2008-
2012

Water Quality Conditions on the Williamson River Delta, Oregon: Five Years Post-Restoration

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2008-2012

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EXECUTIVE SUMMARY

The Nature Conservancy has monitored water quality on the Williamson River Delta Preserve (the Delta) for five years following restoration: in Tulana starting fall 2007 when the first major breaches flooded approximately 3,500 acres and starting in Goose Bay during spring 2009 after another 2,000 acres were flooded; this monitoring effort has continued through fall 2012. One of the fundamental goals of the wetland restoration project was to facilitate improvement in water quality in Upper Klamath and Agency Lakes by removing a major external nutrient source to the lakes originating from former agricultural fields at the Delta and by nutrient sequestration through wetland ecosystem processes. The objective of water quality monitoring was to quantify and describe the effects of the restoration on surface water chemistry, nutrient composition, and chlorophyll-*a* (chl-*a*) levels within and surrounding the Delta. Specific questions addressed by this monitoring effort and presented in this report include: (1) the extent to which the Delta wetlands provided a source or sink for nutrients within the five years after restoration; (2) the effects of restoration on water quality; and (3) the magnitude and timing of water quality conditions in the Delta that may have been detrimental to two endangered sucker species, Lost River sucker (*Deltistes luxatus*) and shortnose sucker (*Chasmistes brevirostris*). This report summarizes data collected from March–November of 2008–2012 (note: sampling did not take place from December–February). From March 2008–November 2012 surface water grab samples for nitrogen (N) and phosphorus (P) were collected at 27 sites. Carbon and chl-*a* samples were collected at 21 sites from April 2008–October 2011. Continuous (hourly) water chemistry parameters including temperature, dissolved oxygen (DO), pH, and specific conductance were recorded at nine sites in the Delta, Upper Klamath and Agency Lakes, and the Williamson River. We modified our sampling design in 2009 by moving four sites in Tulana, one from Agency Straits, and one from the Williamson River to the newly restored Goose Bay portion of the Delta.

Throughout the 5 years of monitoring, phosphorus has progressively become more stable with overall lower concentrations at lake and Tulana wetlands sites from 2009–2012 following an initial pulse of P released from newly flooded agriculture land in 2007 and 2008 (Wong et al. 2011). From 2008 to 2012 total phosphorus (TP) concentrations were up to 4 times lower in 2012 compared to the first year of monitoring in open water and deep water wetlands (permanently flooded wetlands) and 3 times lower in the lakes from mid-August through early October; this late summer period is historically the time when peak algal blooms occur in Upper Klamath and Agency Lakes. Shallow water wetlands in Tulana (emergent and transitional) have experienced a decrease in TP as well, albeit less dramatic. Concentrations of TP have been reduced by up to 2.4 times during June–August from 2008 to 2012. These shallow water habitats are seasonally inundated and usually remain flooded until late June or early August depending on the water year. During monitoring efforts these habitats have exhibited the slowest rate of P decrease and levels may continue to taper off beyond this 5 year analysis. Phosphorus

concentrations in Goose Bay emergent and transitional wetlands were lowest in 2011 and 2012, with TP concentrations up to 2.8 times lower during June–July in 2012 compared against 2009.

At most lake and permanently flooded wetland sites, increases in chl-*a* concentration coincided with increases in total nitrogen (TN) concentration, DO concentration, and pH, while declines in chl-*a* concentration corresponded to peaks in dissolved inorganic nitrogen (DIN) concentration and declines in TN concentration, DO concentration, and pH. These latter trends are typical for this lake system, where water quality is often driven by the bloom and crash dynamics of the cyanobacteria, *Aphanizomenon flos-aquae* (Lindenberg and Wood 2009). Among all wetland sites and years, dissolved organic carbon (DOC) concentrations ranged from 4–22 mg L^{-1}, a range considerably lower than the 24–270 mg L^{-1} range observed in a nearby wetland (Carpenter et al. 2009).

Continuous monitoring data showed that water quality conditions in the Delta exceeded high stress thresholds for endangered Lost River and shortnose suckers for at least one hour for all 5 years of monitoring, conditions which are defined by DO concentration<4 mg L^{-1}, pH>9.7, and temperature>28°C (Loftus 2001). However, throughout previous years, DO and temperature exceedances have decreased across habitat types, from 2008 to 2011 and 2012. Linear regression analysis has revealed a close correlation between the number of years post-restoration and the proportion of time when DO thresholds are surpassed in Tulana transitional and emergent wetlands (R^2=0.97 and 0.87, respectively). Similarly, there has been a strong negative relationship between years following reflooding and temperature exceedances in Tulana transitional and Goose Bay emergent sites (R^2=0.72 and 0.87, respectively). These habitats have the densest wetland vegetation, which provides a shading effect from solar irradiation. In 2012, pH levels were exceptionally high across habitats; the observed trends in elevated pH and fluctuating DO concentrations indicate that phytoplankton blooms peaked in late summer and continued through early fall (US Geological Survey 2008). Despite high pH levels observed in 2012, overall pH threshold exceedances considered critically stressful to endangered suckers have decreased in Agency Lake and open water wetlands since the Delta was reconnected (linear regression R^2=0.88 and 0.71, respectively).

Seasonal inter-annual trends in conditions most stressful for suckers (prolonged periods of DO concentration<4 mg L^{-1}, pH>9.7, and temperature>28°C throughout the day) included pH and DO exceedances in the lakes and permanently flooded wetlands during *A. flos-aquae* bloom and crash periods (July through August for pH, and mid-July through September for DO). The DO threshold was typically exceeded for 80–90% of the hours recorded in August and September in permanently flooded wetlands and lake sites during most monitoring years. These habitats also generally had pH exceedances for up to 90% of hours in July. In the Tulana and Goose Bay emergent and transitional wetlands (seasonally flooded wetlands), DO and temperature exceedances have decreased since 2008; however, it is important to note that the majority of these habitats are dried up by late summer when algae blooms and crashes take place and water quality conditions become the most threatening to fish. During the time period when larval migration of endangered suckers occurs (May through early July) there are very few exceedances observed for pH, DO, or temperature across all five sampling years.

Overall, trends in nutrient and physical water chemistry reveal that the wetlands system was likely in a state of transition in which nutrients were initially released from benthic sources after being flooded. Gradients in water chemistry and primary productivity as measured by chl-*a* levels across the Delta wetlands also reveal the hydrologic influence of lake waters in permanently flooded areas of the Delta and the influence of river waters in seasonally flooded areas of the Delta, particularly in Goose Bay. Site-to-site variability was also observed within habitat types of the Delta, which may be explained by a number of different factors including differences in water depth, wind exposure, vegetation, soil types, historical land management, and other biological, chemical, and physical factors.

Results from five years of water quality monitoring on the Delta provide important information for assessing trends in water chemistry following wetland restoration. As wetland ecosystem processes are restored to the system, changes in surface water chemistry are expected. Documenting these changes is vital, especially considering the wide-ranging efforts by multiple agencies and organizations in the Upper Klamath Basin to restore and manage wetlands.

INTRODUCTION

The widespread loss of wetlands in the Upper Klamath Basin (the Basin) in southern Oregon is extensively cited as one of the underlying factors contributing to the degradation of water quality in Upper Klamath and Agency Lakes (Snyder and Morace 1997, Bradbury et al. 2004, Eilers et al. 2004, National Research Council 2004). Since the late 1800s, 85–90% of wetlands in the Basin have been drained and converted for agriculture (Gearhart 1995). An estimated 20,000 or more acres of wetlands around Upper Klamath Lake were drained since 1885 (National Research Council 2004). The drainage of these wetlands and the associated nutrient sink, coupled with the concurrent expansion of development and agricultural activities over the past century is believed to have increased nutrient loading into the lakes and contributed to their hypereutrophic states (Snyder and Morace 1997, Bradbury et al. 2004, Eilers et al. 2004, Natural Research Council 2004).

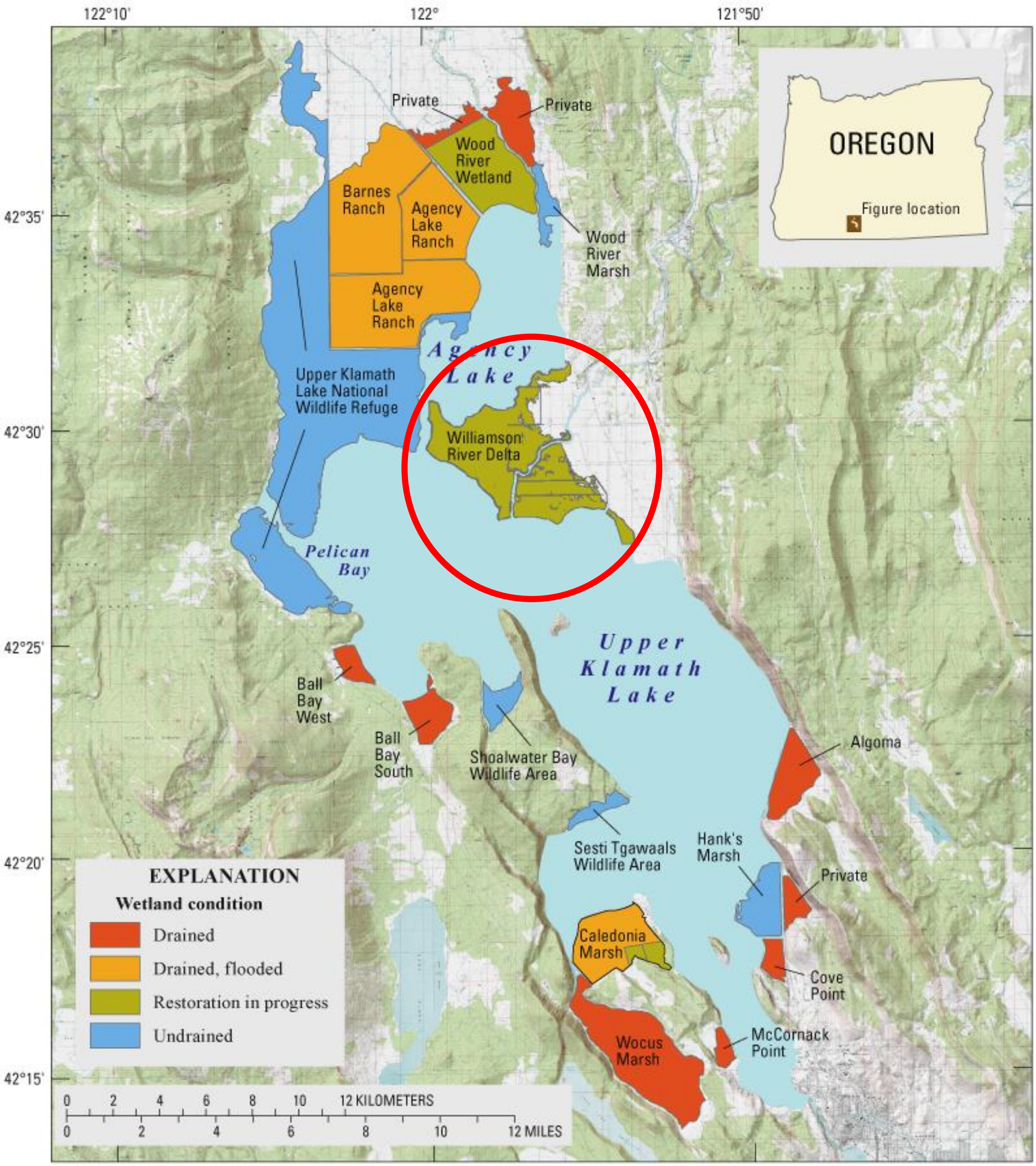
Excessive phosphorus loading is a primary cause of poor water quality conditions in Upper Klamath Lake, contributing to the listing of two fish species as federally endangered and resulting in the listing of the lake on Oregon's 303(d) list of water quality-impaired waters, due to elevated pH and chl-*a* levels and low DO concentrations. The Williamson River is the single largest source of phosphorus to the lake. Restoration of the Delta wetlands, which surround the last 4 miles of the Williamson River before it empties into Upper Klamath Lake, may provide an important buffering capacity for nutient reduction. The restoration plan adheres to Oregon Department of Environmental Quality's (DEQ) *Upper Klamath Lake Drainage Total Maximum Daily Load (TMDL)* and *Water Quality Management Plan (WQMP*; Boyd et al. 2002). Oregon DEQ completed a TMDL in 2002 for Upper Klamath and Agency Lakes. The analysis identified excessive TP loading as the primary factor advancing eutrophication and impairing water quality in these lakes (Boyd et al. 2002). Thus, reducing total nutrient (P in particular) inputs to the lakes is the primary means to improve water quality (Boyd et al. 2002). Restoring wetlands is believed to be a viable strategy for retaining nutrients and improving downstream water quality (Mitsch and Gosselink 1993). As nutrient-laden water passes through wetlands, nutrients are taken up by plants and microbes or deposited in sediments that accumulate over time. Thus, the water leaving a wetland often has lower nutrient concentrations than when entering it.

At present, near monocultural blooms of the cyanobacteria, *Aphanizomenon flos-aquae*, occur seasonally in Upper Klamath and Agency Lakes and frequently drive poor water quality conditions including highly variable DO concentrations (anoxic to supersaturated), elevated pH (9–10), and high un-ionized ammonia concentrations (above 0.5 mg L^{-1}; Lindenberg et al. 2009). These periods of extreme poor water quality during summer and early fall have been linked to lethal conditions for Lost River and shortnose suckers and have led to substantial fish kills within the lake during 1986, 1995, and 1997 (National Research Council 2004, Janney et al. 2008). A recent smaller scale fish kill was also observed during the summer of 2003 (Janney et al. 2008). Furthermore, extended periods of stressful pH, DO, and temperature conditions (24-92 hours) contribute to mortality of larval and juvenile suckers and inhibit annual recruitment (Saiki et al. 1999, Loftus 2001). In particular, the near-anoxic conditions which result from the senescence phase of A. flos-aquae blooms likely induce high mortality for larval and juvenile age classes (Saiki et al. 1999). Water quality impairment in the lakes and associated fish die-off episodes has highlighted the need to address water quality issues in the Basin.

Entities in the Basin are heavily invested in wetland restoration and management projects in order to rehabilitate the diverse functions that wetlands provide, including habitat for fish and wildlife, water storage, and improved downstream water quality. Projects currently include those at Wood River Wetland, Agency Lake Ranch, Running Y Ranch, and the Williamson River Delta (Figure 1). Since 2000, The Nature Conservancy (TNC) and its partners have restored approximately 5,500 acres of wetlands at the Delta in order to restore hydrologic connectivity between the Williamson River, Upper Klamath and Agency Lakes, and the Delta wetlands. The two primary goals of the wetland restoration effort at the Delta were to restore rearing habitat for larval and juvenile endangered suckers and to facilitate improvement in water quality in Upper Klamath and Agency Lakes. Relating to water quality improvements, the objectives were to eliminate the return of agricultural tail water originating in the Delta to the lakes and to remove nutrients through wetland ecosystem processes such as plant uptake and soil accretion.

In fall 2007, large-scale restoration began with the breaching of levees surrounding the western half of the Delta (Tulana), and a long term water quality monitoring program on the Delta was implemented by TNC and project collaborators. The eastern portion of the Delta (Goose Bay) was flooded in the fall of 2008 and monitoring in Goose Bay was initiated in 2009. The objective of the monitoring project was to quantify and describe the effects of wetland restoration at the Delta on surface water chemistry. Monitoring and analysis was designed to address these overarching objectives: (1) measure the extent to which the wetlands provide a source or sink of phosphorus and nitrogen; (2) assess the effects of the restoration on surface water chemistry within the wetlands and adjacent lakes; and (3) evaluate the magnitude and timing of water quality conditions in the Delta that may have been detrimental to endangered suckers.

