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Distribution and Condition of Larval and Juvenile Lost River and Shortnose Suckers in the Williamson River Delta Restoration Project and Upper Klamath Lake, Oregon: 2010 Annual Data Summary

U.S. Department of the Interior
U.S. Geological Survey

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By Summer M. Burdick

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Conversion Factors

Multiply	By	To obtain
Length		
millimeter (mm)	0.03937	inch (in)
meter (m)	3.281	feet (ft)
kilometer (km)	0.6214	mile (mi)
micron (μm)	3.9×10^{-5}	inch (in.)
Area		
square kilometer (km^2)	247.15	acre
square meter (m^2)	10.76	square foot (ft^2)
Speed		
meters per second (m/s)	2.23	miles per hour (mph)
meters per second (m/s)	3.28	feet per second (fps)
Volume		
cubic meters (m^3)	35.314	cubic feet (ft^3)
liter (L)	0.2642	gallon (gal)
Concentration		
milligrams per liter (mg/L)	1.335×10^{-6}	ounce per gallon (oz/gal)
Frequency		
kilohertz (kHz)	1.66×10^{-5}	rounds per minute (rpm)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Datums

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations and Acronyms

Abbreviations	Meaning
CPUE	catch per unit effort
DO	dissolved oxygen
NL	notochord length
OSU	Oregon State University
PIT	passive integrated transponder
rkm	river kilometers
SD	standard deviation of the mean
SNS-KLS	shortnose or Klamath largescale sucker
TNC	The Nature Conservancy
Reclamation	Bureau of Reclamation
USGS	U.S. Geological Survey

Distribution and Condition of Larval and Juvenile Lost River and Shortnose Suckers in the Williamson River Delta Restoration Project and Upper Klamath Lake, Oregon: 2010 Annual Data Summary

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Executive Summary

Federally endangered Lost River sucker (*Deltistes luxatus)* and shortnose sucker (*Chasmistes brevirostris)* were once abundant throughout their range but populations have declined. They were extirpated from several lakes in the 1920s and may no longer reproduce in other lakes. Poor recruitment to the adult spawning populations is one of several reasons cited for the decline and lack of recovery of these species and may be the consequence of high mortality during juvenile life stages. High larval and juvenile sucker mortality may be exacerbated by an insufficient quantity of suitable or high-quality rearing habitat. In addition, larval suckers may be swept downstream from suitable rearing areas in Upper Klamath Lake into Keno Reservoir, where they are assumed lost to Upper Klamath Lake populations.

The Nature Conservancy flooded about 3,600 acres (1,456 hectares) to the north of the Williamson River mouth (Tulana) in October 2007, and about 1,400 acres (567 hectares) to the south and east of the Williamson River mouth (Goose Bay Farms) in October 2008, in order to retain larval suckers in Upper Klamath Lake, create nursery habitat, and improve water quality. The U.S. Geological Survey joined a long-term research and monitoring program in collaboration with The Nature Conservancy, the Bureau of Reclamation, and Oregon State University in 2008 to assess the effects of the Williamson River Delta restoration on the early life-history stages of Lost River and shortnose suckers. The primary objectives of the research were to describe habitat colonization and use by larval and juvenile suckers and non-sucker fishes and to evaluate the effects of the restored habitat on the health and condition of juvenile suckers. This report summarizes data collected in 2010 by the U.S. Geological Survey as a part of this monitoring effort and follows two annual reports on data collected in 2008 and 2009. Restoration modifications made to the Williamson River Delta appeared to provide additional suitable rearing habitat for endangered Lost River and shortnose suckers from 2008 to 2010 based on sucker catches. Mean larval sample density was greater for both species in the Williamson River Delta than adjacent lake habitats in all 3 years. In addition to larval suckers, at least three age classes of juvenile suckers were captured in the delta. The shallow Goose Bay Farms and Tulana Emergent were among the most used habitats by age-0 suckers in 2009. Both of these environments became inaccessible due to low water in 2010, however, and were not sampled after July 19, 2010. In contrast, age-1 sucker catches shifted from the shallow water (about 0.5–1.5 m deep) on the eastern side of the Williamson River Delta in May, to deeper water environments (greater than 2 m) by the end of June or early July in all 3 years.

Differential distribution among sucker species within the Williamson River Delta and between the delta and adjacent lakes indicated that shortnose suckers likely benefited more from the restored Williamson River Delta than Lost River or Klamath largescale suckers (*Catostomus snyderi*). Catch rates in shallow-water habitats within the delta were higher for shortnose and Klamath largescale sucker larvae than for larval Lost River suckers in 2008, 2009, and 2010. Shortnose suckers also comprised the greatest portion of age-0 suckers captured in the Williamson River Delta in all 3 years of the study. The relative abundance of age-1 shortnose suckers was high in our catches compared to age-1 Lost River suckers in 2009 and 2010.

The restored delta also created habitat for several piscivorous fishes, but only two appeared to pose a meaningful threat of predation to suckers—fathead minnows (*Pimephales promelas)* and yellow perch (*Perca flavescens)*. Fathead minnows that prey on larval but not juvenile suckers dominated catches in all sampling areas. Yellow perch also were abundant throughout the study area, but based on their gape size and co-occurrence with suckers, most were only capable of preying on larvae.

Low May lake-surface elevation, below average snow pack, and anticipated irrigation demands indicated late summer water levels in Upper Klamath Lake would be unusually low in 2010. In response to concerns by the Fish and Wildlife Service and The Nature Conservancy that low-water conditions might strand fish on the delta, low water seine surveys were implemented. Eleven fishes, including both endangered suckers, were captured in seine surveys, including both species of suckers, which continued to use shallow water less than 0.4 m deep through September 21. Lake elevation declined to 1,261.54 m (4,138.9 feet) in mid-September 2010, but did not appear to strand fish or cause large-scale fish mortality.

Project Introduction and Background

Lost River sucker (*Deltistes luxatus,* LRS*)* and shortnose sucker (*Chasmistes brevirostris,* SNS*)* were listed as federally endangered in 1988 following apparent declines in adult abundance (National Research Council, 2004). Although once abundant throughout their range, suckers populations were extirpated from Lower Klamath Lake, Sheepy Lake, and Lake of the Woods. It also is suspected that populations in Tule Lake and Keno Reservoir no longer reproduce (National Research Council, 2004). The primary threat to their continued persistence is a lack of recruitment to the adult spawning populations.

The Williamson and Sprague Rivers provide one of two used spawning habitats for LRS and SNS residing in Upper Klamath Lake (National Research Council, 2004). Spawning for both species typically occurs between March and May (Ellsworth and others, 2009). Eggs are spread over gravel and cobble substrates (Andreasen, 1975). Between mid-April and late May, larvae spawned in the river systems emerge from gravel and drift downstream (Ellsworth and others, 2009). Larvae begin to reach the Williamson River Delta by late April (Crandall and others, 2008). By June, most young-of-the-year suckers have developed into juveniles (Kelso and Rutherford, 1996; Ellsworth and others, 2009). Between June and September, age-0 juvenile suckers disperse throughout Upper Klamath Lake and its littoral marshes (Burdick and others, 2009a). Population demography, distribution, and habitat use during the transition from juvenile to adult life states is poorly understood (Burdick and others, 2009a).

Wind driven water currents in Upper Klamath Lake typically flow in a clockwise direction and may push larvae originating from the Williamson and Sprague Rivers south along the eastern shore to the lake outlet and into Keno Reservoir (fig. 1). It is suspected that larvae entering Keno Reservoir are lost to the population due to poor survival and an inability to return to natal spawning locations (Markle and others, 2009). Markle and others (2009) estimate that prior to the restoration of the Williamson River Delta it took an average of 5 days for LRS suckers and 10 days for SNS to be transported from the

mouth of the Williamson River out of Upper Klamath Lake. The difference in transport time appears to be a function of when and where in relation to the major lake currents larvae drift (Markle and others, 2009). One hypothesized method for slowing the transport of larvae from the lake is to create well-vegetated marshes that allow fish to escape the main current (Markle and others, 2009).

Poor survivorship between juvenile and adult life stages is one of several reasons cited for the decline and lack of recovery of LRS and SNS (National Research Council, 2004). Sharp declines in age-0 catch rates during August and early September and extremely low catches of age-1 suckers indicate juvenile survival is the primary factor limiting recruitment into adult spawning populations (Simon and Markle, 2002; Hendrixson and others, 2007; Burdick and Brown, 2010). Poor juvenile survival may result from increased predation due to inadequate shelter from predators, any number of physiological stressors, or some heretofore unrecognized age-class specific factor, all of which may be exacerbated by a lack of high-quality rearing habitat.

Historically, larval and juvenile suckers had access to habitat in vast wetlands along the northern shores of Upper Klamath Lake and in the Williamson River Delta, which may have functioned as nurseries. Extensive diking and draining of wetlands for agriculture between 1915 and 1995 eliminated an estimated 66 percent of wetlands adjacent to Upper Klamath (Larson and Brush, 2011). Recent research indicates that age-0 juveniles use various habitats throughout Upper Klamath Lake, including stands of emergent vegetation in and around the Williamson River Delta (Burdick and others, 2009b). Age-1 suckers are concentrated near patches of vegetation in tributary mouths and springs during April and May (Markle and Simon, 1993; Burdick and Brown, 2010) and found throughout Upper Klamath Lake in June and July (Bottcher and Burdick, 2010).

The Williamson River Delta likely was an important wetland for larval and juvenile suckers, due to its location downstream of known productive spawning grounds in the Williamson and Sprague rivers (fig. 1) (National Research Council, 2004). Established wetlands composed of emergent macrophytes, similar to what probably historically existed in the Williamson River Delta, support more, larger, and better-fed larvae than wetlands composed of submergent macrophytes, woody vegetation, or open water (Cooperman and Markle, 2004). More recently, larval suckers were documented in Riverbend and South Marsh, two pilot restoration wetlands at the Williamson River Delta and in Tulana, the northwestern part of the delta (fig. 2) (Crandall and others, 2008; Hendrixson, 2008). Historically, juvenile suckers may have reared for several months to several years in the emergent or submerged vegetation and deep water wetlands along marsh edges or in the marsh interior (National Research Council, 2004). Without the availability of the delta, larval suckers originating in the Williamson and Sprague rivers could out-migrate into Upper Klamath Lake as rapidly as 1 day. Sucker out-migration into Upper Klamath Lake often occurred prior to caudal fin development. This reduces swimming performance and potentially foraging success of larval suckers (Cooperman and Markle, 2000, 2003).

To "restore and maintain the diversity of habitats that are essential to the endangered [LRS and SNS] (David Evans and Associates, Inc., 2005), The Nature Conservancy began restoring the Williamson River Delta Preserve (here after 'the Preserve') in 1999. Restoration activities include breaching levees along Agency Lake and Upper Klamath Lake shorelines, filling toe drains, excavating and reconnecting a historical oxbow, creating an additional channel at the Williamson River mouth, creating a riparian bench along the Williamson River, and managing vegetation (David Evans and Associates, Inc., 2005). Hydrologic connectivity was achieved for approximately 2,500 ha to the northwest of the Williamson River (Tulana) in October 2007 and an additional 1,000 ha to the southeast of the river in November 2008 (Goose Bay Farms) (Erdman and Hendrixson, 2011).

Prior to restoration, larval sucker monitoring occurred in the Williamson and Sprague Rivers (Ellsworth and others, 2009) in Upper Klamath Lake (Simon and others, 2009), and in Riverbend and South Marsh restoration sites (Crandall and others, 2008). In addition, juvenile sucker monitoring occurred throughout Upper Klamath Lake (Burdick and others, 2009a) and along the shore of Agency Lake (Simon and others, 2009). The U.S. Geological Survey began work under contract with the Bureau of Reclamation (Interagency Agreement 07AA200135) to assess the success of the delta restoration in providing high-quality habitat for larval and juvenile fish, with special attention to the health and retention of young endangered suckers. At the same time TNC expanded their larval sampling program into the newly restored Tulana and Goose Bay Farms portions of the delta (Erdman and Hendrixson, 2010), and Oregon State University (OSU) adjusted their shoreline sampling to the new contours of the lake shore (Simon and others, 2009). U.S. Geological Survey larval sampling differed from TNC's in depth sampled and gear used, but our objectives with regard to understanding larval sucker use of restored habitat were similar. Collaboration among TNC, OSU, and USGS's Oregon Water Science Center and Western Fisheries Research Center also was formed in 2008 to evaluate the effects of hydraulics and larval sucker behavior on larval distribution and retention in the Preserve (T.M. Wood, U.S. Geological Survey, written commun., 2012).

The specific objectives of the USGS Western Fisheries Research Center were:
- **Objective 1:** Describe geographic and temporal use environments in the restored Williamson River Delta by larval and juvenile suckers.

  Objective 2: Compare the probability of habitat use by juvenile suckers among habitats in the Williamson River Delta restoration area and open water areas of Upper Klamath and Agency lakes.

- **Objective 3:** Compare fish species composition, with special attention to non-native and piscivorous fishes, in the Preserve, Upper Klamath, and Agency lakes.

- **Objective 4**: Describe the temporal and spatial colonization of juvenile suckers and other fish species in the Williamson River Delta.

- **Objective 5:** Compare the growth, condition, and health of juvenile suckers from the Williamson River Delta restoration area to those from Upper Klamath and Agency Lakes.

Under contract with the Bureau of Reclamation, the U.S. Geological Survey (USGS) committed to producing annual data summaries as well as a comprehensive report. This report that summarizes data collected in 2010 by the U.S. Geological Survey (USGS) follows two annual reports on data collected in 2008 and 2009. Annual data summaries, like this one, are peer-reviewed open-file reports intended to make data available to our partners and other resource management agencies.

Description of Study Area

The study area is located in south-central Oregon and includes the Williamson River Delta, a southern portion of Agency Lake, and a northern portion of Upper Klamath Lake. The Williamson River is the largest tributary of Upper Klamath Lake. It flows approximately 85 km from its headwaters in Klamath Marsh. The Williamson River Delta spans Agency and Upper Klamath lakes and is divided into two parts by the Williamson River—(1) Goose Bay Farms to the south and east and (2) Tulana to the west and north (fig. 2). The entire study area is hypereutrophic and experiences massive seasonal blooms of the cyanobacteria *Aphanizomenon flos-aquae*. These blooms are associated with dissolved

oxygen (DO) concentrations that fluctuate between supersaturation and anoxia and pH levels that frequently exceed 9.0 (Lindenberg and others, 2008; Wong and others, 2010). High pH and low DO concentrations occur every summer at levels potentially lethal to juvenile LRS and SNS in Upper Klamath Lake and in the Williamson River Delta. High un-ionized ammonia concentration also occasionally occur in Upper Klamath Lake (Wood and others, 2006).

