Larval Shortnose and Lost River Sucker Response to Large Scale Wetland Restoration of the North Half of the Williamson River Delta Preserve, Oregon

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Abstract

Hydrologic reconnection of deltaic wetlands at the mouth of the Williamson River with portions of Agency Lake and Upper Klamath Lake, Oregon is a restoration strategy aimed at increasing the amount of nursery habitat available for larval Lost River suckers *Deltistes luxatus* and shortnose suckers *Chasmistes brevirostris*. We examined the response of larval suckers to this large scale wetland restoration project at the Williamson River Delta by assessing discrepancies in catch rates, habitat preferences, and fish condition (size and gut fullness) at restored and existing lakeshore fringe wetlands. Differences in habitat associations existed between the two wetland types, as larval suckers preferred shallow, vegetated areas in the restored areas of the Williamson River Delta while in existing wetlands deep, non vegetated areas were occupied more frequently. Mean larval sucker length and gut fullness in the restored areas were on average greater than means in existing wetlands, a strong indication that larvae were rearing in the restored wetlands of the Williamson River Delta. Our monitoring suggests that wetland restoration efforts at the Williamson River Delta may contribute to the recovery of these two endangered species through the increase of larval nursery habitat.

Project Background

In 1988 Lost River sucker *Deltistes luxatus* and shortnose sucker *Chasmistes brevirostris* were listed as endangered by the U.S. Fish and Wildlife Service (US Fish and Wildlife Service 1988). Several factors were referred to as key causes for the severe population decline in the Upper Klamath Basin including habitat loss, water management, nonnative species, poor water quality, and overfishing (US Fish and Wildlife Service 2002). Endemic to the large, eutrophic lakes of the upper Klamath River watershed of Oregon and California, these two species are large, long lived, adfluvial fish. Prior to the 1940s, Lost River and shortnose suckers, along with a third catastomid species, the Klamath largescale sucker *Catostomus snyderi*, were abundant and widespread within their range and heavily relied upon by local Indians and settlers (US Fish and Wildlife Service 1993). Today, the largest remaining populations of Lost River sucker and shortnose sucker inhabit Upper Klamath Lake (Buettner and Scoppettone 1990). Recently, recruitment to the adult life history stage in the Upper Klamath Lake populations has been sporadic, a possible consequence of the large reduction in rearing habitat for larvae, age-0, and age-1 suckers (National Research Council 2004).

By 1968, littoral marsh habitat adjacent to Upper Klamath Lake had decreased to ~7,000 hectares, a reduction of roughly 66% and a loss of habitat that has been cited as a principal reason for the declining populations of Lost River sucker and shortnose sucker in the lake (US Fish and Wildlife Service 2002). Studies focusing on larval sucker behavior have concentrated on depth and vegetative cover as two important components of larval rearing habitat. Larval suckers show a strong preference for emergent macrophytes, which may promote good year class formation (Cooperman and Markle 2004) and are important for protection from non-native species, including the fathead minnow *Pimephales promelas* (Markle and Dunsmoor 2007). Emergent macrophytes also provide better feeding and growth opportunities (Buettner and Scoppettone 1990; Crandall et al. 2008; Hendrixson 2008), and allow for greater retention from the clockwise lake circulation pattern which can lead to emigration from the lake (Markle et al. 2009).

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). Before being diked and drained during the 1940s and 50s for agricultural purposes, the lower five kilometers of the Williamson River was a complex system containing wetland vegetation, providing important connectivity between the lake and the river and valuable rearing habitat for larval suckers. Without this expansive deltaic wetland, larvae rapidly exited the Williamson River and often entered Upper Klamath Lake without the development of a tail fin, causing difficulties in foraging and swimming (Cooperman and Markle 2000). Throughout this 2,200 hectare delta, the river channel was u-shaped, dynamic, and lined with critical larval fish habitat (Cooperman and Markle 2003; TNC unpublished data).

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). The Nature Conservancy initiated three small-scale wetland restoration projects in the late 1990s to study the response of larval suckers to wetland restoration. Monitoring at these sites (Riverbend, South Marsh, and Campfields) since 2000 indicates that larval suckers are using these areas and wetland restoration provides critical emergent wetland habitat, which can lead to larger, more abundant, and better-fed larval suckers (Crandall et al. 2008; Hendrixson 2008). Due to the success of these projects, The Nature Conservancy restored the entire northern half of the Delta (Tulana) in October 2007. Roughly two miles of levees were breached, flooding ~1,500 hectares of old agricultural fields and reconnecting the Williamson River and Upper Klamath Lake to former deltaic wetlands on the Delta.

In 2008 we continued larval sucker monitoring in Riverbend and South Marsh, at lake fringe wetlands along the Goose Bay shoreline of Upper Klamath Lake, and expanded our monitoring efforts to the newly restored Tulana portion of the Delta. Our four main objectives were: 1) determine the timing and magnitude of larval sucker use of the Delta, 2) ascertain habitat preferences in the Tulana portion of the Delta, 3) evaluate the response in fish condition (size and gut fullness) to the most recent restoration activities, and 4) compare data collected in 2008 to data collected during previous sampling seasons and outside project sites. By determining the extent of larval use and habitat preferences within the Delta, our 2008 monitoring assessed the response of larval suckers to large scale wetland restoration. Given the results from 2006 and 2007, we hypothesized that larval suckers would utilize habitats in the Tulana portion of the Delta and would prefer shallow water, vegetated areas over deeper water, non-vegetated areas.

Methods

Sampling Design

In 2008 we conducted larval sucker sampling at five locations on the Delta: two early action projects (Riverbend and South Marsh), existing lake fringe wetlands in two sections of Goose Bay (Goose Bay east and west; GBE, GBW), and the newly restored Tulana portion of the Delta (Figure 1). We divided Goose Bay into two distinct sampling locations because the eastern section of Goose Bay could act as an accumulation point for larvae, an anomaly thought to be caused by the clockwise circulation of water in Upper Klamath Lake whereas the western section acts more like a conduit for suckers leaving the Williamson River (Wood and Cheng 2006; Markle et al. 2009).

Every other week beginning 27 May, we conducted sampling in all five sampling locations—this sampling effort will be referred to as bi-weekly sampling. Sampling sites at each of the five locations were selected based on habitat type (depth and vegetation cover) and visited every other week from 27 May – 24 July. During sampling weeks, each location was visited once, with a maximum of eight nets set at each

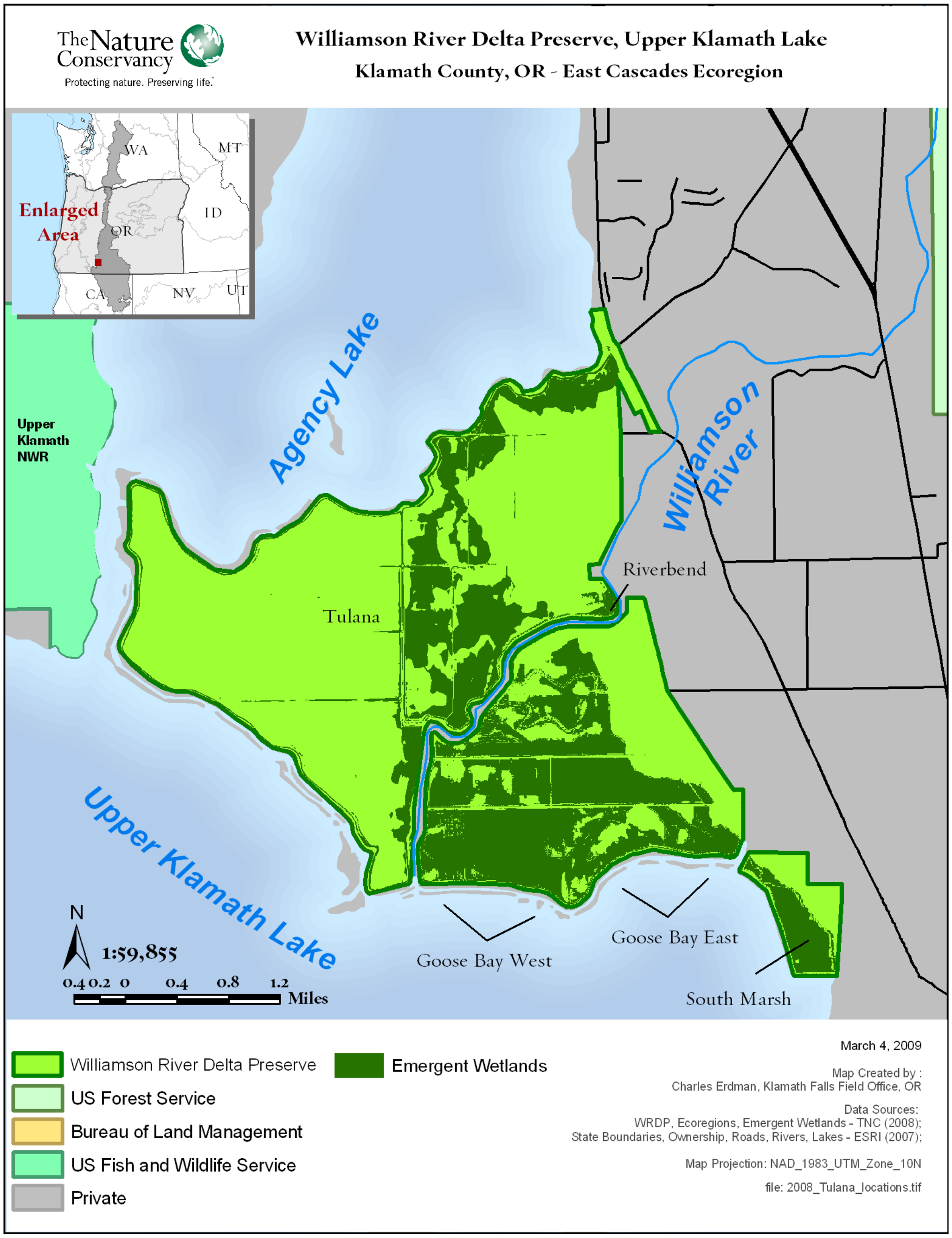

Figure 1. Map showing emergent habitat and the five sampling locations used for larval sucker sampling at the Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

location, thus ensuring that duplicate nets were set in each habitat type in each location.

