Water Quality Conditions on the Williamson River Delta, Oregon: One Year Post-Restoration

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EXECUTIVE SUMMARY

This report summarizes results from The Nature Conservancy's first full year of water quality monitoring on the Williamson River Delta (the Delta) following restoration in fall 2007. The primary objective of water quality monitoring on the Delta is to quantitatively and qualitatively describe the effects of the restoration on nutrient, chlorophyll *a*, and water chemistry dynamics within and surrounding the Delta. From April to November 2008, surface water grab samples were collected for nitrogen and phosphorus at 27 sites; carbon and chlorophyll *a* samples at 15 sites; and continuous physical water chemistry parameters including temperature, dissolved oxygen, pH, and specific conductance at 8 sites within and surrounding the Delta. Sampling sites were stratified by predicted wetland types across the Delta based on differences in water depth ranges and associated wetland plant communities (transitional, emergent, deep water, and open water wetlands).

Phosphorus concentrations measured within the Delta in comparison with concentrations in adjacent lake and river locations indicate higher concentrations of phosphorus within the Delta due to a possible release of phosphorus from previously drained wetland soils as well as from decomposition of existing plant material. Sustained low dissolved oxygen concentrations (< 4mg/L) during the summer in deep water wetland demonstrate the importance of these decomposition processes on surface water chemistry within the Delta. Seasonal changes in nitrogen concentrations in open and deep water locations were closely linked to the bloom and crash dynamics of the cyanobacteria, *Aphanizominon flos-aquae* (AFA). Seasonal declines in dissolved oxygen concentrations were also observed in relation to crashes in AFA. Higher dissolved organic carbon concentrations did not correlate with lower algal abundance as represented by chlorophyll *a* concentrations. However, it is yet to be determined whether particular wetland locations provide a greater diversity of algal speciation.

Continuous physical water chemistry monitoring demonstrated differences between wetland types within the Delta and surrounding water bodies. Lake sites had longer periods of high pH conditions compared to wetland sites, and wetland sites experienced a more prolonged period of low dissolved oxygen concentrations. Specific conductance values were generally higher at wetland sites compared to lake and river sites and reflected the influences of water depth and inflowing lake and river waters.

These initial results from water quality monitoring on the Delta provide a baseline for assessing how restoration of the Williamson River Delta will affect surface water quality in the longer term, and ultimately help to determine whether restoring wetlands is a practical strategy for improving water quality in Upper Klamath Lake.

INTRODUCTION

The Williamson River Delta Restoration Project is a large (~5,000 acre) ongoing wetland restoration effort initiated by The Nature Conservancy (TNC) in 1996. The Williamson River Delta (the Delta) is located at the mouth of the Williamson River in the Upper Klamath Basin of southern Oregon and is situated adjacent to Upper Klamath and Agency Lakes (Figure i). The project area straddles the last four miles of the Williamson River before the river empties into Upper Klamath Lake. The Delta was historically a fully functional freshwater marsh ecosystem and probably provided a substantial nutrient sink for the Sprague and Williamson River watersheds, which account for about 50% of the inflow to Upper Klamath Lake. In the 1940s, the Delta was reclaimed for agricultural purposes. The entire perimeter of the Delta was diked and became hydrologically disconnected from the lake and river. The Delta was intensively farmed for crops such as potatoes, alfalfa, and barley until the late 1900s. In 2000 and 2003, early action projects were carried out by TNC which involved the breaching of levees to restore hydrologic connection between several small portions of the Delta wetland and Upper Klamath Lake, Agency Lake, and the Williamson River (David Evans and Associates, Inc. 2005). In fall 2007 and again in fall 2008, larger scale restoration occurred with the breaching of levees surrounding the perimeter of the Delta.

The Williamson River Delta Restoration Project is part of a wide-ranging, ongoing restoration effort in the Upper Klamath Basin to restore wetlands surrounding Upper Klamath and Agency Lakes. It is estimated that more than 20,000 acres of wetlands surrounding Upper Klamath Lake have been drained and converted for agricultural purposes since 1885 (Snyder and Morace 1997, National Research Council 2004). Upper Klamath Lake is currently classified as hyper-eutrophic. Increased nutrients in the lake have contributed to severe monocultural blooms of the cyanobacteria *Aphanizomenon flos-aquae* (AFA), which dominate the lake each spring and summer. Poor water quality in the lake, including depleted oxygen levels, high pH, and high un-ionized ammonia concentrations are associated with the bloom and crash dynamics of AFA. One of the consequences of poor water quality conditions and the loss of wetland habitats has been the decline and listing of two endangered fish species which are endemic to the Upper Klamath Basin – Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*). With the degradation of water quality in Upper Klamath Lake and listing of the two endangered fish species, large and small scale wetland restoration projects around Upper Klamath and Agency Lakes have been initiated by different agencies.

The two fundamental goals of the Williamson River Delta Restoration Project are to help improve water quality in Upper Klamath Lake and provide and improve habitat for larval and juvenile Lost River and shortnose suckers. Although restoring wetlands is regarded as an important and viable conservation strategy for retaining nutrients and improving downstream water quality (Mitsch and Gosselink 1993, Gearhart et al. 1995), the capacity of restored wetlands to sequester nutrients is uncertain (Fisher and Acerman 2004). For example, a study has shown that restoration wetlands on former agricultural land release nutrients upon initial flooding (Aldous et al. 2007). In order to assess the effectiveness of the wetland restoration as a strategy for improving water quality, a multi-year water quality monitoring project was designed by TNC and project collaborators to quantitatively and qualitatively describe the effects of the restoration on nutrient, chlorophyll *a*, and water chemistry dynamics within and surrounding the Delta. Long-term water quality monitoring on the Delta addresses the following fundamental questions: (1) to what extent do the Delta wetlands provide a source or sink of nutrients; (2) what are the effects of the restoration on water quality in Upper Klamath Lake and *vice versa*; (3) what are the effects of water quality on sucker inhabitance of the Delta wetland. Results from water quality monitoring can be used as a baseline to identify changes in water chemistry that will occur over the longer term as important wetland ecosystem processes are restored to the system. These results can also be used in support of larval and juvenile sucker monitoring efforts in areas within the Delta wetland and on the wetland fringe, where suckers are found.

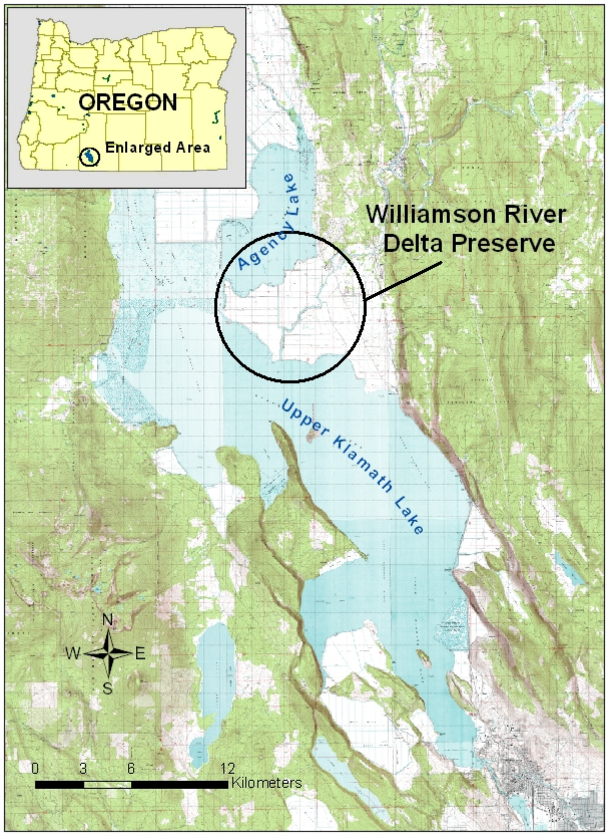

Figure i. Map location of the Williamson River Delta Preserve in southern Oregon

This report highlights results of TNC's first full year of water quality monitoring on the Delta and is divided into two major chapters: (1) surface water grab sample collection for nitrogen, phosphorus, carbon, and chlorophyll *a*, and (2) continuous physical water chemistry monitoring including temperature, dissolved oxygen, pH, and specific conductance.

STUDY AREA DESCRIPTION

Hydrology

On October 30, 2007, levees surrounding the northern half of the Delta, formerly known as Tulana Farms, were breached at seven strategic locations to hydrologically reconnect Upper Klamath and Agency Lakes and the Williamson River to the Delta wetland. Breach locations were based on hydrologic modeling conducted by the U.S. Bureau of Reclamation, which determined the minimum number and location of breaches required for optimal reconnection of the Delta and surrounding water bodies (Daraio et al. 2004). Four breaches ranging approximately 2,100-2,700 ft in length are located on the northern and southwest perimeter of the Delta in Agency and Upper Klamath Lakes, and three breaches ranging approximately 500-1,700 ft in length are located on the Williamson River. Levees between breaches were lowered to an elevation between 4,139 and 4,142 ft, thus allowing water movement over the remaining levees for part of the year. In total, about 3,500 acres of the Delta wetland were flooded at high water level. On November 18, 2008, restoration continued with the breaching of levees surrounding the southern half of the Delta, known as Goose Bay. Three breaches, ranging approximately 1,000-3,000 ft in length occur on the southern end of Goose Bay, and three main breaches occur along the southern/eastern side of the river within the project area. This report focuses on water quality monitoring results from the northern half of the Delta (Tulana).

Repeated draining and flooding of the land during cultivation resulted in the subsidence of soils on large portions of the Delta due to organic matter decomposition and compaction. In the western portion of the Delta, substantial subsidence has occurred such that elevations are currently up to eight feet below average lake levels (David Evans and Associates, Inc. 2005) (Figure ii). Largely as a result of subsidence, those areas are currently inundated year-round, resembling open water conditions. Portions of the Delta nearer the Williamson River resemble more marsh and riparian-like conditions.

Water depths within the Delta vary seasonally as well as spatially. Surface water levels, regulated by the U.S. Bureau of Reclamation, vary by approximately five feet through the year, with high surface water elevations at about 4,143 ft in spring and low water level elevations at about 4,138 – 4,139 ft by fall. At low water levels, typically during late summer to late fall, the majority of flow through the Delta from Agency and Upper Klamath Lakes occurs through the four levee breaches on the northern half of the Delta. Wetland areas receiving water from the Williamson River are largely cut off from the river during this time. At high water levels, typically during spring, lake waters flow across vast portions of the Delta, and wetland areas along the river are flooded. The overall effect is seasonal flooding and drying of marsh and riparian wetland areas along the Williamson River and eastern portions of the Delta, and year-round inundation of areas on the western portions.

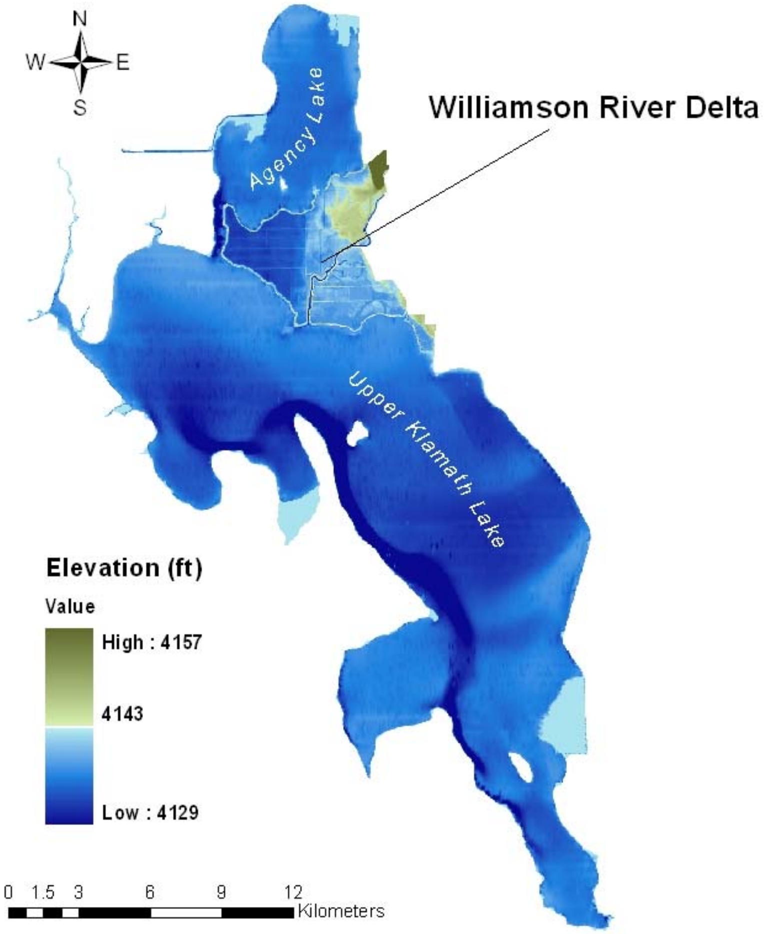

Figure ii. Surface water elevations of Agency and Upper Klamath Lake and the Williamson River Delta illustrating subsidence on the western portion of the Delta. Green depicts elevations within the Delta above high water mark (>4143 ft).

Vegetation and Soils

Vegetation cover also varies throughout the Delta. Inundated areas of the Delta currently consist of pre-existing upland vegetation that colonized the former agricultural fields (now decomposing), pre-existing crop stubble from former agricultural parcels, and seasonal wetland vegetation. Because periodic flooding of agricultural fields prior to the restoration allowed wetland species to establish on portions of the Delta, these now permanently submerged areas also consist of pre-existing wetland vegetation, some of which are now decomposing. As of 2003, over 100 plant species were identified on the Williamson River Delta Preserve which included 80 native species and 38 introduced species (Elseroad 2004). Emergent and submerged macrophytes currently present within the Delta include hardstem bulrush (*Schoenoplectus acutus*), water smartweed (*Polygonum amphibium*), creeping spike-rush (*Eleocharis palustris*), and common mare's tail (*Hippuris vulgaris*), among many others. Exotic plant species were also present prior to restoration and included Canadian thistle (*Cirsium arvense*), stinging nettle (*Urtica dioica*), and golden dock (*Rumex maritimus*).

Approximately seven different soils series are found on the Delta. The dominant soil types include Lather muck and Tulana silt loam. Lather muck soils are poorly drained organic soils found in lower elevations of the Delta on the western side. Silt loam soils are mineral soils found at higher elevations of the Delta nearer the Williamson River.

Stratification of Monitoring Sites

Surface water grab samples and physical water chemistry parameters were collected on the northern half of the Delta and surrounding water bodies in 2008. Sample sites within the Delta were selected based on predicted wetland type and water movement patterns across the Delta. Predicted wetland types were established based on estimated surface water elevations of the Delta once restored and the potential wetland plant communities found within those specific depth ranges (Elseroad 2004). A hydrodynamic circulation model developed by the U.S. Geological Survey (USGS) was used to predict water flow patterns through the Delta (T. Wood, USGS, personal communication). The predicted wetland types are, from shallowest to deepest: transitional wetland; emergent wetland; deep water wetland; and open water wetland (Elseroad 2004). The two distinct vegetative wetland types include transitional wetland and emergent wetland which occur on the eastern half of the Delta nearer the Williamson River. The two less-vegetative wetland types consist of deep water and open water and occur toward the western half of the Delta. Mean seasonal water depths for transitional, emergent, deep water, and open water wetland types in 2008 were respectively 0.5 m, 0.94 m, 2.01 m, and 2.53 m.

CHAPTER 1: SURFACE WATER GRAB SAMPLE COLLECTION

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METHODS

Site Selection

In total, 27 sites within and surrounding the Delta were selected for grab sample collection. Twenty sites occur within the Delta (five in each wetland type). Seven sites occur in water bodies surrounding the Delta. These include three in the Williamson River: one upstream of the project area (~RM 2.5); one near the river mouth (~RM 0.2); and one between the other two river sites (~RM 0.8). The other four sites occur in near-shore areas of Upper Klamath Lake surrounding the Delta: one in Goose Bay, south and east of the river mouth; one in Upper Klamath Lake between Agency Straits and the river mouth; one in Agency Straits; and one in Agency Lake. A map of grab sample sites is provided in Figure 1.1.

Sample Collection

Analytes from the surface grab samples included several constituents of phosphorus [orthophosphate (PO_4-P) and total phosphorus (TP)] and nitrogen [nitrate-nitrogen (NO_3-N)+nitrite-nitrogen (NO_2-N), ammonium nitrogen (NH_4-N), and total nitrogen (TN)] as well as carbon [dissolved organic carbon (DOC) and total organic carbon (TOC)], chlorophyll *a*, and algal speciation.