There are six distinct habitats in the study area. Three are located in Tulana, one in Goose Bay Farms (Goose Bay Farms), one in southern Agency Lake (Agency Lake), and one in northern Upper Klamath Lake (Upper Klamath Lake) (figs. 1 and 2; table 1; David Evans and Associates, Inc., 2005). Tulana habitats include (1) the western portion of Tulana predicted to remain unvegetated (Tulana Open Water), (2) an area located in the center of Tulana predicted to establish submergent vegetation (Tulana Submergent), and (3) the eastern side of Tulana predicted to establish emergent vegetation (Tulana Emergent; fig. 2). Tulana Submergent in our report is referred to as deep water wetland by The Nature Conservancy. The Agency Lake habitat includes a narrow waterway connecting Agency and Upper Klamath lakes known as Agency Strait.

There is substantial variation in water depth and the abundance of aquatic vegetation and very little variation in substrate composition among habitats. Substrate in the Williamson River Delta consists primarily of mud and clay (Lather muck and Tulana silt loam; David Evans and Associates, Inc., 2005). but substrates composed of sand mixed with gravel and cobble exist along the breaches. Agency and Upper Klamath lakes are shallow (about 2–3 m) and mostly devoid of vegetation except along the shoreline. Agency Strait had a maximum depth of 7.4 m. Goose Bay Farms has a maximum depth of about 1.2 m but large portions of this area can be as shallow as 0.1 m at the end of September. This area is vegetated with patches of submergent of emergent vegetation (Elseroad and others, 2010). Tulana Open Water is the deepest and least vegetated of the areas in Tulana, with occasional stands of willows (*Salix* spp.). Intermediate depths were found in Tulana Submergent (about 1.50–2.75 m deep), which was vegetated with scattered patches of submergent vegetation. Tulana Emergent was the shallowest area sampled in Tulana (< 1 m) and vegetation in this area was nearly all emergent macrophytes interspersed between patches of open water. On the eastern edge of Tulana Emergent, some riparian vegetation also occurred (Elseroad and others, 2010).

Larval Fish Retention and Distribution

Preliminary monitoring indicates that the Williamson River Delta created rearing habitat for larval suckers. Larval suckers were found rearing in two pilot restoration wetlands at the Williamson River Delta (Crandall and others, 2008; Hendrixson, 2008). After Tulana was reconnected to adjacent lake environments in the autumns of 2007 and 2008, larger and better fed larvae were consistently captured within the delta than in previously existing wetland habitats or adjacent lake environments (Burdick and others, 2009b; Burdick and Brown, 2010; Erdman and others, 2011). Larval sucker densities also decreased along the Goose Bay shoreline after Goose Bay Farms was flooded in the autumn of 2008 and larvae began to occupy the newly available habitat (Erdman and Hendrixson, 2011). The majority of larvae captured in the Williamson Delta were identified as shortnose or Klamath largescale suckers (SNS-KLS) indicating that delta restoration efforts may provide a greater benefit to SNS-KLS compared to LRS (Burdick and Brown, 2010; Erdman and Hendrixson, 2011).

Preliminary hydrodynamic models predict that localized densities of passively drifting particles originating in the Williamson River are most affected by the initial density of particles in the river, wind direction and speed, lake-surface elevation, and river discharge, in that order (Wood and others, 2012). These models predict that prevailing wind patterns blowing from the north and west push more water into Goose Bay Farms, whereas wind blowing from the south and east push more water into Tulana.

Greater hydrologic communication between the river and the delta, caused by a combination of high lake-surface elevation and river discharge, is associated with longer and more convoluted travel paths and therefore retention for passive particles (T.M. Wood, U.S. Geological Survey, written commun., 2009). With the implementation of several assumptions about larval behavior updated, models predict larval sucker densities will decrease and ages increase as distance from the Williamson River increases (T.M. Wood, U.S. Geological Survey, written commun., 2012). Models also predict that although the restoration of the delta slowed transport of larvae out of Upper Klamath Lake, some larval suckers still passively emigrate down the Link River (Wood and others, 2011).

In cooperation with TNC, OSU, and USGS's Oregon Water Science Center, a sampling strategy was developed to describe the role of hydrodynamics on the spatial and temporal use of the restored Williamson River Delta by larval suckers. In this study, spatially explicit hydrodynamic models were developed to examine influence of hydraulics on larval transport and residence time in the restored habitat. Larval data collected by USGS in this study were used to validate models. Results of the larval transport study are reported in Wood and others (2011). Here, larval fish community within the Williamson River Delta is characterized and a third year of larval sucker data collection is summarized.

Methods

Site Selection and Descriptions

Sample locations were selected in 2010 based on spatially explicit hydrodynamic model predictions of larval sucker age and density (T.M. Wood, U.S. Geological Survey, written commun., 2007). Fixed sample sites were selected to provide the greatest contrast in mean larval sucker age and density. Thirteen fixed sites were sampled weekly from May 3 to July 13 (fig. 2). Of these sites, 9 were sampled in 2008 and 10 were sampled in 2009. Sites did not overlap with shallow water (<1 m deep) sites sampled by TNC.

Larval Sample Collection

Plankton nets were used to collect larvae from the top of the water column. These nets had 0.3-m diameter mouth, a 2.5-m long tail, 800-μm mesh Nitex® netting, and a removable cod end. A General Oceanics™ model 2030R flow meter was mounted in the mouth to estimate volume sampled. The plankton net was towed parallel to a boat at approximately 1 m/s for 3–5 minutes or until algae began to clog the mesh. After retrieval, all material was removed from nets and samples were immediately preserved in 70–95 percent ethanol. Water temperature, depth, and vegetation density were recorded. Three replicate tows were collected at each site between 0810 and 2034 hours to assess sampling efficiency and variability. The exception to this protocol was during the week of May 3, when only one sample was collected at three sites during diurnal visits. The direction but not the starting location of each tow was varied so that different reaches were sampled in each replicate. In the laboratory, fish were identified to species or lowest taxonomic unit practical using characters described by Simon (2004) and Remple and Markle (2005). Larval suckers were identified as LRS or SNS-KLS, due to a lack of unique diagnostic characters. Sculpin (*Cottus* spp.) were only identified to genus due to the lack of a suitable larval identification key for these species. The notochord lengths (NL) of all larval suckers and the first 10 randomly selected larvae of each non-sucker species and all larval fish were enumerated. Larval density for each species was calculated by dividing the total number of fish in each sample by the volume of water filtered.

Data Summary and Analysis

Larval catch data are summarized to describe spatial and temporal patterns in larval presence and sample density. Density was calculated as the number of larvae per cubic meter of water filtered. To accurately depict statistics, only samples collected on or after the first day that each taxa was first collected were included in the dataset. Because larval density data were not normally distributed, variances were frequently unequal between comparison groups, and median catch rates were frequently zero within comparison groups, catch rate data were summarized using graphical displays rather than computing test statistics.

Results

Larval Sucker Distribution and Sample Density

Between May 3 and July 13, 2010, 420 day-time samples were collected from 13 sites. Three replicate samples were collected during 139 sampling events and single samples were collected on 3 sampling events. A total of 990 LRS larvae and 215 SNS-KLS larvae were collected in day-time samples. A small portion (9.8 percent) of the sucker larvae was not identifiable beyond Catostomidae due to lack of distinguishing characteristics. LRS were captured at all 13 sites and SNS-KLS suckers were captured at 8 sites. The overall mean (± SD) density in diurnal samples collected between May 10 (first day sucker larvae were detected) and July 13 (last day of sampling) was 0.22 ± 0.75 larvae/m^2 for larval LRS as compared to 0.05 ± 0.20 larvae/ m^2 for SNS-KLS larvae.

There was a high degree of variability in sample densities between replicate tows for LRS and SNS-KLS larvae. The mean (± SD) difference between the highest and lowest sample densities among replicates when at least one larva was captured was 0.67 ± 1.16 larvae/m^3 for LRS and 0.44 ± 0.48 larvae/m^3 for SNS-KLS larvae. Larval density in our samples did not decrease with each sequential tow, indicating repeat tows did not bias our assessment of sampling efficiency.

Most LRS larvae were captured at the Williamson River site (47 percent) and Tulana Emergent site (25 percent). Smaller portions of LRS larvae were captured at the Goose Bay West (11 percent) and Goose Bay Oxbow (9 percent) sites. The other 8 percent of LRS larvae were captured throughout the remaining sites. Catches of LRS began to increase the week of May 24 at the Williamson River site. LRS catches peaked at this site the week of June 14, and decreased to zero the week of July 12 (fig. 3). LRS catch rates at the Tulana Emergent site began to increase the week of June 7 and remained relatively high but variable until the end of the sampling season. LRS catch rates at the Goose Bay West site were variable but occasionally high between the weeks of June 7 and July 5. LRS catch rates at the Goose Bay Oxbow site increased the week of May 24 and were variable but remained moderately high until the end of the sampling season.

Most of the SNS-KLS larvae were captured in the Williamson River (41 percent) or the Tulana Emergent (40 percent) site. A smaller portion was collected at the Goose Bay Oxbow site (11 percent). The remaining 8 percent of SNS-KLS larvae catches were spread evenly among Breach 3, Goose Bay East, Goose Bay West, Tulana Open Water, and Williamson Mouth sites. Catch rates of larval SNS-KLS began to increase the week of May 31 at the Williamson River site. Catches at this site peaked the week of June 14, and then decreased to near zero the week of July 5 (fig. 3). At the Tulana Emergent site, SNS-KLS larval catch rates began to increase the week of June 7 and were variable but generally high until the end of the sampling season. At the Goose Bay Oxbow site, SNS-KLS larval catch rates slowly increased between the week of June 7 and the end of our sampling season on July 13 (fig. 3).

Spatial and Temporal Patterns in the Larval Fish Community

A total of 1,601 non-sucker larval fish was captured in larval tow samples. Only 46 larval fish were not identifiable due to poor preservation or damage sustained during collection. Six non-sucker taxa common to Upper Klamath Lake were captured (table 2). Fathead minnow (*Pimephales promelas)*, tui chub (*Gila bicolor)*, and blue chub (*Gila coerulea)* were collected at all sample locations except the Williamson River site. Yellow perch (*Perca flavescens*) larvae were collected at all sites except the Williamson River, Williamson Mouth, and Breach 6. Sculpin were collected only at Breach 5, Goose Bay East, Goose Bay West, and Tulana Emergent sites. A single brown bullhead (*Ameiurus nebulosus*) larva was collected at the Tulana Emergent site on July 12. Fathead minnow, tui chub, and blue chub catch densities were slightly greater than yellow perch and sculpin catch densities (fig. 4).

LRS made up the majority of our larval catches at the Williamson River site throughout the sampling season and at the three Goose Bay sites and the mouth of the Williamson River from May 24 to June 16 (fig. 4). SNS-KLS appeared in our nets later and made up the majority of our catches at the Goose Bay Oxbow site in July. A combination of fathead minnows, tui chub, and blue chub were predominant at all sites from late June to mid-July, except the Williamson River, Goose Bay Oxbow, and Breach 3 sites. Catches at Breach 3 in early July also were composed of fathead minnows and tui chub, but instead of blue chub, yellow perch were captured (fig. 4).

Discussion

Larval catch data were summarized to describe spatial and temporal patterns in larval sucker and non-sucker timing, presence, and density. These data contributed to an evaluation of hydrodynamic effects on larval drift in the (Wood and others, 2011). High larval sucker sample densities in shallow habitats indicate larval suckers were retained in the shallow eastern and southern parts of the Williamson River Delta.

Spatial and Temporal Patterns in Larval Sucker Sample Densities among Years

Similar patterns in spatial and seasonal distribution of larval LRS catch rates were documented from 2008 to 2010. Densities of larval LRS were high at the Williamson River site in mid- to late May each year (Burdick and others, 2009b; Burdick and Brown, 2010). Relatively high densities of larval LRS also were captured at all three Goose Bay sites in mid- to late May in 2009 and 2010. LRS larvae were first detected at the Tulana Emergent site on May 18, 2009, compared to June 7, 2010. Catches of LRS larvae were extended later in the season at the Tulana Emergent site than at other sites. LRS catches tended to be extremely low at sites located along breaches 3 to 6 in all 3 years.

Patterns of spatial and seasonal distribution of SNS-KLS larvae varied somewhat among years. Catch rates for SNS-KLS at the Tulana Emergent site peaked sharply during the week of June 30, 2008, between May 18 and June 29, 2009, and between June 7 and July 12, 2010. Catch rates of SNS-KLS were relatively high at the Goose Bay Oxbow site during the week of June 15, 2009, but were not high until the weeks of July 5 and July 12, 2010. Catch rates of SNS-KLS were notable at the Goose Bay East and Goose Bay West sites in 2009 and 2010 but were substantially lower in 2010. SNS-KLS catch rates were similarly low at all four breach sites and the Tulana Open Water site in all 3 years.

Non-Sucker Larval Catch Distributions

Habitat present throughout the study area was suitable for spawning or rearing of non-target larvae. Fathead minnows spawn in shallow, warm water over sand or silt substrates (Lane and others, 1996)—habitat that is common throughout the study area. Tui chub eggs have been observed in dense vegetation at depths of 1–3 m (Bird, 1976) and interstitially in gravel substrate at shallow depths of 0.25–1.00 m (Cooper, 1982). Blue chub spawn in shoreline areas with gravel and cobble substrate, out of direct sunlight, in less than 1.00 m of water (Bird, 1976). Gravel and cobble substrates can be found along the eastern shore of Upper Klamath Lake and in the Williamson River, but are rare in the Preserve. Where gravel does occur in the delta, along breaches, it is mixed with sand and fine substrates and probably is not suitable for spawning. Yellow perch deposit their eggs, which are encased in a gelatinous substance, on woody debris or submerged macrophytes (Huff and others, 2004). The depth at which yellow perch eggs will successfully incubate depends on temperature (8–18 °C) and protection from ultraviolet radiation (Huff and others, 2004). High turbidity or diatom blooms throughout Tulana and the lakes could protect yellow perch eggs from radiation, allowing these fish to spawn in shallow water. Turbidity only occurs in Goose Bay Farms after high wind events, and probably does not provide cover for an adequate duration to allow successful yellow perch egg incubation.

