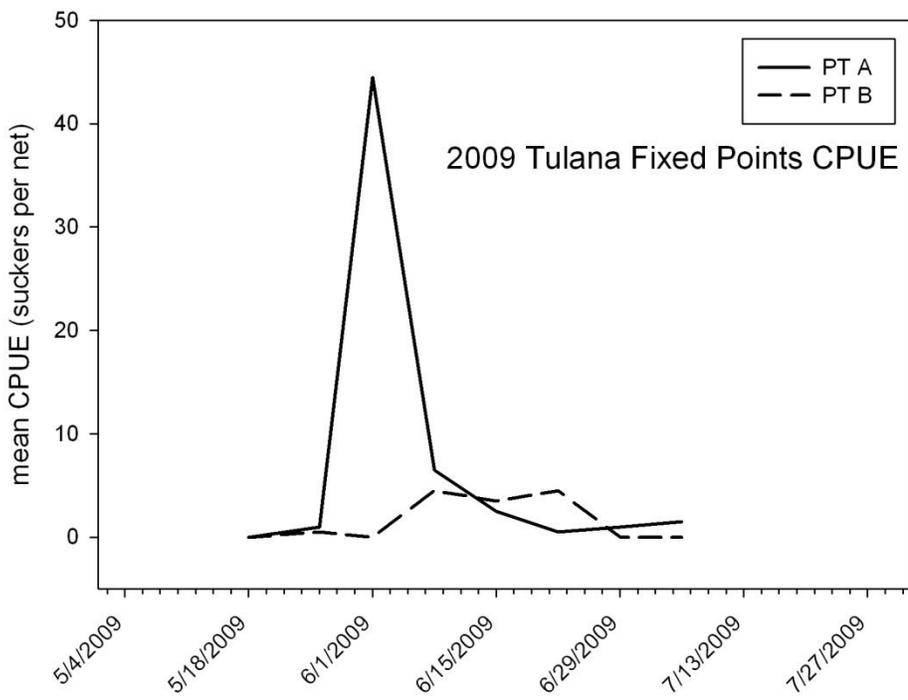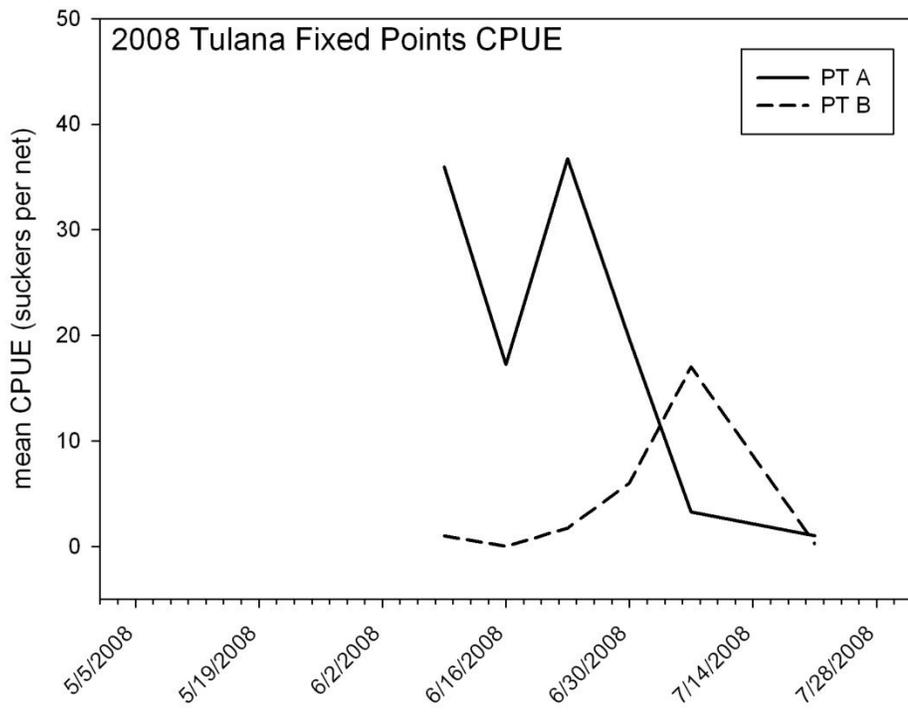
Figure 19. Catches of larval suckers at two fixed points in Tulana from 2008 and 2009, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
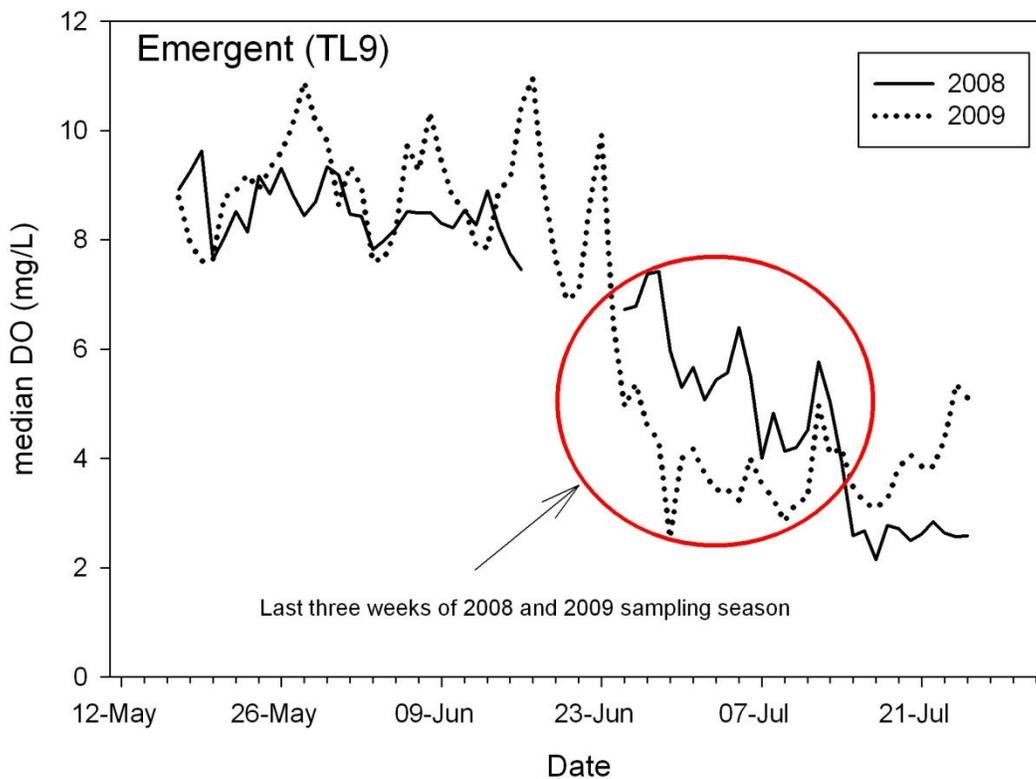
Figure 20. Continuous (hourly) in situ water chemistry data from 2008 and 2009 collected by The Nature Conservancy (Wong et al. 2009) showing daily median dissolved oxygen