Nitrogen and phosphorus samples were collected at all 27 sampling sites within and surrounding the Delta during a total of 14 sampling events from April to November 2008. Carbon, chlorophyll *a*, and algal speciation samples were collected at 15 of the 27 sites during 12 sampling events, although algal speciation samples are not discussed in detail in this report (the data were not completely available at time of writing). Transitional and emergent wetland sites were only inundated seasonally and therefore samples were only collected when sufficient water was present at the site. A

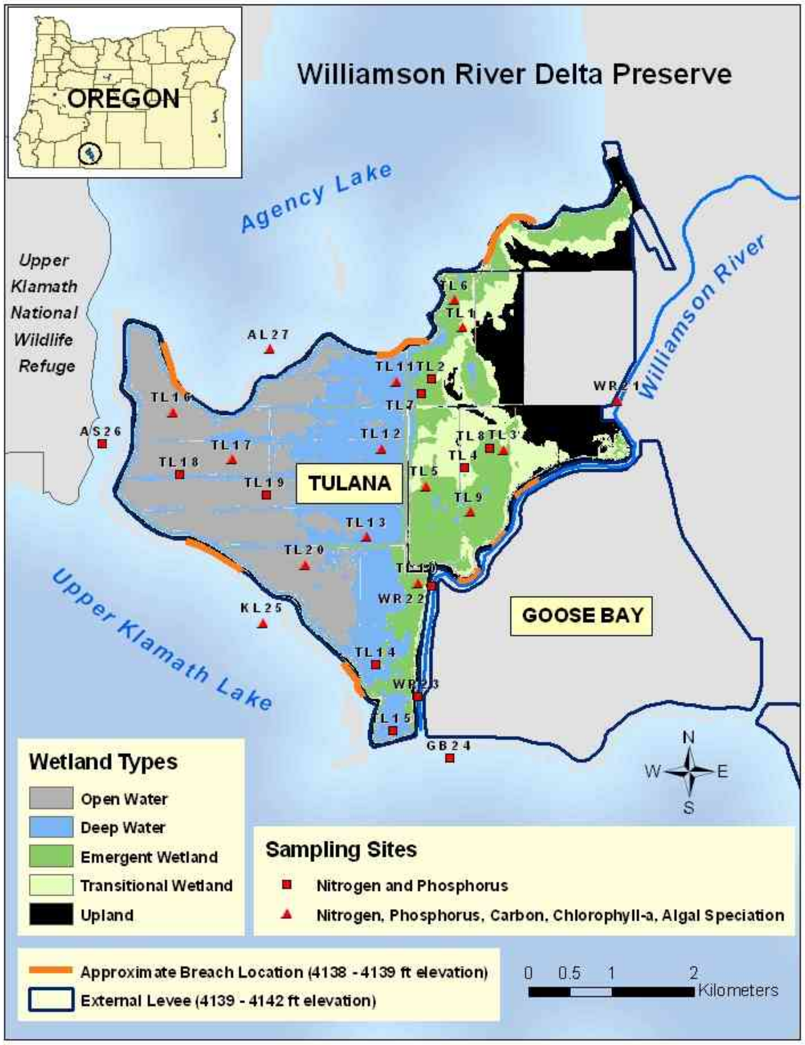

Figure 1.1. Map of the Williamson River Delta, Oregon showing predicted wetland types and grab sample collection sites sampled from April – November, 2008.

map of the sampling area showing predicted wetland types and sampling sites is presented in Figure 1.1. Table 1.1 lists the parameters collected at each individual site.

Other site parameters such as water depth, water transparency (measured with a secchi disk), density of surface algal bloom measured on a 0 – 5 scale, and presence or absence of vegetation was recorded at all 27 sampling sites during grab sample collection. Water temperature, pH, specific conductance, and dissolved oxygen concentration (DO) were also measured instantaneously at each site using a water quality multi-probe, YSI 600 XLM.

Water was collected at mid-depth and 0.5 meters below the water surface. For sites that were less than one meter deep, water was collected at mid-depth in the water column. For sites that were greater than two meters deep, water was collected at one meter and 0.5 meters below the surface. Water was collected from both depths using a 3.2 liter horizontal beta sample collection device (Van Dorn) and homogenized using an eight liter churn splitter. All constituents (nitrogen, phosphorus, chlorophyll *a*, and carbon) were measured from the same churn splitter with the exception of samples collected on June 18 and 20. Samples reported during one sampling week were collected over a consecutive two day period. After each sampling day the Van Dorn was rinsed with 500 mL of dilute hydrochloric acid, rinsed five times with DI water, and stored with DI water. The churn splitter was also rinsed after each sampling day with 500 mL of dilute hydrochloric acid and DI water, air dried, and stored in a plastic bag. Grab sample precision and accuracy was assessed by collecting equipment and laboratory blanks, splits at 10% of the total number of samples, and duplicate samples at least once per sampling event. Number of quality control samples, reporting levels, and collection descriptions are included in Appendix B and follow methods described in the Williamson River Delta Water Quality Monitoring Project Plan (The Nature Conservancy 2007).

Approximately 120 mL of unfiltered water to be analyzed for TN and TP were transferred to triple rinsed amber polyethylene bottles and acidified with 1 mL of 4.5N H_2SO_4 immediately after collection. Samples for NO_3+NO_2, NH_4, and PO_4 were filtered prior to analysis using a vacuum pump, 300 mL magnetic filter funnel (Pall Gelman ®), and 47 mm 0.45 µm sterile membrane filters (Millipore®). All nitrogen and phosphorus samples were stored at 4°C (+/-2°C) for no longer than 28 days. Total organic carbon and chlorophyll *a* samples were acidified with 4.5N H_2SO_4 and shipped on ice overnight to the respective laboratories. Dissolved organic carbon samples were also shipped on ice overnight and were filtered prior to analysis by the laboratory.

Laboratory Analysis

Whole, unfiltered water for TP and TN analysis was digested using potassium persulfate, autoclaved, and run through an automated spectrophotometer at the Klamath Tribe's Sprague River Water Quality Laboratory in Chiloquin, OR. All other nitrogen and phosphorus analyses were completed using the colorimetric method on the same automated spectrophotometer. Carbon samples were sent to Basic Laboratory in Redding, CA and analyzed using the persulfate-ultraviolet oxidation method. Chlorophyll *a* analysis was conducted by Aquatic Research, Inc. in Seattle, WA. Refer to Appendix A for standard method numbers as well as reporting and detection limits.

Table 1.1. Table of sampling sites and corresponding constituents.

Site ID	Location	Nitrogen	Phosphorus	Carbon	Chlorophyll *a*	Algal Speciation*
		April-November		April-October	May-October	
		14 events		12 events	12 events	
TL1	Transitional Wetland	X	X	X	X	X
TL2	Transitional Wetland	X	X			
TL3	Transitional Wetland	X	X	X	X	X
TL4	Transitional Wetland	X	X			
TL5	Transitional Wetland	X	X	X	X	X
TL6	Emergent Wetland	X	X	X	X	X
TL7	Emergent Wetland	X	X			
TL8	Emergent Wetland	X	X			
TL9	Emergent Wetland	X	X	X	X	X
TL10	Emergent Wetland	X	X	X	X	X
TL11	Deep Water Wetland	X	X	X	X	X
TL12	Deep Water Wetland	X	X	X	X	X
TL13	Deep Water Wetland	X	X	X	X	X
TL14	Deep Water Wetland	X	X			
TL15	Deep Water Wetland	X	X			
TL16	Open Water Wetland	X	X	X	X	X
TL17	Open Water Wetland	X	X	X	X	X
TL18	Open Water Wetland	X	X			
TL19	Open Water Wetland	X	X			
TL20	Open Water Wetland	X	X	X	X	X
WR21	Williamson River (N. of Delta)	X	X	X	X	X
WR22	Williamson River (RM ~ 1.2)	X	X			
WR23	Williamson River (RM ~ 0.2)	X	X			
GB24	Upper Klamath Lake (E. of Williamson River)	X	X			
KL25	Upper Klamath Lake (W. of Williamson River)	X	X	X	X	X
AS26	Agency Straits	X	X			
AL27	Agency Lake	X	X	X	X	X

* Algal speciation samples were collected but not reported.

Data Analysis

Results from nitrogen, phosphorus, and carbon analyses are reported if they occurred above the reporting limit or between the reporting limit and detection limit. Concentrations less than the detection limit were reported at half the detection limit value. Reporting and detection limits for all constituents can be found in Appendix A. Un-ionized ammonia concentrations were calculated based on water temperature and pH collected concurrently with the sample and were determined using an equation provided by the USGS (T. Wood, USGS, personal communication). SAS® statistical software, version 9.1.3 (SAS® Institute 2004), was used for all data analysis including means, standard errors, and tests for significance.

Seasonal trends in mean nutrient concentrations were compared across the four wetland types, lake, and river locations. Carbon and chlorophyll *a* samples were only collected at one site in the Williamson River and therefore single values are reported.

PROC MIXED in SAS® (SAS® Institute 2004) was used for repeated measures analysis to compare the mean nutrient concentrations by location for two time intervals, events 1-7 and 8-14. Transitional and emergent locations were excluded from the comparisons for the second time interval, as these locations were not sampled past mid-July due to insufficient water levels. Comparison-wise (uncorrected) *p*-values were used to determine significance ($\alpha = 0.05$), as this analysis is considered to be primarily exploratory (Roback & Askins 2005).

PROG REG analysis was used to model the linear relationship between orthophosphate and dissolved organic carbon over all habitats, and assumptions of normality and homogeneous variances was assessed with residual plots. Preliminary analysis indicated that the assumption of linearity was best met with the model: $LN(PO_4) = Intercept + DOC$, where LN is the natural log transformation. Due to limited replication within each habitat, individual event samples were used as replicates instead of using the mean value for each replicate over events. Because observations within a replicate at consecutive time intervals may be more similar than observations among habitats, observations may not be independent, which could lead to an inflated Type I error (concluding the hypothesis is true when it is actually false). However, analysis for a subset of habitats with higher replication indicated similar results using all event samples and means over events.

RESULTS

A total of 320 phosphorus and nitrogen, 147 chlorophyll *a*, 153 total organic carbon, and 148 dissolved organic carbon samples were collected from April to November 2008 within the Delta and adjacent water bodies. The results are described seasonally and spatially across wetland types and adjacent water bodies, and factors potentially driving water chemistry differences during the first sampling season are explored. Minimum and maximum concentrations for each sampled constituent are shown in Table 1.2.

Seasonal Trends

Phosphorus. Orthophosphate concentrations were highest in transitional wetlands and second highest in emergent wetlands during nearly all sampling events with specific values ranging from 0.045 to 1.68 mg/L for these two locations (Figure 1.2; Table 1.2). Emergent and transitional wetlands had the highest reported mean orthophosphate concentrations during every sampling event compared to all other locations and peaked at 0.714 and 0.742 mg/L for transitional and emergent wetlands, respectively. Trends in orthophosphate in open and deep water followed a similar pattern and specific values ranged from 0.006 to 0.77 mg/L. Mean orthophosphate concentrations in open and deep water wetlands were higher than 0.3 mg/L from August 18 to October 22, peaked at 0.6 mg/L, and then dropped to 0.24 mg/L in November. Mean orthophosphate in lake and river peaked at 0.262 mg/L and 0.142 mg/L, respectively (Figure 1.2). Seasonal trends in total phosphorus within wetlands and lake were very similar to the trends in orthophosphate concentrations, as orthophosphate concentrations made up an average of 71%

Table 1.2. Minimum and maximum concentrations for grab sampling constituents from April – November 2008 within and surrounding the Williamson River Delta, Oregon. Chlorophyll a is reported in µg/L; all other constituents are reported in mg/L.

	TN		TP		NO2+NO3		NH4		PO4	
Location/Site	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Transitional	0.450	4.130	0.086	1.410	0.004	0.013	0.003	0.393	0.052	1.220
Emergent	0.155	5.240	0.073	1.510	0.004	0.034	0.011	1.140	0.045	1.680
Deep Water	0.451	8.710	0.087	1.070	0.004	0.375	0.014	1.570	0.006	0.770
Open Water	0.483	9.340	0.070	1.050	0.004	0.400	0.014	0.555	0.042	0.724
Williamson River	0.100	1.430	0.066	0.229	0.004	0.040	0.006	0.194	0.045	0.196
Goose Bay	0.191	2.110	0.066	0.403	0.004	0.040	0.013	0.288	0.050	0.290
Upper Klamath Lake	0.487	3.320	0.056	0.392	0.004	0.249	0.012	0.414	0.021	0.224
Agency Straits	0.605	2.880	0.062	0.463	0.004	0.201	0.017	0.430	0.019	0.271
Agency Lake	0.518	3.310	0.054	0.567	0.004	0.228	0.011	0.304	0.030	0.344

	TOC		DOC		Chlorophyll a	
Location/Site	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**
Transitional	6.3	22.2	6.5	22.0	2.0	250.0
Emergent	5.4	16.6	6.0	13.4	3.7	287.5
Deep Water	5.4	23.1	5.4	15.7	1.0	750.0
Open Water	4.1	84.7	4.0	14.7	3.7	964.0
Williamson River	1.2	7.6	0.7	7.7	0.5	14.0
Upper Klamath Lake	3.7	14.1	3.5	10.8	6.0	331.0
Agency Lake	4.1	13.2	6.0	9.6	4.3	289.0

(+/- 17%) of the total phosphorus concentration in wetlands and 59% (+/- 15%) at lake locations. Mean total phosphorus concentrations were again highest in transitional and emergent wetlands, and ranged from 0.082 to 1.02 mg/L (Figure 1.2). With the exception of the first sampling event, mean total phosphorus concentrations in lake and river locations were always lower than wetland locations and ranged from 0.079 to 0.412 mg/L in the lake and 0.068 to 0.172 mg/L in the river.

Nitrogen. Concentrations of total nitrogen ranged from 0.155 to 9.34 mg/L across all wetland sites, 0.19 to 3.32 mg/L in lake sites, and 0.10 to 1.43 mg/L in river sites, with seasonal means depicted in Figure 1.2. Averaged over the entire sampling period, ammonia and nitrate + nitrite only accounted for approximately 7 – 11% of the total nitrogen in wetland and lake locations. Mean concentrations of ammonia within wetlands increased throughout the month of July and August and values ranged from 0.0135 to 0.64 mg/L over the entire sampling period. Mean ammonia within lake sites peaked in October at 0.223 mg/L and mean ammonia in the river was below 0.09 mg/L over the entire sampling period (Figure 1.2). Unionized ammonia concentrations were below 0.06 mg/L except at three individual wetland sites that had one-time unionized ammonia concentrations between 0.06 and 0.16 mg/L. Mean nitrate + nitrite values

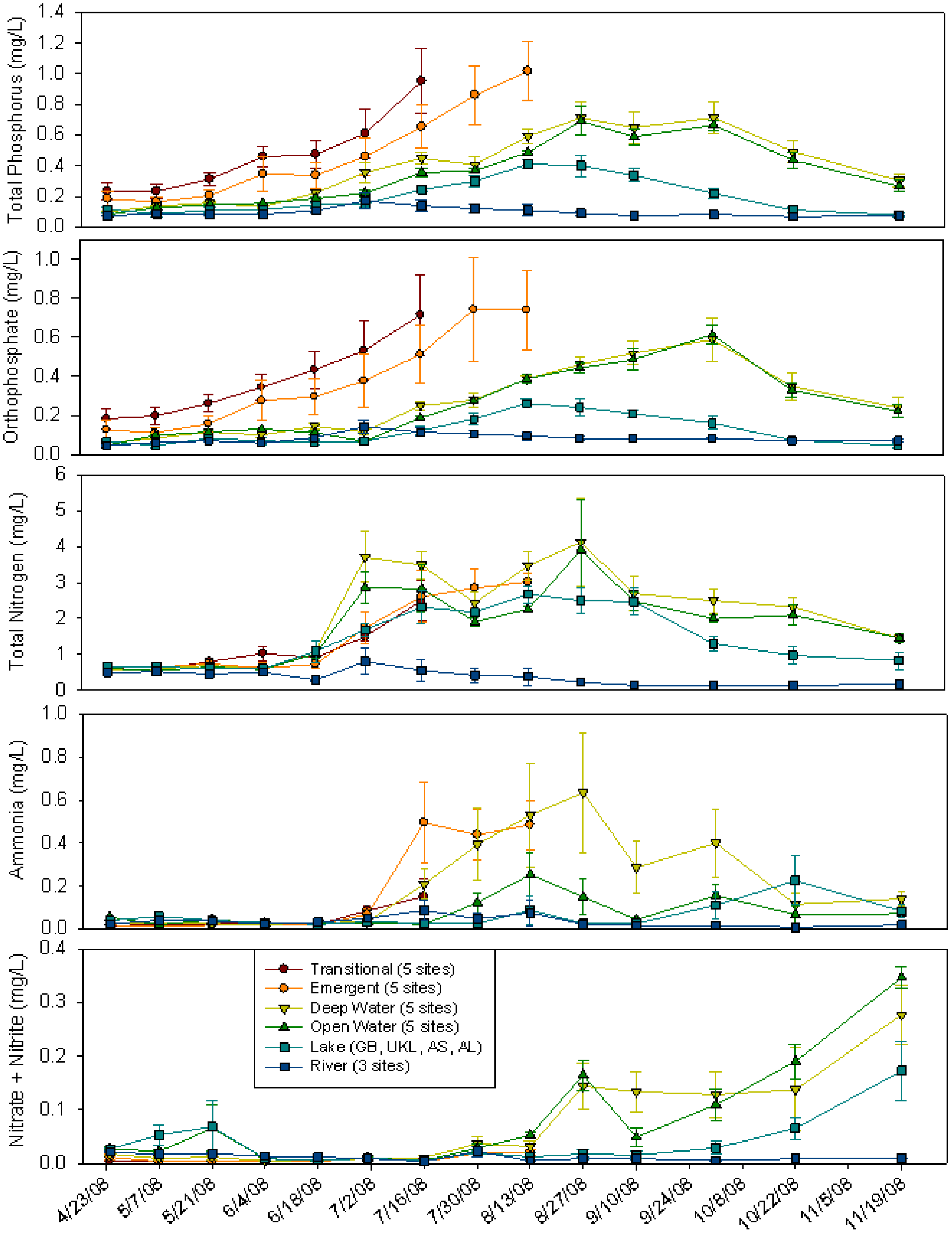

Figure 1.2. Seasonal trends in total phosphorus, orthophosphate, total nitrogen, ammonia, and nitrate + nitrite concentrations from April – November 2008 within and surrounding the Williamson River Delta. Shown are means (± standard error) within each location by sampling event.