Adults expressing gametes (S.M. Burdick, U.S. Geological Survey, unpub., data, 2009) and the presence of larvae indicated piscivorous fathead minnow and yellow perch used the habitat throughout the study area for spawning. Whereas, high abundances of fathead minnows, tui chub, and blue chub indicate the study area was used as rearing habitat for these species. Larvae from these species were not captured at the Williamson River site, which further strengthens the argument that they were spawning in the delta or lakes.

Juvenile Fish Retention and Distribution

The first 2 years of this study suggest that the relationship between juvenile sucker distribution and environmental variables was similar for Upper Klamath Lake and in the Preserve. A random stratified sampling approach and trap nets were used to compare juvenile fish habitat use and condition in the Preserve, northern Upper Klamath Lake, and southern Agency Lake. Sampling effort and data collection were designed to meet the assumptions of a robust multi-season occupancy analysis, which allows for a likelihood-based estimation of detection, occupancy, and colonization probabilities for rare species. Age-0 suckers primarily used shallow water, but appeared to move to avoid temporary and spatially restricted low DO concentrations. Age-1 sucker catch rates were greatest in shallow eastern parts of the delta in May and June and in deeper western parts of Tulana from mid-July through mid-September. This shift from shallow to deep water, occurred prior to low DO concentrations in Tulana Emergent, and therefore is unlikely to be correlated. Spatial and temporal distributions among available environments within the restored Williamson River Delta, northern Upper Klamath Lake, and southern Agency Lake by juvenile suckers in 2010 are described in this chapter.

Both 2008 and 2009 data indicate condition was similar between suckers captured in the Preserve and adjacent lake environments. Relative weight of juvenile suckers collected in the Preserve and adjacent lake habitats also was similar. Juvenile suckers also had similar rates of deformities, parasite loads, and afflictions in the Preserve and adjacent aquatic environments during the first 2 years of the study. These overt, external, indications of fish health were examined again in 2010, with attention given to factors that are thought to be related to reduced survival.

The Williamson River Delta was recolonized by all fishes in the regional species pool between the time each portion of the Preserve (Goose Bay Farms and Tulana) was inundated in the autumn and the following spring. A large number of fish capable of preying on endangered larval suckers and a few fish that could prey on juvenile suckers were captured in the Williamson River Delta, but these species appear to be no more abundant in the Preserve than in adjacent lake habitat.

In early May 2010, the lake-surface elevation for Upper Klamath Lake was a full half-meter lower (i.e., 1,262.24 m) than the 20-year average for the month (U.S. Geological Survey, 2011). This low May lake-surface elevation, low snow pack, and anticipated irrigation requirements in 2010 caused the Bureau of Reclamation to predict September lake-surface elevations would decline to less than 1,261.57 m (4,139.0 ft). Elevation data collected prior to the inundation of the delta and corrected for elevation changes due to restoration activities indicated that isolated ponds may form in Goose Bay Farms and in the eastern portion of Tulana when the lake surface declined below 1,261.57 m (4,139 ft) (The Nature Conservancy, Geographic Information System Data, 2007). An additional goal of this research in 2010 was to determine if low water conditions in the Williamson River Delta (1) trapped or isolated fish in pockets of water, (2) determine if mass mortality of any fishes occurred in the Williamson Delta during periods of low lake-surface elevation, and (3) determine whether breaches made in the Goose Bay dike provide adequate escape routes for fish during low water events.

Juvenile Fish Sampling

Habitat Use Sampling

Beginning May 10, 2010, trap nets were set each week in four areas within the Williamson River Delta, Tulana Emergent, Tulana Submergent, Tulana Open Water, and Goose Bay Farms (fig. 5). Sampling stopped in Goose Bay Farms and Tulana Emergent on July 22 because these areas became too shallow to effectively sample with trap nets. During the week of May 31, 15 sites were sampled located at the mouth of Shoalwater Bay, specifically to compare age-1 sucker habitat use in that area to that of the delta. Starting the week of August 2, additional sites were sampled in Upper Klamath and Agency lakes, alternating between the two lakes each week. Sites within Upper Klamath Lake were equally divided into two areas, a northern offshore region (Mid North) and along the northwestern shore of the lake adjacent to the Klamath Wildlife Refuge (Fish Banks). Agency Lake sites also were equally divided among two areas, along the southern shore (Agency Near Shore) and Agency Straits (fig. 5).

A total of 169 sites were visited at least once and 141 of these sites were revisited up to 10 times each. In each Williamson River Delta sampling area, at least 10 sites were sampled each week on a biweekly basis (20 sites every 2 weeks) until they became too shallow to sample. As shallow sites in Tulana Emergent and Goose Bay Farms were eliminated, new deeper sites were selected to replace them. All but three sites in these two areas were visited five or six times. In Upper Klamath and Agency lakes, at least 10 sites were sampled every 2 weeks between August 2 and September 16. Five additional sites were sampled in Tulana Emergent and Tulana Submergent between the weeks of July 19 and August 9 and in both Agency Lake areas the week of August 9.

Juvenile fish were sampled with rectangular trap nets with mouth dimensions of 0.609 × 0.914 m, a 10-m lead, and three internal fykes. These nets had 6.4-mm mesh, green nylon netting. At each site, nets were set overnight for three consecutive nights. Nets were set between 0740 and 1945 hours each day and pulled the next day between 0730 and 1801 hours for a target soak time of 20 hours for each net set. Lead line and mouth depths for all three nets at each site were averaged for a single measure of depth. Length and abundance were the only data collected on non-target species, whereas additional data were collected on condition and abundance of suckers. Standard length was measured for each

sucker and for the first 10 randomly selected individuals of all other species from 1 out of 10 sites sampled. Parasites, deformities, emaciation, red marks, or an unusual appearance observed without magnification were noted. Suckers captured during the first and second sampling events each week were released alive at the point of capture.

On the last day of each week, all suckers shorter than 70 mm and every third sucker 70 to 140 mm were sacrificed and preserved in 95-percent denatured ethanol for later identification. In the laboratory, each sacrificed sucker was weighed and species was determined (Markle and others, 2005). Suckers were classified as age-0, age-1, or older based on weekly length frequency plots. To estimate the number of suckers of each species, the composition of sacrificed suckers from each area and week was applied to the unsacrificed portion of suckers caught in each net.

Low Water Fish Sampling

Low water habitat use was sampled by juvenile fish in Tulana Emergent and Goose Bay Farms using seines. Nine deep water pockets with the potential to strand fish during very low water events were selected as sites—seven in Goose Bay Farms and two in the Tulana Emergent areas (fig. 6). Sites were sampled three or four times between July 26 and September 21. Our goal was to visit each site every time the lake elevation declined by approximately 0.5ft (0.15 m). Sampling logistics and difficulty with access at lower lake elevations, however, resulted in deviation from this ideal (table 3). A 6 m long, 1.3 m tall, and 5 mm mesh pocket seine was pulled through the water one to four times at each site. Seines were positioned 8–15 m from dry land parallel to shore. The seines were then pulled directly toward shore until they were beached and fish could be removed. Fish were handled following the protocol described for habitat use sampling above and returned to the water between each repeat sample.

To determine if fish were exiting Goose Bay Farms as lake elevation declined, trap nets (described in detail above) were set at breaches in the Goose Bay dike (fig. 6). Nets were set on the lake side of the dike openings with openings facing toward Goose Bay Farms. Each net was set overnight using the same protocol described above. Six of eight breaches were sampled on July 26, August 11, and August 24. Breaches were not sampled during the week of September 20 when the lake-surface elevation was 1,261.54 m, because there was no longer hydrologic connectivity between Goose Bay and Goose Bay Farms through the breaches. Fish were handled following the protocol described for habitat use sampling above, except that non-target species were measured and counted from every other net.

Tagging Juvenile Suckers

Age-1 suckers were given passive integrated transponder (PIT) tags to understand movement patterns and potentially validate ages at maturity. Healthy suckers 70 mm or longer collected in May and June habitat use sampling and pre-season pilot sampling conducted in April were injected with full duplex cylindrical PIT tags 12.45 mm in length, 2.02 mm in diameter, weighed 0.106 g, and operated at a frequency of 134.2 kHz. Healthy suckers 60–69 mm SL were injected with full duplex cylindrical PIT tags 8.00 mm in length, 2.02 mm in diameter, operating on the same frequency. The 12.45 mm tags have the potential to be detected remotely eliminating the need for physical recaptures, but 8.00 mm tags have a smaller read range and are unlikely to be detected on remote antenna systems. Therefore, suckers tagged with the smaller tags must be physical recaptured. Prior to tagging, suckers were scanned for the presence of PIT tags and anesthetized in a solution of MS-222 (concentration between 0.02 and 0.03 mg/L) prepared with lake water. Needles were disinfected between uses with a 3 percent solution of chlorhexidine. Wounds were not closed with sutures and no antibiotics were administered, because short-term tagging mortality was low without these added precautions (Burdick, 2011).

Recontact with PIT tags could be detected in one of three ways—manually scanning subsequently captured suckers, surveys at piscivorous bird colonies, or on remote underwater PIT tag detection systems. American white pelican (*Pelecanus erythrorhynchos*) and double-crested cormorant (*Phalacrocorax auritus*) nesting and loafing locations were scanned for tags by Bird Research Northwest using handheld detection wands in the Clear Lake Wildlife Refuge on March 12, March 23, August 30, and August 31; in the Williamson River Delta on September 2; and in the Upper Klamath Wildlife Refuge on September 23. Locations of fixed detection arrays were upstream and downstream traps on the Williamson River fish weir, at a river-wide array immediately upstream of the weir, at the former Chiloquin Dam site, immediately downstream of the former Chiloquin Dam site, shoreline spawning areas on the eastern shore of Upper Klamath Lake, at a river wide array near Bray Mill, and four antennas in the fish ladder on the Link River Dam (fig. 2). All detection systems were operating by February 26, 2010. The river-wide array located immediately upstream of the Williamson River fish weir and the antennas in the Link River fish ladder were operated continuously year around, whereas, all other antennas were removed between May 21 and July 15, 2010.

Summarizing and Reporting Data

Juvenile fish catch data were summarized to describe spatial-temporal patterns in distribution, relative abundance, species composition, age distributions, and length distributions. Catch rates were calculated to describe the magnitude of catches and naïve occupancy to describe the portion of habitat used. Catch rates were calculated as the number of fish per net rather than the number of fish per hour because there was not a relation between the number of fish captured and the number of hours nets were fished. Naïve occupancy, unadjusted for detection probability (MacKenzie and others, 2006), was calculated as the percentage of sites at which at least one sucker in a category of interest was caught. Fish species composition is described with a series of graphs depicting data collected during the juvenile sucker habitat use sampling, and does not include data collected as part of the low water fish stranding assessment of the Preserve. Special attention was given to species that had potential to prey on larval or juvenile suckers. Seine catches were summarized to describe the potential of stranding juvenile fish on the delta when lake elevation is low.

Results

Juvenile Sucker Distribution and Condition

Between May 10 and September 16, 2,367 nets were set for a grand total of 46,202 hours of soak time. The duration of trap net samples ranged from 13.9 to 26.3 hours and averaged 19.5 ± 1.6 hours. A total of 1,594 juvenile suckers were captured in the Williamson Delta, southern Agency Lake, and northern Upper Klamath Lake.

Based on weekly length frequency distributions, approximately 96.5 percent of suckers were estimated to be age-0 juveniles, 2.8 percent were estimated to be age-1, and less than 1.0 percent were estimated to be age-2 or older juveniles. Standard length increased slightly for all three age groups throughout the sampling period (fig. 7). A total of 451 age-0 and 9 age-1 suckers were sacrificed for identification, histology, age validation, or collection of tissues for a concurrent fish health study. Of the age-0 suckers sacrificed, 67.4 percent were SNS, 27.5 percent were LRS, 3.8 percent were Klamath largescale suckers, and 1.3 percent were suckers identified as having intermediate characteristics of these three species. Of the nine sacrificed age-1 suckers, seven were SNS, one was a LRS, and one was a Klamath largescale sucker.

Age-0 Juvenile Sucker Distribution

Low lake elevation prevented sampling with trap nets in Tulana Emergent and Goose Bay Farms after the week of July 19. Positive catches and relatively high catch rates of age-0 shortnose and LRS were more frequent along Fish Banks and in Tulana Open Water than in either Agency Lake area, Mid North, or Tulana Submergent (figs. 8 and 9; table 4). The timing of age-0 sucker catches was similar among all habitats and was concentrated between late July and late August. Catch rates for age-0 LRS and SNS decreased to near zero in all habitats by late September. Age-0 SNS were three times more abundant in our catches than age-0 LRS.

Age-0 Juvenile Sucker Condition

Median age-0 sucker length increased each sampling week in all areas except in Agency Near Shore (fig. 10). The median age-0 sucker length at this site was slightly smaller during the week of August 23 than during the weeks of August 9 and September 6. Too few age-0 suckers were sacrificed and identified to species to examine species specific trends in length within each area.

External examination of age-0 suckers indicated few deformities, macroparasites, overt signs of illness, or injuries. Fifteen percent were parasitized by at least one adult female anchorworm (*Lernaea* spp.). Of the age-0 suckers with anchorworms, 70 percent had only one and no suckers had more than five. Sixty-two percent of age-0 suckers with adult female anchorworms were SNS, 34 percent were LRS, and 4 percent were Klamath largescale suckers. Eleven percent of age-0 suckers had black spot (encysted metacercarial larvae of Digenea). Seven percent of age-0 suckers had one deformed opercle and less than 1 percent had both opercles deformed (table 5). Fifty-nine percent of age-0 suckers with one or more deformed opercles were SNS, 38 percent were LRS, and 3 percent had characteristics intermediate to the three lake suckers discussed in this report. Five percent of age-0 suckers were reported to have fin damage. Small numbers of age-0 suckers also were noted to have red rashes (3.8 percent), fused vertebrae (1.5 percent), scale loss (1.4 percent), wounds to the body (1.0 percent), scoliosis (0.3 percent), blindness (0.1 percent), fungus (0.1 percent), or were emaciated (0.1 percent).