This five-year comprehensive report summarizes water quality data collected in the Delta and annual comparisons of water chemistry trends for the period of 2008–2012. Annual reports for 2008 (Doehring et al. 2009), 2009 (Doehring et al. 2010), 2010 (Wong and Hendrixson 2011), and 2011 (Hayden and Hendrixson 2012) have been completed and are available at connect.tnc.org. Phytoplankton abundance and composition following restoration is presented in a two-year comprehensive report for 2007-2009 (Wong et al. 2010) and an analysis of initial nutrient release immediately after reflooding of the Delta was published in Wetlands (Wong et al. 2011).



Digital Raster Graphics and Elevation: Produced by U.S. Geological Survey, various scales. Projection: UTM, Zone 10

Figure 1. Location of Williamson River Delta, Oregon in relation to other wetlands surrounding Upper Klamath and Agency Lakes. Map edited from Lindenberg and Wood (2009).

STUDY AREA

Restoration Background

The Delta encompasses 7,500 acres located between Upper Klamath and Agency Lakes in southern Oregon, east of the Cascade Range (Figure 1). These wetlands surround the last four miles of the Williamson River. Before 1940 this freshwater wetland system was naturally functioning with connected hydrology. However, beginning sometime around 1940 the wetlands were drained and cultivated for crops including alfalfa, potatoes, and barley until the 1990s. The entire Delta's hydrology was disconnected from Upper Klamath and Agency Lakes and the Williamson River. Additionally, the Williamson River was separated through the construction of levees along the Delta perimeter.

Restoration of the Delta wetlands was initiated in 1996 by TNC. Early action projects in 2000 and 2003 involved the breaching of levees at three locations and re-establishing hydrologic connectivity between the wetlands and surrounding lake and river at small portions of the Delta. In October 2007, larger scale restoration occurred with the breaching of levees surrounding the western half of the Delta (known as Tulana) using mechanical excavation and explosives, flooding about 3,500 acres. In November 2008, levees surrounding the eastern half of the Delta (known as Goose Bay) were breached by means of excavation, flooding about 2,000 acres. Approximately 5,500 acres total were re-flooded, restoring the wetlands as an open and passively managed system.

Breach locations on the Delta perimeter were sited based on hydrologic modeling (Daraio et al. 2004). On the Tulana portion of the Delta, four breaches ranging 2,100–2,700 feet (ft) in length occur along the northern and southwest perimeters, and three breaches ranging 500–1700 ft in length occur along the Williamson River (Figure 2). On the Goose Bay portion of the Delta, three breaches ranging 1,000–3,000 ft in length occur along the southern perimeter, and three breaches occur along the Williamson River. Levees between breaches were lowered to a surface elevation ranging 4,139–4,142 ft, allowing water to overflow the levees during seasonally high water levels.

Hydrology

Hydrology within the Delta wetlands is dependent on that of Upper Klamath and Agency Lakes and the Williamson River. Lake levels are regulated by the US Bureau of Reclamation (BOR) and fluctuate ±5 feet throughout the year, with highs (~4,143 ft surface water elevation, BOR Vertical Datum) typically in April and lows (~4,138 ft surface water elevation, BOR Vertical Datum) typically in September. At seasonally high water levels, water overflows the majority of remaining perimeter levees and covers vast portions of the Delta; wetland areas along both sides of the river are flooded. During seasonally low water levels, water flow from Upper Klamath and Agency Lakes is restricted to the four half-mile long openings within the perimeter breaches of the Delta. During this time, waters from the Williamson River are largely cut off from the wetlands. Substantial soil subsidence has occurred on the western portion of Tulana as a result of repeated draining, flooding, and tilling of the land during cultivation. Current elevations in these areas are as much as eight feet below average lake levels (David Evans and Associates, Inc. 2005), resulting in open water conditions year-round. Hydrologic seasonal trends include: (1) late spring and early summer flooding of emergent and riparian wetlands in eastern portions of Tulana and in the majority of Goose Bay, (2) followed by receding water levels and subsequent drying out of these sites in late summer and fall, and (3) year-round inundation in the western areas of Tulana, which now resemble lake habitat. Neither groundwater discharge nor recharge is a significant part of the water balance in the Delta (David Evans and Associates, Inc. 2005).

Vegetation and Soils

Wetland vegetation across the Delta is largely influenced by water depth and flooding tolerances of various plant species. Additionally, management of the land prior to restoration is likely to have influenced vegetative cover during the monitoring period. Immediately upon inundation in fall 2007, vegetation within Tulana consisted of a mosaic of flooded upland flora, crop stubble from former agricultural fields, and decomposing wetland vegetation which had been established prior to restoration by means of managed pumping. During the growing seasons in 2008 and 2009, eastern portions of Tulana were dominated by riparian and emergent species including golden dock (*Rumex maritimus*), Norwegian cinquefoil (*Potentilla norvegica*), and hardstem bulrush (*Schoenoplectus acutus*; Elseroad et al. 2009). On western portions of Tulana, open water conditions prevent the establishment of substantial vegetation; however, species such as water smartweed (*Polygonum amphibium*) and hardstem bulrush have been observed in these areas. Prior to flooding in fall 2008, Goose Bay had not been managed as a wetland. After flooding in 2009, wetland vegetation colonized this area for the first time since being drained and converted for agriculture. During the early monitoring period in 2009 and 2010, vegetation in Goose Bay consisted primarily of flooded upland vegetation and sparse coverage of riparian and emergent species of which included exotics such as false mayweed (*Tripleurospermum maritimum*) and quackgrass (*Elymus repens*), native annual forbs such as *Symphyotrichum frondosum* and *Rorippa curvisiliqua*, and other natives such as Norwegian cinquefoil, broadleaf cattail (*Typha latifolia*), creeping spike-rush (*Eleocharis palustris*), and hardstem bulrush (Elseroad et al. 2010). In 2011 and 2012 monitoring years, vegetation has increased exponentially in density and diversity within Goose Bay emergent and transitional marshes. Currently the vegetation composition resembles that of Tulana, despite different restoration techniques. For a full vegetation monitoring report, including documentation of species composition and coverage, see Elseroad et al. (2011).

Soils at the Delta consist primarily of Lather muck and Tulana silt loam (Cahoon 1985). Lather muck soils are poorly drained organic soils found at lower elevations on western portions of Tulana. Silt loam soils are mineral soils found at higher elevations of the Delta near the Williamson River and in Goose Bay. Because of soil subsidence and high exposure to waves and turbidity, re-colonization of substantial wetland vegetation on western portions of Tulana will be difficult in the short-term, although deeper water species such as wocus (*Nuphar lutea ssp. polysepala*) may establish over time.

METHODS

Study Design and Sampling Locations

Water sampling sites within the Delta were stratified based on water depth ranges in which different plant communities were expected to colonize upon flooding (Elseroad 2004) and by water movement patterns across the Delta as predicted by a hydrodynamic circulation model developed by the US Bureau of Reclamation (Daraio et al. 2004) and US Geological Survey (USGS; Carpenter et al. 2009). The water depth ranges used in the stratification of sampling sites within the Delta were classified as the following: transitional wetland (maximum water depth 0.6 meter [m]), emergent wetland (1.5 m), deep water wetland (2.7 m), and open water (4 m; Elseroad 2004). Transitional and emergent wetlands are the two distinct, seasonally flooded, vegetative zones and occur on eastern portions of Tulana and the majority of Goose Bay (Figure 2). Deep water wetland and open water are the two permanently flooded, less or non-vegetative zones and occur on western portions of Tulana and the southern-most areas of Goose Bay.

Monitoring at the Delta consisted of two components: surface water grab sampling and continuous in-situ water chemistry monitoring. All sampling sites were fixed sites which have been monitored for surface water quality since 2008 in Tulana and 2009 in Goose Bay. For surface water grab sampling, a total of 27 sites were sampled, including 4 sites in each of the 4 habitat zones in Tulana (open water, deep water, emergent, and transitional wetlands), 3 sites in each of the 2 habitat zones in Goose Bay (emergent and transitional wetlands), 3 sites near-shore of the Delta perimeter in Upper Klamath and Agency Lakes, and 2 sites in the Williamson River (one upstream ~6 km and one near the mouth before it enters Upper Klamath Lake; Figure 2). Sampling sites in the emergent wetlands were typically discontinued in early to mid-August during an average water year, as water levels declined and sites became too shallow to sample. In 2012 (a below average water year based on USGS mean daily statistics over the past 14 years, see Figure 3), emergent marsh sampling ended on July 3 in Goose Bay and July 31 in Tulana. Sites in transitional wetlands are usually discontinued around mid to late July. During the 2012 sampling year, these sites were dropped due to low water levels after July 3 in Goose Bay and June 20 in Tulana. Nutrients and parameters collected at each site are shown in Table 1.

During the 2008–2012 monitoring period, continuous monitoring fixed sites were selected from a subset of the 27 grab sampling locations. Multi-probe instruments (YSI 600 XLM sondes) were deployed at a total of 9 sites annually, including 1 in each of the 4 habitat zones in Tulana (open water, deep water, emergent, and transitional), 1 in Goose Bay in the emergent wetlands, 1 in the Williamson River upstream of the project area, and 3 in the lakes near-shore of the Delta perimeter (Table 1, Figure 2).

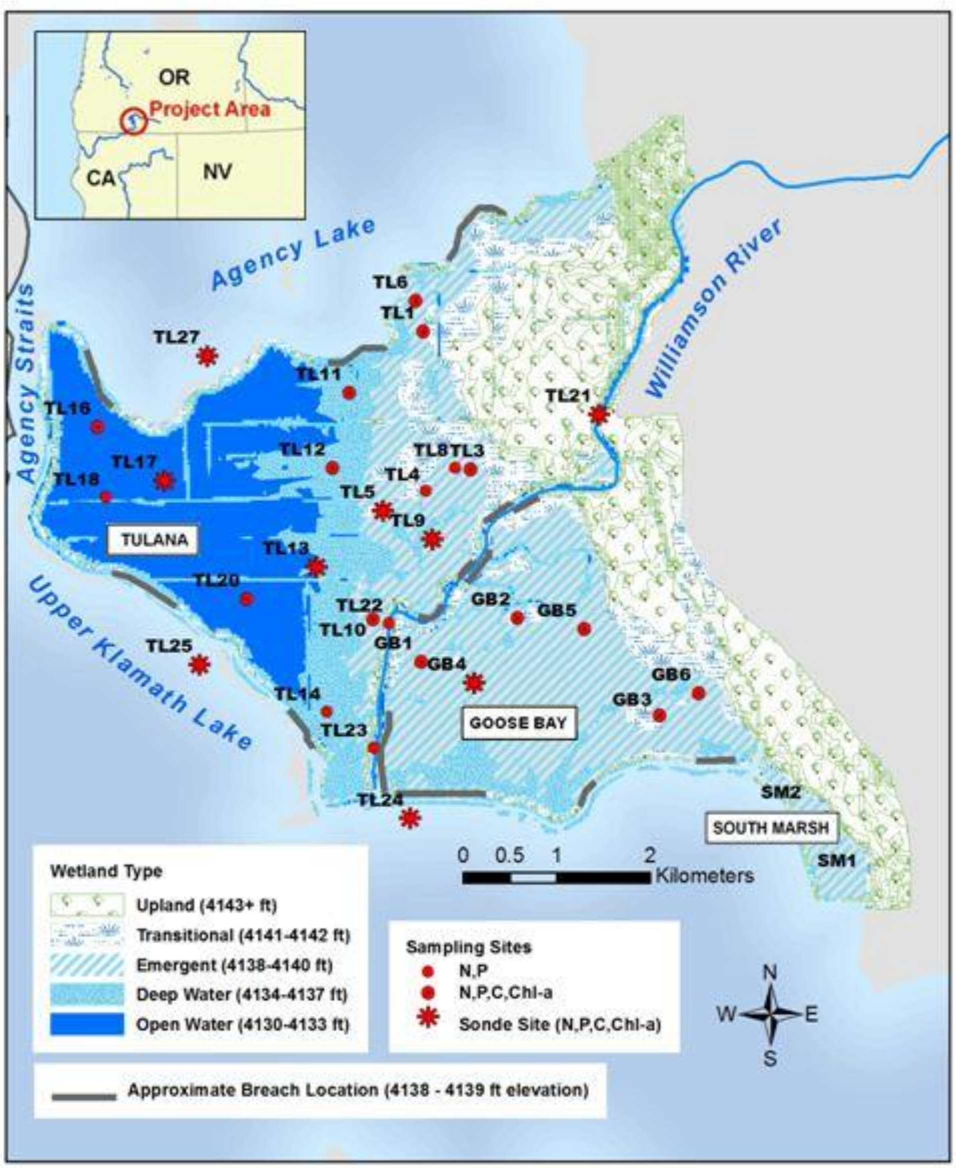


Figure 2. Map of the Williamson River Delta, Oregon showing wetland habitat types and water sampling sites 2008-2012.

Table 1. Water quality data collected at each water sampling site in the Williamson River Delta project area in 2012. 'Sonde' denotes water temperature, dissolved oxygen concentration, pH, and specific conductivity. 'X' denotes sample collected and '-' denotes sample not collected. For previous years sampling schedule see Wong et al. (2010), Wong and Hendrixson (2011), and Hayden and Hendrixson (2012).

Location	Site ID	Habitat	Sonde	Nitrogen	Phosphorus
			Hourly	14 events	
			April-November		
Tulana	TLTR1	Transitional Wetland	-	X	X
	TLTR3	Transitional Wetland	-	X	X
	TLTR4	Transitional Wetland	-	X	X
	TLTR5	Transitional Wetland	X	X	X
	TLEM6	Emergent Wetland	-	X	X
	TLEM8	Emergent Wetland	-	X	X
	TLEM9	Emergent Wetland	X	X	X
	TLEM10	Emergent Wetland	-	X	X
	TLDW11	Deep Water Wetland	-	X	X
	TLDW12	Deep Water Wetland	-	X	X
	TLDW13	Deep Water Wetland	X	X	X
	TLDW14	Deep Water Wetland	-	X	X
	TLOW16	Open Water	-	X	X
	TLOW17	Open Water	X	X	X
	TLOW18	Open Water	-	X	X
	TLOW20	Open Water	-	X	X
Goose Bay	GBTR1	Transitional Wetland	-	X	X
	GBTR2	Transitional Wetland	-	X	X
	GBTR3	Transitional Wetland	-	X	X
	GBEM4	Emergent Wetland	X	X	X
	GBEM5	Emergent Wetland	-	X	X
	GBEM6	Emergent Wetland	-	X	X
River	WR21	Williamson River, upstream	X	X	X
	WR23	Williamson River, downstream	-	X	X
Lake	UKLE24	Upper Klamath Lake, nearshore	X	X	X
	UKLW25	Upper Klamath Lake, nearshore	X	X	X
	AL27	Agency Lake, nearshore	X	X	X

Grab Sampling

Surface water grab samples were collected and analyzed for constituents of N, P, carbon (C), and chl-*a*. Nitrogen and P samples were collected bi-weekly at all 27 sites sampled over 16 events from March–November during 2008–2011. In 2012, sampling occurred during 14 events from April–November at the same fixed sites. Nitrogen constituents included total (TN), nitrate+nitrite (NO_X), nitrite (NO_2), and ammonium (NH_4). Phosphorus constituents included TP and soluble reactive phosphorus (PO_4). Carbon and chl-*a* samples were collected at 21 of the 27 sites from April–late September 2008–2011. Carbon was sampled over 6 events, while chl-*a* was collected over 12 events. Carbon constituents included DOC and total organic carbon (TOC).