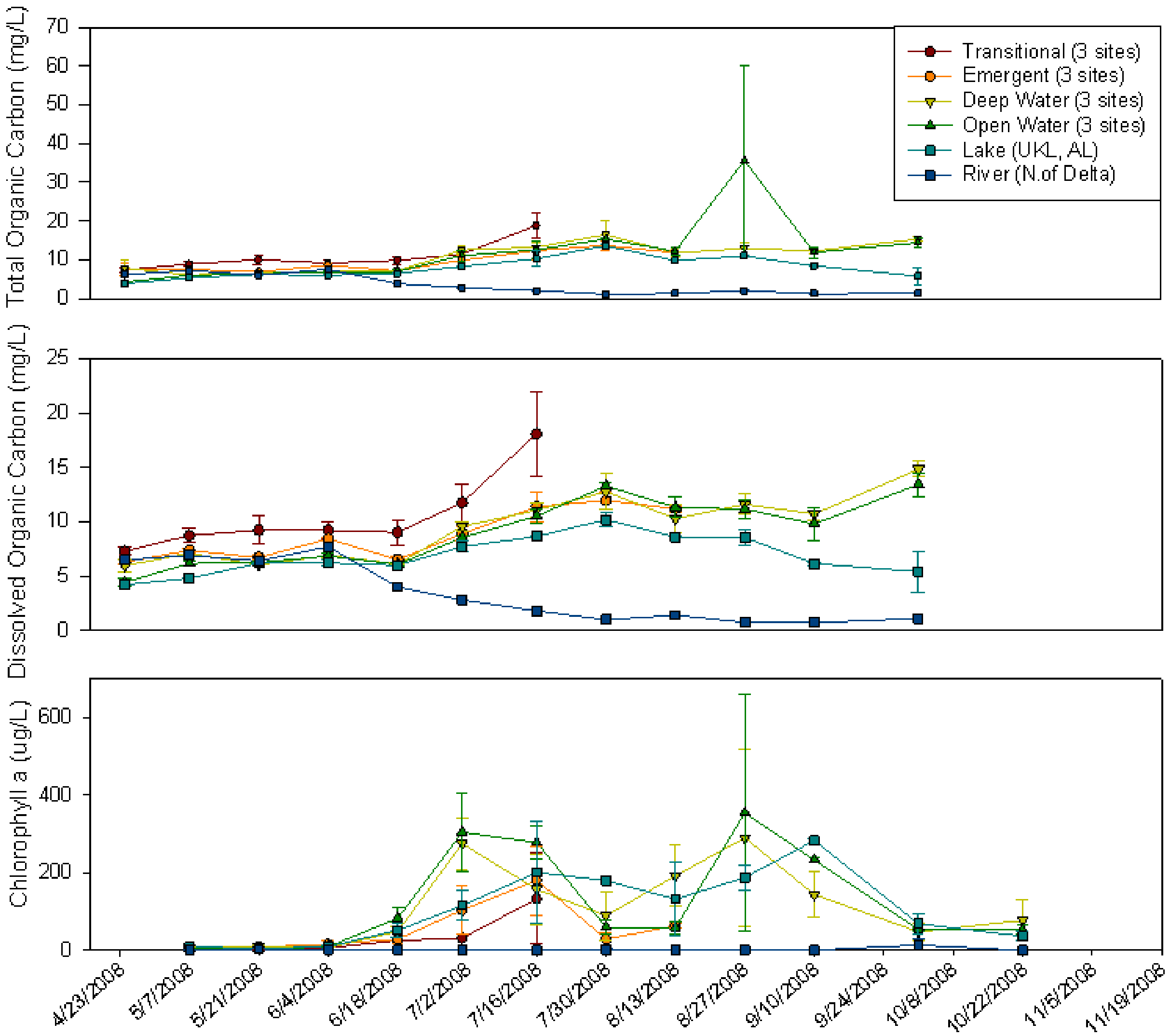

Figure 1.3. Seasonal trends in total organic carbon, dissolved organic carbon, and chlorophyll *a* concentrations from April – November 2008 within and surrounding the Williamson River Delta. With the exception of the Williamson River, which only had one sampling site for carbon and chlorophyll *a*, values are means (± standard error) within each location by sampling event.

were less than 0.1 mg/L for all sampling locations until mid-August when open, deep, and lake sites increased and peaked in November at 0.277 mg/L, 0.346 mg/L, and 0.172 mg/L, respectively (Figure 1.2).

Carbon. Total organic carbon in the Williamson River, upstream of the Delta, ranged from 1.19 to 7.6 mg/L with concentrations decreasing over the sampling season (Figure 1.3). Dissolved organic carbon made up approximately 93% of the total organic carbon in the river during the sampling season. Total organic carbon at lake sites ranged from 3.7 to 14.1 mg/L and dissolved organic carbon accounted for approximately 89% of the total organic carbon. Wetland sites ranged from 4.1 to 84.7 mg/L for total organic carbon and 4.0 to 15.7mg/L for dissolved organic carbon, with dissolved organic carbon comprising 90.4% of the total organic carbon, excluding one anomaly. The anomaly occurred on August 27 in open water when only 13.5% of the total organic carbon was in the dissolved fraction. Trends in dissolved organic carbon at all sampling locations were similar from April to early June. After early June, sites within wetlands and the lake increased in dissolved organic carbon while concentrations in the river decreased. Transitional wetlands had the highest mean concentration of dissolved organic carbon at 18.1 mg/L in mid-July (Figure 1.3).

Chlorophyll *a*. Seasonal variations in chlorophyll *a* are shown in Figure 1.3. The figure shows low mean concentrations at sampling onset, higher mean concentrations from June through September, and then lower concentrations again in October. Mean chlorophyll *a* concentrations in transitional and emergent wetlands were lower than mean lake values for all sampling

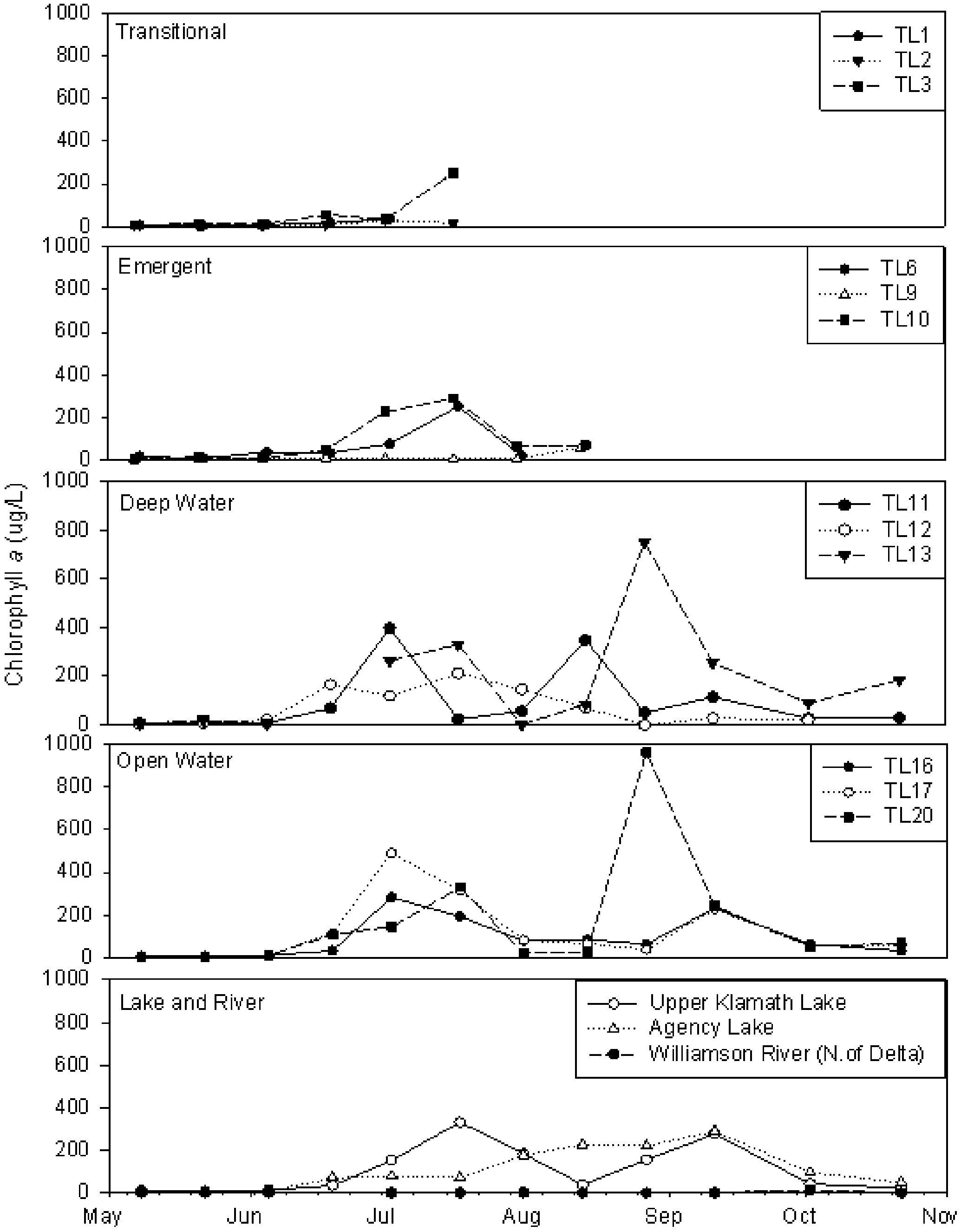

Figure 1.4. Seasonal trends in chlorophyll *a* concentrations for all sampling sites within each sample location within and surrounding the Williamson River Delta, May – November 2008.

events after June 4 (Figure 1.3). There was a strong seasonal component in deep, open, and lake locations which all showed two seasonal peaks in chlorophyll *a* concentrations – the first peak in mid-July and the second peak in late August. During particular sampling events, site specific variability was observed in all wetland types, as evidence by the large standard error bars (Figure 1.3) and variability within locations (Figure 1.4). Peak chlorophyll *a* concentrations during the sampling season for each location included: 14 µg/L in river, 331 µg/L in lake, 964 µg/L in open water, 750 µg/L in deep water, 288 µg/L in emergent wetlands, and 250 µg/L in transitional wetlands (Figure 1.4). The extent to which chlorophyll *a* concentrations reflect AFA biomass still needs to be analyzed. For example, at transitional wetland site TL3 on July 16, the chlorophyll *a* concentration was 250 µg/L, the highest reported value in transitional wetland, however, AFA only made up 0.9% of the total algal biovolume. Instead of AFA, several other species (*Euglena sp.* and *Craticula sp.*) comprised the highest biovolume (TNC unpublished data).

Instantaneous Water Chemistry. Mean dissolved oxygen concentrations within wetland sites ranged from 2.03 to 11 mg/L, varying seasonally, with lows occurring at the end of July (Figure 1.5). In general, mean dissolved oxygen was higher in the lake and river than in wetland. The lowest mean dissolved oxygen concentrations were found in transitional and emergent wetlands. Mean pH values for all wetland types peaked in the beginning of July. In transitional and emergent wetlands pH ranged from 7-8.5 over the entire sampling season. Higher pH values were found in open and deep water wetlands with peak mean values around 9.59. Lake pH increased along with open and deep water wetlands, but remained high from the end of July through September with a peak mean pH value of 9.57 (Figure 1.5). Specific conductance values in emergent marsh and transitional wetlands were higher than open and deep water wetlands during the majority of the sampling season, with values ranging from 71 to 396 µS/cm compared to 75 to 197 µS/cm in open and deep water wetlands. Specific conductance values were generally lower in the lake and river, with mean values ranging from 75 to 105 µS/cm (Figure 1.5). Mean temperature within wetlands was similar during each sampling event, except the shallower transitional and emergent wetland were slightly warmer than deep and open water from late June to early July. The Williamson River stayed cooler than the other locations from mid June to the end of the sampling period. Maximum and minimum temperatures within the Delta ranged from 5.05 to 27.73°C and peaked at the end of June (Figure 1.5).

Differences between Wetland Types and Adjacent Water Bodies

In addition to seasonal trends, differences in mean nutrient concentrations between the wetlands, lake, and river were also examined. The first seven sampling events were combined (April through mid-July), when all sampling locations were inundated, and the last seven sampling events were combined (mid-July through November), and analyzed separately (transitional and emergent wetlands were not sampled during the last seven sampling events). Box plots (Figures 1.6 & 1.7) show the interquartile range, median (solid horizontal line), mean (dotted line), whiskers (10% and 90% percentiles), and outliers (5% and 95%, indicated by dots).