During the alternate weeks, we sampled locations solely in the newly restored Tulana portion of the Delta, including two fixed sampling sites that were included in the bi-weekly sampling. Sampling during these alternate weeks commenced on 3 June and ended 3 July and was aimed at gathering data regarding distribution and habitat preferences within the newly restored wetlands of the Delta. Sampling sites were chosen randomly given accessibility and our sampling parameters (depth and vegetation), with the exception of nets that were set at the two fixed sites (Figure 2). Nets set at the fixed sites were placed within the same 100 m X 100 m area each week. Point A was inside (northwest) of the first river breach (RM 2.25) and point B was located in the middle of the breach at the big bend, further downstream of point A (RM 1.5).

Water depths at all sites were at least 0.15 m and no greater than about 1 m deep due to equipment restrictions and because previous research on larval shortnose and Lost River suckers indicates that larvae occupy shallow, near shore areas during the day (Buettner and Scoppettone 1990; Cooperman and Markle 2003).

All sampling was conducted by setting "pop" nets in areas with vegetative cover (>25% emergent or submerged aquatic vegetation) and in areas without vegetation (0%

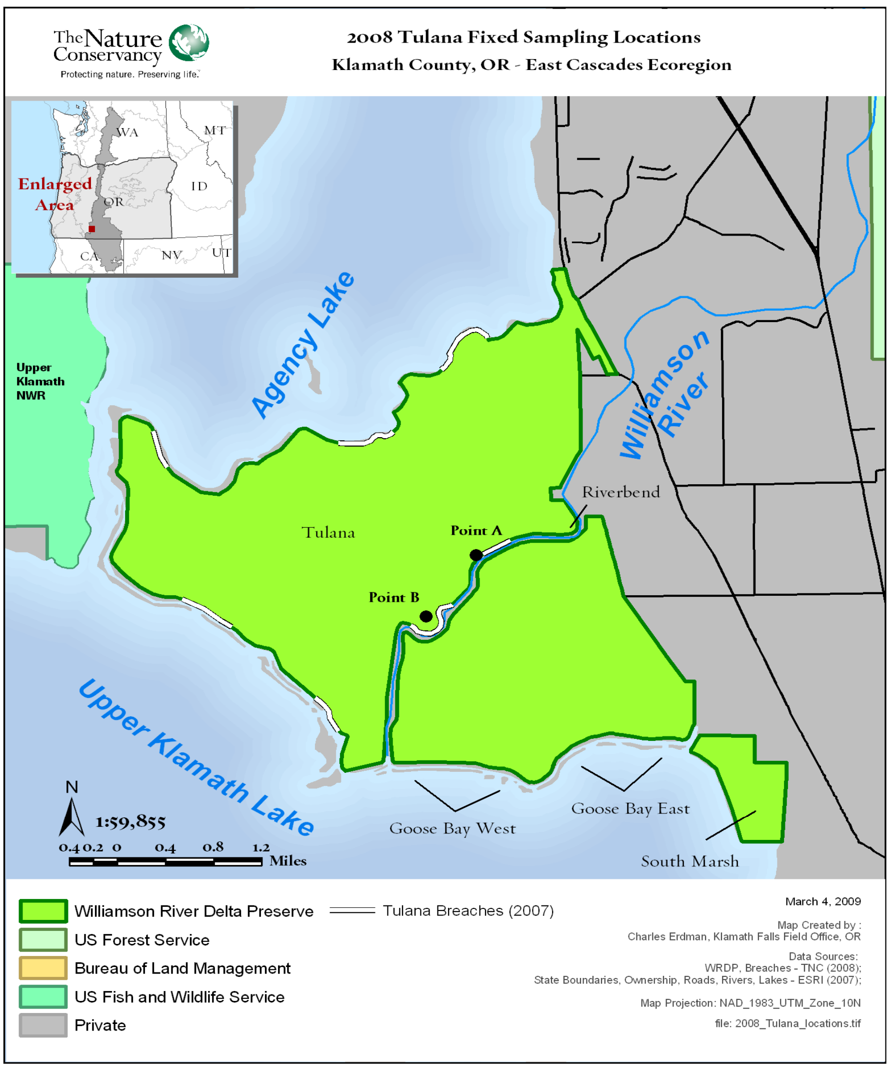

Figure 2. Map showing two fixed sampling locations in Tulana visited weekly during larval sucker sampling at the Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

macrophyte cover), replicated at both shallow (<0.5 m deep, mean = 0.29m) and deep (>0.5 m deep, mean = 0.70m) water depths. This sampling design mimicked the protocol used during the past two sampling seasons to model four habitat types: deep water with vegetation, deep water without vegetation, shallow water with vegetation, and shallow water without vegetation.

The "pop" nets consisted of two 2.5 cm diameter PVC frames (approximately 1.6 m x 1.6 m, area = 2.56 m^2), 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 connected the two frames to form a cube. The nets lacked a bottom and top, allowing them to be set in vegetation. To set the nets, both frames were submerged and secured underwater with two 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, thus allowing sites to recover from disturbances caused while setting the net.

After the net was "popped", we recorded water depth, wind speed, GPS location, and dominant vegetation type and measured water temperature, dissolved oxygen concentration, pH, and specific conductance using a handheld datalogger (Hydrolab Quanta®). All measurements were taken as close to the center of each net as possible, and water quality measurements were taken at approximately mid depth in the water column. Small aquarium dip nets were used to collect all fish enclosed in the net. Each net was swept at least five times after the last fish was caught to ensure that no larvae were missed. Stalks of vegetation in the nets were sometimes removed in order to more effectively capture fish.

Fish Identification and Condition

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

Data Analysis

We analyzed data collected during 2008 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 are visited more often than others (Murphy and Willis 1996).

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 ($\alpha = 0.05$) to compare probability distributions of 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.

In order to gain a better understanding of larval sucker distribution throughout the Tulana portion of the Delta, we divided the area into three areas for analysis: north cul-de-sac (NCDS), south cul-de-sac (SCDS), and river (Figure 3). The cul-de-sac road connects the middle of Tulana with the upland part of Tulana closer to the river. Points located north of the cul-de-sac road were labeled as NCDS points, while points south of the cul-de-sac road were labeled as SCDS, and points adjacent to the river are labeled river points. The cul-de-sac road provides an obvious natural barrier/division point in Tulana.

Results

Bi-Weekly Sampling

We timed the start of sampling to coincide with peak larval sucker drift in the lower Williamson River (Craig Ellsworth, US Geological Survey, personal communication). Biweekly sampling ended when suckers were no longer present at all sampling locations. During the 2008 bi-weekly sampling a total of 150 nets were set: 38 in Riverbend, 36 in Tulana, 18 in GBW, 18 in GBE, and 40 in South Marsh (Figure 4). Thirty-eight (25.3%) nets were set in deep-veg, 35 (23.3%) in deep-no veg, 37 (24.7%) in shallow-veg, and 40 (26.7%) were set in shallow-no veg habitat. Table 1 shows the number of nets set in the different habitat types at each location.

A total of 1,240 suckers were caught during bi-weekly pop net sampling at the Delta. Larval suckers were present in 57% of pop nets, resulting in a total CPUE of 8.3 fish per net. The three highest daily catches occurred in GBE (11 June), Riverbend (9 July), and Tulana (26 June) with 354, 178, and 154 suckers caught, respectively. Larval sucker species composition was 122 Lost River sucker (9.8%), 552 shortnose/Klamath largescale (44.5 %), and 566 unknown (45.7%), or an estimated 18% Lost River sucker and 82% shortnose/Klamath largescale sucker based on the identified portion of sucker catch expanded to the unidentified portion.