Water samples were collected using a 3.2 liter Van Dorn horizontal beta sampler. At sites less than 1 m deep, water was collected at mid-depth in the water column. At sites 1–2 m deep, water was collected at mid-depth in the water column and at 0.5 m below the water surface. At sites greater than 2 m deep, water was collected at 1 m and 0.5 m below the water surface. Water was transferred from the Van Dorn to a churn splitter and mixed slowly and evenly ten times before filling triple-rinsed sample bottles. Quality assurance samples were also collected during each sampling event. Quality assurance results for nutrients are presented in Appendix A. Samples for N, P, C, and chl-*a* analyses were collected from the same mixed water. All samples were stored in a cooler on ice at about 4°Celcius (°C) until further processing immediately after field sampling. Site parameters including water depth, water transparency (measured using a Secchi disk), density of surface algal bloom (measured on a 0–5 scale), and presence or absence of vegetation were recorded at each sampling site. Ambient water temperature, DO concentration, pH, and specific conductivity were also measured instantaneously at each site using a multi-probe sonde (YSI 600 XLM).

For a complete description of field methods and sampling protocol see TNC's Quality Assurance Project Plan (The Nature Conservancy 2008).

Laboratory Analysis

Nitrogen and P samples were analyzed by the Klamath Tribes' Sprague River Water Quality Laboratory in Chiloquin, Oregon. Approximately 120 mL of unfiltered sample water was transferred to triple-rinsed 125 mL amber polyethylene bottles and acidified with 1 mL 4.5N H_2SO_4 for analysis of TN and TP. Total P and TN samples were digested using potassium persulfate, autoclaved, and analyzed on an automated spectrophotometer (SM 4500-P H and Enzymatic NO_3). Samples for analysis of NO_X, NH_4, and PO_4 were filtered on the same day of sampling through 0.45 µm sterile membrane filters (Millipore®) using a vacuum pump and 300 mL magnetic filter funnel (Pall Gelman®). Filtered samples were transferred to triple-rinsed 125 mL amber polyethylene bottles. Analyses of samples for PO_4, NO_X, NO_2, and NH_4 were completed using the colorimetric method on the same automated spectrophotometer (SM 4500-P F, Enzymatic NO_3, SM 4500-NO_2, and MD Krom). All N and P samples were stored at 4°C (±2°C) for less than 28 days (see Appendix B for Standard Method references).

Carbon samples were shipped on ice overnight and analyzed by Basic Laboratory, Inc. in Redding, California. Samples for TOC were preserved with 4.5N H_2SO_4, and DOC samples were filtered prior to analysis. Carbon samples were analyzed using the persulfate-ultraviolet oxidation method.

Chlorophyll-*a* samples were preserved with 4.5N H_2SO_4 and shipped on ice overnight to be analyzed by Aquatic Research, Inc. in Seattle, Washington. Triplicate 50-mL samples were filtered through Whatman 25-mm GF/F filters. Extraction with 90% acetone was performed and fluorometer methodology was used for analysis (Strickland and Parsons, 1968).

Concentrations of nutrient constituents and chl-*a* were reported and included in analyses if they occurred above the reporting limit or between the reporting limit and detection limit. Concentrations less than the detection limit were reported and analyzed at half the detection limit value. Reporting and detection limits for all constituents can be found in Appendix B.

SAS® System for Windows, Release 9.1.3 (SAS Institute Inc. 2004) was used for all data analysis including the calculation of means and standard errors.

In order to assess grab sample precision and accuracy, equipment and laboratory blank samples were collected at least once and twice per year, respectively, split samples at 10% of the total number of samples collected each sampling day, and duplicate samples at least once per sampling event. Protocols for quality assurance sample collection followed methods described in the Williamson River Delta Water Quality Monitoring Project Plan (The Nature Conservancy 2008). Quality assurance results are provided in Appendix A.

Continuous Monitoring

Multi-probe instruments (YSI 600 XLM sondes) were deployed at each continuous monitoring site for the collection of hourly data including water temperature, DO, pH, and specific conductance. Sondes were placed at mid-depth in the water column or at 1 m below the water surface if water depth exceeded 2 m. Monitoring lasted from March/April–November during the 2008–2012 sampling periods. At transitional and emergent wetland sites, monitoring occurred until July and August, after which insufficient water was present to continue monitoring.

Upper Klamath Lake elevation levels (Figure 3) and Williamson River flow data (Figure 4) was monitored by USGS. Water level and flow data were obtained from the USGS online database system and are provisional, subject to revision.

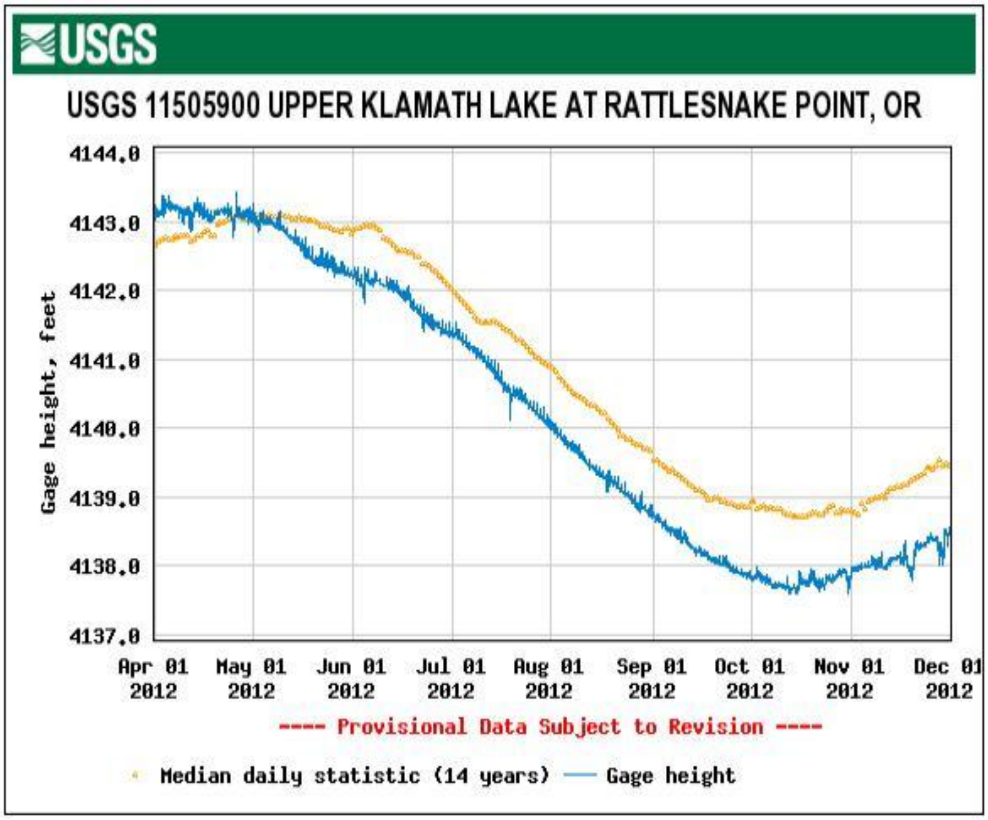


Figure 3. Upper Klamath Lake daily water levels from April-December 2012 compared to daily median over the last 14 years. Data collected at Rattlesnake Point, OR by USGS.

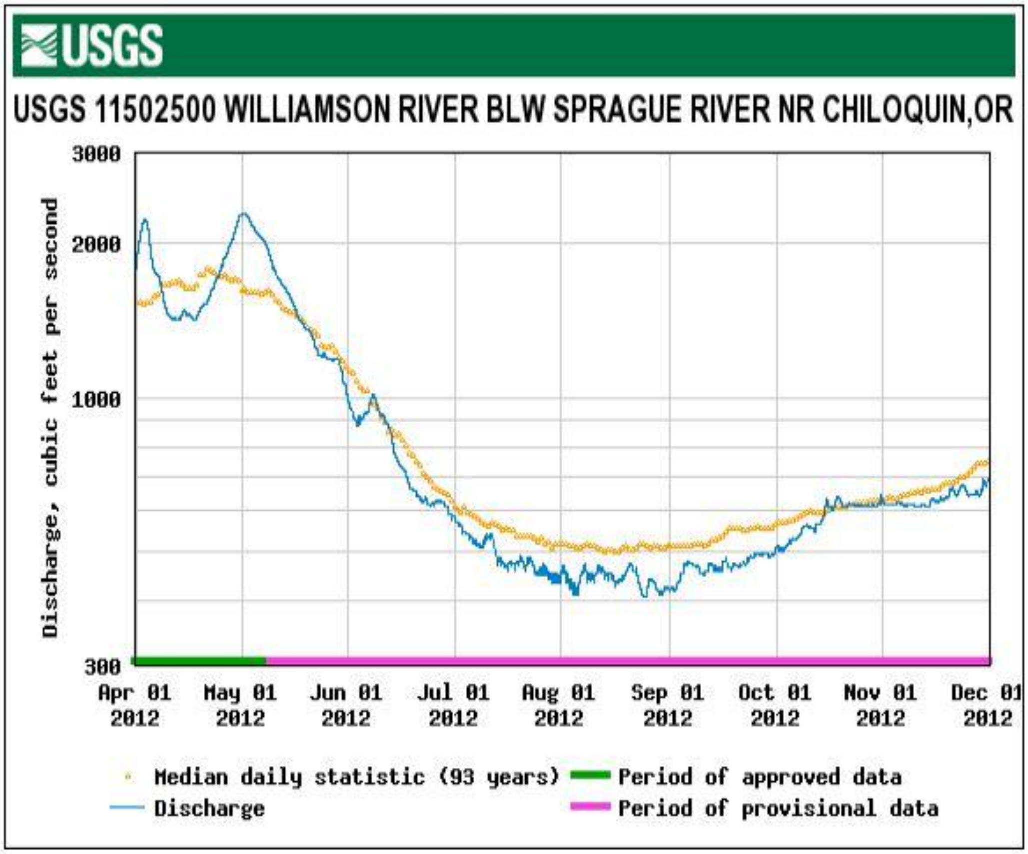


Figure 4. Daily mean discharge levels from April-December 2012 compared to daily median over the last 93 years for Williamson River. Data collected by USGS at site 11502500 on Williamson River below Sprague River near Chiloquin, OR.

Quality assurance checks included weekly calibration of instruments, weekly site visits, and post-calibration checks. Calibration was performed the day prior to deployment of individual sondes. Weekly site visits included the following: precision checks of deployed sondes against a newly calibrated reference sonde; cleaning of deployed sondes; and re-deployment or replacement of sondes such that an individual sonde was deployed at a site for no longer than two-week intervals. Post-calibration checks were performed to verify accuracy of each sonde following a deployment. Data quality objectives adhered to requirements defined in the Quality Assurance Project Plan (The Nature Conservancy 2008). Three levels of quality assurance criteria were used (Appendix C) to determine whether data were deemed acceptable to include in analysis. Instances where data did not meet requirements are reported in Appendix D.

Raw data collected from sondes were quality-checked before being accepted for statistical analysis. Daily statistics were computed only for days in which at least 20 hours of acceptable data were recorded.

RESULTS and DISCUSSION

Measured site water depths varied inter-annually depending on yearly water levels. Low water years, such as 2010 and 2012 (based on USGS vertical gage data) had the following ranges in site levels: 0.28-1.0 m in transitional, 0.3–1.45 m in emergent, 0.4–2.6 m in deep water, and 1.1–3.0 m in open water wetlands, 0.3–2.5 m in the lakes, and 2.3-4.5 m in the Williamson River. Average and high water level years, such as 2008, 2009, and 2011 had minimum water depths within open and deep water wetlands, lake, and river habitat types 0.4-0.6 m higher, comparatively. See Figure 3 and 4 for a comparison of below average water years (i.e., 2012) versus the 14 year median for Upper Klamath Lake (UKL) and the 93 year median for Williamson River flow.

Nutrient, chl-*a*, and water chemistry results are described temporally (seasonally and annually) as well as spatially across the Delta wetlands and near-shore lakes and river. The terms ‘early season’, ‘mid-season’, and ‘late season’ are used to generally describe the periods March–June, July–September, and October–November, respectively. We also explore water chemistry results in relation to high stress threshold conditions for endangered suckers. Additionally, relationships between nutrients and chl-*a* concentrations are explored because these relationships can provide information about nutrient limitation of algal growth in this wetland system. The following text presents both seasonal ranges for 2012 and post-restoration inter-annual trends (2007-2012).

Grab Sampling

Phosphorus

In total, 266 P and N samples were collected in 2012. Total P concentrations ranged from 0.04–1.14 mg L^{-1} among wetland sites, 0.04–0.33 mg L^{-1} among lake sites, and 0.07–0.15 mg L^{-1} among river sites during the sampling period April–November 2012 (Table 2). On average over the year, PO_4 (SRP) comprised about 56% of TP in the wetlands, 51% in lakes, and 70% in the river.

Among habitat types, mean TP concentrations were highest in the Tulana transitional and emergent wetlands during most sampling events from April–July 2012 (0.28 mg L^{-1} in transitional and 0.27 mg L^{-1} in emergent sites), while mean TP concentrations were lowest in the Williamson River (0.09 mg L^{-1}; Figure 5a). Among emergent and transitional wetland locations, mean TP concentrations were about twice as high in Tulana compared to Goose Bay wetland concentrations (0.16 mg L^{-1} in transitional and 0.12 mg L^{-1} in emergent sites; Figure 5a). These trends are consistent with previous years. Overall, Tulana transitional and emergent wetlands have had the highest TP and SRP concentrations, about twice as high as similar Goose Bay habitats (Figures 6a, b). Transitional and emergent wetlands maintained relatively stable TP concentrations throughout the spring and summer, particularly in Goose Bay with the exception of an isolated peak observed in May occurring in Goose Bay transitional (Figures 5a and 6a). Tulana transitional wetlands experienced a slight TP increase in late spring, from the beginning of May and peaked in early June then decreased until sampling was discontinued after June 26, due to water levels dropping below sampling protocol (<0.3 m). Similarly, Tulana emergent wetlands also increased modestly in early summer from the beginning of June, peaking at the beginning of July, then decreased till sampling was discontinued after August 1. The trend of TP decreasing in shallow wetland habitats in mid-summer (i.e., July) is unique to the 2012 sampling year (Figure 6a). In previous years (2008-2011) TP increased considerably from June and continued increasing until sites dried up, typically during August. Due to 2012 being a below average water year for UKL, sites dried out earlier.

Total P across habitat types was the lowest observed during the past 5 years of monitoring with the exception of Goose Bay transitional (Figures 6a and 7a), particularly from late summer through fall in deep and open water wetlands, as well as lake sites. Historically the deep and open water wetland habitats have experienced increases in TP starting in late June and reaching maximal levels in late August and September and remaining elevated until October, when water temperatures and cyanobacteria blooms within the lake decrease. However, in 2012, deep water, open water, and lake sites had minimal peaks in TP around the beginning of August then decreased and remained stable through the fall (Figure 6a).