Age-1 and Age-2 Juvenile Sucker Distribution

The majority of age-1 suckers were captured in Goose Bay Farms and Tulana Emergent between mid-May and mid-July (fig. 11). Age-1 suckers were captured in Tulana Emergent every week that sample collection was possible there except the weeks of June 28 and July 19, and in Goose Bay Farms every week that sample collection was possible in that area except for a 3-week period between May 24 and June 13. Age-1 suckers were captured only during 4 of the 19 sample weeks in Tulana Submergent and only during 2 weeks in Tulana Open Water. The only age-1 sucker to be captured outside the Preserve was collected on August 9 in Agency Straits, less than 400 m from Tulana Open Water boundary. Age-1 suckers tended to be captured at shallower sites the week of May 10 to the week of May 24, but in deeper sites from the week of May 31 to the week of July 5. SNS were seven times more abundant in delta samples than LRS in 2010, but none of the age-1 suckers captured in Agency or Upper Klamath lakes in 2010 were sacrificed and therefore identifiable to species.

Five age-2 and four older juvenile suckers were captured between May 13 and September 19, 2010. Standard lengths of age-2 suckers ranged from 131 to 184 mm. Three of the five age-2 suckers were captured in Tulana Emergent in May and July, one in Tulana Emergent in August, and one along Fish Banks in September. Standard length of juvenile suckers older than age-2 ranged from 284 to 360 mm. Two of the older juveniles were captured in Mid North, one along Fish Banks, and one in Agency Straits. All juvenile suckers older than age-2 were captured in August.

Age-1 and Older Juvenile Sucker Condition

External examination of age-1 and age-2 suckers indicated that deformities and overt signs of illness or injury were uncommon, but macroparasites were not. Nine percent of age-1 suckers had at least one deformed opercle and only one had two deformed opercula (table 5). None of the age-2 or older suckers captured had deformed opercula. Twenty percent of age-1 suckers, 40 percent of age-2 suckers, and one of the four juvenile suckers older than age-2 had at least one anchorworm. Of the age-1, age-2, and older juvenile suckers with anchorworms, 33 percent had only 1 anchorworm, 59 percent had between 2 and 6 anchorworms, and only one older juvenile sucker had 18 anchorworms. Small numbers of age-1 and age-2 suckers also were noted to have red rashes (2) or caudal fin damage (3).

Juvenile Sucker PIT Tag Summary

A total of 40 age-1 and 2 age-2 suckers were PIT tagged between April 20 and June 28. Tagging stopped at the end of June, because increasing air and water temperatures. Of tagged fish, 63 percent were released in Tulana Emergent, 29 percent in Goose Bay Farms, and 8 percent in Tulana Open Water.

In 2010, four juvenile sucker PIT tags were detected on remote antennas located at the Williamson River weir, but none were detected on any other remote systems or on bird colonies. Two of the juvenile suckers detected in 2010 were released in 2009 (Burdick and Brown, 2010) and two were released in 2010. One of these tags was given to a 97 mm sucker on May 12, 2009, in Tulana Emergent, detected in June and August 2009, and then detected again on March 17, 2010. The other tag was given to a 208 mm sucker on May 20, 2009, in an unnamed ditch south of Coon Point. This fish was detected 11 times at the Williamson River weir between May 15 and May 28, 2010. Of the fish tagged and redetected in 2010, one was tagged on May 3 in Tulana Emergent and detected on June 21 in the Sprague River and the other was tagged on May 17 in Tulana Emergent and detected on November 12 at the Williamson River weir.

Fish Community and Distribution of Piscivorous Fishes

A total of 11 non-sucker fish taxa was captured between May 10 and September 16 during juvenile sucker habitat use trap net sampling (table 2). Catches were dominated by fathead minnow, but tui chub, blue chub, and yellow perch also were common. Brown bullhead *Ameiurus nebulosus*, Klamath Lake sculpin *Cottus princeps,* Upper Klamath marbled sculpin *Cottus klamathensis klamathensis*, sunfish *Lepomis sp.*, lamprey *Lampetra sp.,* slender sculpin *Cottus tenuis*, and largemouth bass *Micropterus salmoides* (listed in descending order of abundance) were less common in our catches. Six species could potentially prey on larval suckers, but only three potentially prey on juvenile suckers (table 2). The four most common species could all potentially prey on larval suckers (fathead minnow, tui chub, blue chub, and yellow perch, whereas, of the three species that have potential to prey on juvenile suckers (table 2) only yellow perch were common.

Fathead minnows were present in all sampling areas in all weeks sampled, but were caught most frequently in Tulana Open Water and Tulana Submergent sampling after August 9. Yellow perch were captured frequently in all habitats, but only a small portion were large enough to prey on juvenile suckers.

Low Water Fish Stranding Assessment

Potential stranding ponds were sampled at lake elevations between 1,261.99 m (4,140.4 ft) and 1,261.54 m (4,138.9 ft). Ponds ranged in depth from 0.1 to 1.2 m. All ponds were connected by water to either Upper Klamath Lake or the Williamson River during all sample events. When the lake elevation was 1,261.54 m, ponds were less than 0.4 m deep with the exception of ponds G01 and G02, which had pockets of water 0.5 and 1.1 m deep, respectively. Pond area or area of inundated vegetation was not estimated during each visit, but photographic records indicate that the surface area of these ponds drastically decreased over the sampling season.

Eleven species commonly found in Upper Klamath Lake were captured in seine samples. Eighty-six percent of these were fathead minnow, 8 percent were chub *Gila* spp., 4 percent were juvenile suckers, and the remaining 2 percent were combination of yellow perch, brown bullhead, pumpkinseed, and sculpin *Cottus* spp. (table 2). A total of 88 juvenile suckers were captured in seines, one or more in ponds G01, G02, G03, G04, and T01. Juvenile suckers were captured in at least one pond during every sampling event. Shortnose, Lost River, and Klamath largescale suckers were all identified in seine samples. Ninety percent of suckers caught in seines were between 24 and 51 mm long.

Thirteen species were captured in trap nets set in Goose Bay dike breaches, including all three sucker species (table 2). Forty-four percent of non-suckers were fathead minnows, 29 percent were chubs, 22 percent were yellow perch, and the rest were a combination of pumpkinseed, brown bullhead, largemouth bass sculpin, and lamprey. Three suckers were captured on July 26, 34 on August 11, and 38 on August 24.

Discussion

Comparison of Juvenile Sucker Catch Rates among Sampling Areas

Throughout most of the study area, age-0 suckers primarily were captured in August and early September 2010. Exceptions occurred in Tulana Emergent where age-0 suckers were not captured in 2010 and in Goose Bay Farms where age-0 suckers were captured only on July 19, 2010. The initiation of catches each year depends on age-0 suckers reaching a size that can be retained by the mesh size of the nets, whereas, the decrease in catches is due to mortality, emigration from sampling areas, or some combination of the two. Small numbers of age-0 suckers in Goose Bay Farms and no age-0 suckers captured in Tulana Emergent in 2010 indicate suckers did not recruit to our gear before these areas became too shallow to sample after July 19. Seine samples, however, indicate some juvenile suckers continued to use these areas until September 22, but they do not provide a way to compare the relative density or abundance of suckers in these habitats among years.

Catches of age-1 suckers occurred slightly earlier in shallow Goose Bay Farms and Tulana Emergent when compared to the other four deeper areas. This observation may be confounded by our inability to effectively sample shallow water habitats after July 19. The initiation of age-1 sucker catches roughly coincided with the start of sampling, whereas, the decrease in catches probably is a result of mortality, emigration from the study area, reduced selectivity of this age class as they learn to avoid our nets or a combination of these.

Juvenile Sucker Species Composition

SNS made up the largest portion of juvenile sucker catches from the Williamson River Delta, indicating this habitat was used more by SNS than the other two sucker species. The ratio of age-0 SNS to age-0 LRS in the delta was 3:1. The ratio of age-1 SNS to age-1 LRS was 7:1 in the delta in 2010. None of the age-1 suckers captured in Agency or Upper Klamath lakes in 2010 were sacrificed and therefore identifiable to species. Proportionally greater numbers of age-0 shortnose may indicate better spawning success, greater spring survival, better retention, habitat preferences by this species, or a combination of these factors. Whereas, proportionally greater numbers of age-1 SNS may indicate better over winter survival, habitat preferences for this species, or a combination of these factors.

Juvenile Sucker Condition, Deformities, and Parasites

The prevalence of skeletal deformities in juvenile suckers in our study are of concern, given their potential for lethal side effects, inconsistency with other fish species in the study area, and an increase from juvenile suckers collected in Upper Klamath Lake in the early 1990s. The most common skeletal deformity was shortened opercula, but scoliosis and fused vertebrae also were observed in 2010. The portion of age-0 suckers with shortened opercula was nearly always greater than the 4.7 percent of age-0 Lost River and 1.4–3.1 percent of age-0 SNS with this deformity that Plunkett and Snyder-Conn (2000) collected in 1993. This deformity was not noted for any other species captured in our study, but has been noted for bull trout *Salvelinus confluentus* (Smith and Tinniswood, 2008) and adult suckers (E. Janney, U.S. Geological Survey, oral commun., 2011) in the Upper Klamath Basin. Opercle deformities that expose gill filaments are a common phenomenon in hatchery fish but are less prevalent in wild fish (Beraldo and others, 2003). These deformities are non-lethal for hatchery-raised fish (Beraldo and others, 2003), but may lower resistance to oxygen stress and predispose fish to infections by bacteria, parasites, and fungi (Galeotti and others, 2000; Beraldo and others, 2003). Deformed opercula could be caused by inbreeding (Winemiller and Taylor, 1982; Tringali and others, 2003), a lack of dietary ascorbic acid (Chávez de Martínez, 1990), pollution (Lindesjoo and others, 1994), a lack of dietary calcium (Lindesjoo and others, 1994), low environmental pH during periods of rapid growth (Lindesjoo and others, 1994), or infestations of Digenea (Quist and others, 2007). In Upper Klamath Lake, daily summer time median pH is rarely less than 8.0 (Lindenberg and others, 2008), suggesting low pH is not the cause of the deformities observed. Because fish were not examined microscopically, it was impossible to determine if there was an association between Digenea and this deformity in juvenile suckers. Whatever the determinant factor, skeletal deformities are irreversible (Beraldo and others, 2003).

The presence of parasitic female anchorworms on juvenile suckers is noteworthy given their historical absence prior to 1996 (Simon and others, 2009), but this parasite is unlikely to cause mortality in young suckers. Anchorworm intensity is not associated with deleterious health effects for suckers at intensities less than 30 per fish (Robinson and others, 1998), and the maximum parasite intensity in this study was 18 anchorworms per sucker. Although direct mortality from anchorworms is unlikely, this parasite creates a wound at the point of attachment where a secondary infection may occur (Khalifa and Post, 1976).

PIT Tag Detections

The use of PIT-tag technology has the potential to provide new information on movement patterns and the sources of mortality for juvenile suckers. The small number PIT tagged fish and even smaller number redetected in 2009 (169 fish tagged,14 redetected) and 2010 (40 fish tagged, 2 redetected), however, provide only limited information about the movement pattern of juvenile suckers. Tags were detected on bird colonies, at the Link River fish ladder, and at the Williamson River weir in 2009 (Bottcher and Burdick, 2010; Burdick and Brown, 2010) but only at the Williamson River weir in 2010. It is possible that predators, such as redband trout *Oncorhynchus mykiss* subsp., may have eaten suckers with PIT tags and detections on remote antennas may indicate the presence of predators but not live suckers. Four tags detected in 2009 and one in 2010 over a period of several weeks and one tag detected in both years at the Williamson River weir suggest tags were in live suckers at the time of detection. If suckers with these tags were eaten by predators, they probably would have passed through the predator's digestive system within several days making the pattern of detections recorded unlikely. Juvenile sucker PIT-tag data provides the first indication of the distances age-1 and age-2 suckers can travel. The farthest distance between tagging and recapture locations was for a sucker tagged in Short Creek in 2009 and detected in the Link River ladder more than 30 km away.

Potential for Fish Stranding at Low Lake Elevations

The slow draw down of lake water in 2010 posed no more than a minor threat of stranding juvenile suckers in the Williamson River Delta, given that isolated ponds did not form in the Williamson River Delta in 2010. However, the wetted area available for fish use and water depth decreased. If isolated ponds were to form at lake-surface elevations lower than those observed in 2010 (lowest observed 1,261.54 m or 4,138.9 ft), the ponds could potentially strand a number of fish species, including endangered Lost River and SNS. An increase in suckers captured in trap nets set along escape routes on the Goose Bay shoreline between July and August indicate suckers were able to exit the delta as it was dewatered or that suckers were still recruiting to trap nets during this period. Temperature and DO concentrations were not recorded in the shallowest portions of the Williamson River Delta in August and September 2010 (S. Wong, The Nature Conservancy, oral commun., 2011), but the presence of a several fish species indicates both were adequate to support suckers during this time period.

Threat to Endangered Suckers by Piscivorous Fishes

Fish that could potentially prey on larval suckers were abundant throughout the study area, but those that could potentially prey on juvenile suckers were less common. Fathead minnows probably present the greatest threat of predation to larval suckers due to their abundance. Yellow perch, which can prey on fish up to 47 percent of their body length (Truemper and Lauer, 2005) and were abundant throughout the study area, present the largest potential threat of predation to juvenile suckers. Only a small portion of the yellow perch captured, however, were large enough to prey on juvenile suckers. The abundance of both species is similarly high in the Preserve and adjacent lakes.

Summary

Data were summarized to describe spatial-temporal distribution of juvenile suckers in the Williamson River Delta, northern Upper Klamath Lake, and southern Agency Lake in 2010. Age-0 suckers primarily were captured in August and early September throughout the study area, whereas, age-1 suckers primarily were captured between early May and early June in the delta. Seine samples collected in Goose Bay Farms and Tulana Emergent indicated continued use of very shallow water through September (< 0.4 m deep). Catches of age-0 and age-1 suckers decreased to near zero throughout the study area by mid-September. Greater catches of age-0 SNS compared to Lost River or Klamath largescale suckers may indicate SNS experienced better spawning success, greater spring survival, better retention, more appropriate habitat, or a combination of these factors. Greater catches of age-1 SNS compared to the other two sucker species probably indicates SNS experienced better over winter survival, expressed habitat use preferences, or a combination of these.