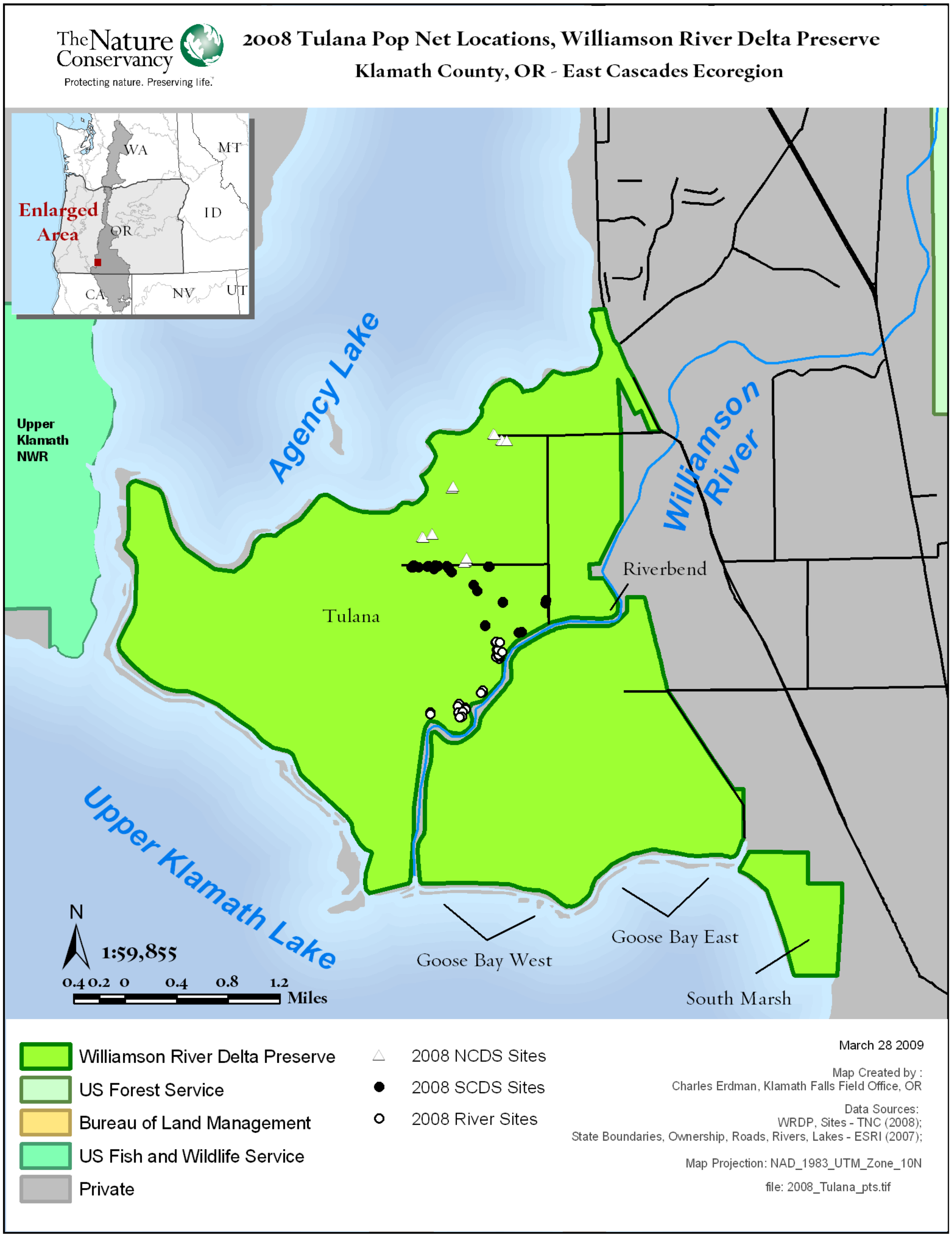

Figure 3. Map of northern (NCDS), southern (SCDS), and river pop net locations in the Tulana portion of the Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

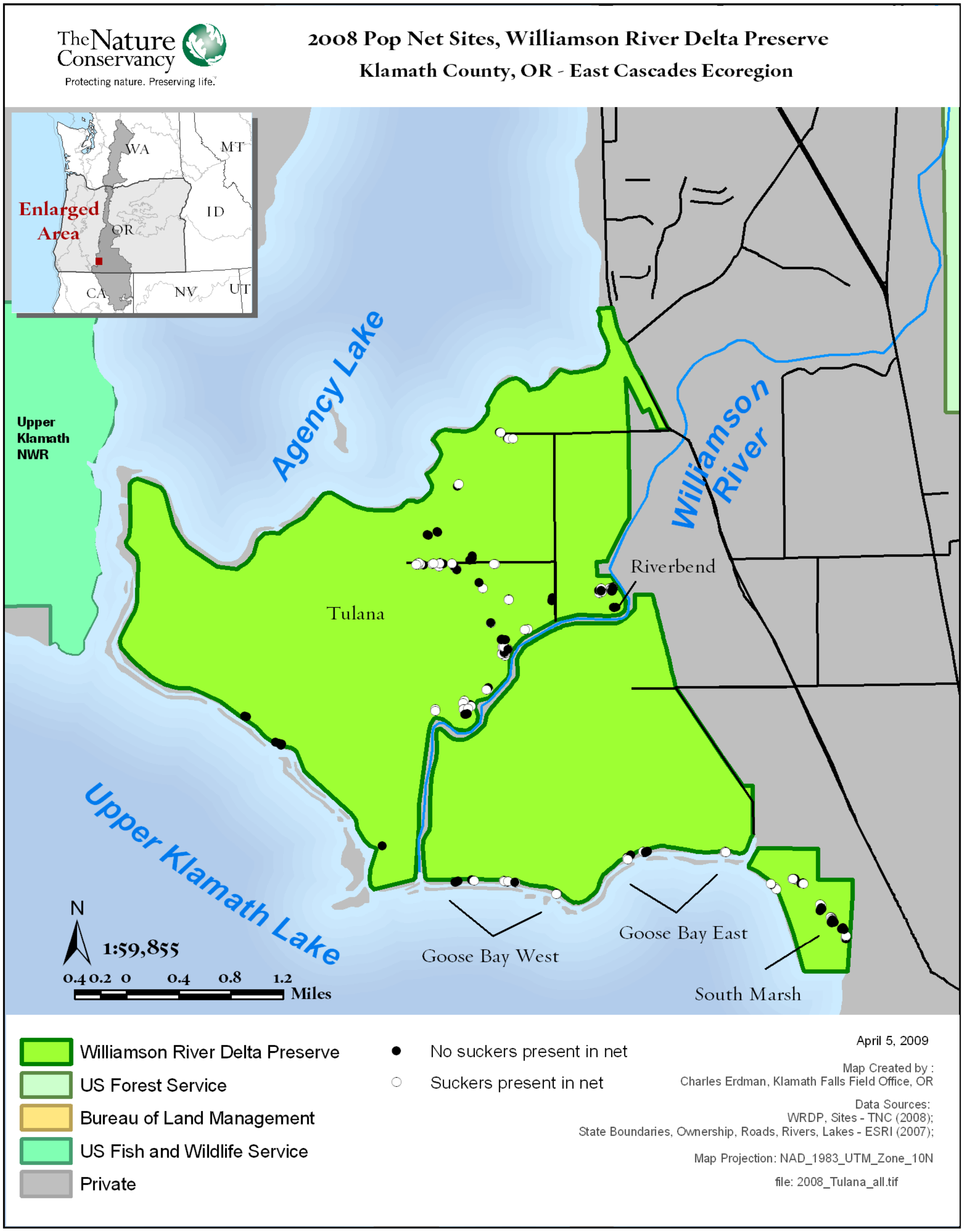

Figure 4. Map showing location of each pop net and the presence/absence of suckers during 2008 larval sampling at the Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

Table 1. Total number of nets set in the four different habitat types in five sampling locations during bi-weekly sampling, Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

Location	Deep-Veg	Deep-No Veg	Shallow-Veg	Shallow-No Veg	Total # Nets
Riverbend	9	9	10	10	38
Tulana	9	8	9	10	36
Goose Bay west	4	5	4	5	18
Goose Bay east	5	4	4	5	18
South Marsh	11	9	10	10	40

The 2008 larval sucker catch appeared bimodal, with a large peak during the week of 9 June and a second smaller peak occurring during the week of 7 July (Figure 5). Catches in GBW, GBE, and South Marsh were highest during the week of 9 June, while catches in Tulana were highest during the week of 23 June, and catches in Riverbend were highest during the week of 7 July (Figure 6).

Catch per unit effort was highest in GBE with 23.4 suckers per net, followed by Tulana with 10.6, Riverbend with 5.4, South Marsh with 4.1, and GBW with a CPUE of 3.7. Catches of larval suckers in the four respective habitat types (deep-veg, deep-no veg, shallow-veg, shallow-no veg) differed at the five sampling locations, although these differences were not significant (Kruskal-Wallis test, $\alpha = 0.05$, $P = 0.5817$; Figure 7). Generally in the three restored wetlands larval suckers were caught more frequently in vegetated areas at both shallow and deep sites. Along the Goose Bay shoreline (GBW and GBE), catches were higher at deep sites without vegetation and shallow sites with vegetation (Figure 7). Cumulative larval sucker catches during bi-weekly sampling were higher in shallow, vegetated habitat than other habitat types, although the differences were not significant (Table 2; Kruskal-Wallis test, $\alpha = 0.05$, $P = 0.9895$).