Compared to previous years of monitoring, ranges in SRP concentrations were generally lower in 2011 and 2012 among all habitat types when compared to 2008–2010 (Figures 6b and 7a). This trend was most pronounced during late summer (August—September) in deep water, open water, and lake sites (Figure 6b). Overall, TP and SRP have gradually decreased each subsequent year following restoration (Figure 7a). Deep water and open water wetlands had three times higher TP and SRP concentrations in 2008 immediately following levee removal and reflooding of previously agricultural land compared to 2012. Concentrations between 2009 through 2011 have been relatively stable. In 2012, TP and SRP concentrations during July through November were the lowest observed during post-restoration monitoring (Figure 6a, b). River concentrations have been consistent between sampling years, with 2009 being the exception, where TP was doubled during July-August (Figure 6a). Similarly, SRP in the river was highest in 2008 and 2009 during July (Figure 6b).

Nitrogen

Total N concentrations ranged from 0.20–6.40 mg L^{-1} among wetland sites, 0.15–2.89 mg L^{-1} among lake sites, and 0.11–0.68 mg L^{-1} among river sites in 2012 (Table 2). On average over the year, dissolved inorganic nitrogen (DIN; the sum of NO_X and NH_4 concentrations) comprised 4.2–12.9% of TN within wetland sites, 10.6% among lake sites, and 17.9% of TN at river sites.

Mean TN concentrations in open water and deep water wetlands peaked one time in late July 2012 and concentrations were lower from August–November 2012 compared to previous years (Figure 6c). An inter-annual trend was exhibited between 2008 through 2011, where TN concentrations have increased considerably during the fall season (up to twice the levels that were observed during 2012) and 2 peaks have typically been observed, the first being in late July and the second in early September (Figure 6c). Late summer and fall peaks in TN are a direct result of *A. flos-aquae* blooms, a nitrogen fixing cyanobacteria and the dominant species of phytoplankton in UKL.

In the lake sites TN had a modest peak once in late July, similar to pervious years (Figures 5a and 6c). Goose Bay transitional and emergent wetlands reached maximal TN levels in late April and then decreased and remained stable throughout the period of inundation (Figure 5a). Tulana transitional and emergent wetlands, as well as the Williamson River sites all had consistently low levels of TN throughout the 2012 sampling year compared to previous years (Figure 6c). Particularly in Tulana emergent wetlands, TN levels were considerably higher in June and July 2008–2010 versus 2011 and 2012.

Ranges and trends in NO_X concentrations in 2012 were within the range of values and similar to trends observed in 2008-2011 (Figure 6d). During all monitoring years the highest NO_X concentrations have been consistently observed in deep water, open water, and lake sites. In 2012, NO_X concentrations in the wetlands and lakes increased significantly at the beginning of August, then decreased in October and increased again through November (Figure 5a). However, this trend was not as pronounced as in previous years, especially compared to peaks reached in September and October of 2008, 2009, and 2011 sampling years (Figure 6d).

Overall, NH_4 concentrations have decreased considerably across habitat types since restoration (Figure 7b). Ammonium remained relatively stable throughout 2012 with a modest peak in late July; concentrations were lower than 2008–2010 (Figures 6e and 7b). Ammonium was lower in 2011 and 2012 in deep water and open water wetlands sites, failing to exhibit the same seasonal peaks during late summer and early fall that characterized the 2008–2010 sampling years. Goose Bay emergent and transitional wetlands and the Williamson River had more variability in NH_4 ranges. In all habitat types, concentrations were lowest in 2011 (Figures 6e and 7b).

During October–November 2012, following *A. flos-aquae* blooms, DIN comprised a greater majority of TN (22.7% among wetlands, 22.6% among lakes, and 24.1% among river sites) compared to the average range over the year. The trend has been observed in previous years, albeit 2012 DIN proportions were lower comparatively. For example, in earlier years fall DIN has comprised ~40% of TN in wetlands, ~35% in the lake, and ~15% in the river.

Total N concentrations in wetland habitats were slightly lower in 2012 and similar to concentrations observed during 2011, when compared to years directly following reflooding

(2008-2010; Figure 6c). Similar to the trend observed with TP, TN gradually decreased at these sites for 4 years post-restoration and have become relatively stable in the fifth year. Currently, it appears that TP and TN in reconnected Tulana wetlands are largely influenced by lake water quality dynamics. This may be due to west and northwest spring and summer dominant winds (Wood 2012), circulating lake water throughout the Tulana portion of the Delta and pushing Williamson River lake water into Goose Bay emergent and transitional wetlands. Goose Bay wetlands sites have consistently had similar N and P levels compared to river sites for the 5 year monitoring duration and are often half of the concentrations observed in similar Tulana habitats. Additionally, Tulana soils have a significantly higher level of phosphorus rich peat, which has resulted in severe subsidence in Tulana deep and open water wetlands (Aldous et al. 2007, Wong et al. 2011)

Carbon

Carbon was sampled from 2008–2011. Sampling was discontinued in 2012, due to budget constraints and lack of any significant spatial or temporal trends. Among sampling years, TOC concentrations ranged from 3.5–84.7 mg L^{-1} in wetland sites, 3.6–15.5 mg L^{-1} among lake sites, and 1.0–7.6 mg L^{-1} in river habitats (See Wong et al. 2010, Wong and Hendrixson 2011, Hayden and Hendrixson 2012). On average, DOC comprised the majority of TOC in all habitats (~85%). Seasonal trends showed C concentrations were highest from late July through late August at deep water wetlands, open water, lake sites, and Tulana emergent wetlands (Figure 6f, g). Goose Bay emergent and transitional wetlands deviated from this trend as C levels increased until sampling was discontinued due to receding water levels in early–late July (transitional) and late July to mid-August (emergent).

From April to the beginning of July, Tulana transitional wetlands sites had the highest TOC and DOC, while Goose Bay transitional and Williamson River sites had the lowest concentrations during spring and early summer (Figures 6f and 6g). From July through October, open water and deep water wetlands had the highest C level, while river sites were the lowest during this time period. Both TOC and DOC concentrations from 2008 to 2011 were similar in range. General seasonal trends within habitat types have shown little inter-annual variation.

Chlorophyll-a

Chlorophyll-*a* was also sampled from 2008–2011 and discontinued in 2012. Concentrations ranged from 0.05–964 µg L^{-1} in the wetlands, 2.7–1143 µg L^{-1} in the lakes, and 0.05–14 µg L^{-1} in the river (Refer to Wong et al. 2010, Wong and Hendrixson 2011, Hayden and Hendrixson 2012).

Chlorophyll-*a* levels had high inter-annual variability (Figure 6h). Chlorophyll-*a* is a measurement of primary productivity and phytoplankton biomass, which is highly dependent on ambient water temperatures, solar irradiation (a factor of water depth and transparency), and nutrient availability in the form of DIN and SRP (primarily SRP in UKL because *A. flos-aquae* is P limited and capable of nitrogen fixation; De Nobel et al. 1997). These factors fluctuate between years, particularly in a heavily managed lake where water levels change ±5 ft from spring to late summer. This reduction in water availability leads to lake site depths of 0.3–0.45 m during August through October (Figure 5b). This also coincides with the time of year when lake ambient water temperature is highest (July-August; Figure 8a) and water column transparency is the clearest (late July–early September; Figure 5b). Shallow water columns and frequent wind-induced water circulation allow for constant nutrient resuspension from the benthic layer to the water surface where it is easily accessible to cyanobacteria (Cheng et al. 2005).

General post-restoration trends in chl-*a* included the lowest wetland levels consistently being observed in transitional and emergent wetlands (particularly in Goose Bay). Primary productivity peaked in these habitats in July of 2008, likely due to a pulsed P release after reflooding (Aldous et al. 2007, Wong et al. 2011). However, even during peak chl-*a* levels in 2008 these concentrations were approximately half of the value observed in deep water, open water, and lake sites (Figure 6h). Since 2008, emergent marsh vegetation has reestablished which has altered the nutrient cycle in these habitats (Jordan et al. 2003); P is taken up in spring and early summer by macrophytes reducing nutrient availability during late summer when algal blooms are prevalent.

Open water and deep water wetlands have similar chl-*a* trends compared to lake sites. Seasonal peaks occur between late July and the end of September. In 2011 only one peak was observed in these habitats, whereas pervious years had exhibited 2 annual peaks. In 2010, a low water year, chl-*a* averaged 640 µg L^{-1} in lake sites; the highest levels recorded during the 4 year monitoring effort (Figure 6h). Among all habitats, TN concentration followed trends in chl-*a* levels and was positively correlated to chl-a (Figures 6c, h). Peak timings in NO_X concentrations generally resulted directly after peak chl-*a* levels during the period mid-September–November (Figure 6d, h).

Table 2. Median, minimum, and maximum concentrations of grab sampling constituents by location during the 2012 sampling year, Williamson River Delta, OR. For previous years (2007-2011) see Wong et al. (2010), Wong and Hendrixson (2011), and Hayden and Hendrixson (2012).

	Total Phosphorus (mg/L)			**Soluble reactive phosphorus (mg/L)**		
Location/Habitat	**Med**	**Min**	**Max**	**Med**	**Min**	**Max**
Tulana- Emergent Wetland	0.14	0.08	1.14	0.10	0.01	0.87
Tulana- Deep Water Wetland	0.12	0.06	0.51	0.07	0.00	0.19
Tulana- Open Water	0.13	0.05	0.43	0.08	0.00	0.22
Tulana- Transitional Wetland	0.16	0.11	0.80	0.13	0.05	0.66
Goose Bay- Emergent Wetland	0.11	0.04	0.29	0.06	0.01	0.10
Goose Bay- Transitional Wetland	0.15	0.05	0.76	0.07	0.03	0.17
Williamson River	0.08	0.07	0.15	0.06	0.04	0.09
Lake Sites	0.10	0.04	0.33	0.06	0.00	0.19
	Total Nitrogen (mg/L)			**Nitrate+Nitrite (mg/L)**		
Location/Habitat	**Med**	**Min**	**Max**	**Med**	**Min**	**Max**
Tulana- Emergent Wetland	0.75	0.36	1.74	0.009	<0.008	0.252
Tulana- Deep Water Wetland	0.79	0.21	5.10	0.016	<0.008	0.234
Tulana- Open Water	0.92	0.43	6.40	0.026	<0.008	0.252
Tulana- Transitional Wetland	0.68	0.37	1.43	<0.008	<0.008	0.022
Goose Bay- Emergent Wetland	0.60	0.34	1.88	<0.008	<0.008	0.092
Goose Bay- Transitional Wetland	0.65	0.20	2.33	<0.008	<0.008	0.013
Williamson River	0.32	0.11	0.68	0.014	0.009	0.124
Lake Sites	0.70	0.15	2.89	0.013	<0.008	0.275
	Ammonium (mg/L)			**Nitrite (mg/L)**		
Location/Habitat	**Med**	**Min**	**Max**	**Med**	**Min**	**Max**
Tulana- Emergent Wetland	0.018	<0.006	0.088	<0.001	<0.001	0.028
Tulana- Deep Water Wetland	0.034	<0.006	0.357	<0.001	<0.001	0.027
Tulana- Open Water	0.039	<0.006	0.219	<0.001	<0.001	0.021
Tulana- Transitional Wetland	0.023	<0.006	0.062	<0.001	<0.001	<0.001
Goose Bay- Emergent Wetland	0.013	<0.006	0.064	<0.001	<0.001	0.001
Goose Bay- Transitional Wetland	0.014	<0.006	0.072	<0.001	<0.001	<0.001
Williamson River	0.022	<0.006	0.117	<0.001	<0.001	0.024
Lake Sites	0.022	<0.006	0.280	<0.001	<0.001	0.016

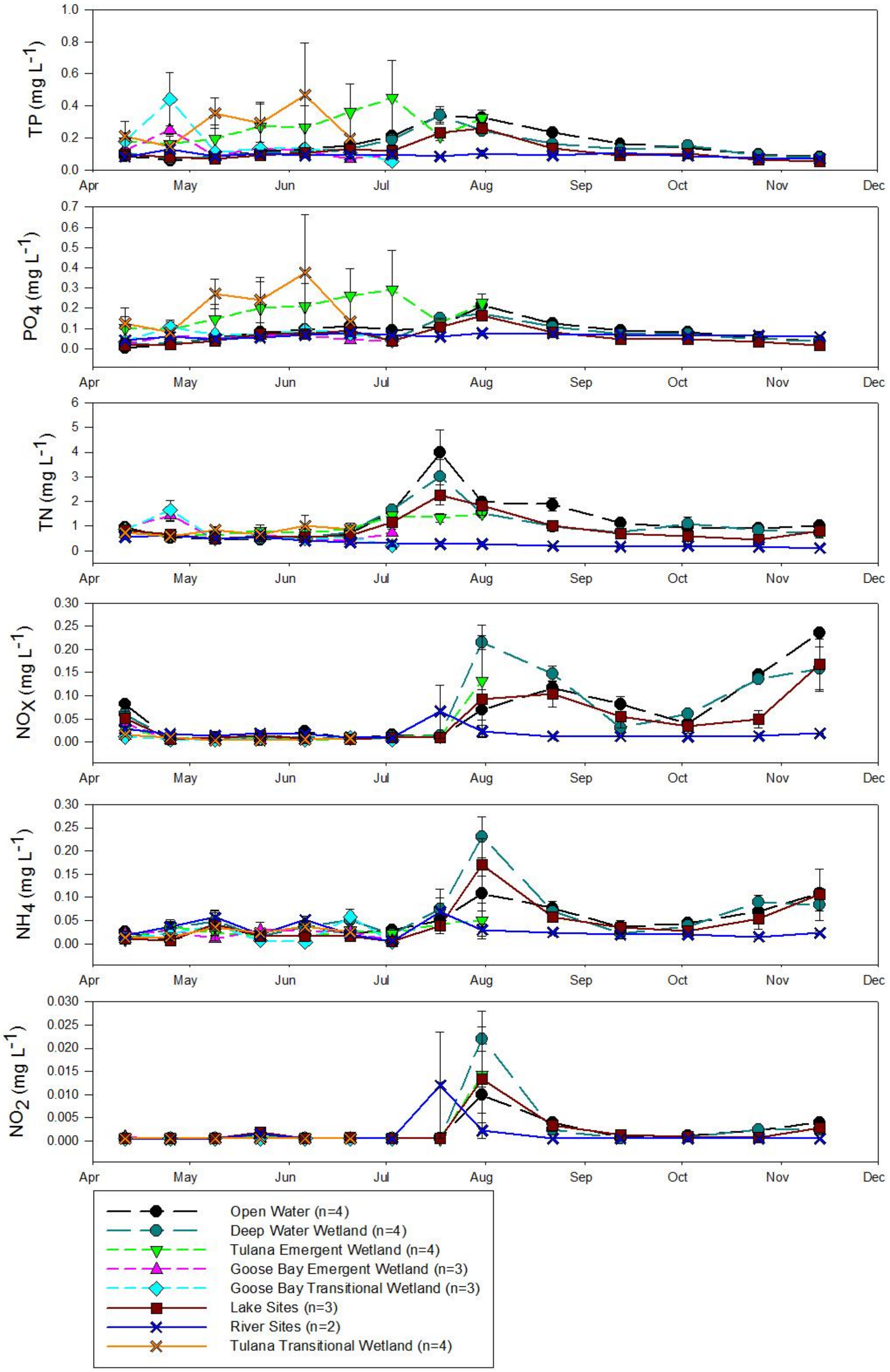


Figure 5a. Seasonal trends in grab sample constituents, Williamson River Delta, OR, 2012. Shown are means (± standard error) by location/habitat and sampling event.