Nitrogen. Mean total nitrogen concentrations were significantly higher in wetland sites compared to the Williamson River during events 1-7 (April to July) and

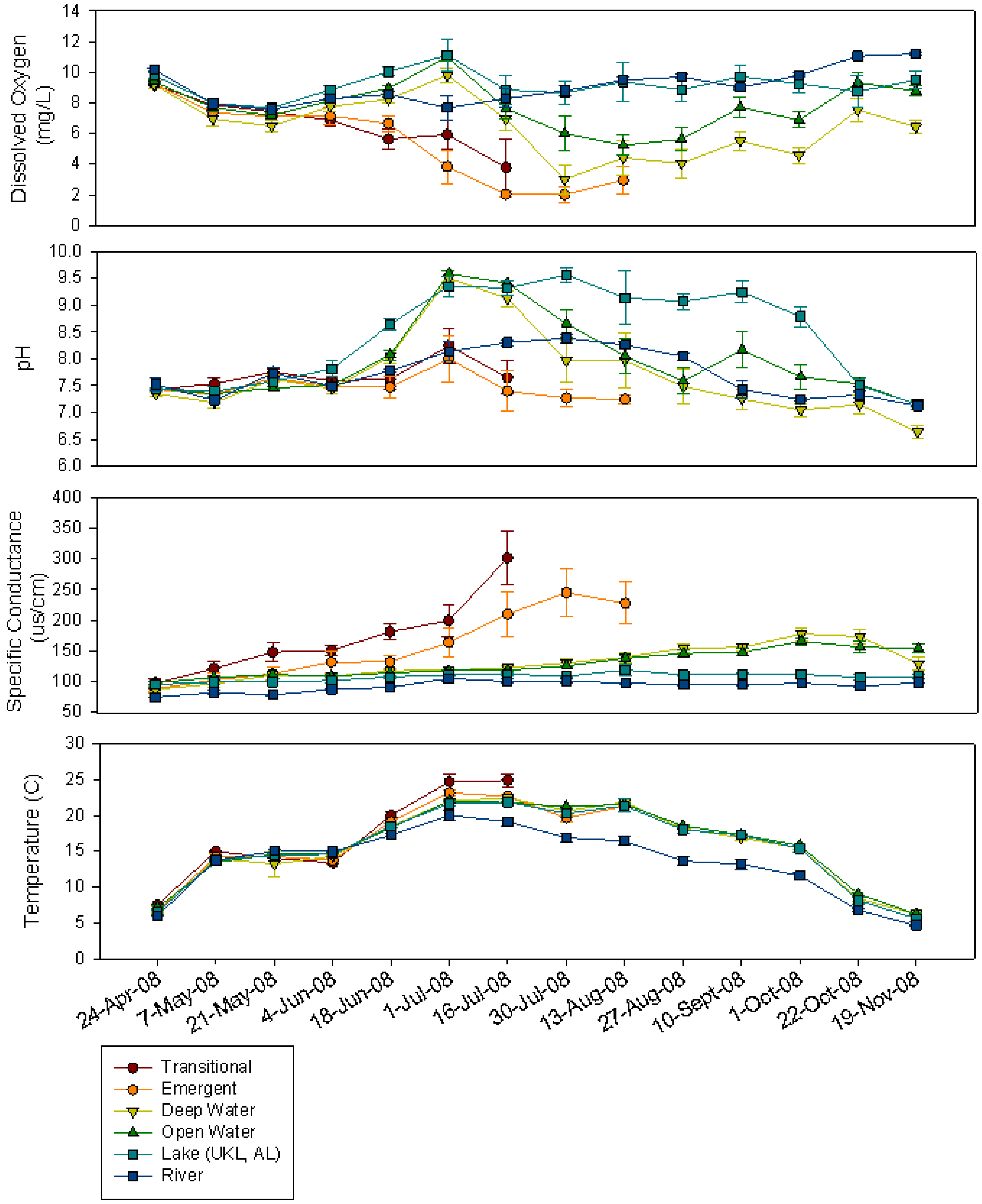

Figure 1.5. Seasonal trends in in-situ water chemistry parameters – dissolved oxygen, pH, specific conductance, and temperature – collected concurrently with each grab sample event from April to November 2008 at locations within and surrounding the Williamson River Delta. Values are means (± standard error) within locations for each sampling event.

events 8-14 (July to November) (Figure 1.6). Total nitrogen concentrations during events 1-7 were not significantly different between all four wetland types and the lake. From July to November, deep and open water locations had significantly higher total nitrogen than the lake and also significantly higher concentrations than the Williamson River. In general, total nitrogen, ammonia, and nitrate + nitrite concentrations were higher during the second half of the season, events 8-14, than the first half, except in the river (Figure 1.6). Ammonia concentrations did not vary by location during April to mid-July (events 1-7). After mid-July, mean ammonia concentrations were significantly higher in deep water wetland than open water wetland, lake, and river. Nitrate + nitrite concentrations during events 1-7 were significantly lower in emergent, transitional,

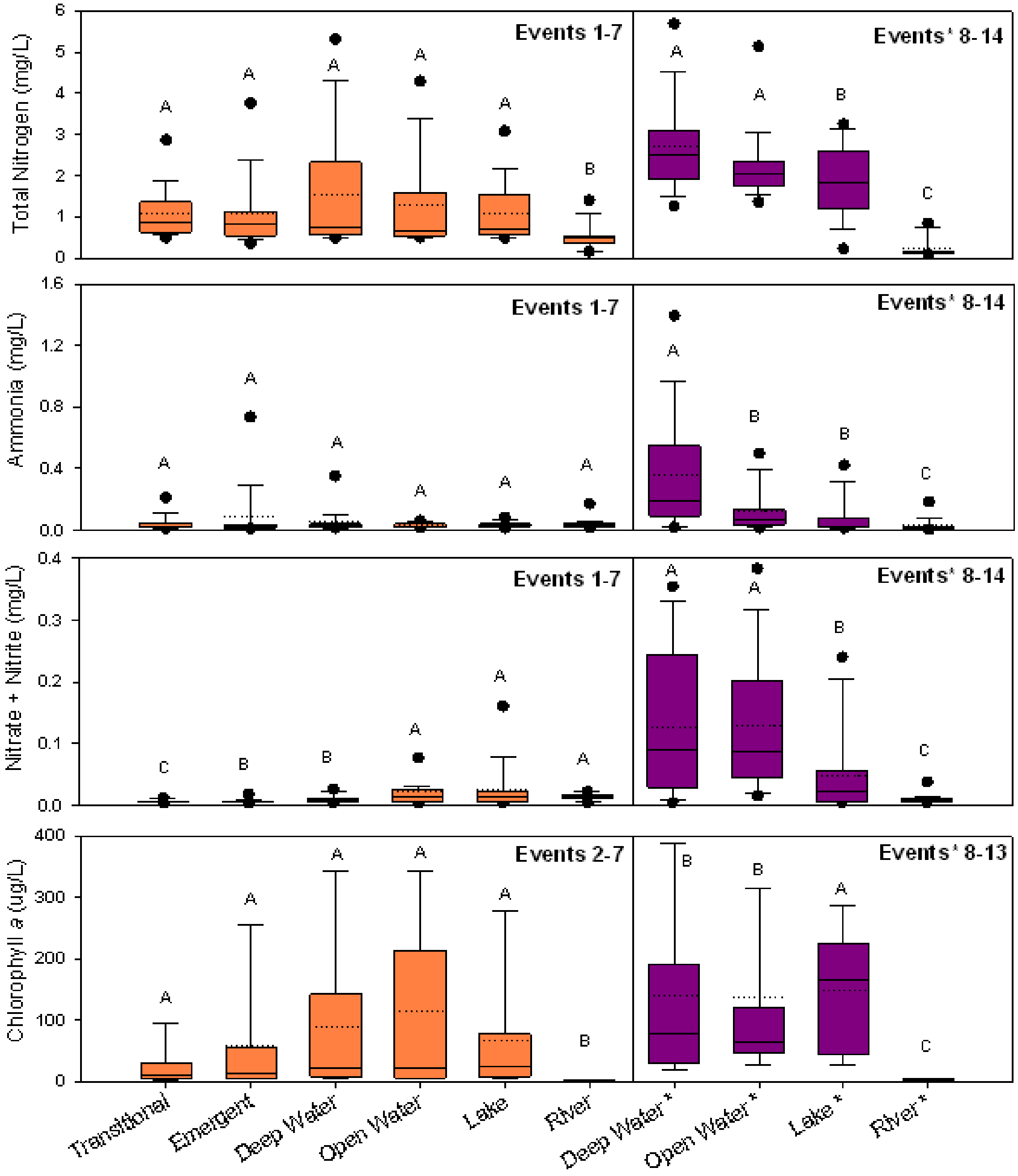

Figure 1.6. Boxplots showing total nitrogen, ammonia, nitrate + nitrite, and chlorophyll *a* concentrations from April – November 2008 within and surrounding the Williamson River Delta. Locations with different letters are statistically different. Panels on the left represent the time period when all locations were sampled. Panels on the right represent the time period when transitional and emergent wetlands were not sampled. Boxes represent the interquartile range with the median marked by a solid line and the mean marked by a dotted line. Whiskers show 10% and 90% percentiles. Outliers are indicated by dots.

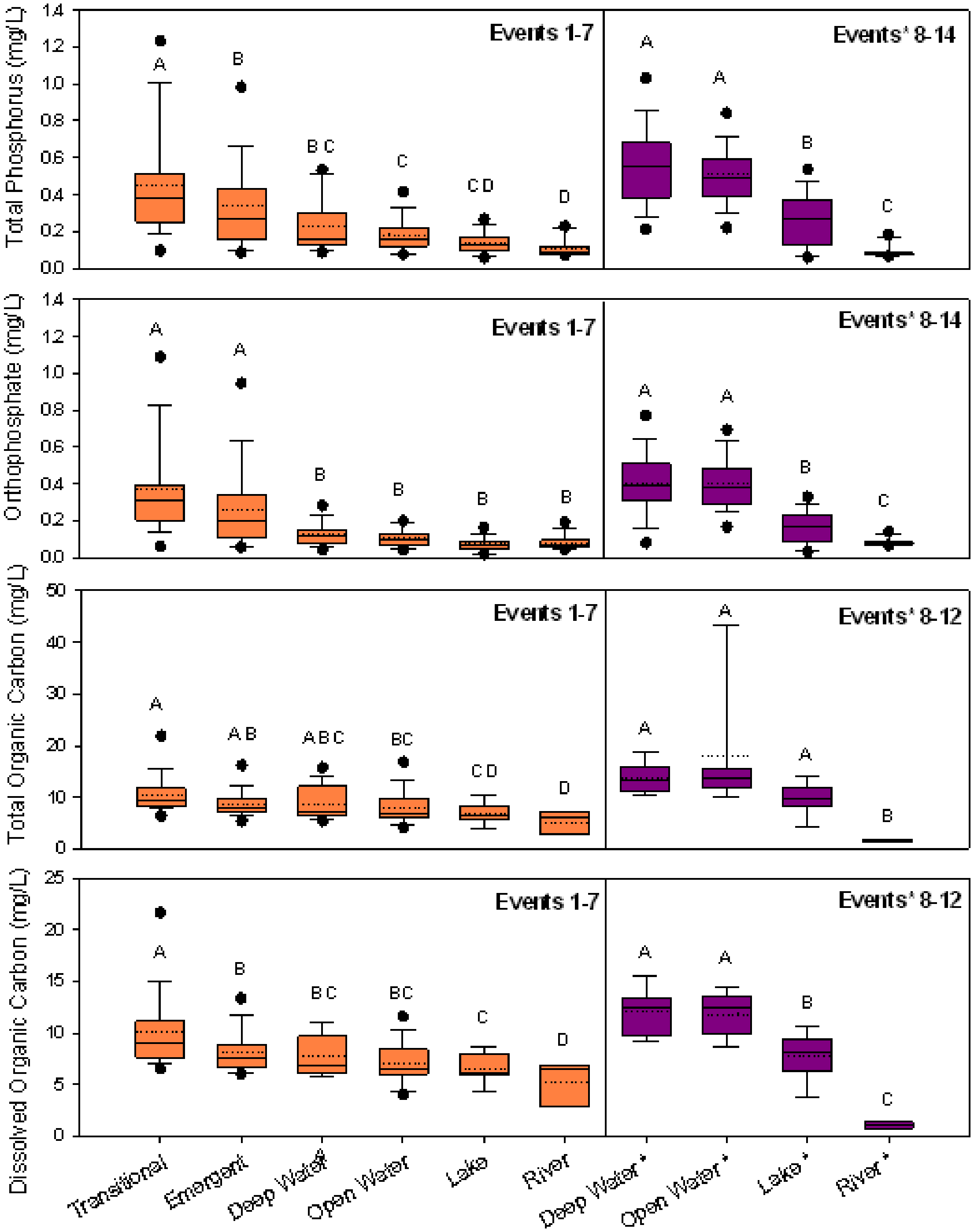

Figure 1.7. Boxplots showing total phosphorus, orthophosphate, total organic carbon, and dissolved organic carbon concentrations from April – November 2008 within and surrounding the Williamson River Delta. Locations with different letters are statistically different. Panels on the left represent the time period when all locations were sampled. Panels on the right represent the time period when transitional and emergent wetlands were not sampled. Boxes represent the interquartile range with the median marked by a solid line and the mean marked by a dotted line. Whiskers show 10% and 90% percentiles. Outliers are indicated by dots.

and deep water wetlands compared to open water wetlands, lake, and river. During events 8-14 however, deep and open water wetlands had significantly higher nitrate + nitrite concentrations than lake and river locations.

Chlorophyll *a*. Chlorophyll *a* was not sampled during the first or last grab sampling event. During events 2-7, early May to mid-July, the highest to lowest mean chlorophyll *a* concentrations were observed in open water wetland, deep water wetland, lake, emergent wetland, transitional wetland, and river, respectively, and median values were less than 50 µg/L at all locations. During this period, wetland chlorophyll *a* concentrations were not significantly higher or lower than the lake but all locations were significantly higher than the river. During mid-July to November (events 8-13), chlorophyll *a* concentrations in the lake were significantly higher than deep water wetlands, open water wetlands, and river locations. Deep and open water wetlands had similar chlorophyll *a* concentrations – significantly higher than the Williamson River and lower than in the lake.

Phosphorus. Mean total phosphorus and orthophosphate concentrations were higher in wetlands than lake and river during events 8-14 (Figure 1.7). From April to mid-July (events 1-7), transitional and emergent wetlands had the highest mean total phosphorus concentrations and transitional wetlands had significantly higher concentrations than all other locations. Concentrations of total phosphorus in all four wetland types were also significantly higher than in the Williamson River. From mid-July to November (events 8-14), mean total phosphorus and orthophosphate concentrations in open and deep water wetlands were significantly higher than lake and river locations, and river locations were also significantly lower than lake locations (Figure 1.7).

Carbon. Mean total organic carbon in transitional and emergent wetlands was significantly higher than in lake and river locations during events 1-7 (Figure 1.7). For events 1-7 and 8-12, mean total organic carbon in open and deep water wetlands was not significantly higher than lake but was significantly higher than the Williamson River. Mean dissolved organic carbon concentration during events 1-7 was significantly higher in transitional wetlands compared to all other sampling locations, and both transitional and emergent wetlands had significantly higher concentrations than lake and river locations (Figure 1.7). After mid-July, dissolved organic carbon was significantly higher in open and deep water wetlands compared to both lake and river locations.

Algal Dynamics

Chlorophyll *a* concentrations were examined in relation to ammonia and nitrate + nitrite concentrations, nitrogen to phosphorus ratios, as well as carbon dynamics to help explain algal productivity within the Delta wetlands.

During 2008, seasonal variability in ammonia and nitrate + nitrite concentrations corresponded to changes in chlorophyll *a* concentrations in open and deep water wetlands. Figure 1.8 shows chlorophyll *a* concentrations increasing as ammonia and nitrate + nitrate concentrations decrease and *vice versa* in several sites. This trend also held true in Agency Lake and to a lesser degree in Upper Klamath Lake (data not shown). Within transitional and emergent wetland sampling sites, ammonia and nitrate + nitrate concentrations did not seem to increase or decrease with fluctuating chlorophyll *a* concentrations.

Total nitrogen to total phosphorus ratios (TN:TP) were less than 10 for all sites in transitional wetland, emergent wetland, and the river (Figure 1.9). The majority of open and deep water wetland sites had TN:TP ratios less than 10, however, five sites had ratios greater than 10. Approximately 26% of samples taken at lake sites had TN:TP ratios between 10 and 17. No sampling sites had TN:TP ratios greater than 17 (Figure 1.9). In the wetlands as well as lakes, chlorophyll *a* concentrations increased as TN:TP ratios increased. That was not the case in the river where an increase in TN:TP was not accompanied by an increase in chlorophyll *a*. Total nitrogen and chlorophyll *a* concentrations had a strong positive relationship in all sampling locations, excluding sites in the Williamson River, with the strongest relationships in open water wetlands and lake (Pearson's correlation coefficient of 0.94 and 0.91, respectively).