Tulana had the greatest CPUE compared to the two other small-scale wetland restoration projects, Riverbend and South Marsh. Catch rates in Tulana were higher in non-vegetated areas (13.5) than in vegetated areas (13.0) at shallow depths. Conversely, at deep sites CPUE was higher in sites with vegetation (11.6) than where no vegetation existed (3.3). In both Riverbend and South Marsh, CPUE was higher in shallow, vegetative sites.

Larval sucker standard length (SL) for all suckers collected ranged from 11 mm to 27 mm with a mean SL

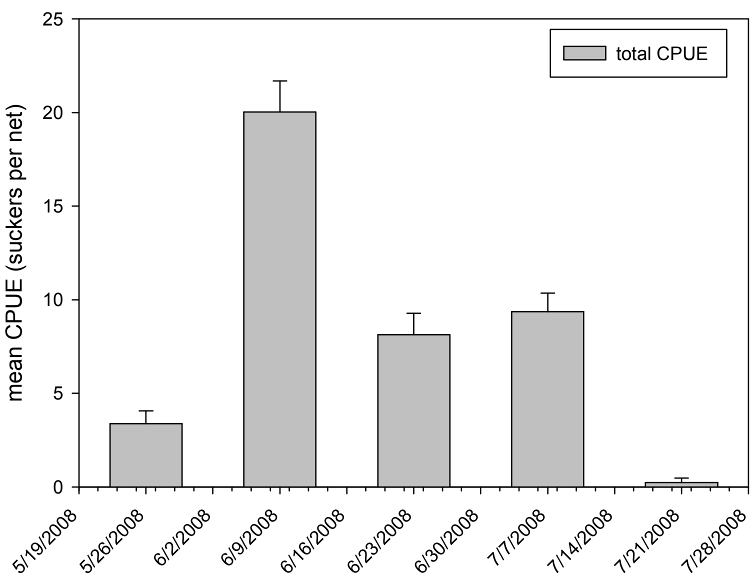

Figure 5. Bi-weekly cumulative 2008 larval sucker catch per unit effort (CPUE; suckers per net) at Riverbend, Tulana, Goose Bay West and East, and South Marsh, Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

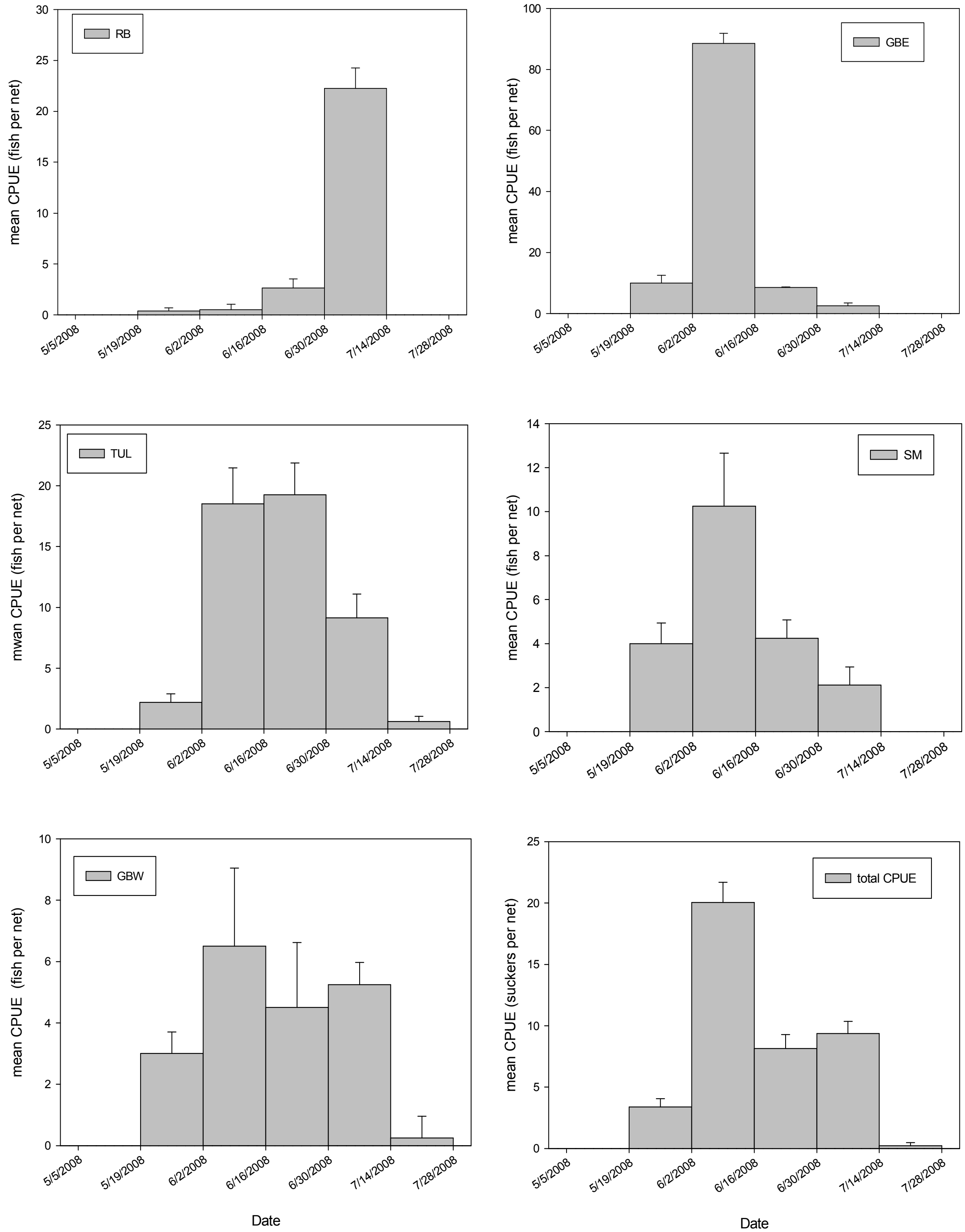

Figure 6. Bi-weekly mean (± SE) catch per unit effort (CPUE; suckers per net) in Riverbend (RB), Tulana (TUL), Goose Bay West (GBW), Goose Bay East (GBE), and South Marsh (SM), Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

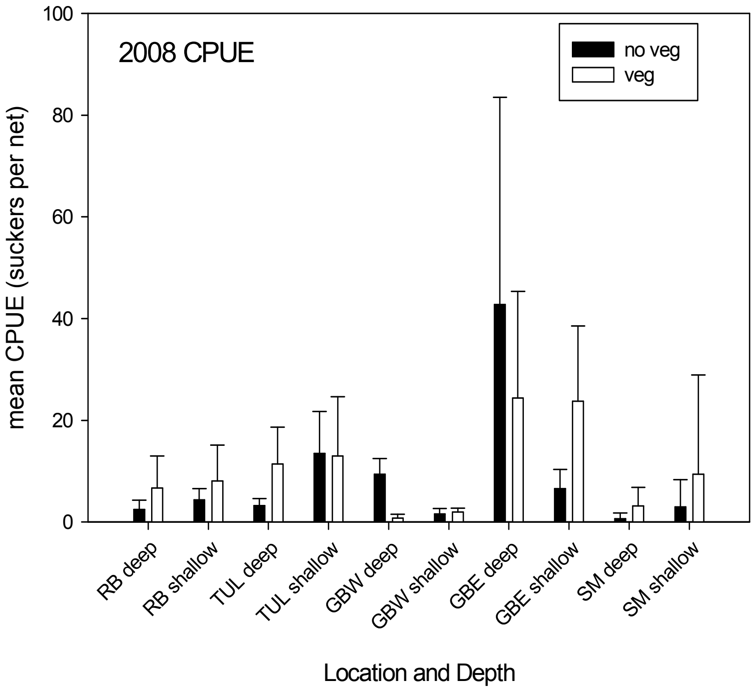

Figure 7. Bi-weekly mean (± SE) catch per unit effort (CPUE; suckers per net) of larval suckers in four different habitat types (deep-veg, deep- no veg, shallow-veg, shallow-no veg) at Riverbend (RB), Tulana (TUL), Goose Bay West (GBW), Goose Bay East (GBE), and South Marsh (SM), Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

of 14.7 mm. Shortnose/Klamath largescale sucker larvae were on average 0.6 mm larger than Lost River sucker larvae ($mean_{SNS/KLS}$ = 13.3 mm ± 0.04 SE; $mean_{LRS}$ = 12.7 mm ± 0.08 SE). Larval sucker lengths were greatest in South Marsh (mean SL = 15.5 mm), followed by Tulana (mean SL = 14.9 mm), GBE (mean SL = 14.6 mm), GBW (mean SL = 14.2 mm), and Riverbend (mean SL = 14.2 mm), differences that were significant (Kruskal-Wallis test, $\alpha = 0.05$, $P < 0.0001$). Significant differences in SL existed between suckers captured in shallow sites (mean SL = 15.1 mm) and suckers captured at deep sites (mean SL = 14.3 mm) (Kruskal-Wallis test, $\alpha = 0.05$, $P < 0.0001$). Suckers captured in non vegetated sites (mean SL = 15.1 mm) were on average 0.7 mm larger than suckers captured at sites containing vegetation (mean SL = 14.4 mm), a difference that was significant (Kruskal-Wallis test, $\alpha = 0.05$, $P < 0.0001$). When the five sampling sites (Riverbend, Tulana, GBW, GBE, South Marsh) and the four habitat types (deep-veg, deep-no veg, shallow-veg, shallow-no veg) were combined for analysis, significant differences in larval sucker SL existed (Kruskal-Wallis test, $\alpha = 0.05$, $P < 0.0001$). The length frequency distribution of larval suckers caught in the five sampling locations shows the higher frequency of larger fish in South Marsh and Tulana (Figure 8).