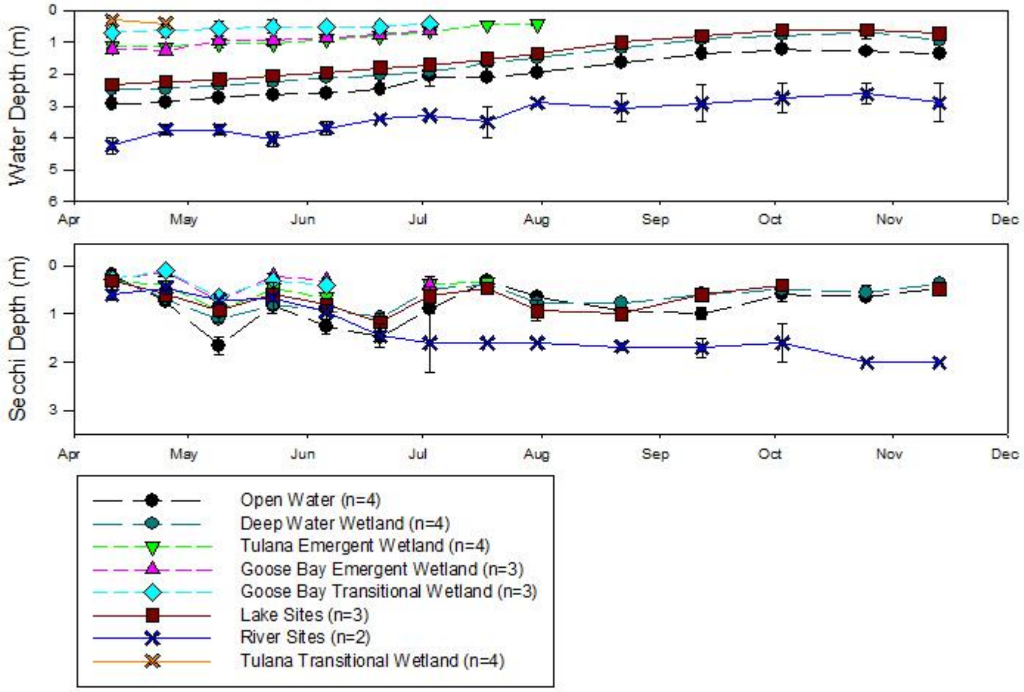


Figure 5b. Seasonal trends in water depth and transparency, Williamson River Delta, OR, 2012. Shown are means (± standard error) by location/habitat and sampling event.

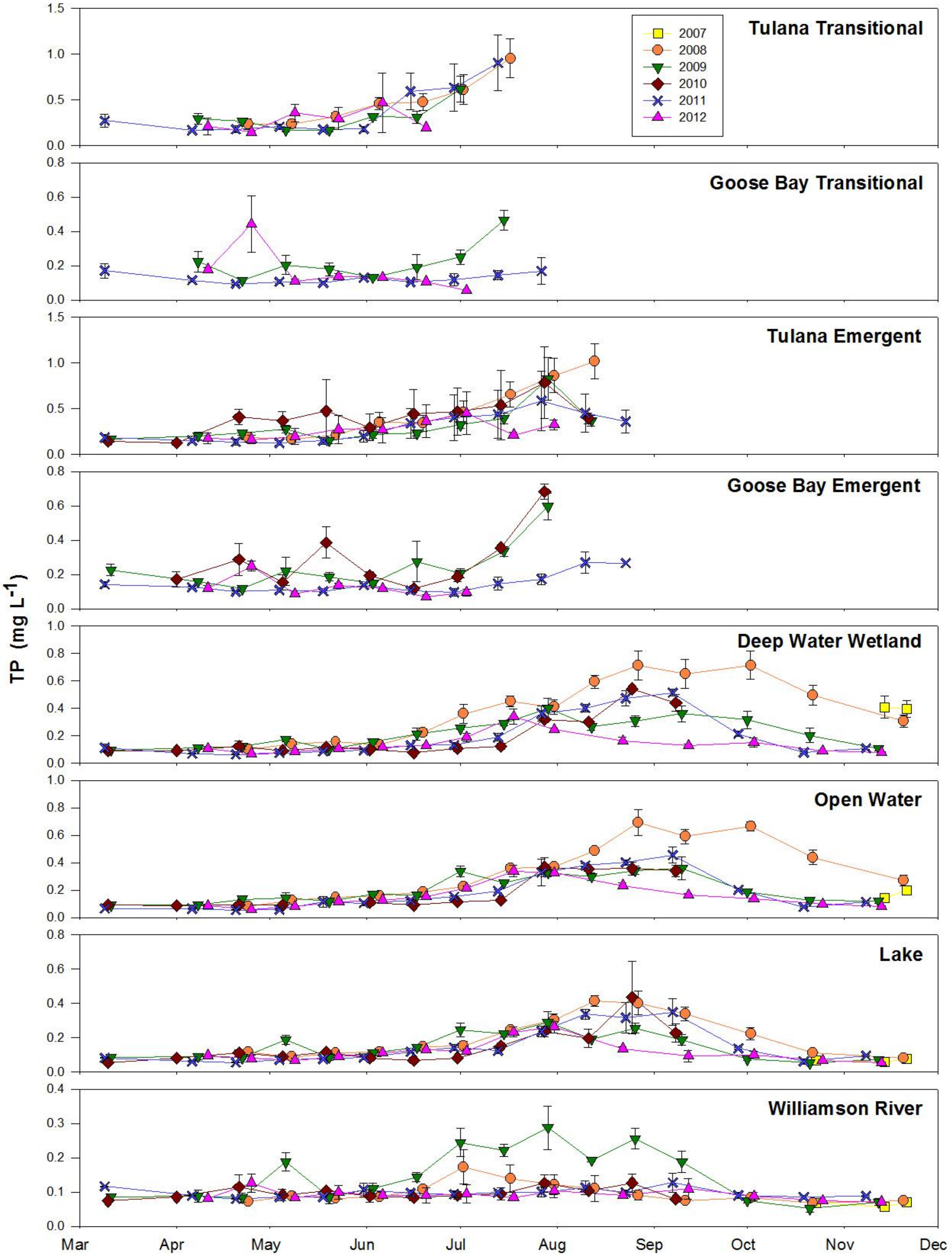


Figure 6a. Total phosphorus concentrations from 2007–2012 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event. Note different y-axis scales.

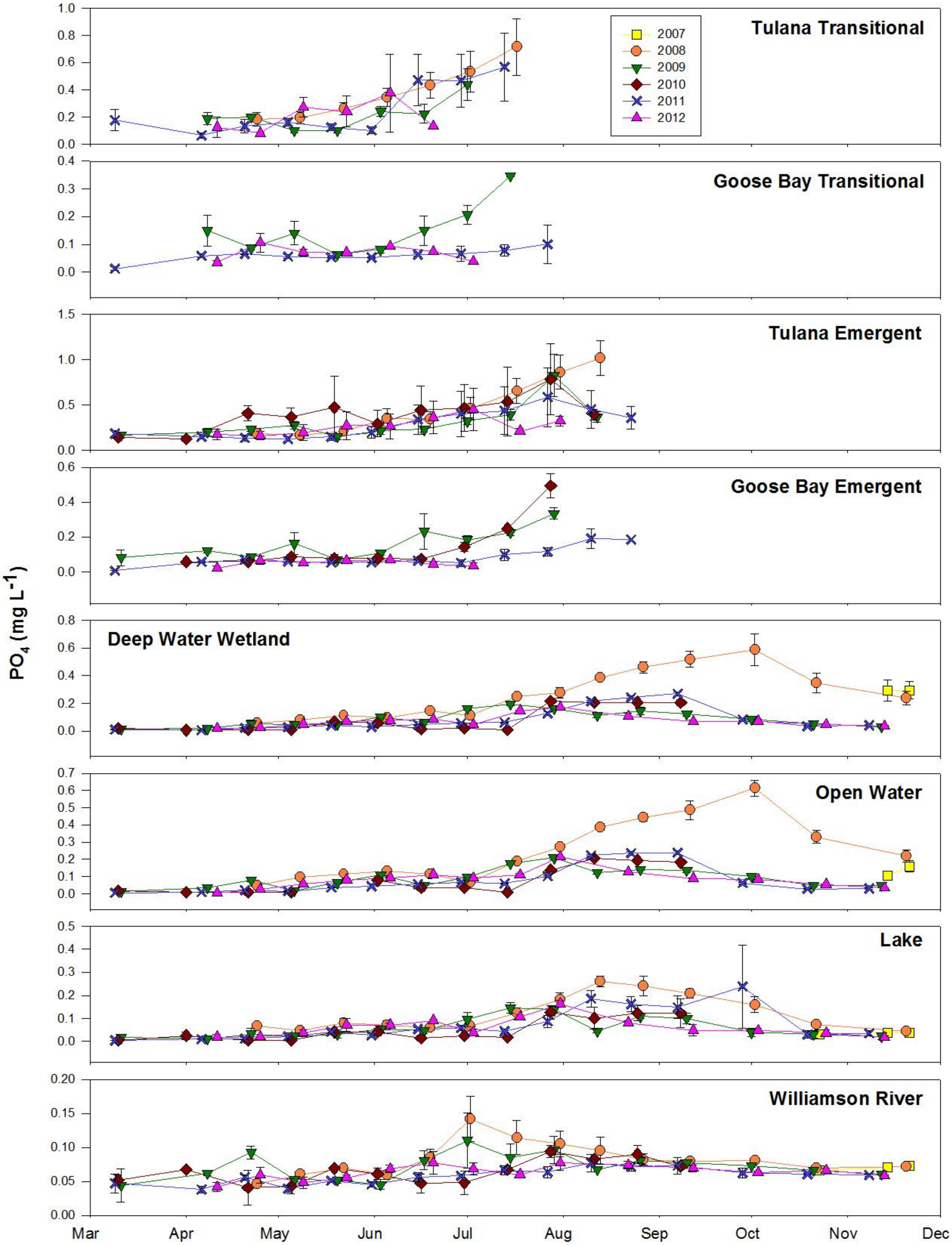


Figure 6b. Soluble reactive phosphorus concentrations from 2007–2012 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event. Note different y-axis scales.

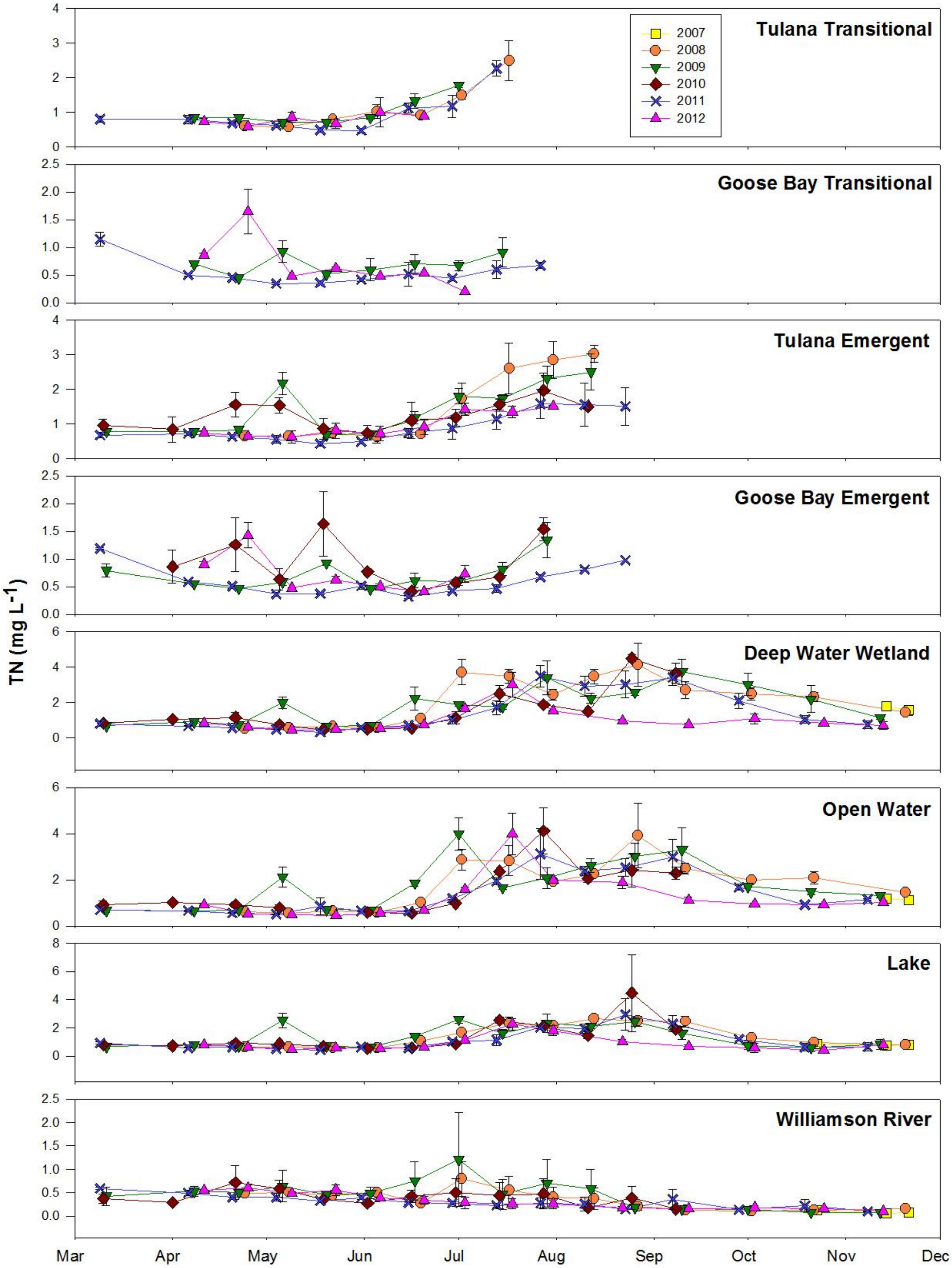


Figure 6c. Total nitrogen concentrations from 2007–2012 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event. Note different y-axis scales.