The causes of high apparent mortality of age-0 and age-1 suckers in August and September were investigated. The prevalence of shortened and deformed opercula are a concern due to their potential for lethal side effects and their near absence from other species in the lake, but the cause of the deformity is unknown. Although the presence of parasitic female anchorworms is noteworthy due to their historical absence, the low intensity parasitism reported here is not a serious concern for juvenile suckers. Most of the piscivorous fish present in our study area were either too small or too rare to pose a serious threat to juvenile suckers, but could prey on juvenile suckers.

Acknowledgments

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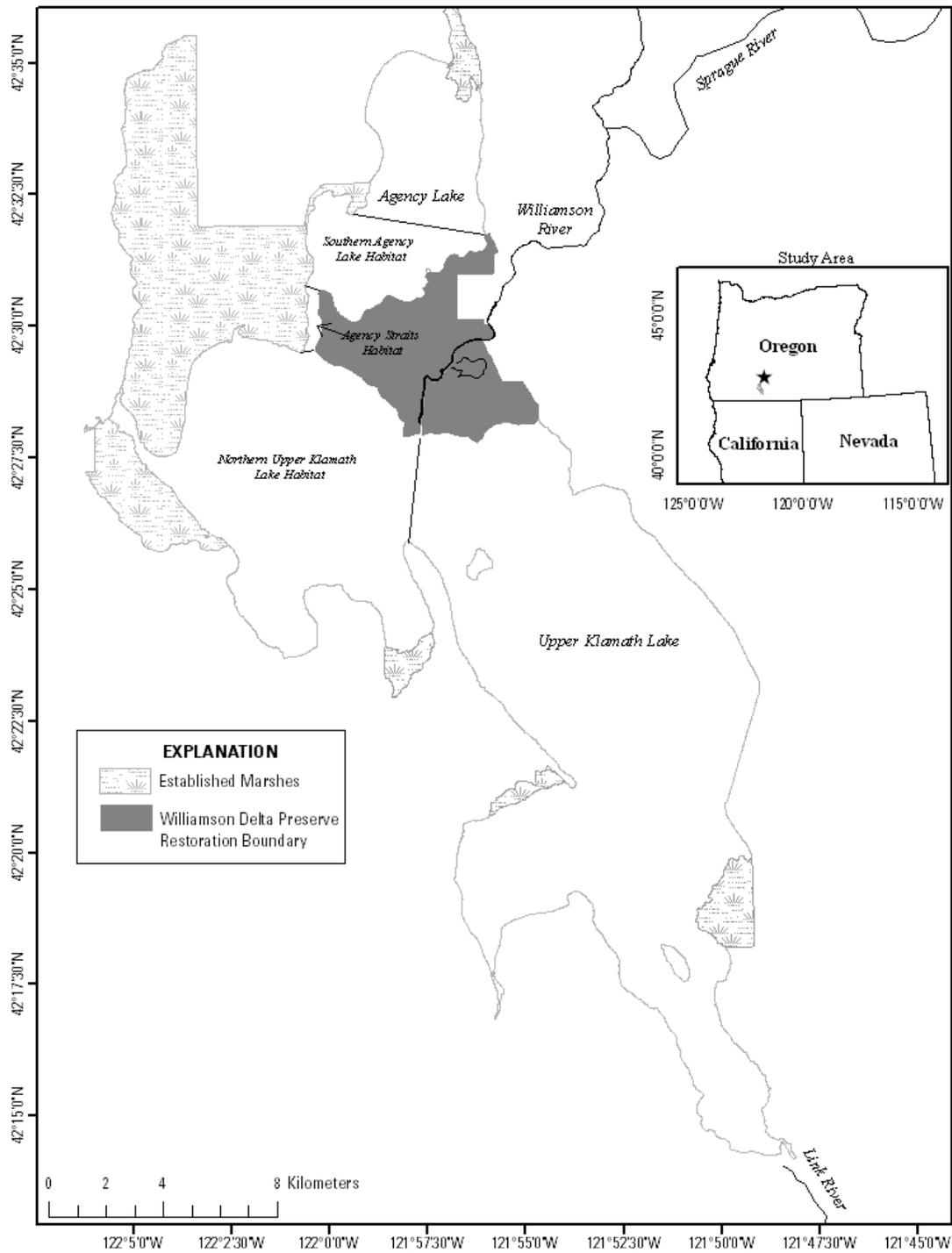
Figure 1. Geographic location of the Williamson River Delta in relation to other aquatic environments and state boundaries. The map coverage for the Williamson River Delta restoration area was provided by The Nature Conservancy.
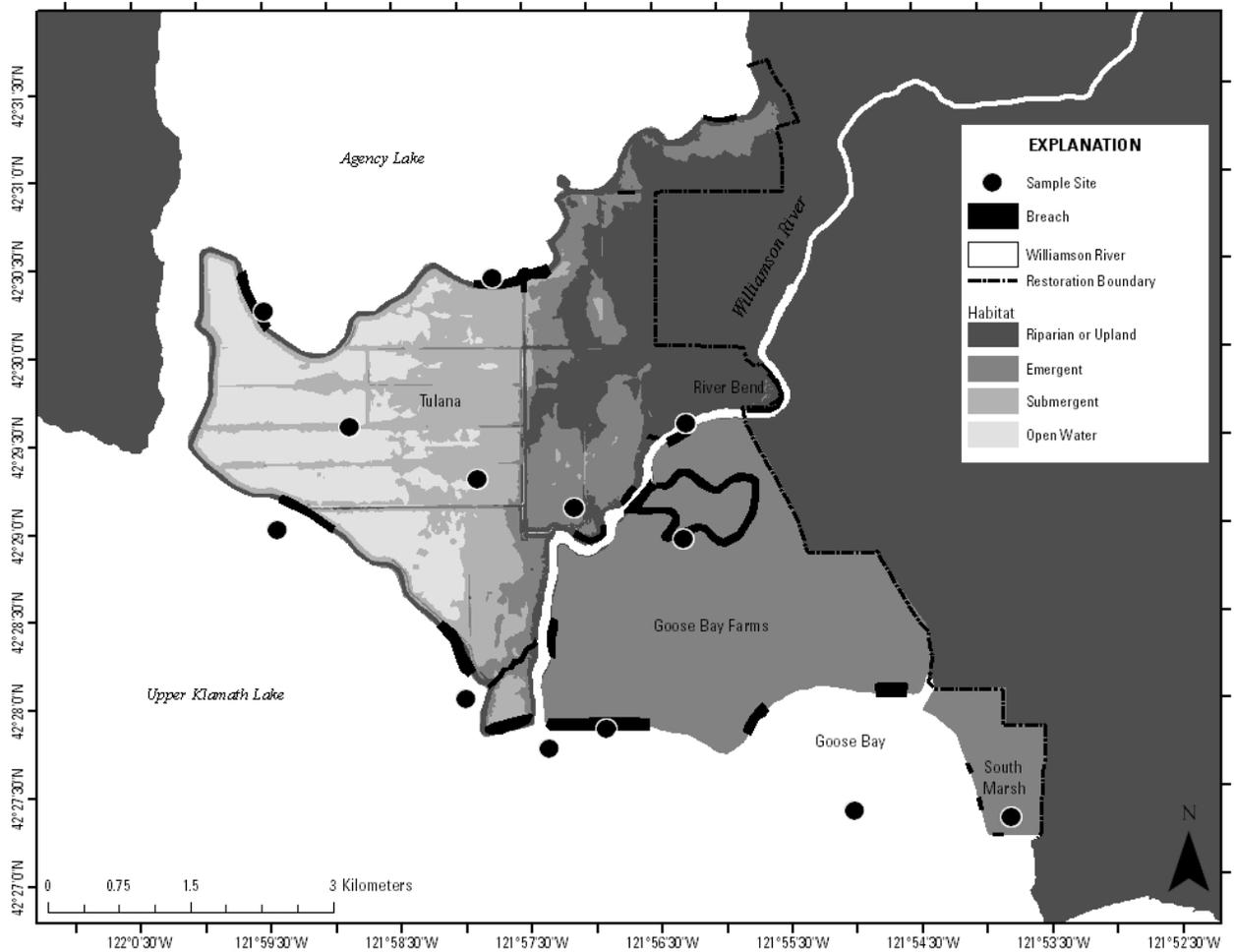
Figure 2. Larval fish sampling locations in and adjacent to the Williamson River Delta, Oregon. Sampling sites, which were visited once weekly, were selected to capture larval suckers as they were passively transported across the delta by water currents. Map layers for vegetation types were provided courtesy of The Nature Conservancy. The locations of excavated dikes (breaches), which were removed to flood water into the delta, also are shown.
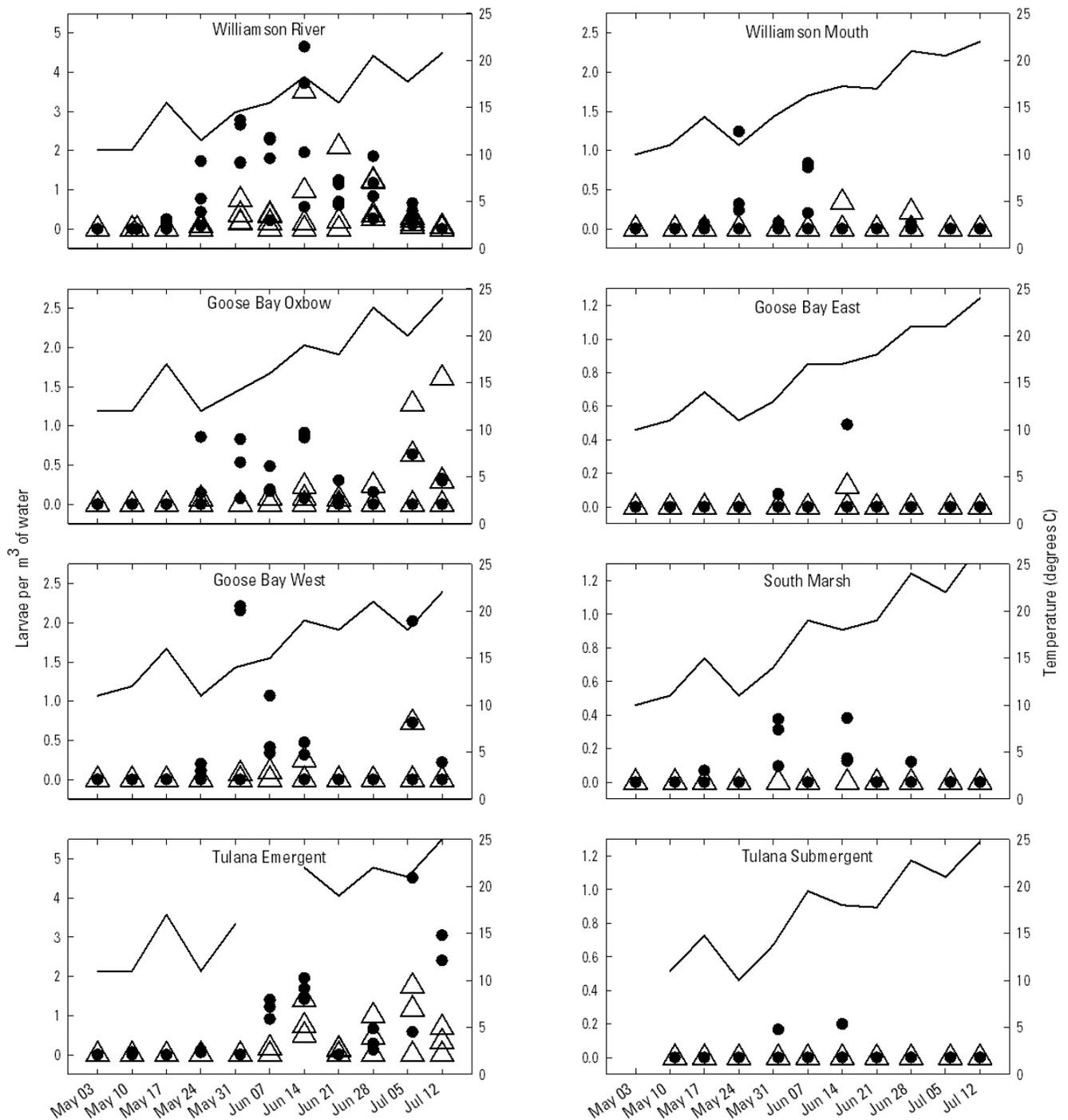
Figure 3. Larval Lost River sucker (black dots) and the group of larvae identified as either shortnose or Klamath largescale (open triangles) sucker sample densities at 13 fixed sites. Sites were sampled one to three times weekly in and adjacent to the Williamson River Delta, Oregon, between May 3 and July 13, 2010. Larvae were collected in surface-oriented plankton nets towed laterally to a boat at slow speeds. Solid lines indicate water temperatures recorded at the time of sampling. Note y-axis scales were adjusted to improve display and therefore are not the same between panels.
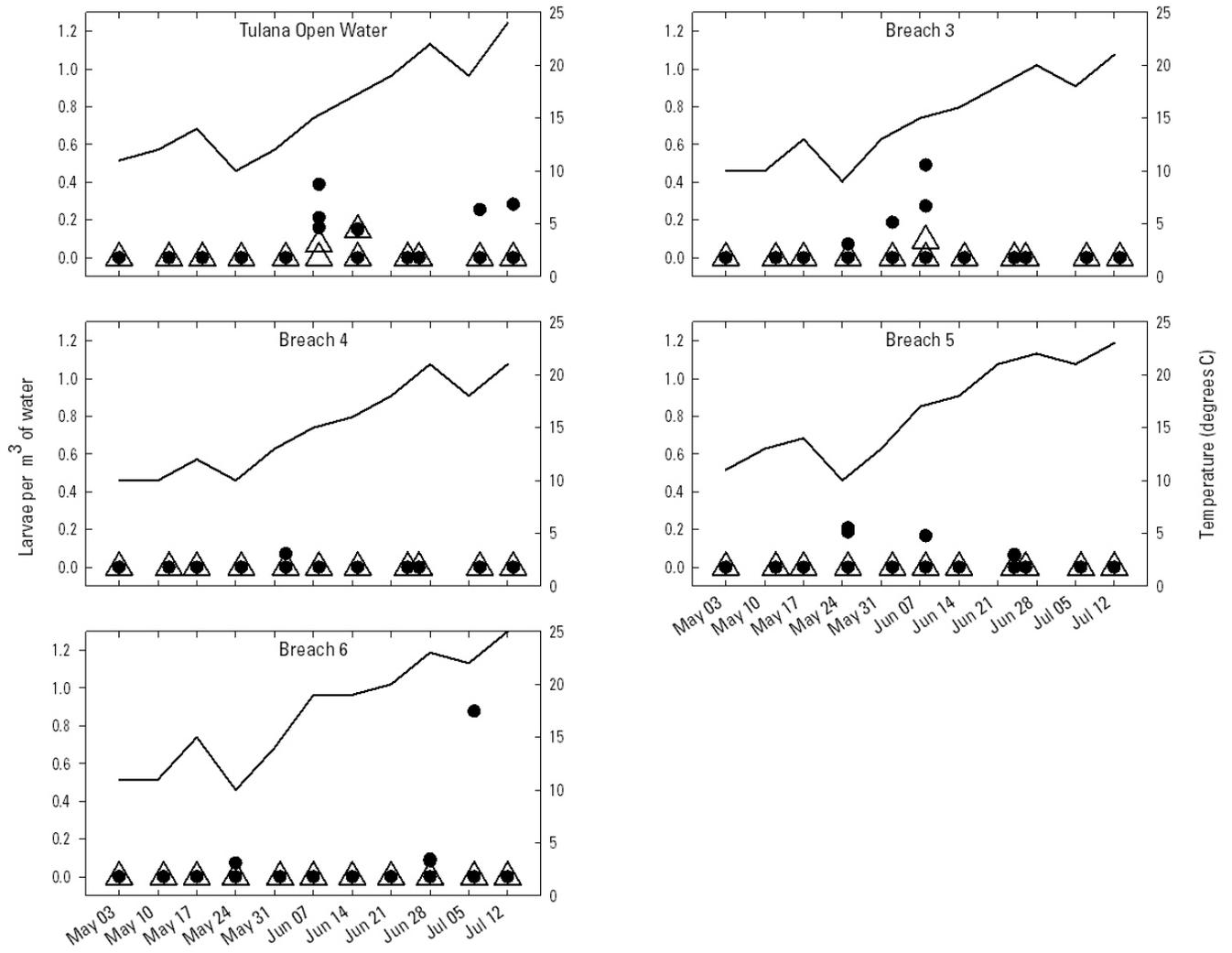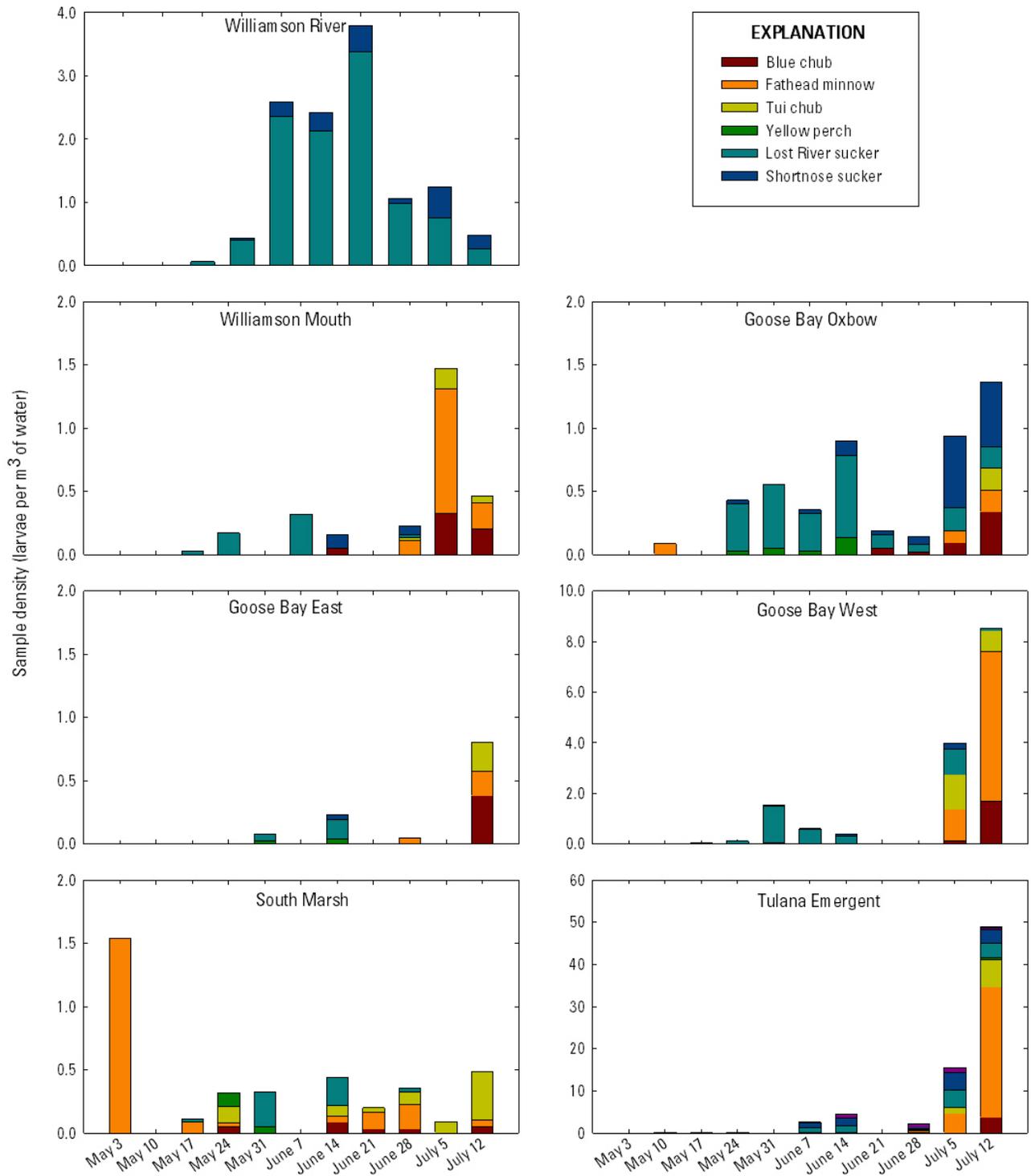
Figure 3. Continued.