The gut fullness of larval suckers was significantly greater in restored wetlands (mean = 53.0%) than in wetlands along the Goose Bay shoreline (mean = 32.1%; Kruskal-Wallis test, $\alpha = 0.05$, $P < 0.0001$). Larvae captured in shallow, vegetated sites had fuller guts (mean = 49.0%) than larvae captured in shallow, open sites (mean = 46.2%), deep, vegetated sites (mean = 41.7%), and deep, open sites (mean = 41.0%). These differences were significant (Kruskal-Wallis, $\alpha = 0.05$, $P = 0.0011$). Because larger larvae tend to have fuller guts we analyzed gut fullness in two size groups—suckers 11-13 mm SL and suckers 14-22 mm SL. Gut fullness was much lower in the 11-13 mm size class (mean = 34.9%) than the 12–22 mm size class (mean = 50.8%). Fish captured in Riverbend had significantly fuller guts for both size classes of larval suckers, followed by fish captured in Tulana, South Marsh, GBE, and GBW (Figure 9; Kruskal-Wallis, $\alpha = 0.05$, $P < 0.0001$).

Smaller fish captured in restored areas also had fuller guts than similar size fish in GBE and GBW, and these differences were significant (Kruskal-Wallis, $\alpha = 0.05$, $P < 0.0001$).

Table 2. Catch per unit effort (CPUE; suckers per net) in "pop" nets in a variety of different habitat types during bi-weekly sampling, Williamson River Delta Preserve, Upper Klamath Lake, OR, 2008.

Depth	CPUE (suckers per net)	Standard Error
Shallow (mean depth = 0.28 m)	8.4	±2.3
Deep (mean depth = .70 m)	8.2	±2.9
Cover		
Vegetation (n = 75 nets)	9.6	±2.7
No vegetation (n = 75 nets)	7.0	±2.5
Habitat Type (Depth and Cover Combined)*		
Shallow-Veg	10.7	±3.7
Shallow-No Veg	6.3	±3.5
Deep-Veg	8.5	±3.6
Deep-No Veg	7.8	±3.8

* indicates no significant differences found (Kruskal-Wallis test, α = 0.05, P = 0.9895).

Shortnose/Klamath largescale sucker larvae in the 11-13 mm size class had significantly fuller guts (mean = 35.1%) than Lost River sucker larvae in the same size class (mean = 26.3%; Kruskal-Wallis, α = 0.05, P = 0.0107).

Several other species of fish were caught during bi-weekly "pop" netting, including tui chub *Gila bicolor*, blue chub *G. coerulea*, fathead minnow *Pimephales promelas*, yellow perch *Perca flavescens*, marbled sculpin *Cottus klamathensis,* slender sculpin *C. tenuis,* Klamath Lake sculpin *C. princeps*, and brown bullhead *Ameiurus nebulosus*. A total of 638 blue chub (CPUE = 4.3), 565 tui chub (CPUE = 3.8), 196 fathead minnow (CPUE = 1.3), 27 yellow perch (CPUE = 0.2), 17 brown bullhead (CPUE = 0.1), and 10 sculpin spp. (CPUE = 0.07) were captured in pop nets in 2008. The cumulative non-sucker CPUE in 2008 was 8.1 fish per net. Species composition at each sampling location is shown in Figure 10.

Catch per unit effort of non-sucker species was greater in GBE and GBW than in restored wetlands (Figure 11). The greatest CPUE of non-suckers was in GBE (27.1 fish per net). Of the three restored wetlands, Tulana had the greatest CPUE of non-sucker species, 11.1 fish per net, compared to 6.2 in South Marsh and 2.7 in Riverbend. Along the Goose Bay shoreline non-suckers were captured more frequently in deep water while in restored wetlands, non-suckers were found more often in shallow areas. These differences were significant in existing wetlands (Wilcoxon test, α = 0.05, P = 0.0035) but not in restored wetlands (Wilcoxon test, α = 0.05, P = 0.1872). Overall, catches of non-suckers in vegetation ($CPUE_{veg}$ = 9.4) was greater than catches of non-suckers in areas devoid of vegetation ($CPUE_{no\text{-}veg}$ = 6.8).

We sampled for larval suckers in numerous native wetland plant species for the "vegetated" habitat type, including *Schoenoplectus ssp.*, *Eleocharis spp.*, *Typha latifolia*, *Polygonum spp.*, *Potamogeton spp.*, *Salix spp.*, and a variety of dead, submerged vegetation remaining from when the land was in agriculture production. The two most dominant vegetation types sampled were *Schoenoplectus spp.* (27% of nets set in vegetation) and *Eleocharis spp.* (42% of nets set in vegetation). In Riverbend, Tulana, and GBE larval sucker CPUE was highest in vegetated habitat types

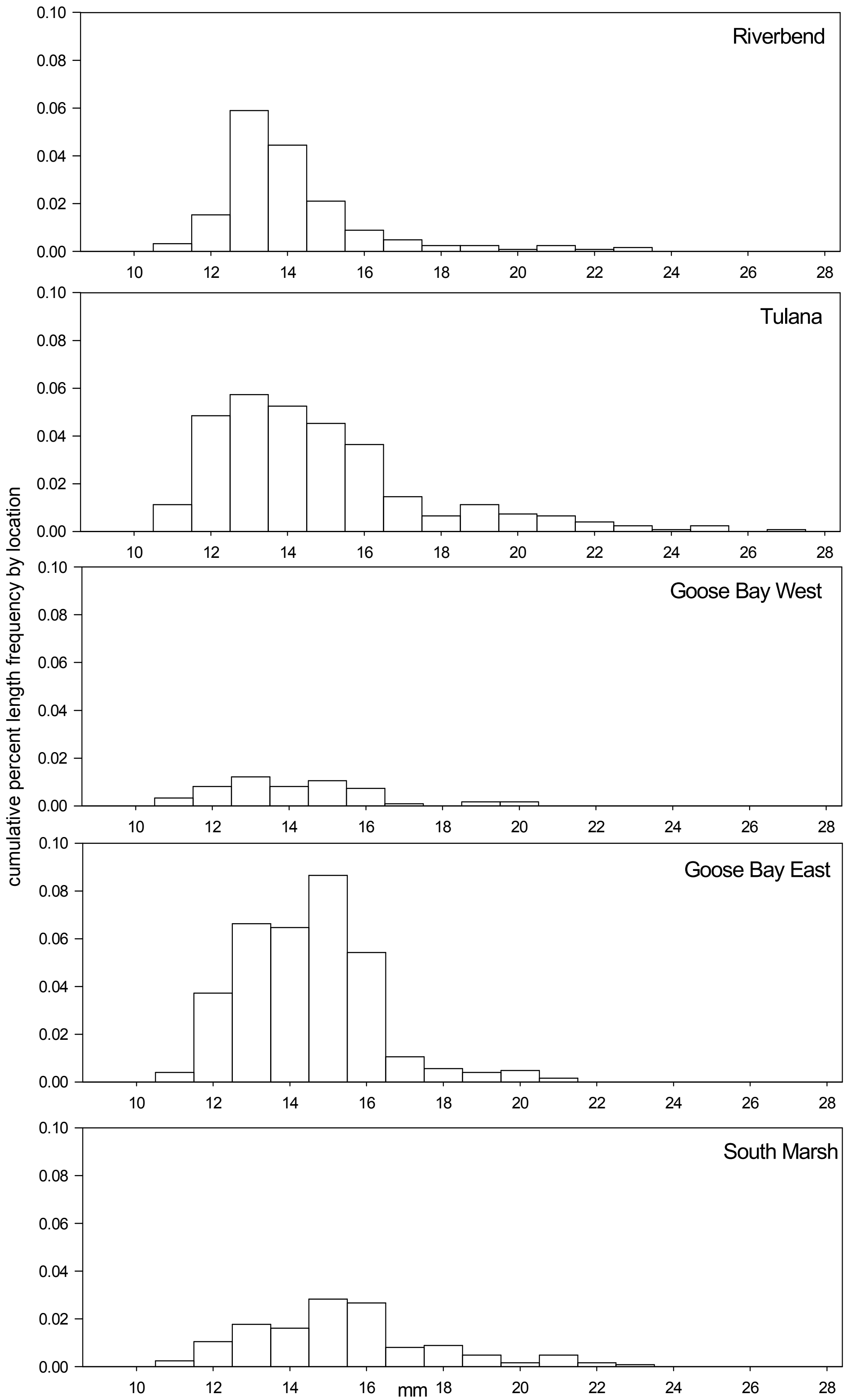

Figure 8. Cumulative percent length frequency distribution of larval suckers captured in pop nets at five locations in Upper Klamath Lake, OR, 2008 during bi-weekly sampling.

when *Scirpus spp.* was the dominant vegetation sampled (Figure 12).