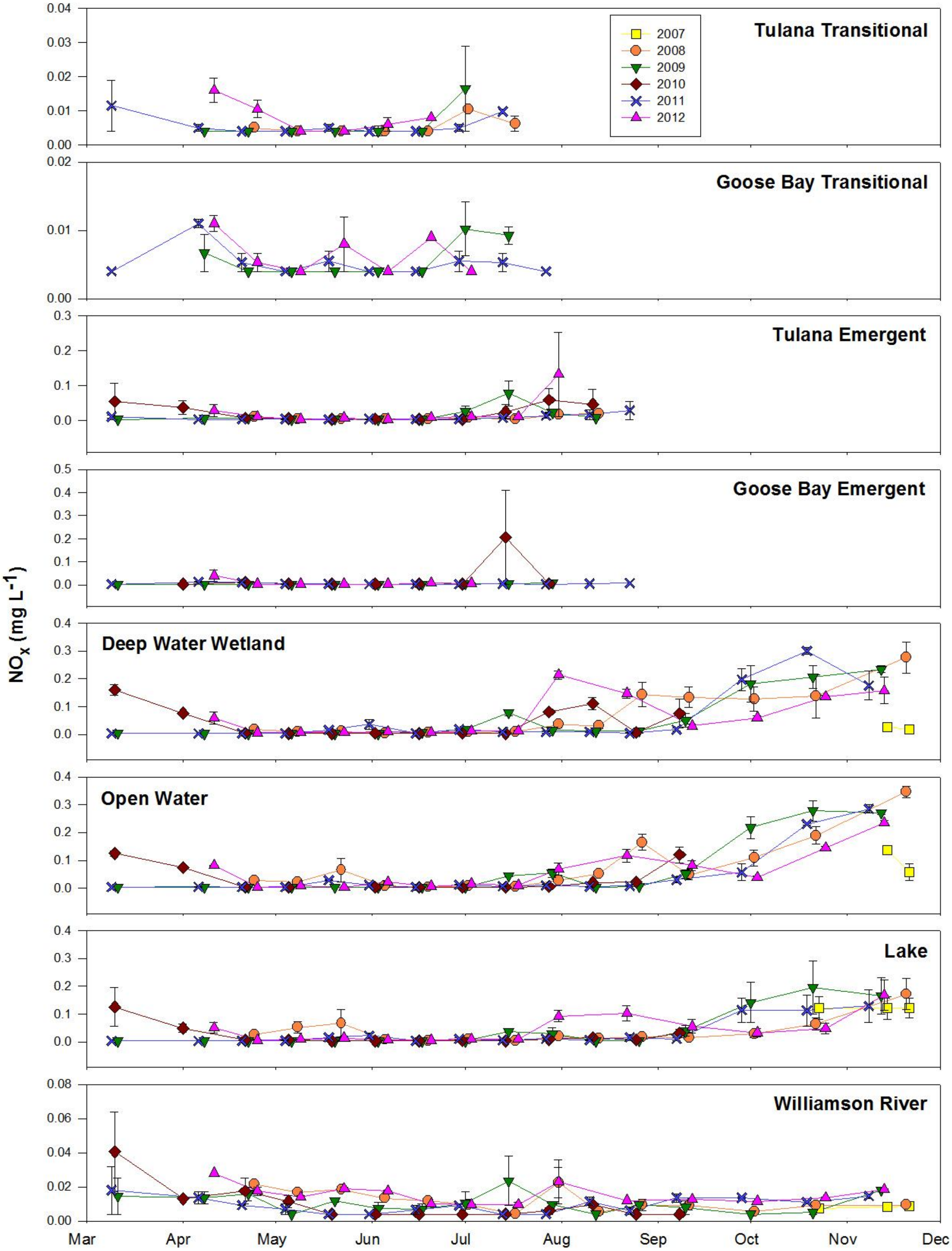


Figure 6d. The sum of nitrate and nitrite (NO$_X$) concentrations from 2007–2012 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event. Note different y-axis scales.

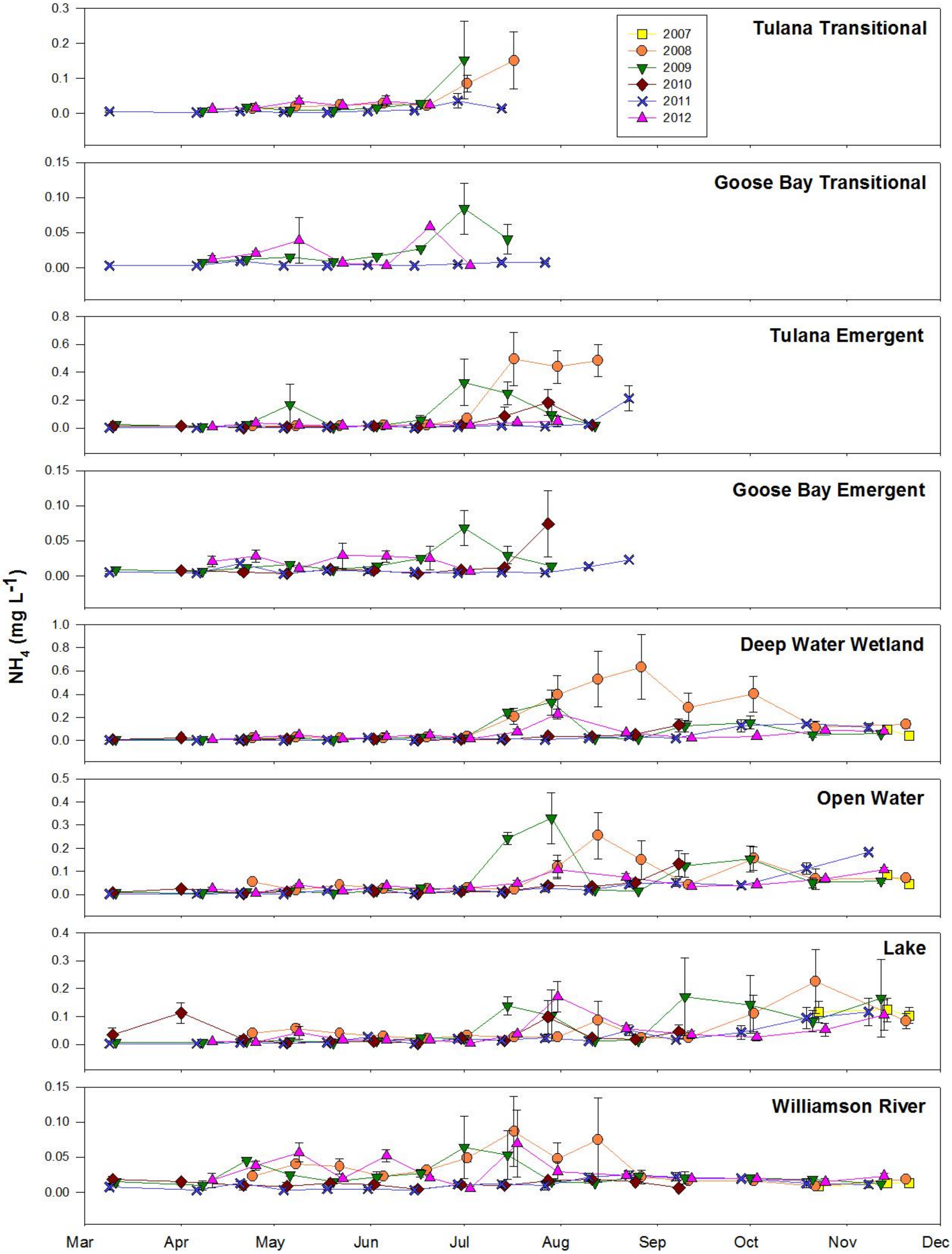


Figure 6e. Ammonium concentrations from 2007–2012 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event. Note different y-axis scales.

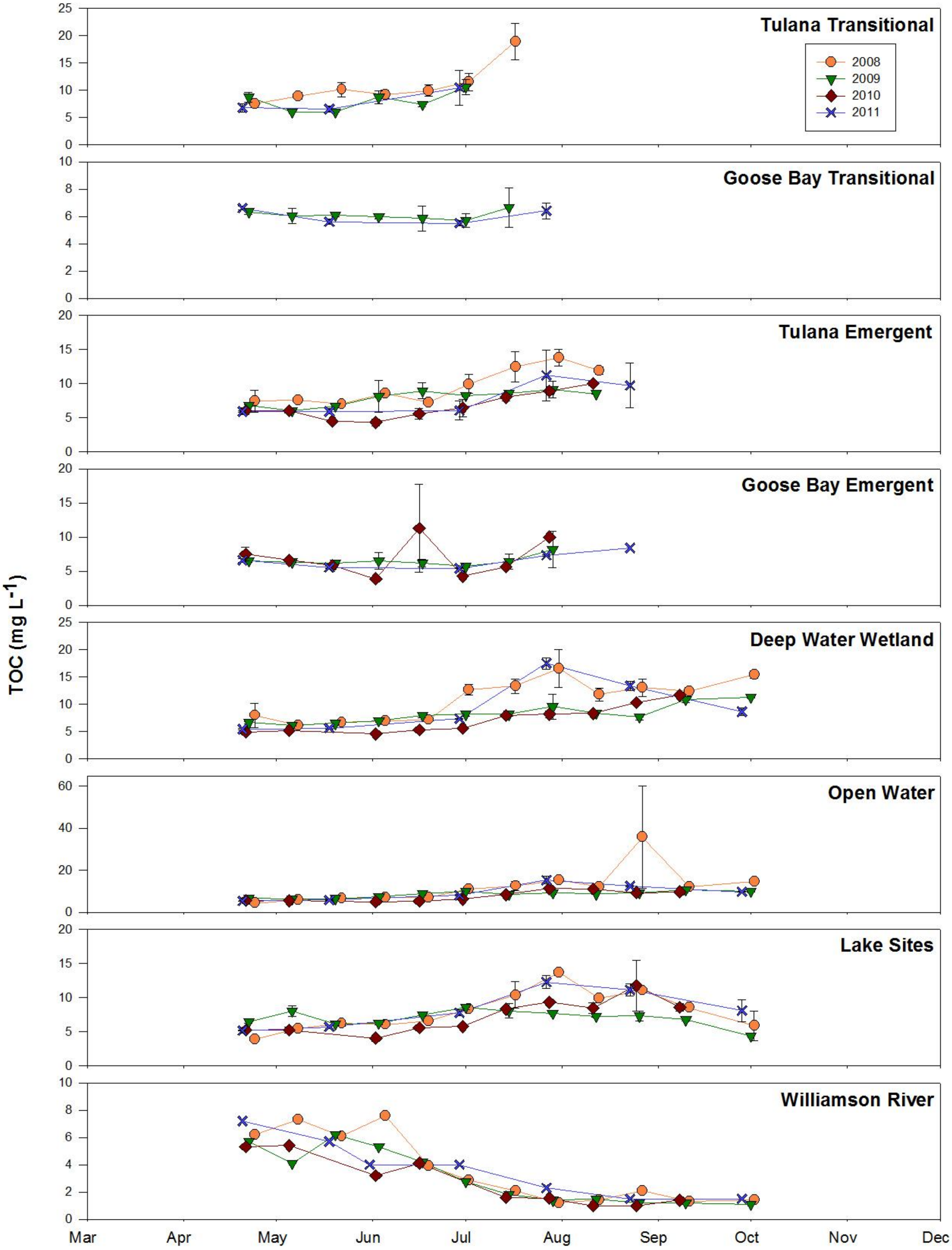


Figure 6f. Total organic carbon concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.

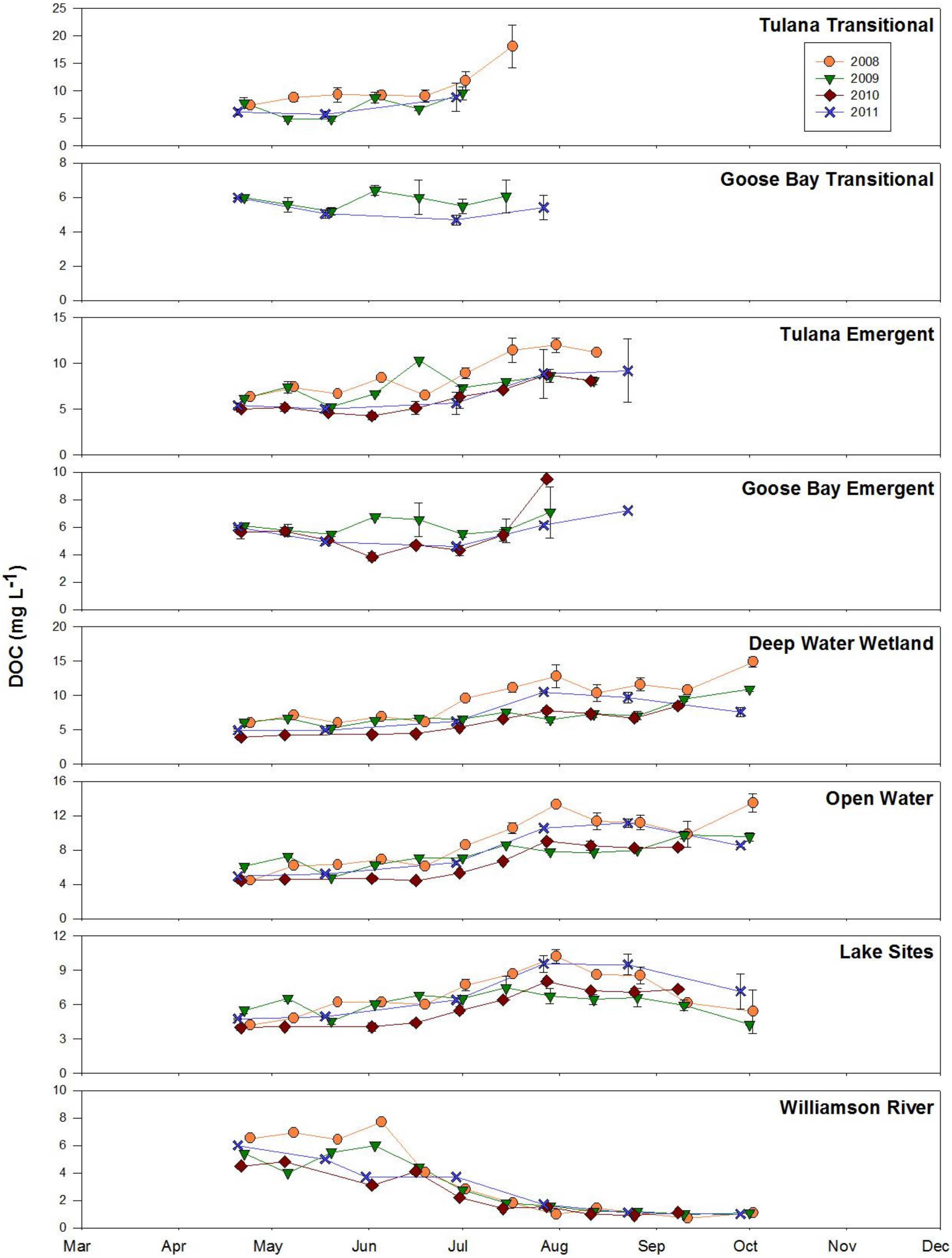


Figure 6g. Dissolved organic carbon concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.