Figure 4. Larval sample density (larvae/m^3 of water filtered) by week and species at 13 sites sampled weekly in and adjacent to the Williamson River Delta, Oregon, between May 3 and July 13, 2010. The scale of the y-axis varies among panels to better illustrate the species composition at each site.
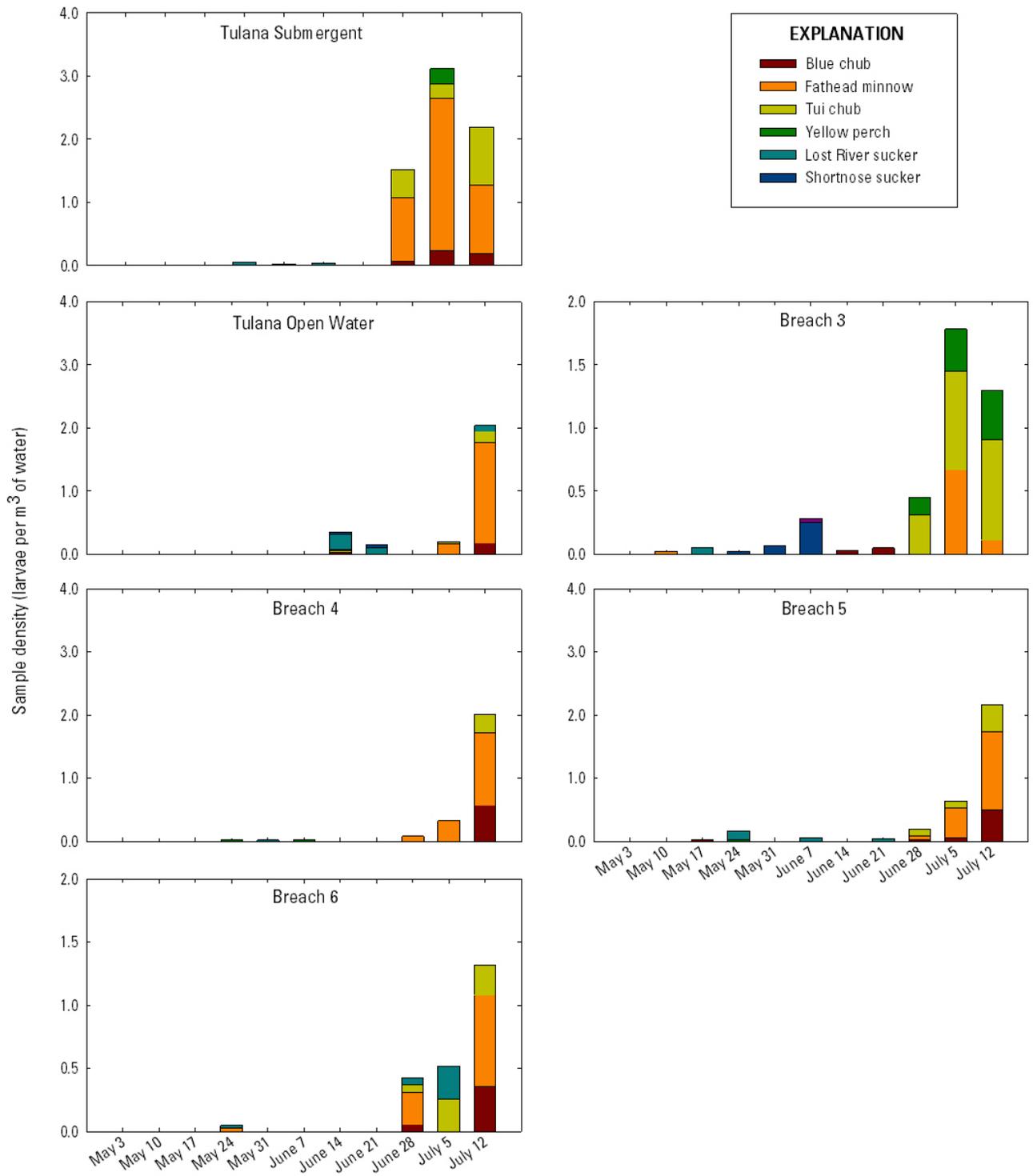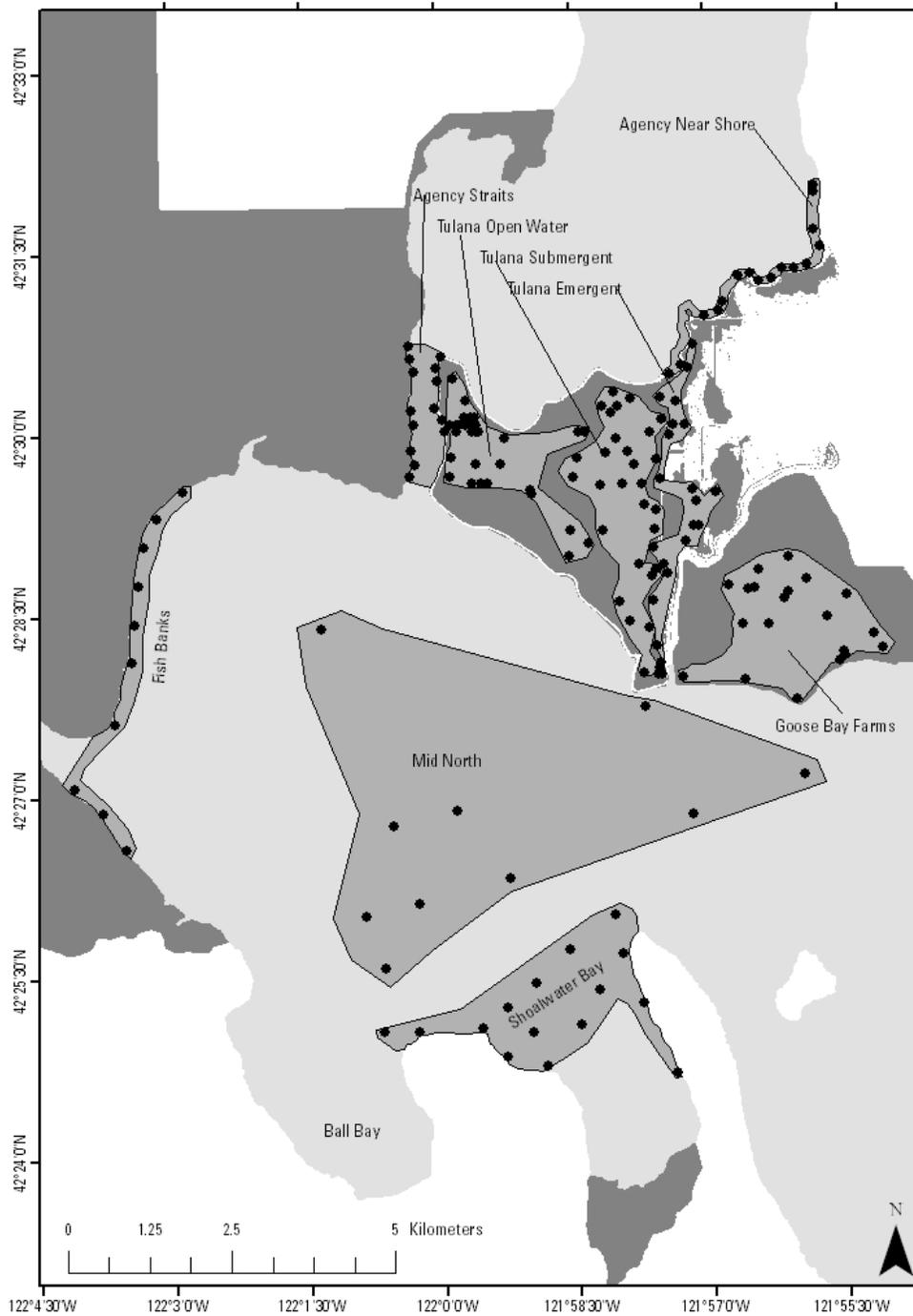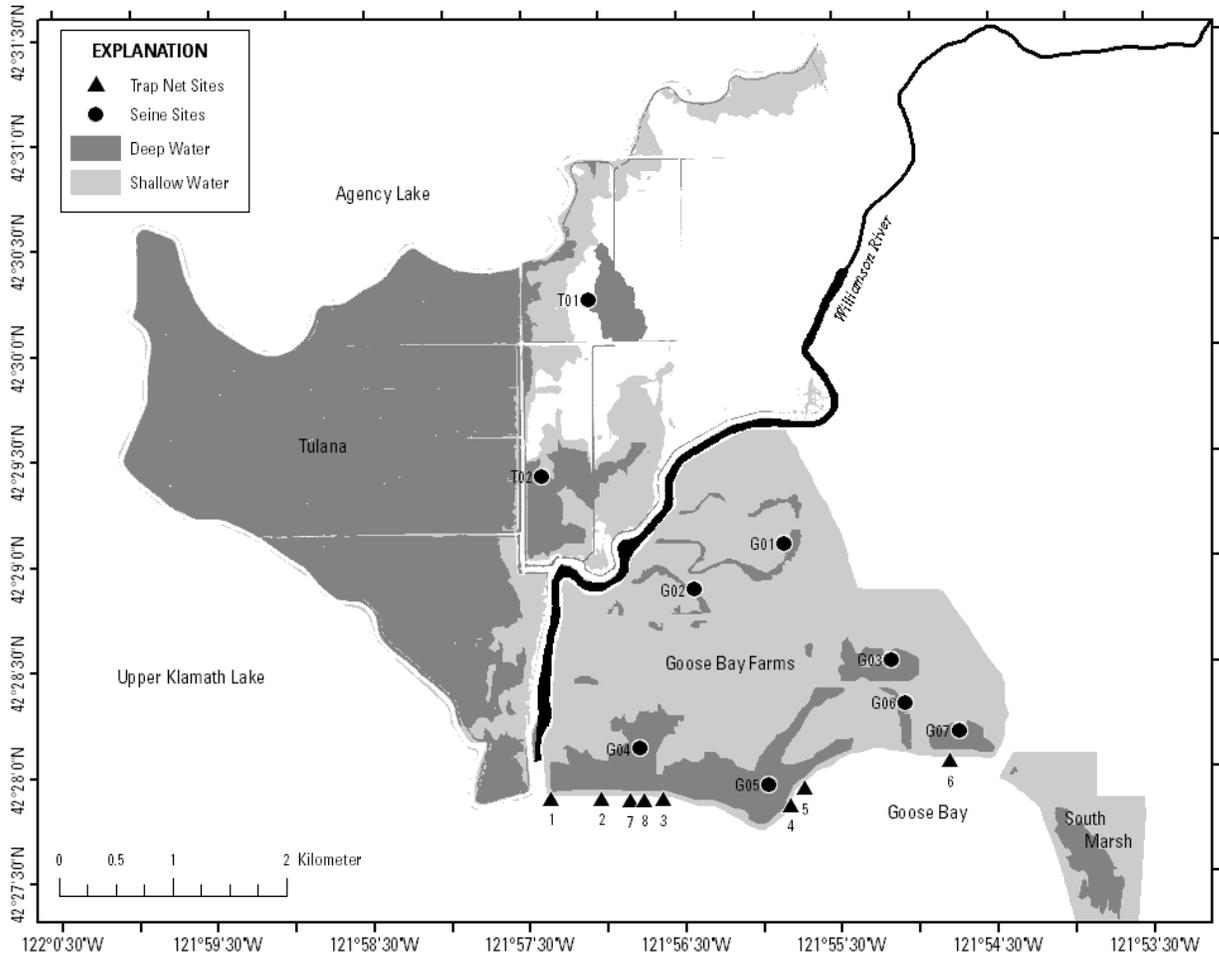
Figure 4. Continued.