Dissolved organic carbon concentrations were not strongly correlated

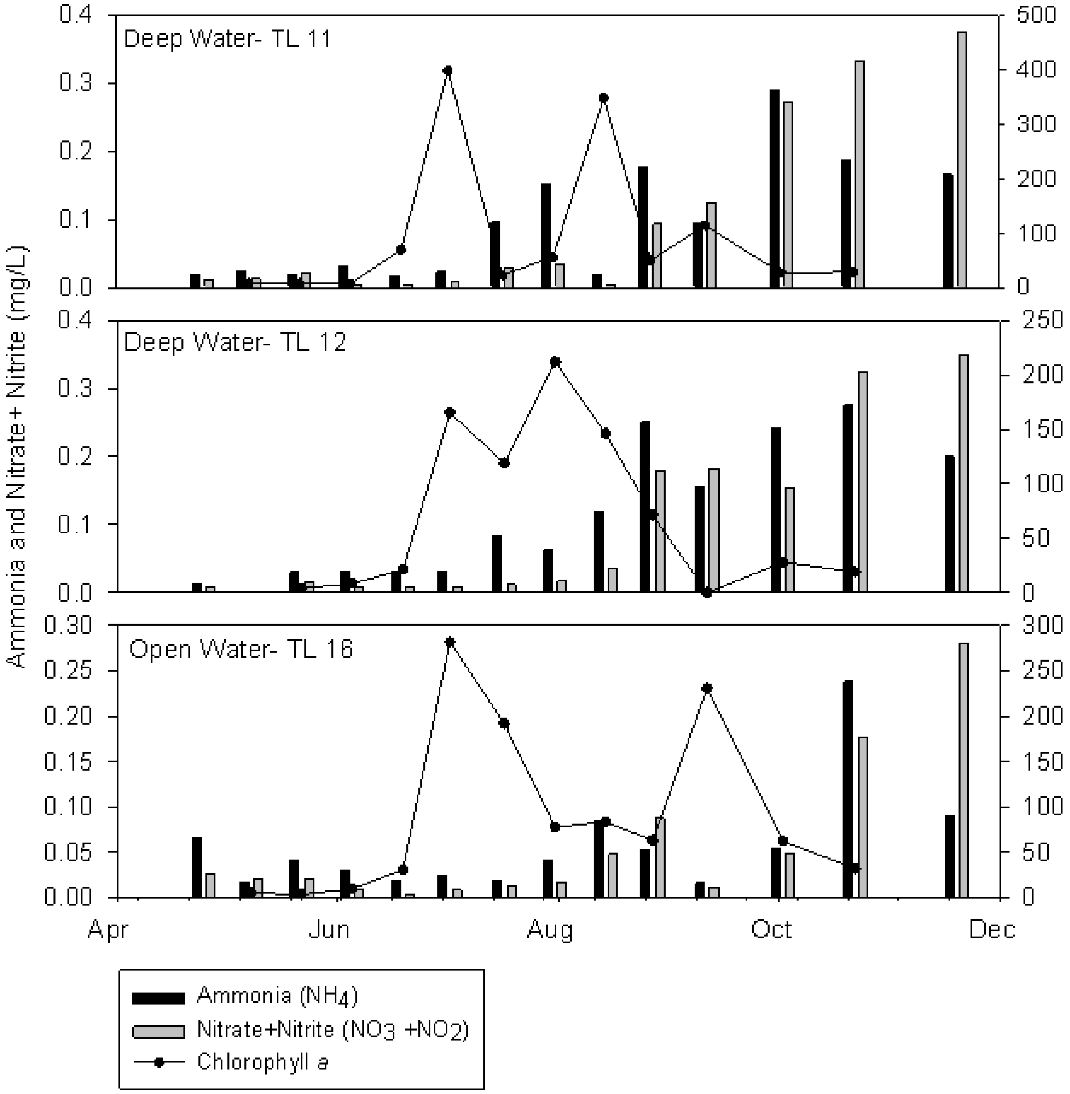

Figure 1.8. Relationship between inorganic nitrogen and chlorophyll *a* concentrations at individual sampling sites (TL11, TL12, and TL16) within deep and open water wetlands of the Williamson River Delta from April – November 2008. Bars represent ammonia and nitrate + nitrite concentrations. Line represents chlorophyll *a* concentrations.

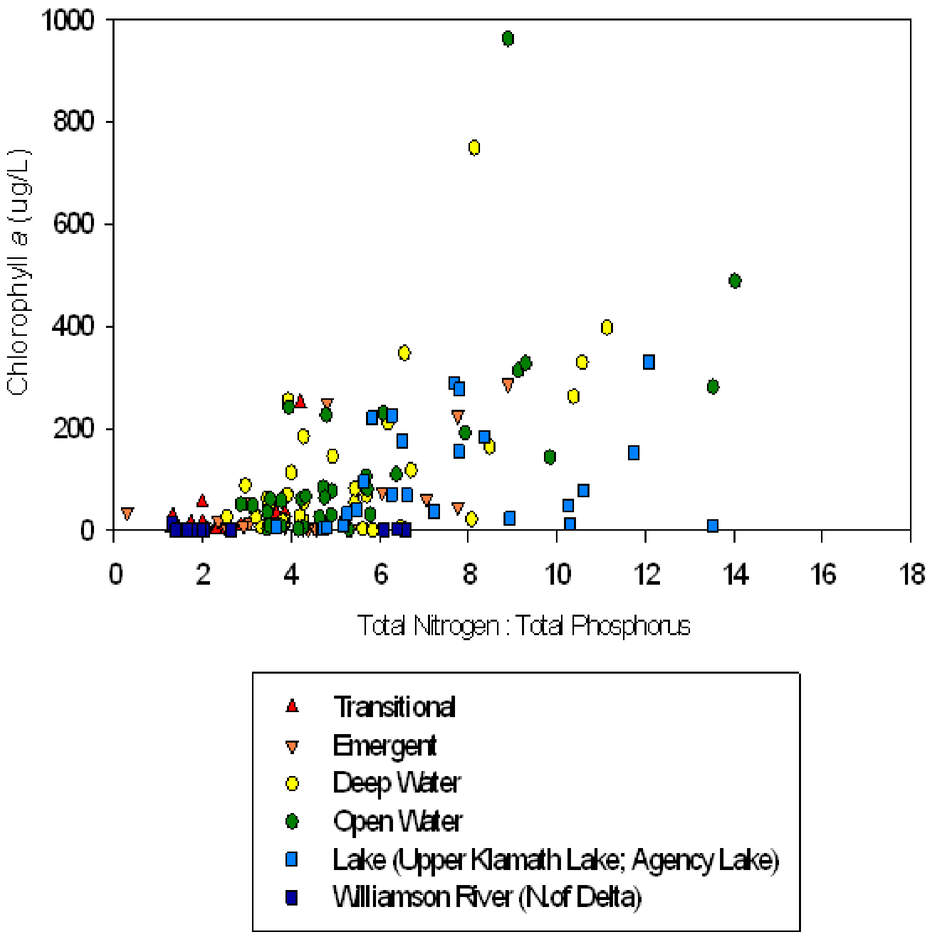

Figure 1.9. Relationship between total nitrogen to total phosphorus ratio and chlorophyll *a* concentration at sampling sites within and surrounding the Williamson River Delta from May – October 2008. Each point on the graph represents one sample.

with chlorophyll *a* concentrations in the newly restored wetlands. Pearson's correlation coefficients for dissolved organic carbon versus chlorophyll *a* for all data collected were 0.245 in transitional wetlands, 0.565 in emergent wetlands, 0.306 in deep water wetlands, and 0.185 in open water wetlands.

Decomposition and Soil Flux of Dissolved Nutrients

The relationship between orthophosphate, ammonia, and dissolved organic carbon concentrations was examined by regressing orthophosphate and ammonia against dissolved organic carbon. A positive relationship suggests the role that decomposition processes play in nitrogen and phosphorus release into the water column.

Orthophosphate increased as dissolved organic carbon increased in the wetlands (R^2= 0.65) with a slope of 0.06 (Figure 1.10). The opposite happened in the Williamson River with orthophosphate decreasing as dissolved organic carbon increased (slope = -3.58 and R^2 = 0.76). Analysis of covariance (ANCOVA) was used to determine that

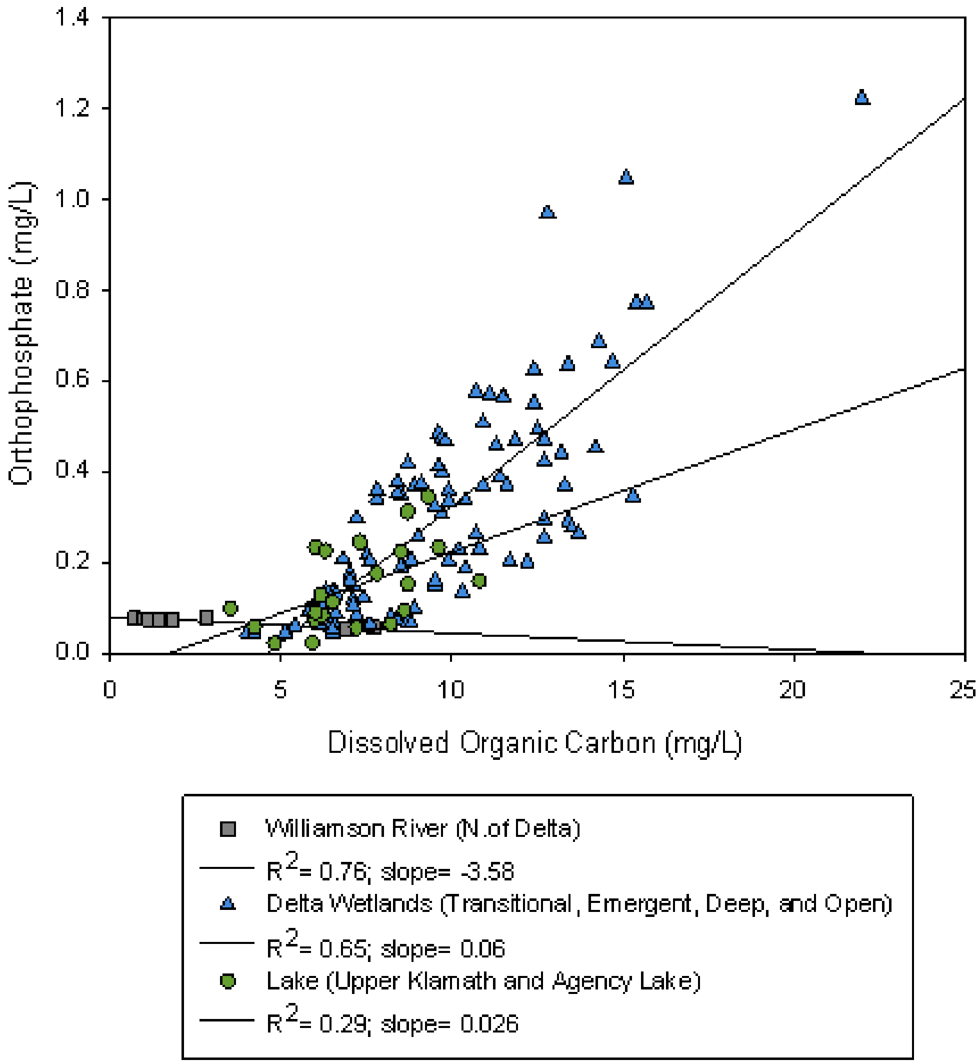

Figure 1.10. Scatter plot of dissolved organic carbon and orthophosphate for all wetland locations combined and lake and river locations. All samples during the first twelve events from April – October 2008 are included, when both constituents were sampled concurrently

there was no difference in the slope or intercept between wetland types and the lake. However, there were significant differences in slopes and intercepts between the river and wetland types (*P*<0.001) as well as river and lake locations (*P* = 0.0016).

A correlation between dissolved organic carbon and ammonia was detected in emergent wetlands with a Pearson's correlation coefficient of 0.83. Regression analysis of dissolved organic carbon versus ammonia yielded an R^2 of 0.69 with slope 0.11 for emergent wetlands, although this was not tested statistically.

DISCUSSION

Algal Dynamics

During this initial year of monitoring, chlorophyll *a* concentrations varied by individual site, event, and location. Higher concentrations in open and deep water wetlands compared to transitional and emergent wetlands could be due to their proximity and increased exchange with water from Agency and Upper Klamath Lakes, which both experience high AFA blooms (Hoilman et al. 2008). Furthermore, three out of the five transitional and emergent wetland sites were under the hydrologic influence of the Williamson River which could explain the lower chlorophyll *a* concentrations in these two locations. Additionally, a shorter inundation period in transitional and emergent wetlands means water was only present in those areas through the first observed chlorophyll *a* peak. Chlorophyll *a* concentrations in transitional and emergent wetlands were comparable to concentrations found in Caledonia Marsh, a previously drained and flooded area adjacent to Upper Klamath Lake that had minimal surface water exchange with Upper Klamath Lake. Similar to our findings in transitional and emergent wetlands, mean chlorophyll *a* values below 200 µg/L were observed at three sites in Caledonia Marsh from June through September 2006 (Lindenberg and Wood 2009).

Seasonal changes in ammonia and nitrate + nitrite concentrations seemed to be linked to AFA dynamics in deep water wetlands, open water wetlands, and in the lake during this first year of sampling. This is illustrated by observed increases in ammonia and nitrate + nitrite concentrations following decreases in chlorophyll *a* concentrations, which may be indicative of algal die-off and subsequent release of dissolved nutrients from senescing algal cells. This relationship has also been shown in other sites around Upper Klamath Lake (Hoilman et al 2008; Lindenberg 2008). A portion of the inorganic nitrogen could have resulted from soil release or flux from decomposition processes; however, it seems that during this year algal growth and decay may have had a greater impact in regulating inorganic nitrogen concentrations, especially in the deeper wetland areas with more hydrologic connection to the lake.

It is hypothesized that wetland biogeochemical processes may act to inhibit AFA production, although the exact mechanism for this process is unknown (Milligan et al. 2009, Wetzel 1983). For example, humic substances, which are end products of organic matter degradation, are hypothesized to inhibit algal growth through direct toxicological effects (Milligan et al. 2009), or by binding with essential nutrients making them unavailable for plant uptake (Wetzel 1983). Humic substances are comprised of between 41-59% carbon (Reddy and DeLaune 2008). Our initial findings from this first year of data collection suggest that dissolved organic carbon concentration (surrogate for humic substances) did not negatively affect algal growth as evidenced by a lack of strong correlation between carbon and chlorophyll *a*. However, growth inhibition caused by wetland humics may have occurred, but the interaction may have been obscured because of mixing of river water and algal-rich lake water across the Delta. Future monitoring will address the relationship between carbon and algal abundance.

Total nitrogen to total phosphorus ratios were below 10 for all sampling events in transitional and emergent wetlands as well as during many sampling events in open and deep water wetlands. Within this first year of monitoring, phosphorus does not seem to be a limiting nutrient to algal growth. However, other factors could be involved in limiting algal growth (Forsberg and Ryding 1980; Kuwabara 2009).

Decomposition and Soil Flux of Dissolved Nutrients

Seasonal trends in nutrient concentrations indicate higher concentrations of phosphorus within the Delta compared to the Williamson River, Agency Lake, and Upper Klamath Lake, which was not unexpected. Previous draining and agricultural use of the Delta likely built up large concentrations of stored phosphorus in the soils which was released upon flooding in fall 2007 (TNC unpublished data). Many of the sites sampled on the Delta also had partially decomposed detritus as well as decomposing upland plants which are now inundated. The flux of nutrients within the wetland could have been caused by microbial decomposition of organic matter, or release from the soil. Although inorganic nitrogen (ammonia and nitrate + nitrite) concentrations seemed to be inversely related to chlorophyll *a* concentrations in open and deep water wetlands, ammonia concentrations in emergent wetlands were correlated to dissolved organic carbon and could have been influenced to a greater degree by decomposition or soil nutrient flux than by chlorophyll *a* concentrations. Overall, these relationships are expected to change as residual upland vegetation decomposes and wetland vegetation reestablishes in some wetland locations.

Shallower water depths in transitional and emergent wetlands could have led to higher phosphorus concentrations in these locations relative to deep and open water wetlands because evaporative processes may act to concentrate nutrients more in shallow areas than deep areas. The majority of transitional and emergent wetlands were also only inundated once water levels rose in spring 2008, compared to open and deep water wetlands which were inundated in fall 2007. Thus observed higher phosphorus concentrations in transitional and emergent wetland could also be attributed to the initial, larger pulse of phosphorus in the shallower areas when they became flooded during the spring sampling in 2008.

Other studies have shown a relationship between water temperature and phosphorus release on the Delta wetlands (Aldous et al. 2007, Stevens 2008). Although open and deep water wetlands were flooded in fall 2007, surface water temperatures were only between 3 to 7 ºC. As temperatures increased and peaked at the beginning of July, dissolved organic carbon and orthophosphate concentrations also increased. Higher temperatures may have accelerated microbial decomposition rates leading to higher fluxes of nutrients into the water column.

Higher concentrations of orthophosphate were observed in the Delta during the 2008 sampling season compared to the immediate post-breach sampling conducted in fall 2007 and in Caledonia Marsh, a previously drained wetland adjacent to Upper Klamath Lake (Lindenberg 2008). Surface water samples collected after the initial flooding of the Delta in November 2007, 7 and 14 days post-breach, showed higher orthophosphate concentration in open and deep water wetlands compared to the lake. However, during these two sampling events, mean orthophosphate concentrations for deep water, open water, and lake locations were lower than concentrations seen in 2008. Median phosphorus concentrations in Caledonia Marsh in 2006 were also higher than median concentrations in Upper Klamath Lake but lower than concentrations seen in the Delta.

The question of whether or not the Delta will act as a net nutrient sink versus source over the longer term is yet to be determined. As more vegetation establishes and organic soils begin accreting, the Delta wetlands may provide more of a net phosphorus sink. The geographic location of the Delta and mixing of waters from the Williamson River and Agency and Upper Klamath Lakes present a challenge for interpreting water chemistry data. Incorporating our water chemistry results into the U.S. Geological Survey's hydrodynamic circulation model of the Delta is planned to help further describe nutrient transport and mixing in the Delta and surrounding water bodies. Algal production and nutrient flux could change over time as vegetation changes and wetland plant species re-establish over a greater portion of the Delta. Continuing water quality monitoring in the future to document long-term trends in nutrient cycling and effects of restoration on water chemistry is beneficial. In time, the cycling of nutrients in these wetlands could show more natural wetland function.