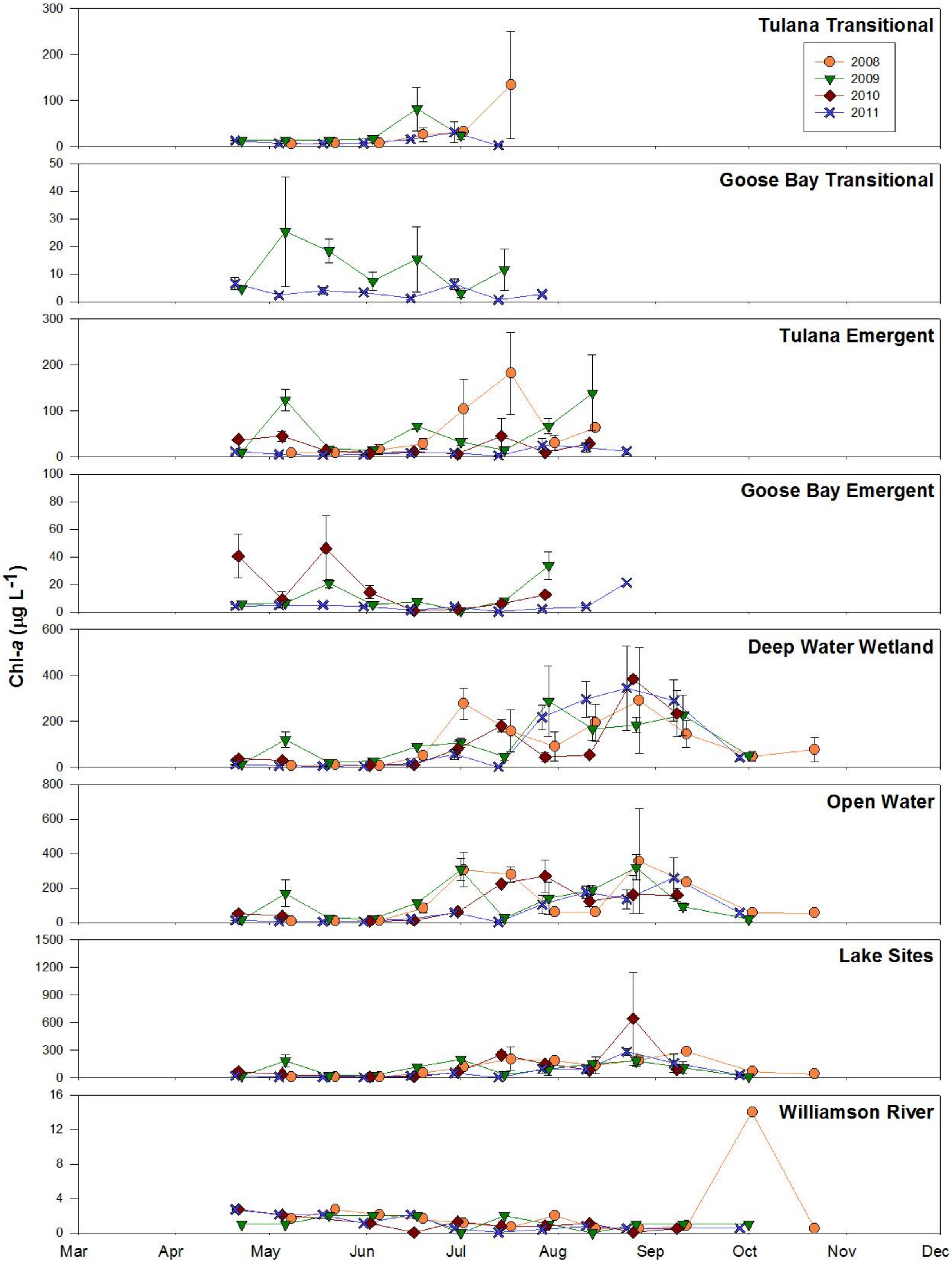


Figure 6h. Chlorophyll-*a* concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.

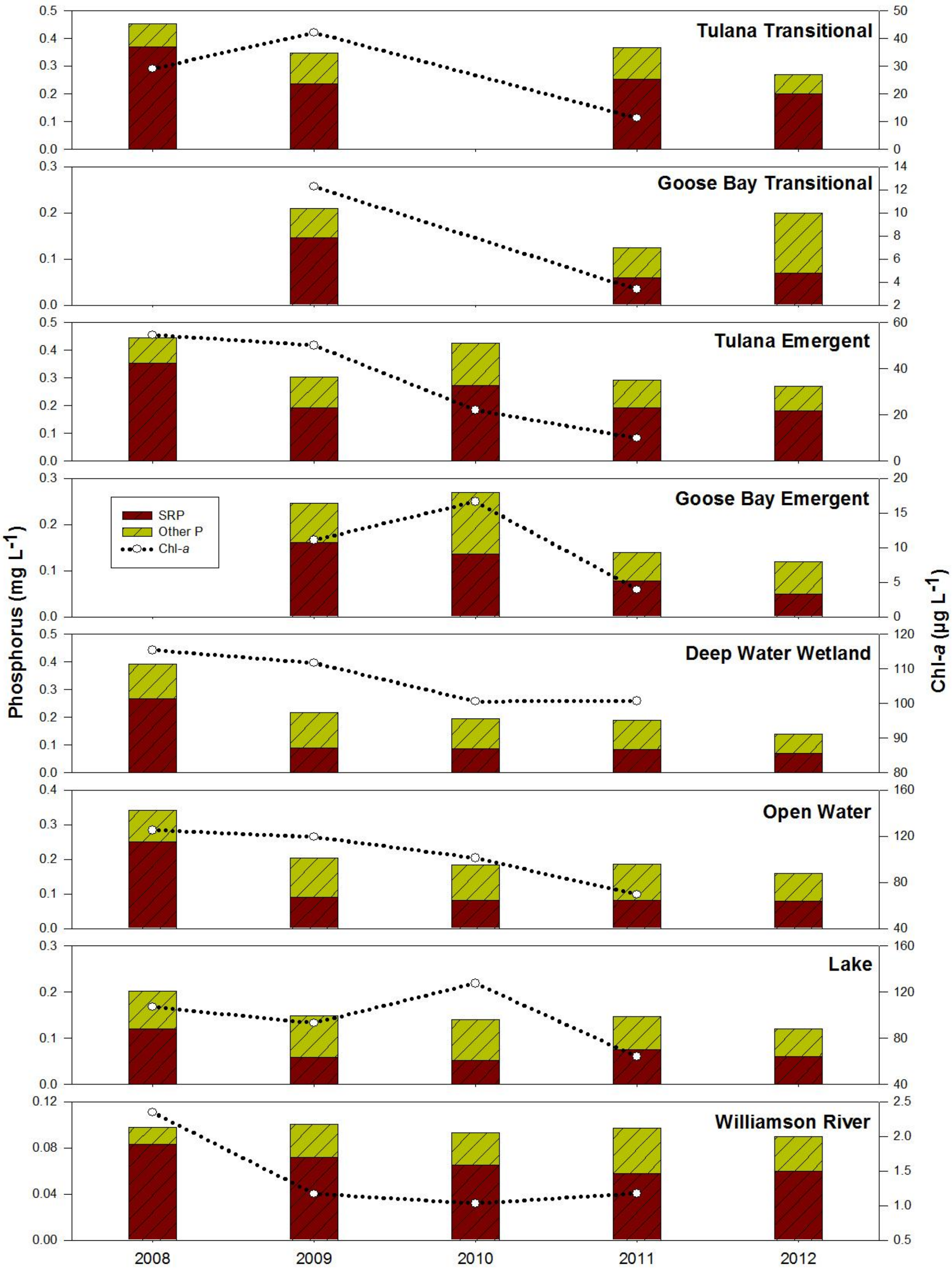


Figure 7a. Phosphorus averages by year (SRP and other P) along with Chlorophyll-*a* concentrations from 2008–2012 by habitat type, Williamson River Delta, OR.

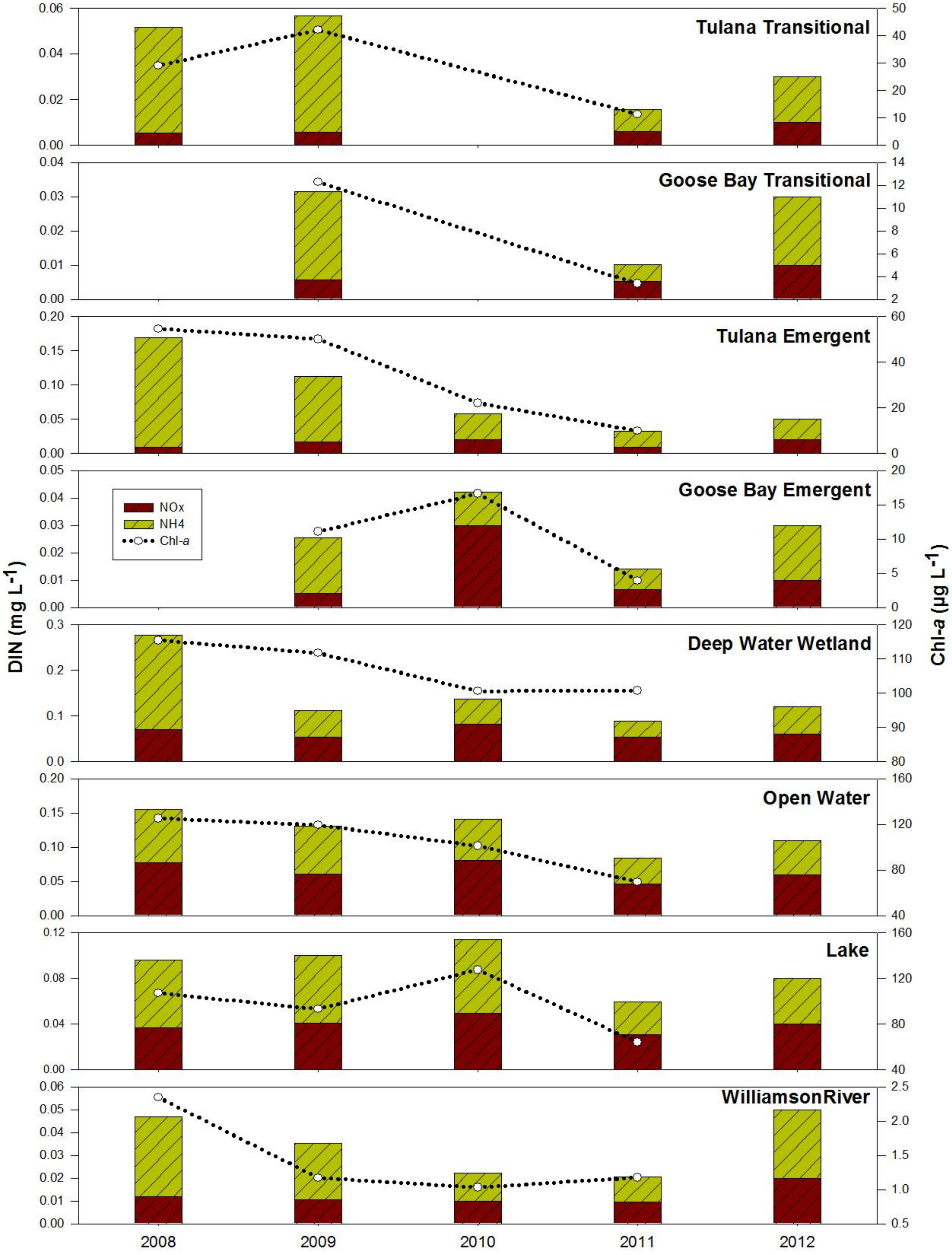


Figure 7b. Dissolved inorganic nitrogen (NO_X and NH_4) averages by year along with Chlorophyll-*a* concentrations from 2008–2012 by habitat type, Williamson River Delta, OR.

Continuous Monitoring

Seasonal Trends

Ranges in water chemistry parameters at all locations during the 2008–20012 monitoring period are shown in Table 3, while seasonal trends for 2012 are shown in Figure 8. In 2012, water temperatures from April–November ranged from 0.6–32.2 °C among all sites (Table 3). Ambient water temperatures were generally highest in the emergent and transitional wetlands, while lowest temperatures were observed in the river sites (Figure 8a,b). During the period May–June, water temperatures between habitat types were similar: average wetland and lake temperatures were 15.7 °C (±0.2), while river sites were slightly lower averaging 14.6 °C. From July-September, the highest average water temperatures were observed in Goose Bay and Tulana emergent wetlands (22.6 and 22.4 °C). Lake sites, deep water, open water, emergent, and transitional wetlands had similar average temperatures during July–September sampling (21.0 °C ±1.3), while river temperatures remained considerably colder (15.2 °C), respectively. The maximum recorded temperature among all sites was reached on August 7 in Tulana emergent wetlands (32.2 °C). Maximum temperature in the Williamson River was reached on July 12 (20.1 °C) and at the lake sites between July 9 and August 17 (27.0–27.5 °C) creating an extended period of elevated temperatures within lake habitats which coincided with decreasing water depths (Figure 5b). In the deep water and open water wetlands, the maximum recorded temperatures occurred on August 15 (26.7 and 26.6°C), about 1–5 weeks later than in other habitat types. Shallow sites like Goose Bay emergent and Tulana transitional wetlands reached maximal temperatures early in the summer on July 11 (29.7°C in Goose Bay) and June 21 (28.8°C in Tulana transitional). Sampling in these habitats was discontinued abnormally early in 2012 due to receding water levels.

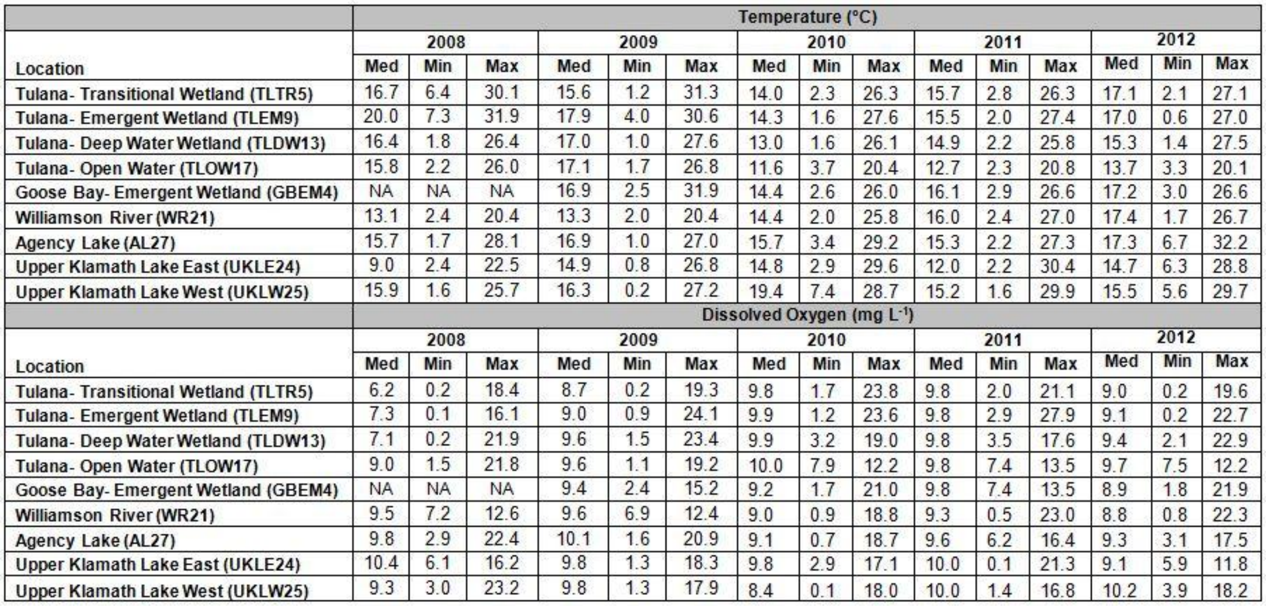
In previous years, water temperatures at all sites peaked in late July/early August. Seasonal trends in water temperature at lake and wetland sites followed trends in the Williamson River until about mid-June, when temperatures increased and diverged from river temperatures. The highest temperatures were generally observed in the shallow transitional and emergent wetlands. During the mid-season period, daily median water temperatures were on average about 5–6°C higher at Tulana sites compared to the river. During the period May–June, water temperatures were about 1–2°C higher in transitional and emergent wetlands compared to the river. Overall, 2008, 2009, and 2012 had elevated median temperature, while 2010 and 2011 were slightly cooler years (Table 3).

Dissolved oxygen concentrations in 2012 were variable throughout the year with concentrations ranging 0.8–22.3 mg L^{-1} in the wetlands, 0.2–22.9 mg L^{-1} in the lakes, and 7.5–12.2 mg L^{-1} in the river (Table 3). Dissolved oxygen concentrations < 1.0 mg L^{-1} were reached in Agency Lake and Upper Klamath Lake West, whereas the lake station located near the mouth of the Williamson River (Upper Klamath Lake East) never reached DO < 2.1 mg L^{-1}. Deep water was the only wetland site that experienced DO levels < 1.0 mg L^{-1} in 2012 (Figures 8a, b).