Figure 5. Locations of nine sampling areas and sites sampled with trap nets during the summer of 2010 in Upper Klamath Lake, Agency Lake, and the Williamson River Delta restoration area, Oregon. The map coverage for the Williamson River Delta restoration area was provided by The Nature Conservancy.

**Figure 6.** Locations of nine sites sampled with seines between July 26 and September 21, 2010, in the Williamson River Delta restoration area, Oregon. Shallow water habitats were predicted to be dry and deep water was predicted to be inundated when the surface elevation of Upper Klamath Lake was below 4,139.0 ft (1,261.6 m). The map coverage for the Williamson River Delta restoration area was provided by The Nature Conservancy.
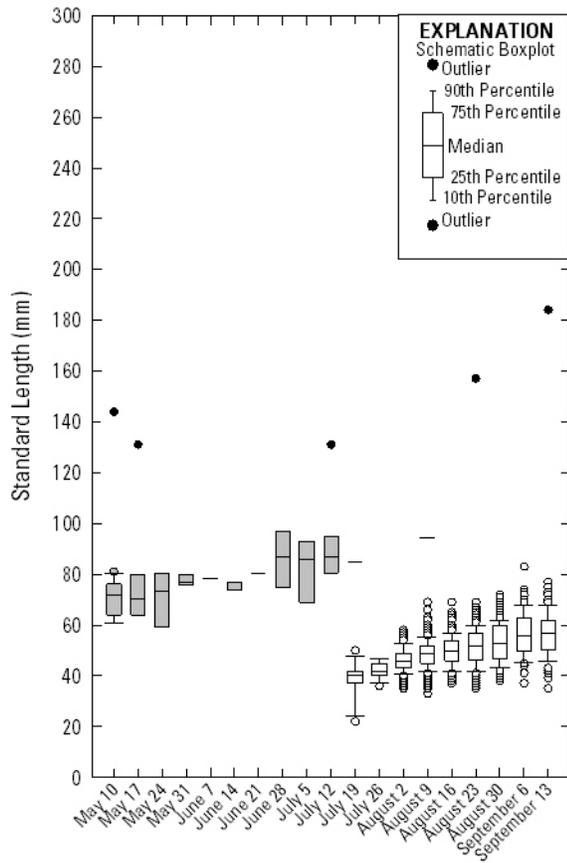
**Figure 7.** Length of juvenile suckers collected in trap nets set in the Williamson River Delta, northern Upper Klamath Lake, and southern Agency Lake, Oregon, between May 3 and September 16, 2010. Three age classes are shown, juvenile age-0 suckers are shown in white, age-1 suckers in gray, and suckers suspected to be age-2 or older are shown with black dots. Dates shown are for the Monday that started each week.
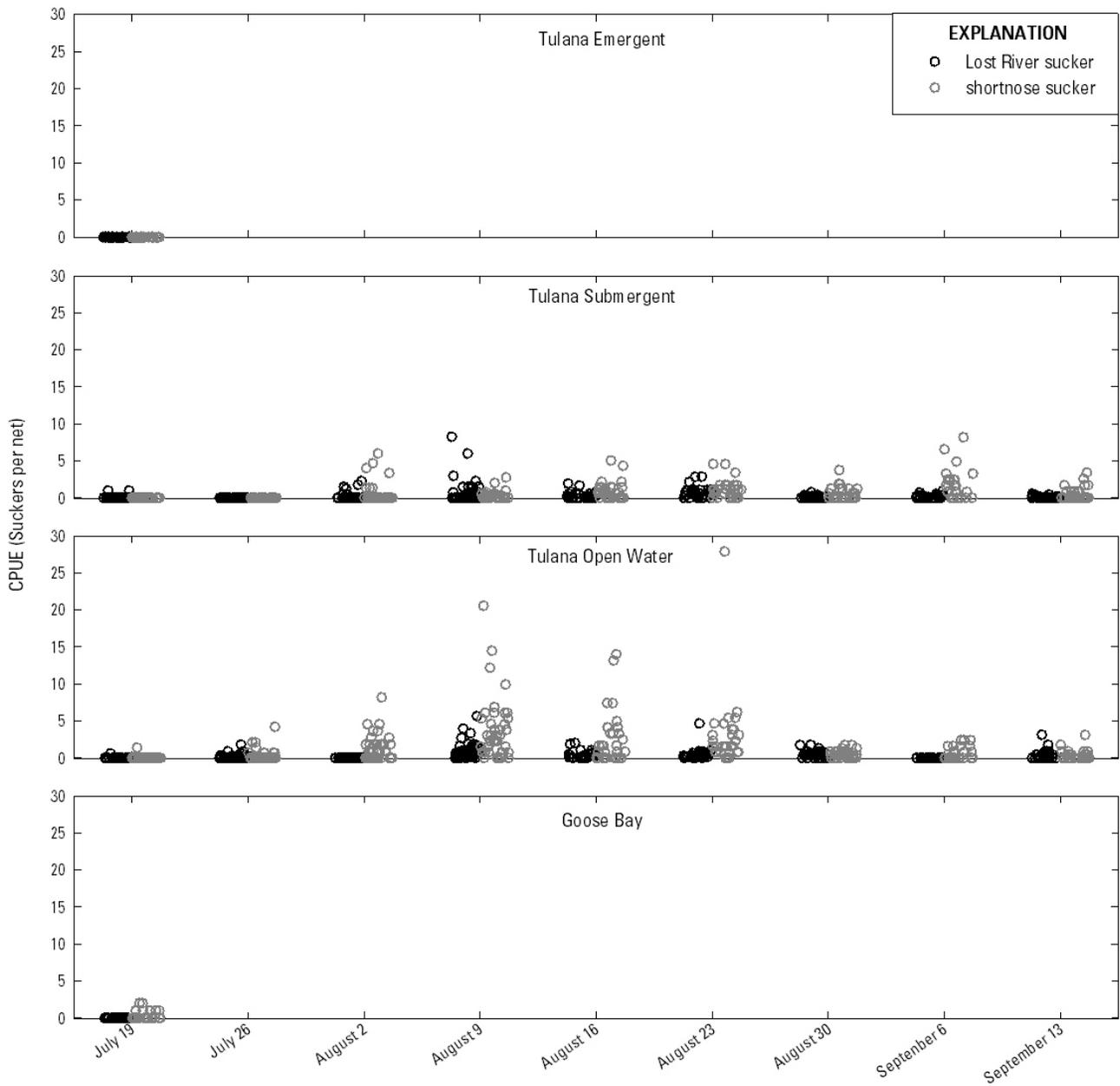
Figure 8. Catch per unit effort (CPUE; suckers per net) for age-0 Lost River (black circles) and shortnose (gray circles) suckers caught four areas (fig. 1) in the Williamson River Delta, Oregon, between July 19 and September 16, 2010. Lost River sucker data are randomly jittered along the x-axis to the left of the point and shortnose sucker data are randomly jittered to the right of the point to improve the display. Dates shown are for the Monday that started each week. Neither species was captured before July 19 in any areas. Sampling was discontinued in Tulana Emergent and Goose Bay areas after the week of July 19 due to low water.
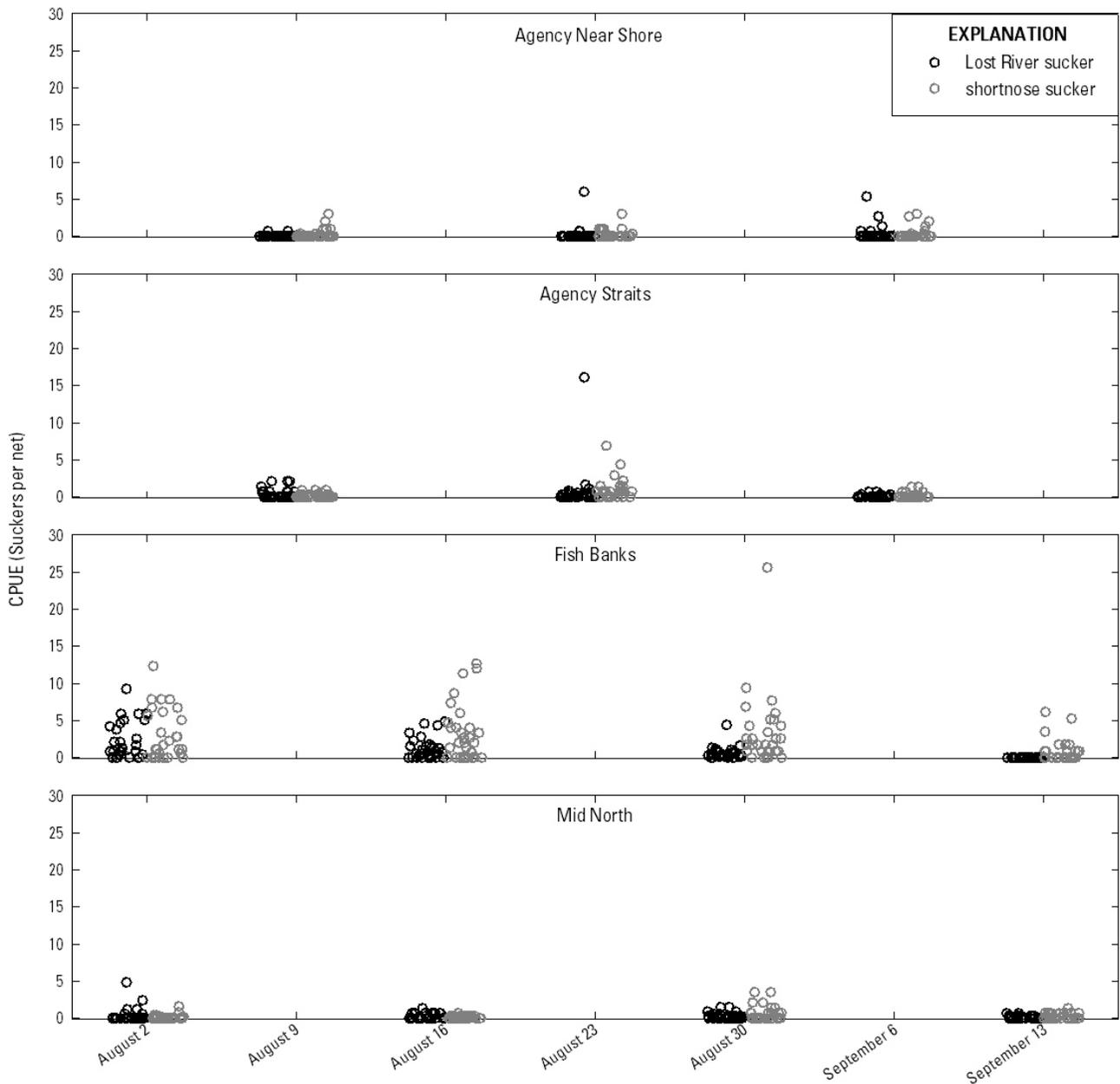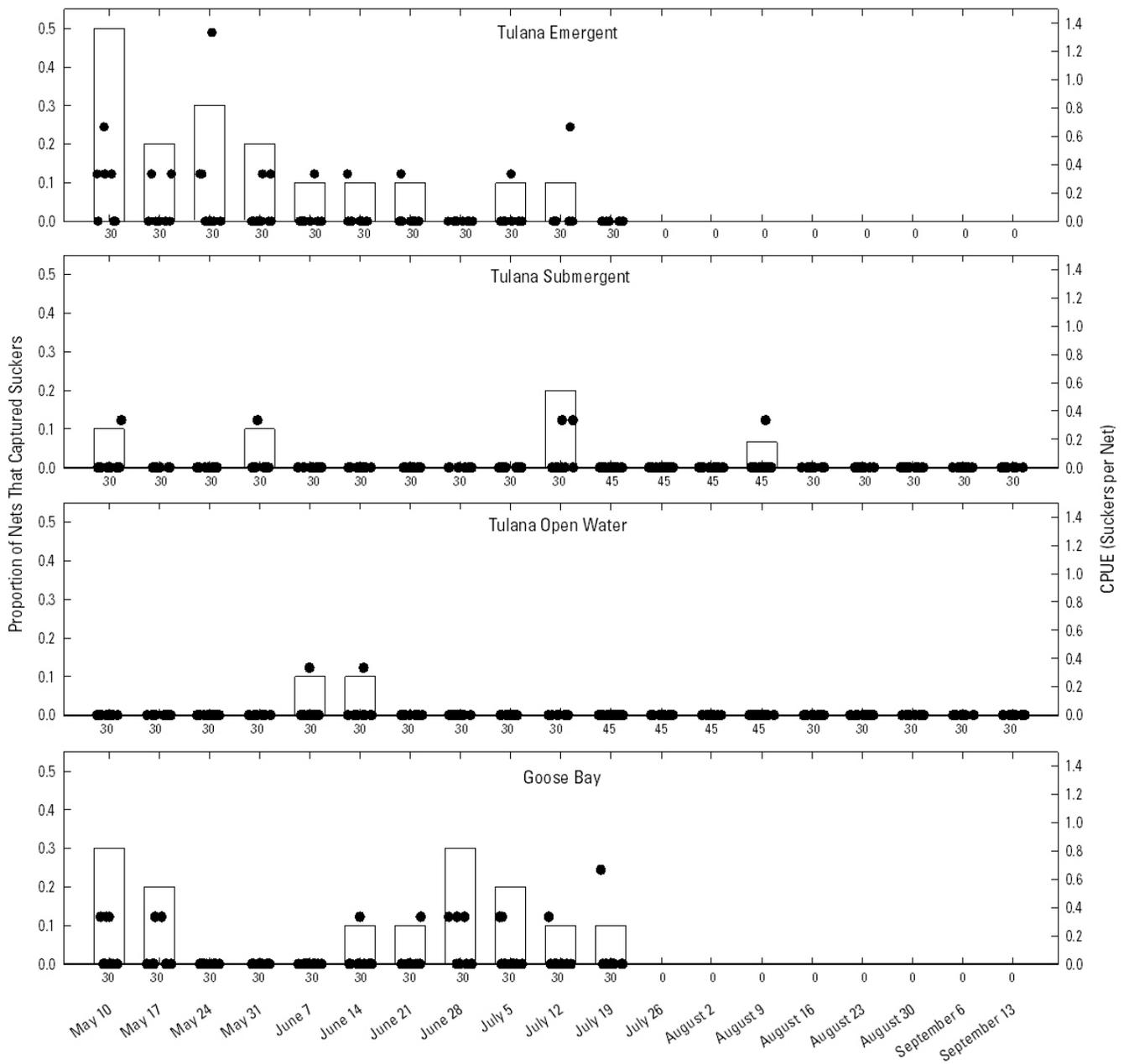
Figure 9. Catch per unit effort (CPUE; suckers per net) for age-0 Lost River (black circles) and shortnose (gray circles) suckers caught in two areas in Upper Klamath Lake and two in Agency Lake (fig. 1), Oregon, between August 2 and September 16, 2010. Lost River sucker data are randomly jittered along the x-axis to the left of the point and shortnose sucker data are randomly jittered to the right of the point to improve the display. Dates shown are for the Monday that started each week.
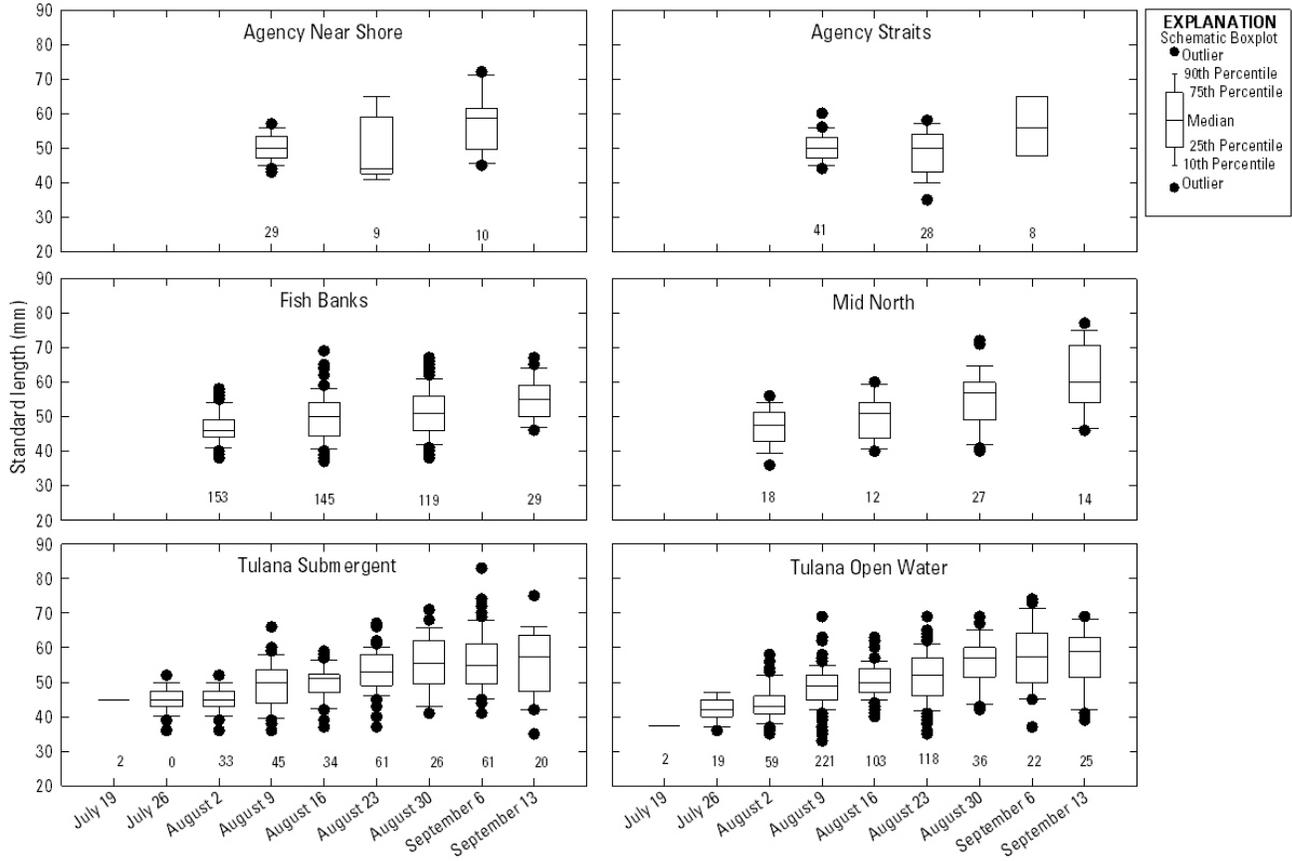
Figure 10. Standard length (mm) of age-0 suckers caught in trap net sampling in two areas in northern Upper Klamath Lake (Fish Banks and Mid North), two in Agency Lake (Agency Near Shore and Agency Straits), and two in the Williamson River Delta (Tulana Submergent and Tulana Open Water) (fig. 1), Oregon, between July 19 and September 16, 2010. The numbers of age-0 suckers caught each week in each area, and used in the creation of each boxplot are given along the x-axis. Upper Klamath and Agency Lakes were only sampled every other week after between August 2 and September 16. Dates shown are for the Monday at the start of each week.