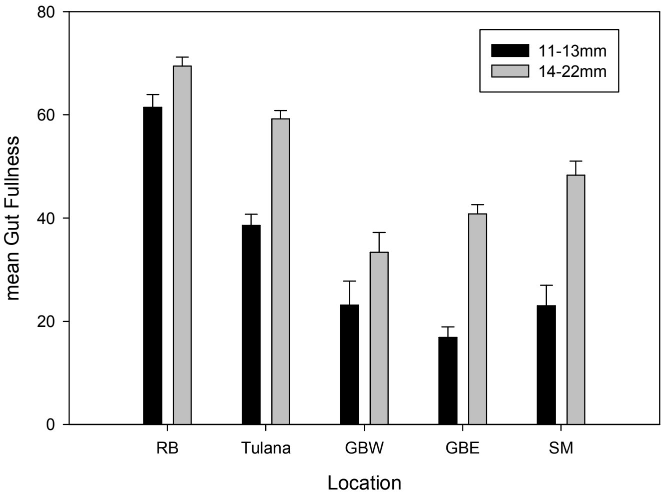

Figure 9. Mean gut fullness of two size classes of suckers (11-13 mm and 14-22 mm standard length) captured in pop nets at five sites in Upper Klamath Lake, OR, 2008 during bi-weekly sampling. Gut fullness was assigned to one of the following categories: 0, 25, 50, 75, or 100% full. RB = Riverbend, GBW = Goose Bay West, GBE = Goose Bay East, and SM = South Marsh.

Larval Sucker Response to a Recently Flooded Wetland

We combined data collected from the Tulana portion of the Delta during all sampling weeks in order to assess the response of larval suckers to large scale wetland restoration and gain a greater understanding of larval sucker habitat preference and distribution in Tulana. A total of 93 nets were set—22 in deep-veg, 22 in deep-no veg, 23 in shallow-veg, and 26 in shallow-no veg. A total of 633 larval suckers were caught in Tulana, comprised of 63 Lost River sucker, 239 shortnose/Klamath largescale sucker, and 331 unknown suckers. Lost River suckers represented 20.9% of identified fish while 79.1% of identified fish were shortnose/Klamath largescale suckers. Cumulative CPUE in Tulana was 6.8 larval suckers per net. Catch per unit effort in shallow habitats (CPUE = 8.6) was greater than in deep habitats (CPUE = 4.8). In vegetated habitats, CPUE was 7.4 while in non-vegetated habitat only 6.3 suckers per net were caught. With the two variables combined, CPUE in Tulana in shallow-veg habitat was 8.7, 8.5 in shallow-no veg, 6.0 in deep-veg, and 3.7 in deep-no veg. Significant variation did not exist in larval sucker catches when taking depth and vegetation into account in Tulana (Kruskal-Wallis test, $\alpha = 0.05$, $P = 0.3653$).

We saw significant differences in sucker catch rates and fish condition spatially across Tulana. A total of 527 larval suckers were captured in areas adjacent to the river, while only 102 fish were caught in the area south of the cul-de-sac road (SCDS) and 4 were caught north of the cul-de-sac road (NCDS). Statistically significant

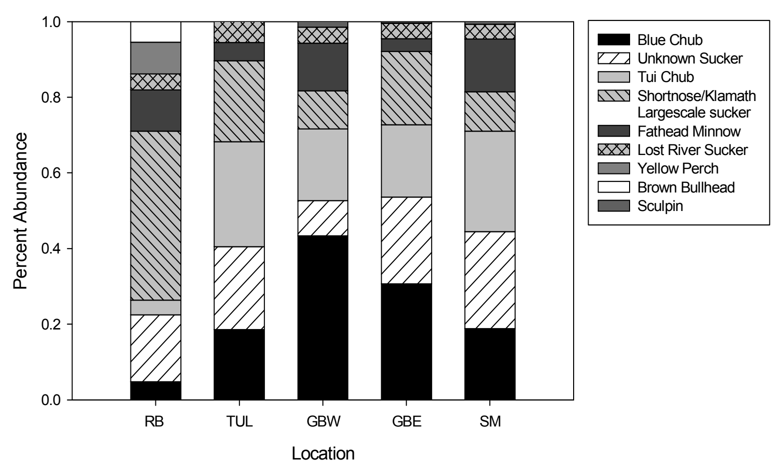

Figure 10. Proportional species composition of pop net catches during bi-weekly sampling at five sampling locations in Upper Klamath Lake, OR, 2008. RB = Riverbend, GBW = Goose Bay West, GBE = Goose Bay East, and SM = South Marsh.

differences existed in mean CPUE at the three Tulana locations, with the highest CPUE at the river points (11.0 fish per net), followed by 3.5 suckers per net at SCDS points, and 0.25 fish per net at NCDS points (Kruskal-Wallis test, α = 0.05, *P* = 0.0004). Mean length of larval suckers captured at SCDS points (mean SL = 16.2 mm) was on average 0.4 mm larger than fish captured at NCDS points (mean SL = 15.8 mm) and 1.0 mm larger than suckers captured at river points (mean SL = 15.2 mm), differences that were statistically significant (Kruskal-Wallis, α = 0.05, *P* <0.0001). Mean gut fullness was greater in fish captured at NCDS points (mean = 58.3% full) compared to fish captured at SCDS (mean = 50.3% full) and river points (mean = 51.6% full). Although larvae caught in NCDS had fuller guts, the differences were not statistically significant (Kruskal-Wallis test, α = 0.05, *P* = 0.8062).

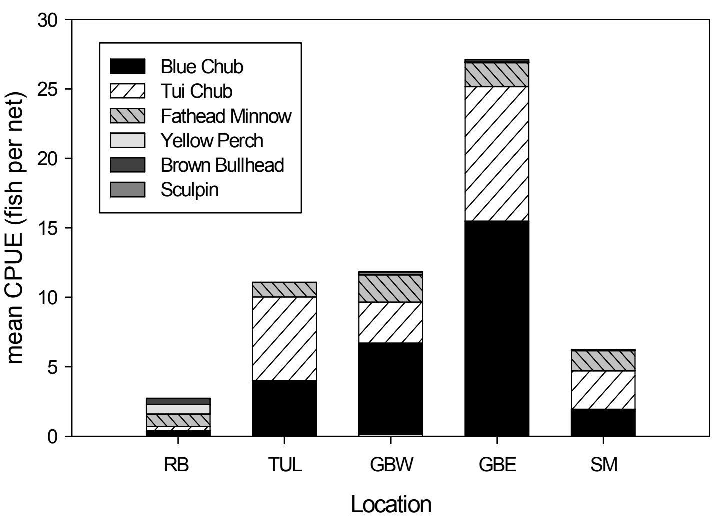

Figure 11. Mean catch per unit effort (CPUE; number of fish per net) of non-sucker species caught in pop nets during bi-weekly sampling at five sampling locations in Upper Klamath Lake, OR, 2008. RB = Riverbend, TUL = Tulana, GBW = Goose Bay West, GBE = Goose Bay East, and SM = South Marsh.

Similar spatial distribution of non-sucker species existed throughout Tulana, with the majority of fish captured at river sites and SCDS sites. Non-sucker combined CPUE in Tulana was 17.2 fish per net. Non-sucker CPUE was highest at SCDS sites (CPUE = 32.9 fish per net), followed by river sites (CPUE = 11.4 fish per net), and NCDS sites (CPUE = 6.0 fish per net). Catch rates were slightly higher in areas with vegetation (CPUE = 17.2) than in areas without (15.0), and significantly higher in shallow water habitat (CPUE = 26.5) than in deep water habitat (CPUE = 6.8). Non-sucker catches in Tulana were dominated by tui chub (n = 937; CPUE = 10.1) and blue chub (n = 578; CPUE = 6.2).

Fixed Points in Tulana

Two different sites within Tulana (point A and point B) were visited weekly (for 7 weeks) in order to gain data to validate a flow model for the Delta (Tammy Wood, US Geological Survey, personal communications; Wood and Cheng 2006). All nets set at these two sites were placed within the same 100 m x 100 m area each week to ensure that all habitat types were sampled. Twenty three nets were set at point A, and 22 nets were set at Point B.