concentrations in the emergent areas of Tulana, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.
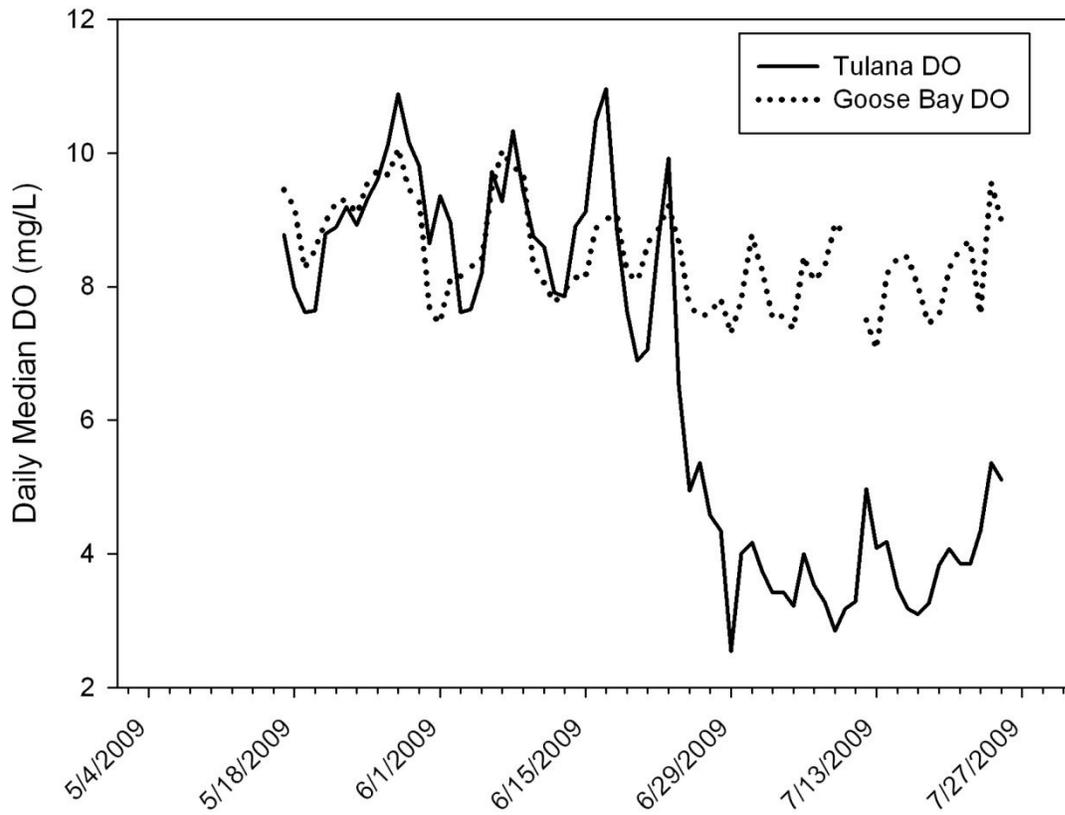
Figure 21. Continuous (hourly) in situ water chemistry data from 2009 collected by The Nature Conservancy (Wong et al. 2009, 2010) showing daily median dissolved oxygen concentrations in the emergent areas of Tulana and Goose Bay, Williamson River Delta Preserve, Upper Klamath Lake, Oregon, 2009.