CHAPTER 2: CONTINUOUS PHYSICAL WATER CHEMISTRY MONITORING

By: Siana Wong, Carolyn Doehring, Heather Hendrixson

METHODS

Location of Continuous Monitoring Stations

Multi-probe instruments (YSI 600XLM sondes) were deployed at eight fixed monitoring stations within and surrounding the north half of the Delta to collect continuous (hourly) physical water chemistry data including temperature, dissolved oxygen concentration (DO), pH, and specific conductance. At each station, sondes were placed at mid-depth in the water column, or 1 m below the water surface if water depth exceeded 2 m. The eight monitoring stations were located in the following areas: one in each of the four wetland types within the Delta (open water, deep water, emergent wetland, and transitional wetland); one in the Williamson River upstream of the project area (~RM 2.5); one in Upper Klamath Lake approximately half-way between Agency Straits and the river mouth; one in Upper Klamath Lake east of the river mouth, called Goose Bay; and one in Agency Lake. Each station coincided with a grab sampling site. Figure 2.1 shows a map of the project area, wetland types, and continuous monitoring stations.

Monitoring Period

Sondes were deployed at seven sites in mid-April 2008. In mid-August, a site was added in Goose Bay in order to collect baseline data prior to restoration of the Goose Bay portion of the Delta in November 2008. Sondes were pulled from the transitional and emergent wetland sites in early July and mid-August, respectively, due to declining water levels during the summer months and lack of sufficient inundation for sampling at these sites beyond those dates. Sondes at the remaining six sites were pulled in mid-December. Data from the Upper Klamath Lake site during the period May 6 to October 15 were collected by the USGS, which has

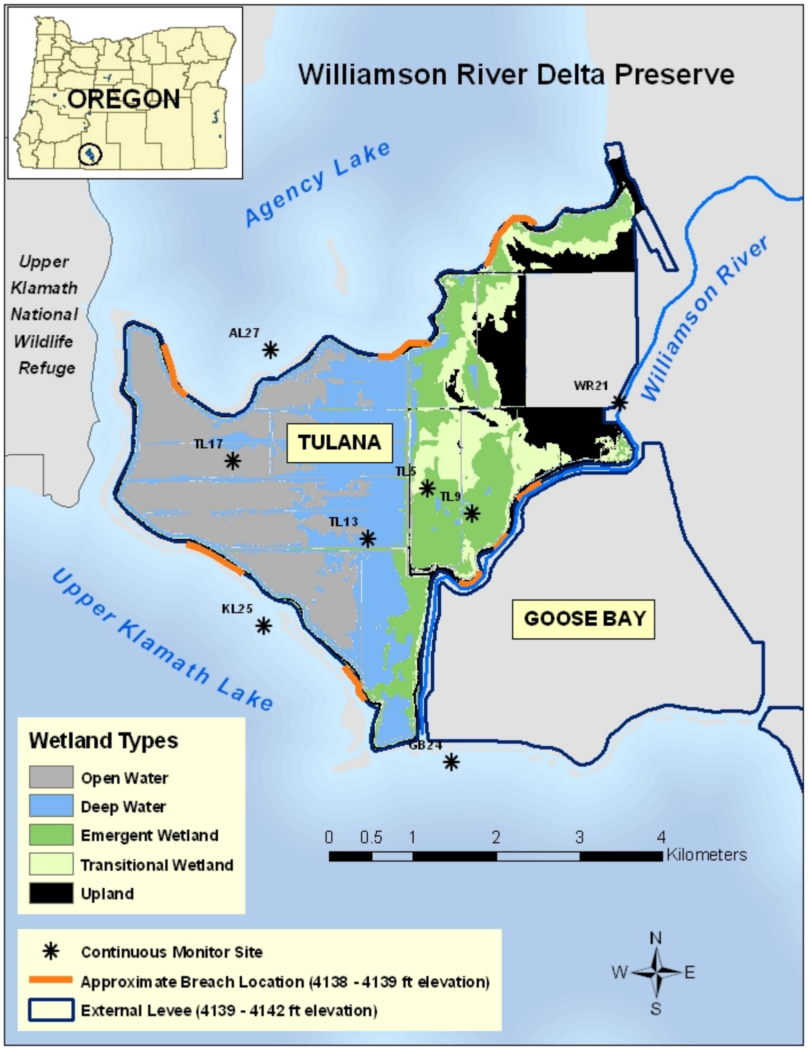

Figure 2.1. Map of Williamson River Delta project area, predicted wetland types, and location of continuous monitor stations used from April – December 2008.

approximately the same site location in Upper Klamath Lake as TNC (USGS Data Grapher, M. Lindenberg, USGS, personal communication). Data collected prior to May 6 and after October 15 at the Upper Klamath Lake site are provided by TNC. It should be noted that data collected by USGS and presented in this report are provisional and subject to revision.

Quality Assurance

Calibrations were performed prior to sonde deployment to verify accuracy of each instrument. Sonde performance was checked for precision against a freshly calibrated reference instrument during weekly site visits. Sondes were cleaned, rechecked, and either redeployed or replaced such that an individual sonde was deployed at a site for no longer than two weeks at a time. Post-calibration checks were performed to verify accuracy of each sonde following a deployment. Data quality objectives adhered to requirements defined in TNC's Water Quality Monitoring Project Plan. Instances where data did not meet requirements were reported and/or omitted. Quality assurance criteria are shown in Appendix C, and results are presented in Appendix D.

Data Analysis

All raw data collected from sondes were quality-checked before computing statistics. Data that passed quality assurance criteria were deemed acceptable. Daily statistics were computed only for days with at least 20 hours of acceptable data recorded in a single day. All statistics were computed using SAS® System for Windows, Release 9.1.3 (SAS Institute).

RESULTS

Seasonal Trends

Ranges for water chemistry parameters at each site during the monitoring period from late April to early December 2008 are shown in Table 2.1. In general, the warmest temperatures occurred in the wetland, with maximum temperatures reaching 30 – 32ºC in transitional wetland and emergent wetland. The highest specific conductance values and lowest DO concentrations also occurred in the wetland.

Temperatures at all sites peaked during the months of July and August and declined after mid-August (Figure 2.2). Seasonal trends in temperature at all sites followed trends in the Williamson River until mid-June, when a noticeable divergence occurred between the river and all other sites. During the period of May – June, daily median temperatures in the river were on average 1.1ºC cooler than all other sites combined. From July – September, daily median temperatures were on average 5.5ºC cooler in the river compared to all other sites combined, excluding Goose Bay. Daily median temperatures in emergent wetland were on average 0.2ºC warmer than Upper Klamath Lake and 1.1ºC warmer than the Williamson River from May – June. During the same period, daily median temperatures in transitional wetland were on average 0.5ºC warmer than Upper Klamath Lake and 1.4ºC warmer than the Williamson River. A noticeable spike in temperatures at all sites occurred in mid-May (Figure 2.2). During the eight-day period from May 12-19, when the early-season spike occurred, daily median temperatures in the Williamson River and Upper Klamath Lake increased by 6.6ºC and 7.5ºC respectively, while increasing by 9.3ºC and 10.8ºC in emergent wetland and transitional wetland (Figure 2.3). Immediately following the early-season

Table 2.1. Range values for physical water chemistry parameters collected hourly at eight monitoring sites in and around the Williamson River Delta, Oregon from April – December 2008. The first four sites are in water bodies surrounding the Delta and the second four refer to wetland sites within the Delta.

	Temperature (°C)		Specific Conductance (µS/cm)		Dissolved Oxygen (mg/L)		pH	
	Min	Max	Min	Max	Min	Max	Min	Max
Agency Lake	1.71	28.05	96	184	2.91	22.39	6.81	10.41
Klamath Lake	1.56	25.7	88	157	3.01	23.21	6.93	10.44
Goose Bay	2.35	22.48	90	145	6.06	16.19	6.94	9.69
Williamson R.	2.39	20.36	73	103	7.16	12.64	6.95	8.95
Open Water	2.22	26.01	100	193	1.52	21.75	6.98	10.42
Deep Water	1.81	26.42	77	203	0.23	21.87	6.58	10.41
Emergent	7.33	31.88	75	247	0.08	16.12	6.77	9.47
Transitional	6.39	30.1	81	275	0.15	18.36	6.68	9.96

spike in temperatures, there was a noticeable drop in temperatures (Figure 2.2). During an eight-day period from May 24-31 after temperatures dropped, emergent wetland and transitional wetland were respectively about 0.5ºC and 1.4ºC warmer than the Williamson River, but 1.2ºC and 0.4ºC cooler than Upper Klamath Lake (Figure 2.3). From August – September, daily median temperatures at Goose Bay averaged 2.1ºC warmer than the river and 2.7ºC cooler than Upper Klamath Lake (Figure 2.2).

The highest specific conductance values and the greatest ranges in values occurred in the four wetland sites (Table 2.1). The lowest maximum values and smallest range in values occurred in the Williamson River. In the wetland sites, maximum values were greater with shallower water depth. The general trend at each wetland site was an increase in values through the course of the monitoring period, beginning in April (Figure 2.2). From April until mid-June, trends in specific conductance at the emergent wetland site followed trends in the Williamson River, with values in emergent wetland closely reflecting values in the river (daily median values in emergent wetland and the river differed by 2.3 µS/cm on average in May). After mid-June, values in emergent wetland increased and diverged from river values, which remained relatively lower than the other sites through the monitoring period. In open water and deep water sites, trends in specific conductance paralleled trends in Agency and Upper Klamath Lakes, with values reflecting those in the lakes until mid-July. After mid-July, values in open and deep water diverged and increased from lake values.

Dissolved oxygen concentrations ranged from below 1 mg/L to above 21 mg/L in the wetland sites, with maximum concentrations well above 100% saturation (Table 2.1). Maximum DO concentrations above 22 mg/L were observed in Agency and Upper Klamath Lakes, but minimum concentrations in the lakes were greater than those observed in the wetland sites. Excluding the open water site, at least one minimum hourly measurement of DO below 1 mg/L was recorded in each of the wetland sites. Among wetland sites, trends in DO were relatively stable until mid-June (Figure 2.2). Beginning in mid-June, daily median DO increased and then peaked in late June at open and deep water sites with a second peak occurring in early September. The June peak was followed by a sharp decline from late June to mid-July. A prolonged period of low daily median DO ensued from mid-July to the end of August. During this period, daily median DO concentrations below 4

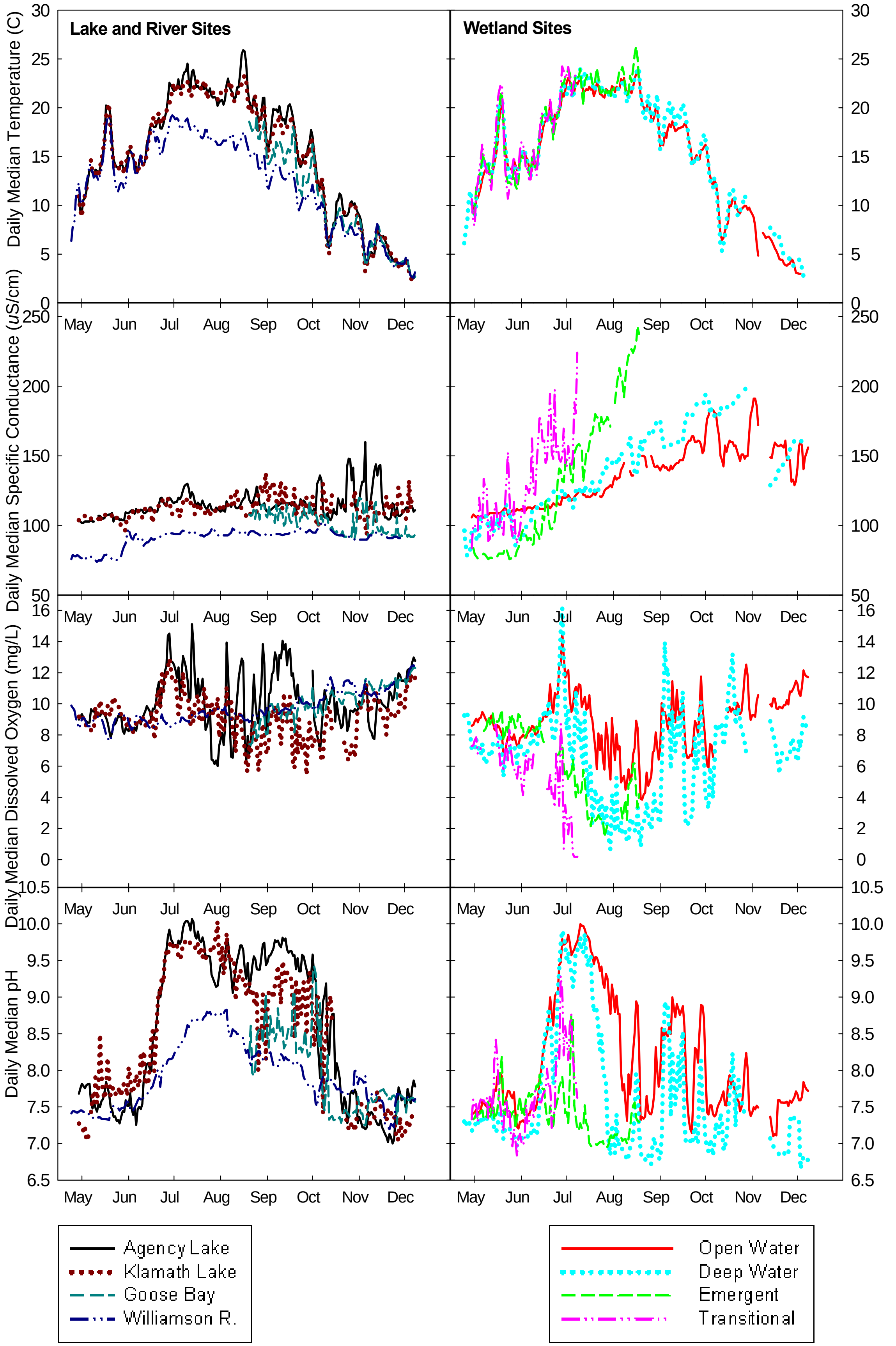

Figure 2.2. Daily median water temperature, specific conductance, dissolved oxygen concentration, and pH from April – December 2008 at sites in and around the Williamson River Delta. Panels on the left represent sites surrounding the Delta. Panels on the right represent sites within the Delta.

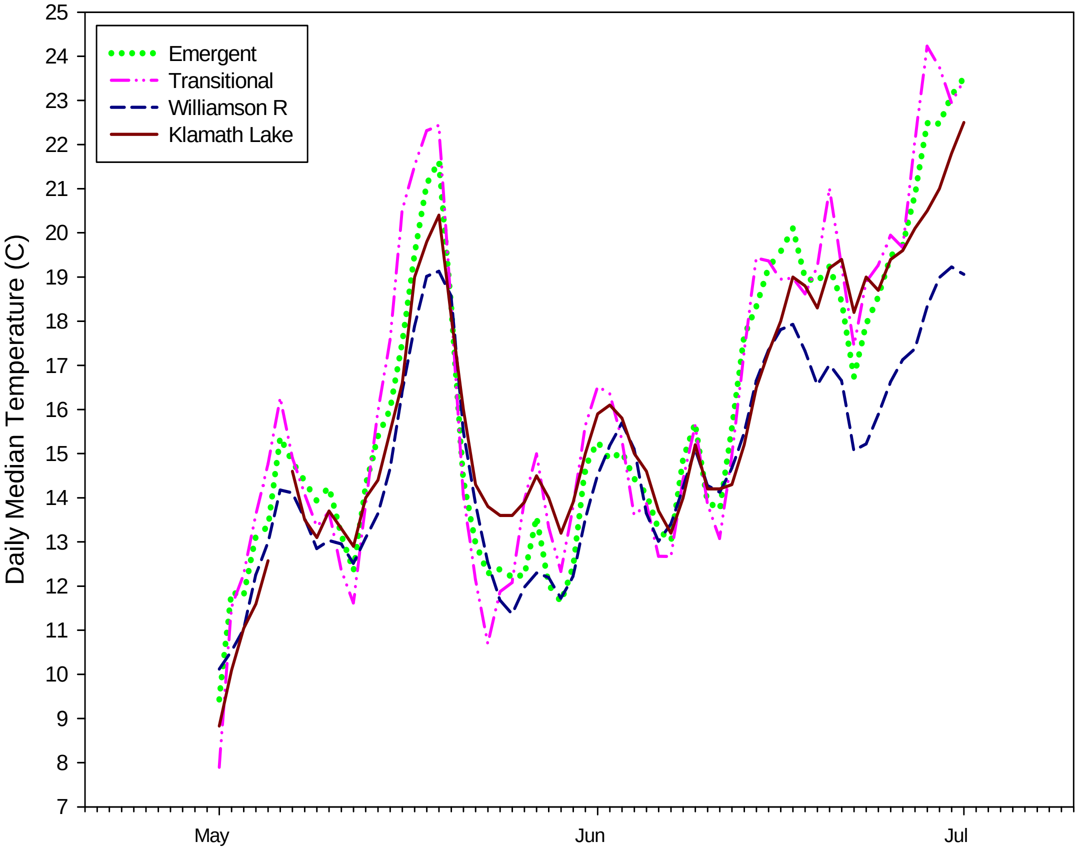

Figure 2.3. Daily median water temperature from May – June 2008 in emergent wetland, transitional wetland, the Williamson River, and Upper Klamath Lake sites.

mg/L lasted up to 24 consecutive days at the deep water site. From May – June, daily median DO concentrations in deep water were on average 1 mg/L lower than in open water and 2.3 mg/L lower than Upper Klamath Lake. From July – August, daily median DO concentrations in deep water were 3.6 mg/L lower than open water and 5.1 mg/L lower than Upper Klamath Lake. Dissolved oxygen concentrations in emergent wetland were relatively stable from May – June, with daily median concentrations averaging 8.3 mg/L over the two-month period. A decline in DO was observed in emergent wetland after mid-June, with daily median concentrations below 4 mg/L lasting from mid-July to early August. In transitional wetland, DO concentrations were relatively stable from May – June, with daily median concentrations averaging 6 mg/L over the two-month period. Dissolved oxygen concentrations dropped after late-June, with daily median concentrations averaging 1.3 mg/L during the month of July.