Catches of larval suckers at the two points were statistically different: mean CPUE at point A was 19.0 suckers per net while mean CPUE at point B was 3.8 suckers per net (Kruskal-Wallis test, α = 0.05, *P* = 0.0057). During the first four weeks in which both points were sampled, 9 June through 30 June, CPUE was higher at point A (CPUE = 36.0, 17.3, 36.8, and 19.7 suckers per net during weeks 1-4, respectively) than at

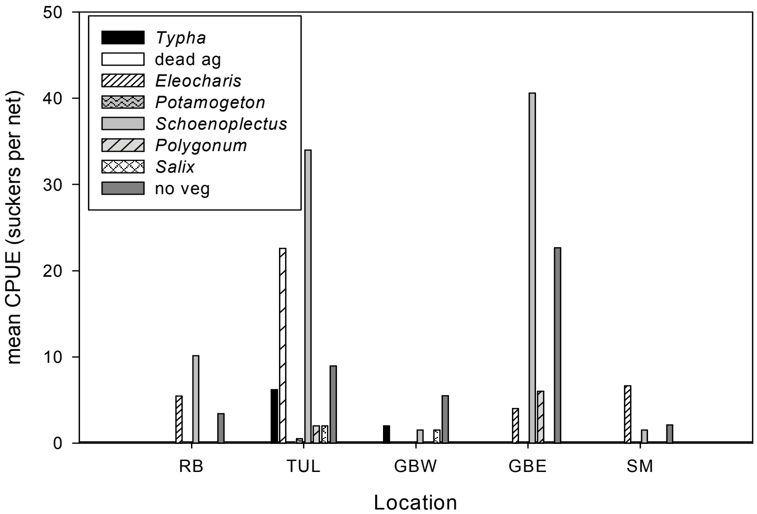

Figure 12. Mean larval sucker catch per unit effort (CPUE; suckers per net) at five pop net sampling locations in a variety of different wetland vegetation plant species, Upper Klamath Lake, OR, 2008. RB = Riverbend, TUL = Tulana, GBW = Goose Bay West, GBE = Goose Bay East, and SM = South Marsh.

point B (CPUE = 1.0, 0.0, 1.8, 6). However, the opposite occurred during the week of 7 July when higher catch rates were experienced at point B (17.0) than at point A (3.3). Catch per unit effort at both points during the final week of sampling were equally low (1.0 at point A and 0.25 at point B) (Figure 13).

Habitat preferences were also different at point A and B. At point A, CPUE was higher in vegetated habitats in both shallow and deep water. Catch per unit effort was 17.3 in deep-veg nets while only 5.7 in deep-no veg nets; CPUE in shallow-veg nets was 29.8 while only 23.8 in shallow-no veg nets. At point B, CPUE was higher in areas without vegetation in both shallow and deep water sites. In the deep-veg habitat type, CPUE was 1.4 while in deep-no veg CPUE was 2.0; CPUE in the shallow-veg habitat type was 1.3 while in shallow-no veg areas, CPUE was 9.8.

Water Quality

Instantaneous water temperature data collected in 2008 during larval sucker sampling indicated shallow water sites were on average 1.15°C warmer than deeper water sites. Average instantaneous water temperature was highest in Tulana (mean = 20.85°C), followed by GBW (mean = 20.60°C), South Marsh (mean = 20.49°C), GBE (mean = 20.29°C), and Riverbend (mean = 18.44°C). Sites without vegetation were on average 0.62°C warmer than sites with vegetation throughout the sampling period.

Dissolved oxygen concentrations (DO) were on average 0.32 mg/L higher in sites without vegetation than in sites with vegetation and 0.71 mg/L higher in deep water than in shallow water. Mean DO concentrations throughout the sampling period were lowest in Tulana (mean = 6.18 mg/L), followed by South Marsh (mean = 6.80 mg/L), GBE (mean = 8.50 mg/L), Riverbend (mean = 8.75 mg/L), and GBW (mean = 8.91 mg/L). Dissolved oxygen concentrations at or below 4.0 mg/L were recorded in 18 nets; one in South Marsh on 9 June and 17 in Tulana, all of which were recorded after 5 June. A total of 120 larval

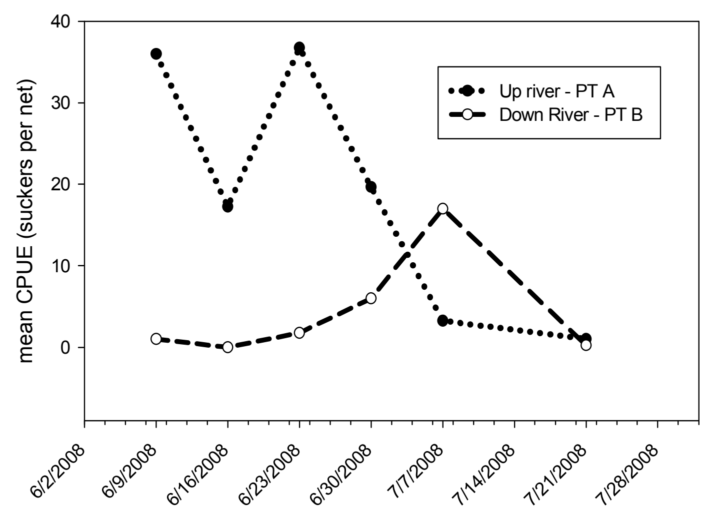

Figure 13. Weekly catch per unit effort (CPUE; suckers per net) at two sampling points (point A and B) in Tulana beginning 9 June 2008, Upper Klamath Lake, OR.

suckers (8.0% of all suckers caught) were present in 11 of the 17 nets, including 3 larvae captured in the net with the lowest DO reading (1.6 mg/L). Larval sucker threshold stress values for DO were defined as 6.0 mg/L low stress level and 4.0 mg/L high stress level (Loftus 2001). All 17 sites in Tulana measuring DO levels less than 4.0 mg/L were located in the interior of Tulana, at either NCDS (n = 3 sites) or SCDS sites (n = 14 sites). Dissolved oxygen concentrations were not measured beginning the week of 23 June due to equipment malfunction.

The highest seasonal mean pH levels were measured in GBE (mean pH = 8.37), followed by GBW (mean pH = 8.14), South Marsh (mean pH = 8.14), Tulana (mean pH = 7.82), and Riverbend (mean pH = 7.60). In one net set in South Marsh on 10 July we recorded a pH greater than 9.5. Twenty three nets had a pH of 9.0 or higher, the majority of which were located in SM (n = 11 nets).

Discussion

With the restoration of the north half of the Delta and the subsequent hydrologic reconnection of the former wetlands with the Williamson River, Upper Klamath Lake, and Agency Lake, an additional ~1,700 hectares became available for larval sucker rearing in Upper Klamath Lake. Annual monitoring of sucker response to this large scale restoration provides important information pertaining to the potential recovery of Lost River and shortnose suckers in Upper Klamath Lake.

Larval suckers were consistently captured in a variety of habitats in the restored wetlands of the Delta, suggesting that restored deltaic wetlands provide suitable habitat complexity for larval suckers. Because larval survival was found to be partially dependant on the volume of emergent vegetation in the lake (Cooperman and Markle 2004), an increase in deltaic wetlands could lead to enhanced larval survival. Increased survival of larval suckers could translate into greater recruitment into the adult spawning population; poor recruitment has been a possible limiting factor for sucker recovery in Upper Klamath Lake (National Research Council 2004). Results from 2008 monitoring, as well as results from previous sampling at the Delta in 2006 and 2007, indicate that larval suckers are using portions of the restored wetlands to feed and grow (Crandall et al. 2008; Hendrixson 2008).

Catch rates of larval suckers in pop nets during 2008 were similar to catches in 2007, but roughly half of those in 2006. The Goose Bay shoreline had the highest CPUE of larval suckers in 2008, a trend present during the 2006 and 2007 sampling seasons (Table 3).

This year, catches in GBE were more than six times higher than in GBW; this was reversed in 2007 when catches in GBW were greater than in GBE. One possible explanation for the high mean sucker catches in GBE is the high mean CPUE of larvae on 11 June 2008, which made up 84.1% of the total catch. If the catch from that day is removed, CPUE in GBE becomes 4.8 fish per net, compared to 23.4 fish per net when the catch is included. The high catch rate on that day seems like an outlier in the dataset, although it does coincide with the timing of the first peak in larval sucker catches in 2008. This could suggest that the data from GBE on 11 June should be included in analysis and should not be treated as an outlier.

Table 3. Yearly summary of catch per unit effort (CPUE; suckers per net) at different sampling locations, Williamson River Delta Preserve, Upper Klamath Lake, OR, 2006—2008.

Location	Year	2008	2007	2006
Riverbend		5.4	6.5	3.9
Tulana		6.8	n/a	n/a
Goose Bay West		3.7	18	n/a
Goose Bay East		23.4	7.4	n/a
Goose Bay (East & West)		13.5	13.3	34.2
South Marsh		4.1	3.9	9.9
Cumulative		7.2	9.0	20.4

When larval suckers exit the mouth of the Williamson River, the clockwise current in Upper Klamath Lake sweeps the fish along the Goose Bay shoreline, and large concentrations of larval suckers can accumulate in GBE (Markle et al. 2009).