Figure 11. Catch per unit effort (CPUE; suckers per net) for age-1 suckers caught in trap net sampling in Tulana Emergent, Tulana Submergent, Tulana Open Water, and Goose Bay Farms (fig. 1) located in the Williamson River Delta, Oregon, between May 10 and September 16, 2010. CPUE values (dots) were randomly jittered along the x-axis to improve the display. The percentages of sites each week at which least one sucker was caught are shown with bar plots. The numbers of sites sampled each week are given below the x-axis. Dates shown are for the Monday at the start of each week.

Table 1. Plant communities predicted to develop in the Williamson River Delta, Oregon.

[Data from David Evans and Associates, Inc., 2005. The potential for these environments to be habitat for endangered larval or juvenile Lost River or shortnose suckers is given]

Predicted plant community	Maximum depth (m)	Habitat for larval suckers	Habitat for juvenile suckers
Upland	0.2	No	No
Riparian	0.6	Yes	No
Emergent Wetland	1.5	Yes	Yes
Deep Water Wetland	2.7	Yes	Yes
Open Water	4.0	Yes	Yes

Table 2. Fishes, excluding endangered suckers, captured in and adjacent to the Williamson River Delta, Oregon.

[Fish were captured in plankton nets, trap nets or beach seines. The life stages detected are A, adult; J, juvenile; L, larval. Abundance is a qualitative classification based on the number of fish captured. Sucker life stage at risk of predation is assumed based on diet and feeding behavior reported in the literature for each species]

Common name	Latin name	Native or Non-Native	Life stages detected	Abundance	Diet	Sucker life stage at risk of predation
blue chub	*Gila coerulea*	Native	L,J,A	Abundant	Algae, detritus, invertebrates, and fish (Bond and others, 1968)	Larval
brown bullhead	*Ameiurus nebulosus*	Non-Native	L,J,A	Common	Invertebrates (Kline and Wood, 1996)	None
fathead minnow	*Pimephales promelas*	Non-Native	L,J,A	Abundant	Larval fish (Markle and Dunsmoore, 2007)	Larval
Klamath Lake sculpin	*Cottus princeps*	Native	[1]J,A	Common	Invertebrates (Bond and others, 1968)	None
Klamath largescale sucker	*Catostomus snyderi*	Native	L,J	Very rare	Probably invertebrates (Markle and Clauson, 2006)	None
Klamath speckled dace	*Rhinichthys osculus klamathensis*	Native	A	Very rare	Invertebrates (Angradi and others, 1991)	None
Klamath tui chub	*Siphatales bicolor bicolor*	Native	L,J,A	Abundant	Algae, detritus, and invertebrates (Bond and others, 1968)	[2]Larval
largemouth bass	*Micropterus salmoides*	Non-Native	J	Very rare	Invertebrates and fish (Dibble and Harrell, 1997)	Larval and juvenile suckers up to ~150 mm TL (Johnson and Post, 1996)
Sunfish (blue gill or pumpkinseed)	*Lepomis sp.*	Non-Native	J,A	Rare	Invertebrates and fish (Garcia-Berthou and Moreno-Amich, 2000)	Larval
slender sculpin	*Cottus tenuis*	Native	[1]J,A	Rare	Invertebrates (Bond and others, 1968)	None
unidentified species of lamprey	*Lampetra sp.*	Native	A	Rare	Parasitic (Beamish, 1980)	Juvenile and adult
Upper Klamath marbled sculpin	*Cottus klamathensis klamathensis*	Native	[1]J,A	Abundant	Invertebrates (Bond and others, 1968)	None
yellow perch	*Perca flavescens*	Non-Native	L,J,A	Abundant	Invertebrates and fish (Bond and others, 1968)	Larval and juvenile suckers up to ~121 mm TL (Truemper and Lauer, 2005)

[1]Larval and juvenile sculpin were only identified to genus.

[2]Bond and others (1968) found fish in the diets of blue chub but not tui chub collected from Upper Klamath Lake.

Table 3. Seine sampling effort in the Williamson River Delta, Oregon, 2010.

[Site locations are shown in figure 6. Site visits were planned at 0.5-ft intervals, however, sampling logistics and difficult access reduced the number of times each site could be visited]

Sampling period	Lake-surface elevation		Site								
	feet	meters	G01	G02	G03	G04	G05	G06	G07	T01	T02
July 26-27	4,140.4	1,261.99	2	3	3	3	3	3	3		
August 11-12	4,139.9	1,261.84		3	3	3	3	3	3	3	3
August 16	4,139.8	1,261.81		3	4		1				
August 26	4,139.4	1,261.69	3			3				3	3
September 20-22	4,138.9	1,261.54	3	3	3	3	3	3	3	3	3

Table 4. Number of age-0 and age-1 suckers caught per net set in each of six areas in and adjacent to the Williamson River Delta, Oregon, 2010.

[Sampling areas are shown in fig. 2]

Area	Age-0	Age-1
Southern Agency Lake	0.595	0.005
Northern Upper Klamath Lake	1.039	0.000
Tulana Emergent	0.000	0.067
Tulana Open Water	0.960	0.003
Tulana Submergent	0.448	0.008
Goose Bay	0.027	0.045

Table 5. Portion of age-0 and age-1 suckers that had deformed opercles captured in six areas in and around the Williamson River Delta, Oregon, 2010.

[Sampling areas are shown in fig. 2]

Area	Age-0	Age-1
Southern Agency Lake	0.11	0
Northern Upper Klamath Lake	0.07	–
Tulana Emergent	---	0.09
Tulana Submergent	0.06	0.2
Tulana Open Water	0.07	0
Goose Bay	0	0.07

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