Ranges in pH were highest in Agency and Upper Klamath Lakes and open and deep water wetlands (Table 2.1). The general trend in open and deep water sites was a period of relative stability from May to mid-June, followed by a sharp increase to daily median values over 9 from late June to mid-July (Figure 2.2). During the month of August, daily median pH in both open and deep water wetlands declined to average daily median values of 7 – 8. Beginning in August and into September, pH was highly variable at these sites. A second peak in pH was observed at the open and deep water sites in early September, although peak values in September were lower compared to in late June. In open and deep water, trends in pH paralleled those in Agency and Upper Klamath Lakes until mid-July. During the month of August, pH in Agency and Upper Klamath Lakes remained relatively high compared to open and deep water, with daily median values remaining above 9. Daily median pH in emergent and transitional wetlands were less variable and lower than Agency and Upper Klamath Lakes and open and deep water wetlands, and maximum values above 10 were not observed during the monitoring period at these sites. The general trend in emergent and transitional wetlands was a period of stability until about mid-June. Daily median pH increased and peaked in late June and early July to values of 8 – 9, but these conditions did not persist, and values began to decline within days of peaking.

Diel Variability

In addition to seasonal trends, diel trends in physical water chemistry within the Delta were examined (Figures 2.4 & 2.5). Among all wetland sites during the monitoring period from May – July, lows in DO concentrations tended to occur around

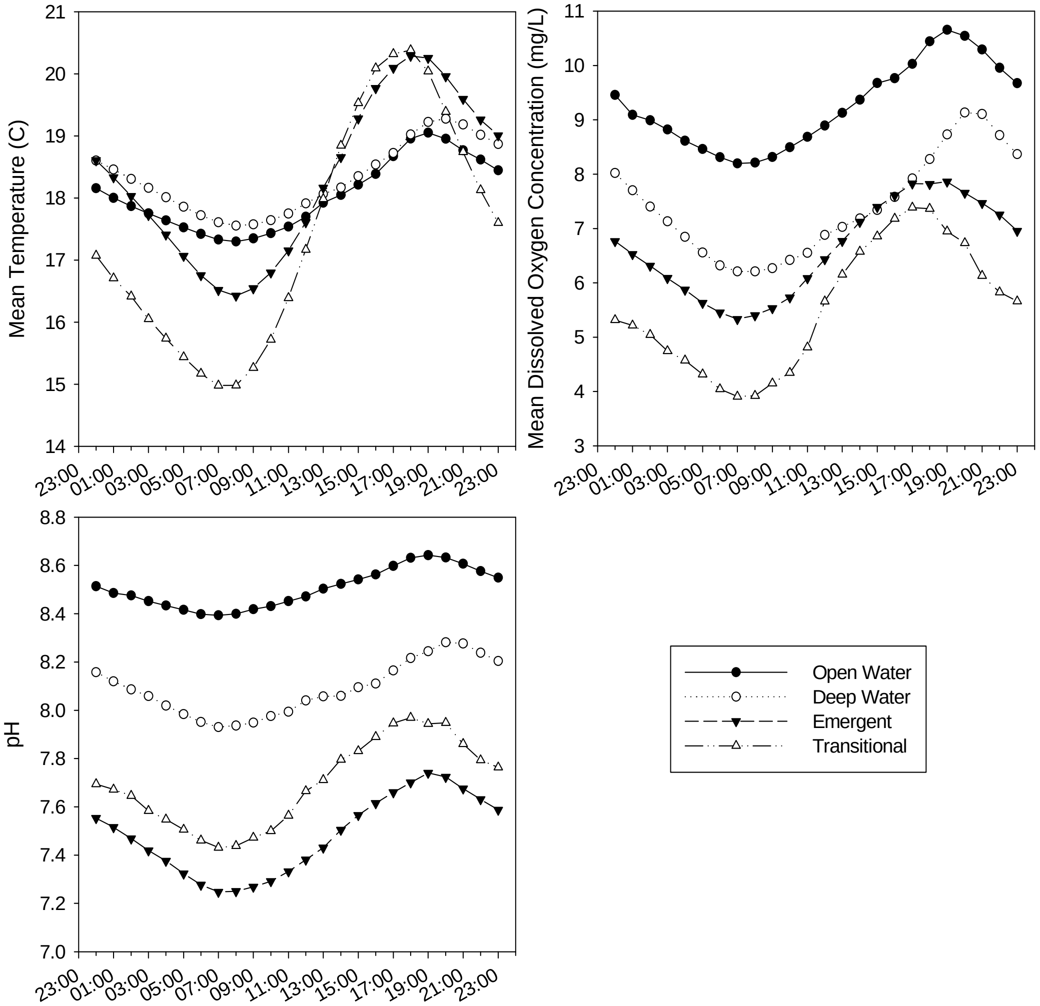

Figure 2.4. Hourly mean water temperature, pH, and dissolved oxygen concentration in each wetland type at the Williamson River Delta during the period May – July 2008.

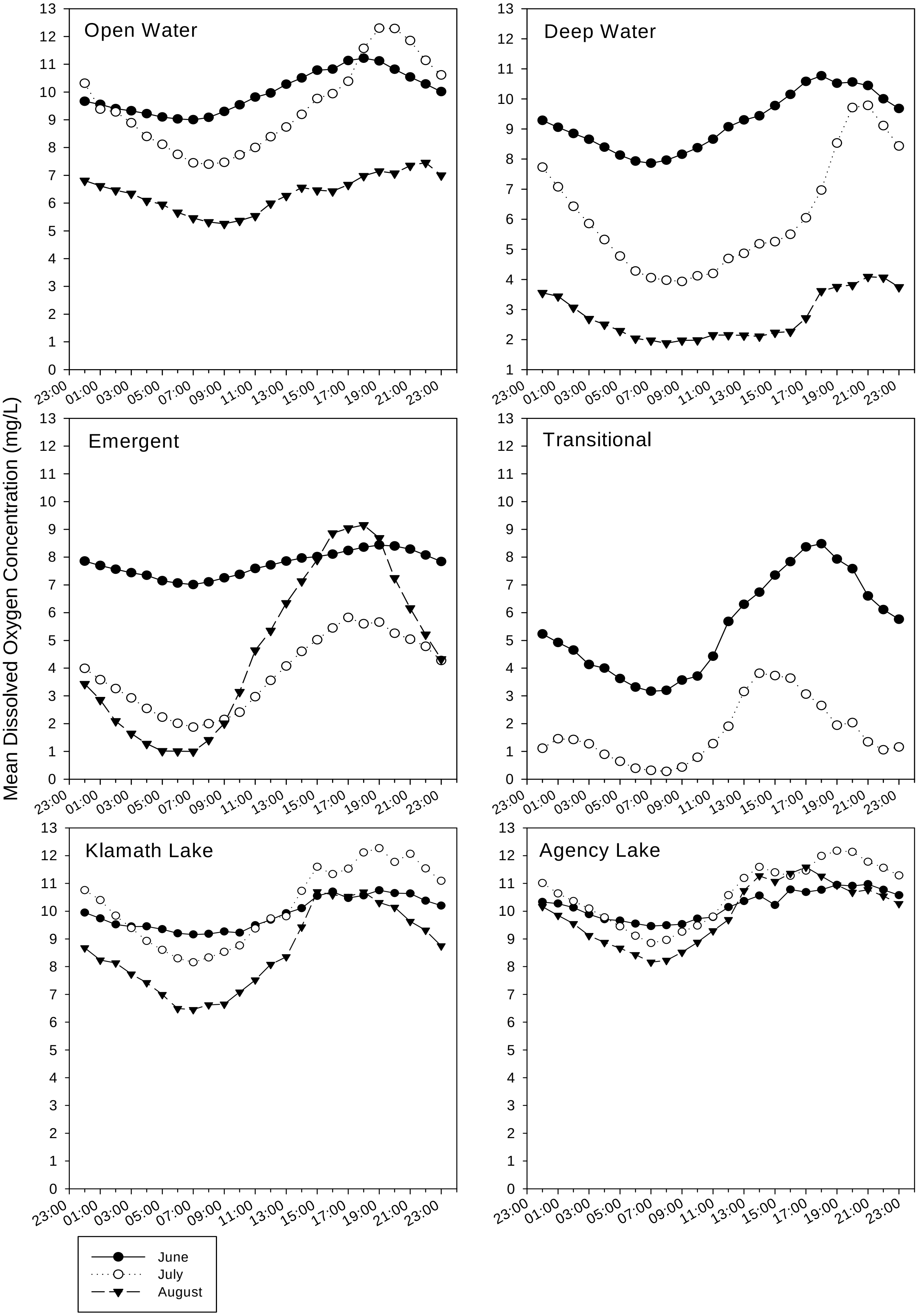

Figure 2.5. Hourly mean dissolved oxygen concentration in open water, deep water, emergent wetland, transitional wetland, and Upper Klamath and Agency Lakes for June, July, and August 2008.

7:00 – 8:00 AM (Figure 2.4). Peaks in DO occurred around 5:00 – 6:00 PM in emergent wetland and transitional wetland, and 7:00 – 8:00 PM in open and deep water. Peaks in temperature and pH tended to occur around 6:00 – 7:00 PM while lows tended to occur around 7:00 – 8:00 AM. Greater diel variability in temperature and pH was observed in emergent wetland and transitional wetland compared to open and deep water. June, July, and August diel trends in DO are shown to examine variations between wetland types and lake sites during the period of elevated biological activity (Figure 2.5). In June, DO concentrations at all sites peaked around 6:00 PM. However, later in the year in July and August, DO concentrations in open and deep water peaked later in the day between 7:00 – 9:00 PM. In transitional wetland, concentrations peaked earlier in the day at around 2:00 PM during July compared to 6:00 PM in June. Transitional wetland appeared to experience the greatest diel variation in DO in June – earlier in the year than other sites. Emergent wetland experienced its greatest diel variation in DO in August, while open and deep water experienced the greatest variation in July. In July and August, lows in DO concentration occurred for a longer portion of the day in deep and open water wetland compared to emergent and transitional wetlands and Upper Klamath and Agency Lakes.

High Stress Threshold Conditions for Endangered Suckers

Figure 2.6 shows the seasonal timing, location, and duration of high stress threshold conditions for suckers within and surrounding the Delta. High stress threshold conditions are defined as conditions potentially threatening to the health of juvenile suckers in Upper Klamath Lake based on DO, temperature, and pH (Loftus 2001). These conditions are characterized by DO concentration < 4 mg/L, temperature > 28ºC, and pH > 9.7.

Exceedance of thresholds was not observed for any of the three parameters at either the Williamson River or Goose Bay sites. At the other sites, conditions with pH > 9.7 tended to occur early in the season, beginning near the end of June and peaking in mid-July. Exceedance of pH thresholds were observed mostly in Agency and Upper Klamath Lakes and open water and deep water wetland. Conditions with pH > 9.7 lasting 100% of the day were observed in Agency Lake from July 7-16 and in open water from July 10-14. On June 28-29, 80-90% of the day exceeded pH conditions at the deep water site. In open water and deep water, pH exceedance conditions lasted until the end of July, compared to Agency and Upper Klamath Lakes where potentially stressful conditions lasted until mid-August. A second peak of pH exceedance conditions in Agency Lake began in early September and lasted until the end of September. Exceedances of pH occurred in transitional wetland for part of two days in late June, but these conditions did not persist. Exceedances of pH thresholds were not observed in emergent wetland.

Dissolved oxygen concentrations below 4 mg/L were observed mostly in the four wetland types within the Delta. Exceedance of low DO conditions occurred at Agency and Upper Klamath Lake sites, but these conditions did not persist throughout the day (up to 3 hours in Agency Lake and 4 hours in Upper Klamath Lake) or the season (2 days of at least one hourly occurrence in Agency Lake and 5 days of at least one hourly occurrence in Upper Klamath Lake). Within the wetland sites, periods of DO exceedance tended to occur earlier in the season with shallower water depth. In deep water and open water, exceedance of DO threshold conditions tended to occur later in

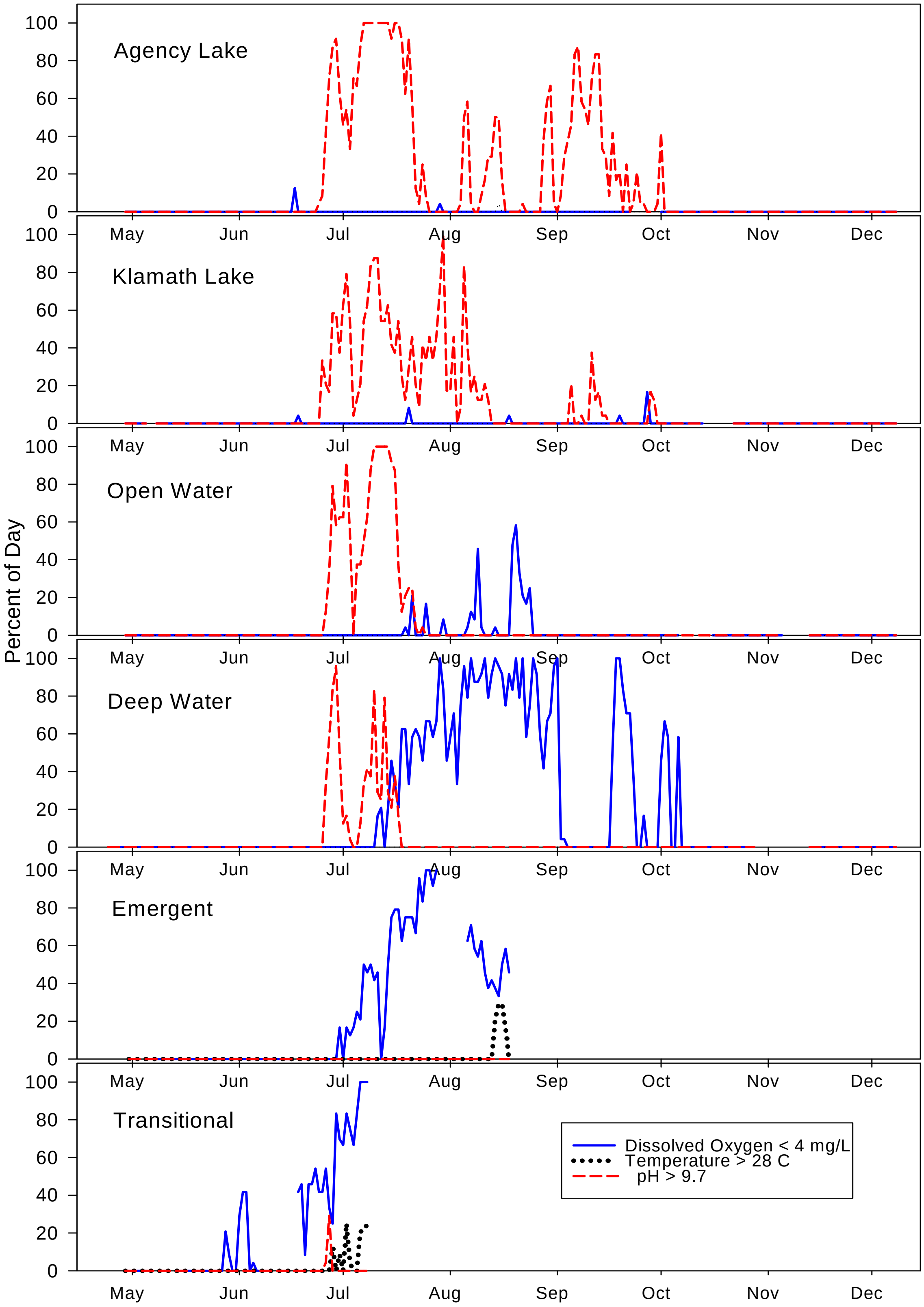

Figure 2.6. Timing, location, and duration (expressed as a percent of day) of water quality conditions potentially stressful to Lost River and shortnose suckers in Upper Klamath Lake, April – December 2008.

the season compared to peaks in pH threshold exceedance. Conditions where DO was in exceedance for 100% of the day were observed in deep water, emergent wetland, and transitional wetland. During the month of August, approximately 80% of the total hours recorded at the deep water site exceeded DO threshold conditions, and about one-third of the days in August experienced DO exceedance conditions persisting the entire day. In open water, stressful DO conditions were less prolonged throughout the day and through the season compared to deep water. Conditions were most pronounced in open water on August 19 and 20, with 50-60% of the day in exceedance of the DO threshold. In transitional wetland, DO concentrations less than 4 mg/L first occurred on May 28, although conditions persisting more than half the day were not observed at that site until June 23. DO exceedance conditions lasting 100% of the day occurred from July 6-8, when the transitional site was pulled for the season. In emergent wetland, the first DO exceedance condition occurred June 30, but conditions lasting more than half the day did not occur until July 7. Conditions lasting 90-100% of the day were observed from July 25-28 in emergent wetland. During the months of July and August, approximately 50% of the total hours recorded at the emergent wetland site were recording DO concentrations less than 4 mg/L.