Marginal differences in Lost River sucker and shortnose/Klamath largescale sucker habitat preferences were observed in 2008. While our results indicated that there was no preference towards deep or shallow water for Lost River suckers, shortnose/Klamath largescale suckers were captured more frequently at shallow sites. Larval Lost River suckers in our study area showed no preference towards any particular habitat type, as indicated by catch rates, but catches of shortnose suckers were 1.4 times greater in vegetated habitats compared to non-vegetated habitats. Speculation exists that there are differences in habitat preferences among the larval and juvenile stages of both sucker species, with Lost River suckers possibly exhibiting more lacustrine (open water) early life histories and shortnose suckers preferring shallow, vegetated areas. Markle et al. (2009) showed that differences existed in the retention rates of shortnose suckers and Lost River suckers in restored wetlands, possibly a result of species specific habitat differences.

Although our results do not indicate a significant difference in habitat preference it is something that should be investigated in the future. Interestingly, while our catches were dominated by shortnose/Klamath largescale suckers (81.5%), which is consistent with our larval sucker data collected in 2006 and 2007, larval suckers collected in deeper, open water areas of Tulana during 2008 by other researchers were dominated by Lost River suckers (S. Burdick, US Geological Survey, personal communication). These differences could be caused by real differences in spatial distributions of suckers, by habitat characteristics such as depth or presence of vegetation, or because different gear types were used to collect fish (pop nets versus net tows).

In restored wetlands, larval suckers were caught more frequently in shallow water sites than in deep water sites. Suckers rearing in Tulana show a strong association with shallow, vegetated habitats over all others, whereas the fish that make it to the lake show no habitat preference. It could be that there is less of their preferred habitat available, as there is much less shallow, vegetated habitat along the Goose Bay shoreline. This is consistent with results from other studies focused on habitat use by larval suckers (Crandall et al. 2008;

Hendrixson 2008). This could also be a result of the clockwise, wind-driven current in the lake as the Goose Bay shoreline could be serving as a travel corridor rather then a rearing area for larval suckers. These results mimic trends witnessed in 2006 and 2007.

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 could be directly related to the amount of emergent macrophytes in Upper Klamath 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 vegetation in shallow water has been shown to increase larval survival by providing a refuge from predators, especially during the larval stage when swimming ability is poor (Markle and Dunsmoor 2007). Larval suckers captured in non-vegetated sites were significantly larger than larvae captured in vegetated sites, suggesting a possible advantage to smaller larvae of residing in the vegetation to escape predation.

When the entire data set is analyzed, results show that larval suckers captured in restored wetlands were larger and had fuller guts than fish caught in the existing lakeshore fringe wetlands along Goose Bay. These two findings are consistent with our larval sucker monitoring results from 2006 and 2007 and suggest that larval suckers are extensively using these restored wetlands within the Delta for rearing. This data is also corroborated by the fact that the restored wetlands at the Delta allow for greater retention of larval suckers from the clockwise gyre and ultimate emigration from Upper Klamath Lake (Markle et al. 2009), thus allowing for increased rearing opportunities. Also, emergent macrophytes have been shown to be an important component for freshwater macroinvertebrate abundance (Parsons and Matthews 1995; Hargeby 1990) and larval suckers feed primarily on surface macroinvertebrates, mainly adult *Chironomidae* (Markle and Clauson 2006). 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.

Catches of larval, non-sucker species were about twice as large along the Goose Bay shoreline as in restored wetlands. In 2006 and 2007, catches of non-sucker species were also higher in lakeshore fringe wetlands compared to restored wetlands. Differences in habitat use patterns of non-suckers were witnessed in 2008. In GBE and GBW, catches of non-suckers were higher in deep water than at shallow depths; in contrast, CPUE in restored wetlands was much higher at shallow depths than in deep water. Non-sucker species were captured in both restored and existing wetlands more frequently in vegetation than in open water. These habitat use patterns are similar to habitat use patterns of larval suckers. This suggests that some overlap in shallow emergent habitat utilization exists between larval suckers and non-sucker species. The predator-prey relationship between introduced fathead minnows and larval suckers is potentially the most significant larval sucker/non-sucker relationship in Upper Klamath Lake (Simon and Markle 1997; Markle and Dunsmoor 2007). Markle and Dunsmoor (2007) report that avoidance of sucker predation by fathead minnow during laboratory studies is roughly 75% better in shallow water when vegetation is present. Wetland restoration at the Delta should increase the area of shallow, emergent macrophytes, thus leading to enhanced larval sucker survival by providing cover for larval suckers to avoid predation.

Although our results indicate that larval suckers show some preference for several species of emergent macrophytes, other studies have shown that differences do not exist (Cooperman and Markle 2004). Ideally, these wetland vegetation species will colonize the shallow areas of Tulana naturally and planting will not be necessary. In Riverbend and South Marsh, the natural establishment of emergent macrophyte vegetation took up to five years post restoration. However, planting certain species of emergent macrophytes (*Schoenoplectus spp.* and *Eleocharis spp.*) in areas where larval suckers have been shown to occur in high numbers (SCDC and river areas of Tulana) might be an effective future restoration action at the Delta to stimulate native emergent macrophyte colonization. More data regarding the relationship between emergent macrophyte species and larval sucker presence is needed.

Tulana

Although overall sucker catch rates in Tulana were significantly lower than catches of larval suckers along the Goose Bay shoreline, it is important to note that a significant portion of the sampling in Tulana was exploratory, with the main objective to sample a wide variety of locations throughout this ~1,700 hectare portion of the WRDP rather than focus on specific areas that we would expect to contain higher densities of larval suckers. Also, catches in Tulana are of the same magnitude as the other restored wetlands. The exception is in the two stationary points that we sampled every week (higher catch rates compared to the rest of Tulana). Therefore, it is no surprise that catches of larval suckers were greater during our bi-weekly sampling than cumulative Tulana catches.

Catches of larval suckers in Tulana were, however, slightly greater than catches at the two other restored wetland sites. This suggests that the large-scale Tulana restoration is providing suitable rearing habitat for larval suckers, since these other areas have been shown to provide suitable habitat for larval suckers (Crandall et al. 2008; Hendrixson 2008).

Capture rates of larval suckers in Tulana were significantly higher closer to the river than at sites further from the river. This is logical since suckers exhibit upstream spawning and downstream transport of larvae, indicating that points close to the river act as 'upstream' areas and the interior wetland points can be considered 'downstream' points. Catches were lowest north of the cul-de-sac road, suggesting that larval sucker navigation around the cul-de-sac road was infrequent. With significant emergent macrophyte vegetation in the region south of the cul-de-sac road, and no barriers to migration from the Williamson River, it is not surprising that more suckers were captured there than north of the road. Also, larvae captured there were significantly larger than fish captured close to the river and north of the road, suggesting that the emergent habitat in the interior of Tulana is sufficient for larval sucker rearing. As more areas of emergent wetland habitat become available along larval sucker outmigratory routes, feeding and growing opportunities for larvae also increase which is critical for larval sucker survival. (Klamath Tribes Natural Resources Department 1996).

Fixed points in Tulana

Two stationary sampling points near the Williamson River in the Delta were sampled weekly to help validate a hydrologic flow model of the Williamson River Delta (Wood and Cheng 2006). Because larval suckers mainly drift with river and lake currents (Cooperman and Markle 2003; Markle et al. 2009), understanding flow patterns throughout the Delta is essential to understanding larval sucker distribution throughout the Delta.

Catches of larval suckers were higher during the first four weeks of sampling at the point furthest upstream (point A); after that, catches were higher at the site further downstream. One hypothesis for this change in catch rates at points A and B is that early in the sampling season, when the Williamson River flow is greater and the elevation of Upper Klamath Lake is higher, much of the flow entering the Delta occurs at the first river breach, close to point A. Therefore, the larvae might enter this area more frequently than the breach adjacent to point B, which is further down river. Development of the hydrodynamic model will verify this. It is possible that larval suckers entered at the first breach in Tulana because it is the initial opening into newly restored emergent habitat. Additionally, the sampling area at point B was almost completely devoid of vegetation, a factor that could have led to lower catches at point B as larval suckers have an early association with emergent vegetation (Cooperman and Markle 2004). A decrease in lake elevation and growth of emergent vegetation at point B could have resulted in the increased catches later in the sampling period.

Summary

The results from 2008 larval sucker monitoring at the restored Williamson River Delta indicate that larval suckers are rearing in the restored wetlands of Riverbend, Tulana, and South Marsh. Larval suckers in restored wetlands were more frequently caught in shallow, vegetated areas, which is consistent with data from 2006 and 2007. Over ~1,700 hectares of shallow, emergent wetland habitat are now available in Tulana. 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).

The Nature Conservancy finished levee removal in the southern half of the Delta, Goose Bay, on 18 November 2008, effectively completing the large scale restoration of the Delta. With the breaching of levees and the subsequent flooding of the southern portion of the Delta, sucker distribution and catch rates along the Goose Bay shoreline in 2009 and beyond will likely be much different than what we have seen previously. We expect to find more larvae in the interior, newly flooded areas of Goose Bay instead of along the shoreline levees where sampling has occurred in the past. With a total of ~2,500 hectares of restored wetland habitat available in 2009 for larvae rearing, continued monitoring of larval sucker distribution and habitat use patterns throughout the Delta and various metrics of fish condition remains important.

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