Temperatures above 28ºC were observed in transitional and emergent sites during the months of July and August, but conditions did not persist throughout the day (less than 30% of the day) or the season (4 and 6 days in emergent and transitional wetland). A total of one hour above 28ºC was recorded in Agency Lake, on August 15. Temperature thresholds were not exceeded in Upper Klamath Lake, open water, or deep water wetlands.

DISCUSSION

Seasonal Trends

Surface water temperatures were generally warmer in emergent wetland and transitional wetland compared to the Williamson River and Upper Klamath Lake during the typical peak period of larval fish migration from May – July. This is consistent with previous research on the Williamson River Delta showing warmer temperatures in restored wetland areas within the Delta compared to river and lake temperatures during the larval sucker period (Crandall et al. 2008). Temperature differences between the Williamson River and Upper Klamath Lake were also comparable to previous years. Crandall et al. (2008) reported Williamson River temperatures 4 – 5ºC lower than Upper Klamath Lake and restored wetland sites after June. From July – September, Williamson River temperatures were on average 4.6ºC cooler than Upper Klamath Lake, which falls within the range observed by Crandall et al. (2008) in 2003 and 2004.

Seasonal trends in specific conductance reflected the influence of inflowing river and lake water on the wetland early in the summer, and the lack of river and lake influence later in the summer. Field notes document the complete exposure of levees along the perimeter of the Delta by July 17. After this time, the majority of flow through the Delta was occurring through the four main breaches on the north half of the Delta, and limited flow was occurring through the breaches along the Williamson River. The increase in specific conductance in the wetland after June in emergent wetland and after July in deep and open water wetlands reflects the increasing concentration of dissolved ions in the water column after flow through the Delta became restricted.

Seasonal trends in DO and pH in open water and deep water wetlands appeared to coincide with the yearly bloom and crash cycle of AFA. Peaks in DO and pH at lake sites and deep and open water wetland sites occurred in mid to late June, generally within the peak period of AFA bloom in Upper Klamath Lake (Hoilman et al. 2008, Lindenberg et al. 2008). This period of heightened photosynthetic activity associated with AFA was followed by a sharp decline in DO and pH in July, and a period of low DO and pH through August. In early September, a second seasonal peak in DO and pH was observed, which is not uncommon in Upper Klamath Lake and has been observed in prior years as a late season AFA bloom (Hoilman et al. 2008, Lindenberg et al. 2008).

Seasonal trends in median DO and pH differed between wetland and lake sites (Figure 2.2). Dissolved oxygen concentrations in deep water and open water wetlands were lower on average during the summer months of July – August compared to lake sites. During that same time period, pH declined to values below 7.5 in deep and open water wetland while values in Agency and Upper Klamath Lake generally stayed above 8 and 9. Variability in DO and pH observed during this first year of monitoring following restoration could reflect the influence of different processes occurring within the wetland compared to the lake.

Diel Variability

In emergent and transitional wetlands, diurnal patterns in DO (Figure 2.4) were characteristic of photosynthetic processes occurring during the day and respiration processes occurring during the evening. Patterns in chlorophyll *a* at these sites, however, did not follow chlorophyll *a* patterns in open and deep water wetland sites (Figure 2.7). Chlorophyll *a* concentrations from June – July tended to be lower in emergent and transitional wetlands (concentrations typically less than 100 µg/L) compared to open and deep water (concentrations greater than 300 µg/L). Additionally, field observation indicated that AFA was present but not pronounced at these sites. It should be noted that although AFA is the dominant algal species in Upper Klamath Lake (Lindenberg et al. 2008), other forms of algae were present in the wetland and were likely contributing to effects on water chemistry (TNC unpublished data). For example, on July 16 chlorophyll *a* concentration in transitional wetland was 250 µg/L although field notes

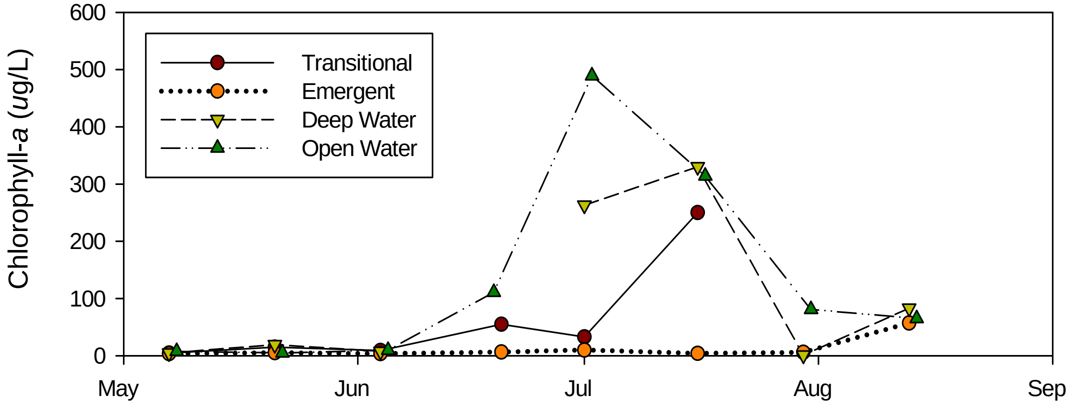

Figure 2.7. Chlorophyll *a* concentrations at continuous monitor sites located in transitional, emergent, deep water, and open water wetland within the Williamson River Delta, 2008.

documented the presence of another form of algae that was more prevalent than AFA.

In deep water and open water wetlands, daily lows in DO tended to last throughout the day, especially during July and August, a pattern that was not observed at any of the other sites (Figure 2.5). The sustained period of low DO throughout the day during summer in open and deep water further suggests that different processes were occurring within the wetlands compared to the lake.

High Stress Threshold Conditions and Implications for Endangered Suckers

Water quality within the Delta has important implications for Lost River and shortnose suckers since the wetlands may provide critical rearing habitat for larval and juvenile fish. Physical water chemistry results show sustained periods of low DO conditions (< 4 mg/L) on a time scale of several hours to several days within the Delta wetland, particularly in deep water, emergent wetland, and transitional wetlands. pH values exceeding 9.7 occurred at some frequency in all locations, except emergent wetlands. Temperatures exceeding 28˚C occurred for up to several hours within emergent and transitional wetlands during the last few weeks of monitoring before water depth became too shallow to continue.

Results from larval fish monitoring conducted by The Nature Conservancy in 2008 indicate that suckers were using restored wetland habitat from late May to early July. Adverse water quality conditions in deep water wetland through July and August could have provided poor habitat conditions for suckers. During this period, USGS observed few or no catches of juvenile suckers in deep water wetland areas (S. Burdick, USGS, personal communication). In September, juvenile suckers returned to deep water wetland areas coincident with an improvement in water quality conditions.

CONCLUSION

This report presents data from the first full year of surface water grab sample collection and continuous physical water chemistry monitoring following restoration of the Williamson River Delta in fall 2007. Differences between the restoration wetland and surrounding water bodies in regard to seasonal and diurnal trends in water chemistry parameters were observed. Results indicated a substantial influence of AFA on deep water and open water wetland sites, but not in emergent or transitional wetland sites. The potential significance of decomposition processes and soil nutrient flux on nutrient dynamics and water chemistry parameters within the wetland was also implicated. The influence of circulation between the wetland and surrounding waters on surface water chemistry was evident in trends of specific conductance within and surrounding the Delta. Additionally, combined efforts of fish monitoring and water quality monitoring within the Delta helped inform the influence of water chemistry on juvenile sucker inhabitance of the Delta wetland.

Overall, results from the first full year of monitoring following restoration provide a solid baseline with which to identify changes that will occur in the Delta over the longer term. As wetland vegetation becomes more established and functional ecosystem processes associated with wetlands are returned to the system, changes are expected in water chemistry within the Delta and potentially in Upper Klamath Lake. Further monitoring of water quality on the Delta will provide the necessary information and understanding regarding the potential benefits of wetland restoration for Lost River and shortnose suckers as well as when the short-term impacts of nutrient release from soils are offset by the expected long-term benefits of nutrient sequestration. Ultimately, results from further monitoring will be important for determining whether restoring wetlands is a practical strategy for sufficiently reducing nutrient loads to Upper Klamath Lake.

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APPENDICES

Appendix A. Detection and reporting limits for sample constituents, standard method number, and laboratory conducting the analysis.

Constituents	Detection Limit (µg/L)	Reporting Limit (µg/L)	Method	Laboratory
Total Phosphorus	9	12	SM4500-P H	Spraque River Water Quality Lab, OR
Orthophosphate	3	6	SM4500- PF	
Ammonia	6	10	MD Krom methods	
Nitrate + Nitrite	8	10	Enzymatic NO3; SM4500-NO2	
Total Nitrogen	10	30	Enzymatic NO3	
Total Organic Carbon	300	500	SM 5310	Basic Laboratory, CA
Dissolved Organic Carbon	300	500	SM5310C	
Chlorophyll *a*	0.1	NA	SM10200H	Aquatic Research, WA

Appendix B. Quality Assurance/Quality Control results for split, duplicate, lab blank, and equipment blank samples.

Split samples are collected to assess sample collection and laboratory precision. Split samples are collected by filling an additional sample bottle for each constituent during grab sample collection. Both samples are taken from the same churn splitter. Duplicate samples are collected to assess repeatability of sample collection. Duplicate samples are collected by taking a complete separate sample from the identical location and depth as the regular grab sample. Lab blanks are collected to assess laboratory accuracy. Lab blanks are collected by filling a sample bottle with DI water which has been rinsed three times prior with DI water. Equipment blanks are collected to detect any contamination during initial cleaning of sampling equipment. Equipment blanks are collected by: (1) filling the Van Dorn with DI water; (2) transferring it to a churn splitter; and (3) to a sample bottle that has been rinsed three times with DI water.

Split Samples	Number of Samples			Difference between splits	
Analyte	Duplicates	Total	% Split Samples	Median (mg/L)	Median (%)
Total Phosphorus	35	320	11%	0.004	0
Orthophosphate	35	320	11%	0.001	1
Total Nitrogen	35	320	11%	0.032	1
Ammonia	35	320	11%	0.002	0
Nitrate + Nitrite	35	320	11%	0	0
Chlorophyll *a*	20	147	14%	0.004	1
Total Organic Carbon	19	153	12%	0.2	3
Dissolved Organic Carbon	19	148	13%	0.2	3

Duplicate Samples	**Number of Samples**		**%**	**Difference between splits**	
Analyte	**Duplicates**	**Total**	**Duplicate Samples**	**Median (mg/L)**	**Median (%)**
Total Phosphorus	14	320	4%	0.006	0.02
Orthophosphate	14	320	4%	0.004	0.02
Total Nitrogen	14	320	4%	0.061	4.24
Ammonia	14	320	4%	0.004	0.02
Nitrate + Nitrite	14	320	4%	0.001	0.03

Lab Blank	**Number of Samples**		**% of Blank Samples**	**Minimum Reporting Level (mg/L)**	**Value of Blank Samples greater than reporting limit**
Analyte	**Blank**	**Total**			**Maximum (mg/L)**
Total Phosphorus	5	320	2%	0.012	0.01
Orthophosphate	5	320	2%	0.03	NA
Total Nitrogen	5	320	2%	0.03	0.004
Ammonia	5	320	2%	0.01	0.007
Nitrate + Nitrite	5	320	2%	0.01	NA
Chloropyhll a	1	147	1%	0.0001	0.0011

Equipment Blank	**Number of Samples**		**% of Blank Samples**	**Minimum Reporting Level (mg/L)**	**Value of Blank Samples greater than reporting limit**
Analyte	**Blank**	**Total**			**Maximum (mg/L)**
Total Phosphorus	1	320	0.3%	0.012	NA
Orthophosphate	1	320	0.3%	0.03	NA
Total Nitrogen	1	320	0.3%	0.03	NA
Ammonia	1	320	0.3%	0.01	0.014
Nitrate + Nitrite	1	320	0.3%	0.01	NA

Appendix C. Quality assurance criteria for continuous physical water chemistry monitoring. Level A criteria represent the highest quality data as defined in TNC's Water Quality Monitoring Project Plan. Level B criteria represent data outside Level A criteria, but deemed acceptable. Level C criteria represent data deemed unacceptable and omitted.

Data Quality Level	**Quality Assurance Plan & Action Steps**	**Water Temperature**	**pH**	**Dissolved Oxygen**	**Specific Conductance**
A	QA Criteria Met Data Accepted	± 0.5°C	± 0.2	± 0.3 mg/L	± 7% of std value
B	QA Criteria Not Met Data Accepted; QA Reported	± 2.0°C	± 0.5	± 1.0 mg/L	± 10% of std value
C	QA Criteria Not Met Data Omitted; QA Reported	> ± 2.0°C	> ± 0.5	> ± 1.0 mg/L	> ± 10% of std value

Appendix D. Quality assurance results for the 2008 continuous monitoring season. Only dissolved oxygen data fell under Level B and C criteria and are reported in this table. Data meeting Level A criteria are not shown, which include all data for temperature, pH and specific conductance. 'No Data' indicates no data were recorded for all four parameters due to equipment malfunction.

Data Quality Level	Continuous Monitor Site	Dates
B	Agency Lake	4/28/2008 - 5/6/2008
B	Agency Lake	5/20/2008 - 5/28/2008
B	Agency Lake	6/16/2008 - 6/24/2008
B	Agency Lake	7/29/2008 - 8/5/2008
B	Agency Lake	9/3/2008 - 9/9/2008
C	Agency Lake	9/23/2008 - 9/30/2008
B	Agency Lake	10/15/2008 - 10/29/2008
B	Agency Lake	11/6/2008 - 11/12/2008
B	Upper Klamath Lake	10/29/2008 - 11/6/2008
B	Williamson River	7/29/2008 - 8/5/2008
C	Williamson River	11/25/2008 - 12/2/2008
B	Goose Bay	8/19/2008 - 8/26/2008
B	Open Water	5/6/2008 - 5/13/2008
B	Open Water	8/12/2008 - 8/19/2008
B	Open Water	8/19/2008 - 8/26/2008
C	Open Water	10/7/2008 - 10/15/2008
B	Deep Water	5/6/2008 - 5/13/2008
B	Deep Water	7/9/2008 - 7/15/2008
B	Deep Water	7/22/2008 - 7/29/2008
B	Deep Water	8/19/2008 - 8/26/2008
B	Deep Water	10/15/2008 - 10/29/2008
C	Emergent	4/29/2008 - 5/6/2008
B	Emergent	6/17/2008 - 6/24/2008
B	Emergent	7/29/2008 - 8/5/2008
C	Transitional	5/6/2008 - 5/13/2008
B	Transitional	6/30/2008 - 7/9/2008
NO DATA	Open Water	11/6/2008 - 11/12/2008
NO DATA	Deep Water	10/29/2008 - 11/12/2008