Similarly, during the 2011 sampling year DO levels < 1.0 mg L^{-1} were observed in deep water and transitional wetlands; however, on average ambient water temperatures were cooler and water levels were higher. In 2010 deep water, Tulana emergent, and South Marsh emergent wetlands all had DO crashes < 1.0 mg L^{-1} (note: transitional sites were never sampled in 2010 due to low water levels). Tulana transitional and emergent wetlands experienced DO < 1.0 mg L^{-1} in 2008 and 2009, while in 2008 deep water also had DO < 1.0 mg L^{-1}. Overall, during 5 consecutive post-restoration years Tulana emergent, transitional, and deep water wetlands have consistently experienced DO crashes below 1.0 mg L^{-1}. Interestingly, 2012 was the only year when these severe DO crashes were observed in Agency and Upper Klamath Lake sites, subsequently poor DO conditions were also observed in deep water wetlands. Throughout previous years, the habitats that have been buffered from DO crashes are the Williamson River sites and sites most closely located to flow from the river (Goose Bay emergent and Upper Klamath Lake east).

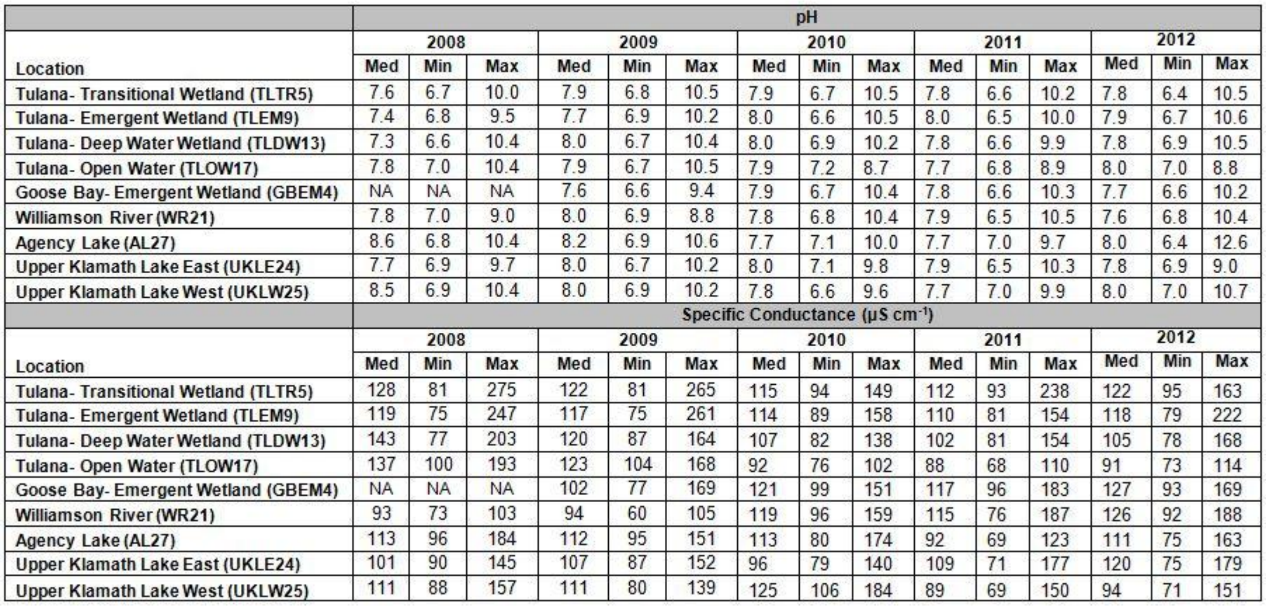
The strongest influences on DO appear to be diel trends in photosynthesis and respiration. Chlorophyll-*a* samples and DO results indicated that more intense diel swings are experienced from late July–September, when phytoplankton biomass and primary production are highest (Figure 6h). Deep water sites, such as lake, open water, and deep water were mostly influenced by phytoplankton dynamics, whereas DO in emergent and transitional marsh sites were largely affected by submerged macrophytes. Diel trends were most pronounced during August, coinciding with the temporal trend of increased chl-*a*. Low DO swings were typically observed between 3am and 8am, while the highest DO levels were reached during 3pm and 6pm. During these peak times DO in the lake can reach well above 100% saturation, with maximum concentration >20 mg L^{-1}.

Table 3. Median, minimum, and maximum values in continuous monitoring variables at continuous monitoring sites in 2008 through 2012, Williamson River Delta, OR.



	Temperature (°C)														
	2008			2009			2010			2011			2012		
Location	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max
Tulana- Transitional Wetland (TLTR5)	16.7	6.4	30.1	15.6	1.2	31.3	14.0	2.3	26.3	15.7	2.8	26.3	17.1	2.1	27.1
Tulana- Emergent Wetland (TLEM9)	20.0	7.3	31.9	17.9	4.0	30.6	14.3	1.6	27.6	15.5	2.0	27.4	17.0	0.6	27.0
Tulana- Deep Water Wetland (TLDW13)	16.4	1.8	26.4	17.0	1.0	27.6	13.0	1.6	26.1	14.9	2.2	25.8	15.3	1.4	27.5
Tulana- Open Water (TLOW17)	15.8	2.2	26.0	17.1	1.7	26.8	11.6	3.7	20.4	12.7	2.3	20.8	13.7	3.3	20.1
Goose Bay- Emergent Wetland (GBEM4)	NA	NA	NA	16.9	2.5	31.9	14.4	2.6	26.0	16.1	2.9	26.6	17.2	3.0	26.6
Williamson River (WR21)	13.1	2.4	20.4	13.3	2.0	20.4	14.4	2.0	25.8	16.0	2.4	27.0	17.4	1.7	26.7
Agency Lake (AL27)	15.7	1.7	28.1	16.9	1.0	27.0	15.7	3.4	29.2	15.3	2.2	27.3	17.3	6.7	32.2
Upper Klamath Lake East (UKLE24)	9.0	2.4	22.5	14.9	0.8	26.8	14.8	2.9	29.6	12.0	2.2	30.4	14.7	6.3	28.8
Upper Klamath Lake West (UKLW25)	15.9	1.6	25.7	16.3	0.2	27.2	19.4	7.4	28.7	15.2	1.6	29.9	15.5	5.6	29.7

	Dissolved Oxygen (mg L^{-1})														
	2008			2009			2010			2011			2012		
Location	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max
Tulana- Transitional Wetland (TLTR5)	6.2	0.2	18.4	8.7	0.2	19.3	9.8	1.7	23.8	9.8	2.0	21.1	9.0	0.2	19.6
Tulana- Emergent Wetland (TLEM9)	7.3	0.1	16.1	9.0	0.9	24.1	9.9	1.2	23.6	9.8	2.9	27.9	9.1	0.2	22.7
Tulana- Deep Water Wetland (TLDW13)	7.1	0.2	21.9	9.6	1.5	23.4	9.9	3.2	19.0	9.8	3.5	17.6	9.4	2.1	22.9
Tulana- Open Water (TLOW17)	9.0	1.5	21.8	9.6	1.1	19.2	10.0	7.9	12.2	9.8	7.4	13.5	9.7	7.5	12.2
Goose Bay- Emergent Wetland (GBEM4)	NA	NA	NA	9.4	2.4	15.2	9.2	1.7	21.0	9.8	7.4	13.5	8.9	1.8	21.9
Williamson River (WR21)	9.5	7.2	12.6	9.6	6.9	12.4	9.0	0.9	18.8	9.3	0.5	23.0	8.8	0.8	22.3
Agency Lake (AL27)	9.8	2.9	22.4	10.1	1.6	20.9	9.1	0.7	18.7	9.6	6.2	16.4	9.3	3.1	17.5
Upper Klamath Lake East (UKLE24)	10.4	6.1	16.2	9.8	1.3	18.3	9.8	2.9	17.1	10.0	0.1	21.3	9.1	5.9	11.8
Upper Klamath Lake West (UKLW25)	9.3	3.0	23.2	9.8	1.3	17.9	8.4	0.1	18.0	10.0	1.4	16.8	10.2	3.9	18.2



	pH														
	2008			2009			2010			2011			2012		
Location	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max
Tulana- Transitional Wetland (TLTR5)	7.6	6.7	10.0	7.9	6.8	10.5	7.9	6.7	10.5	7.8	6.6	10.2	7.8	6.4	10.5
Tulana- Emergent Wetland (TLEM9)	7.4	6.8	9.5	7.7	6.9	10.2	8.0	6.6	10.5	8.0	6.5	10.0	7.9	6.7	10.6
Tulana- Deep Water Wetland (TLDW13)	7.3	6.6	10.4	8.0	6.7	10.4	8.0	6.9	10.2	7.8	6.6	9.9	7.8	6.9	10.5
Tulana- Open Water (TLOW17)	7.8	7.0	10.4	7.9	6.7	10.5	7.9	7.2	8.7	7.7	6.8	8.9	8.0	7.0	8.8
Goose Bay- Emergent Wetland (GBEM4)	NA	NA	NA	7.6	6.6	9.4	7.9	6.7	10.4	7.8	6.6	10.3	7.7	6.6	10.2
Williamson River (WR21)	7.8	7.0	9.0	8.0	6.9	8.8	7.8	6.8	10.4	7.9	6.5	10.5	7.6	6.8	10.4
Agency Lake (AL27)	8.6	6.8	10.4	8.2	6.9	10.6	7.7	7.1	10.0	7.7	7.0	9.7	8.0	6.4	12.6
Upper Klamath Lake East (UKLE24)	7.7	6.9	9.7	8.0	6.7	10.2	8.0	7.1	9.8	7.9	6.5	10.3	7.8	6.9	9.0
Upper Klamath Lake West (UKLW25)	8.5	6.9	10.4	8.0	6.9	10.2	7.8	6.6	9.6	7.7	7.0	9.9	8.0	7.0	10.7

	Specific Conductance (µS cm^{-1})														
	2008			2009			2010			2011			2012		
Location	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max	Med	Min	Max
Tulana- Transitional Wetland (TLTR5)	128	81	275	122	81	265	115	94	149	112	93	238	122	95	163
Tulana- Emergent Wetland (TLEM9)	119	75	247	117	75	261	114	89	158	110	81	154	118	79	222
Tulana- Deep Water Wetland (TLDW13)	143	77	203	120	87	164	107	82	138	102	81	154	105	78	168
Tulana- Open Water (TLOW17)	137	100	193	123	104	168	92	76	102	88	68	110	91	73	114
Goose Bay- Emergent Wetland (GBEM4)	NA	NA	NA	102	77	169	121	99	151	117	96	183	127	93	169
Williamson River (WR21)	93	73	103	94	60	105	119	96	159	115	76	187	126	92	188
Agency Lake (AL27)	113	96	184	112	95	151	113	80	174	92	69	123	111	75	163
Upper Klamath Lake East (UKLE24)	101	90	145	107	87	152	96	79	140	109	71	177	120	75	179
Upper Klamath Lake West (UKLW25)	111	88	157	111	80	139	125	106	184	89	69	150	94	71	151

Among all sites, pH ranged from 6.4–12.6 throughout the 2012 sampling year, with values reaching above 10.0 at all sites except transitional wetland and the Williamson River (Table 3). Peak pH levels were observed in shallow water wetlands from mid-June through mid-July and in deep water wetlands and lakes sites from the end of June through mid-August. The Williamson River remained consistent throughout the year. These trends are similar to pH ranges and peaks in previous years, during the 2008–2011 sampling years increases in pH across habitat types have corresponded to seasonal peaks in chl-*a* and DO concentrations.

Specific conductance values in 2012 ranged from 71–188 µS cm^{-1} in the wetlands, 163–222 µS cm^{-1} in the lakes, and 73–114 µS cm^{-1} in the river (Table 3). The lowest range in values occurred in the river and Goose Bay emergent wetland, while the highest values occurred in deep water, open water, and Agency Lake from July–October (Figure 8a, b). Tulana transitional wetlands had high conductance values early in the year (May–July). Across previous years seasonal trends showed that higher conductance values corresponded to shallower water depths. At Tulana emergent and transitional wetland sites and in Goose Bay, values reflected those in the river until June, when values increased and diverged from river values. Conductance peaked in these shallow water wetlands from late July through early August as water levels receded and sites began to dry out. Lake and deep water wetland sites peaked later in the summer, starting in July and remaining elevated throughout the fall which coincided with increased chl-*a* levels.

Further results for seasonal trends in water chemistry during previous years can be found in annual reports Doehring et al. (2009, 2010) Wong and Hendrixson (2011), and Hayden and Hendrixson (2012).

High Stress Threshold Conditions for Endangered Suckers

Water quality was examined in relation to conditions of water temperature, DO, and pH potentially threatening to the health of endangered Lost River and shortnose suckers in Upper Klamath Lake. Based on Loftus (2001), conditions in which high stress thresholds for suckers are reached include water temperature>28°C, DO<4 mg L^{-1}, and pH>9.7. The seasonal timing and duration, location, and severity of these conditions in the wetlands and near-shore lakes are described.

Threshold exceedances did not occur for any of the three parameters in the Williamson River during any of the five sampling years. The site located closest to the river mouth, Upper Klamath Lake east, also consistently had few exceedances over the course of this monitoring effort.

In 2012, Tulana transitional wetlands experienced temperature exceedances only 0.1% of the total time from April–November and no pH or DO thresholds were surpassed (Figure 9 and 10). The conditions for sensitive fish species have improved dramatically since the first year following restoration (2008) when Tulana transitional wetlands had DO<4.0 mg L^{-1} for 25.2% of the time from April–November. Temperature and pH were also exceeded that year 1.6% and 0.5% of the time, respectively. The proportion of time when suckers have been exposed to extremely stressful conditions within Tulana transitional wetlands has gradually decreased over the 5 year monitoring timespan with a correlation of R^2=0.97 for DO exceedances decreasing from 2008–2012 and R^2=0.72 for pH exceedances decreasing over time (Figure 11).

Similarly, Tulana emergent wetlands previously experienced DO exceedances as frequently as 25.6% in 2008. This proportion decreased consistently and resulted in no exceedances of all 3 parameters in 2011 and only 0.2% of total time exceeded DO thresholds in 2012 (Figure 9 and 10). A linear regression revealed a strong correlation between a reduction in DO exceedances in Tulana emergent sites over time (R^2=0.87; Figure 11). It is important to note that 2012 was an abnormally high year for pH levels lake wide (Figure 10), represented by elevated periods of pH exceedances observed at Goose Bay and Tulana emergent sites starting in mid-June and continuing until sites dried up, as well as Upper Klamath Lake west and Agency Lake throughout the month of July (Figure 9). These trends in high pH indicate a spike in primary productivity due to an *A. flos-aquae* bloom; the dominant phytoplankton species in Upper Klamath Lake (USGS report 2008).

Although Goose Bay emergent wetland had the highest proportion of pH exceedances in 2012, the amount of time with temperature>28°C has decreased from 2% the first year proceeding reflooding in 2009 to 0.3% in 2012 (R^2=0.87; Figures 8 and 9).

Deep water and open water wetlands have also improved post-restoration, albeit to a lesser degree. Deep water habitats had less DO exceedances in 2011 and 2012 (5.5% and 6.4%) compared to 2008 (20.5%; Figure 8). Open water pH exceedances have decreased significantly in the past 5 years, from 7–8.5% of the time in 2008 and 2009 to 2% in 2012 (R^2=0.71; Figures 10 and 11).

Agency Lake pH exceedances have decreased from 16% of the time in 2008 to 4% in 2012, this trend has a strong correlation to time in the 5 years following wetland restoration (R^2=0.88; Figures 10 and 11). However, wetland restoration seems to have had little effect on DO exceedances in Upper Klamath Lake west and Agency Lake. These sites had no temperature>28°C recorded from 2008-2012.

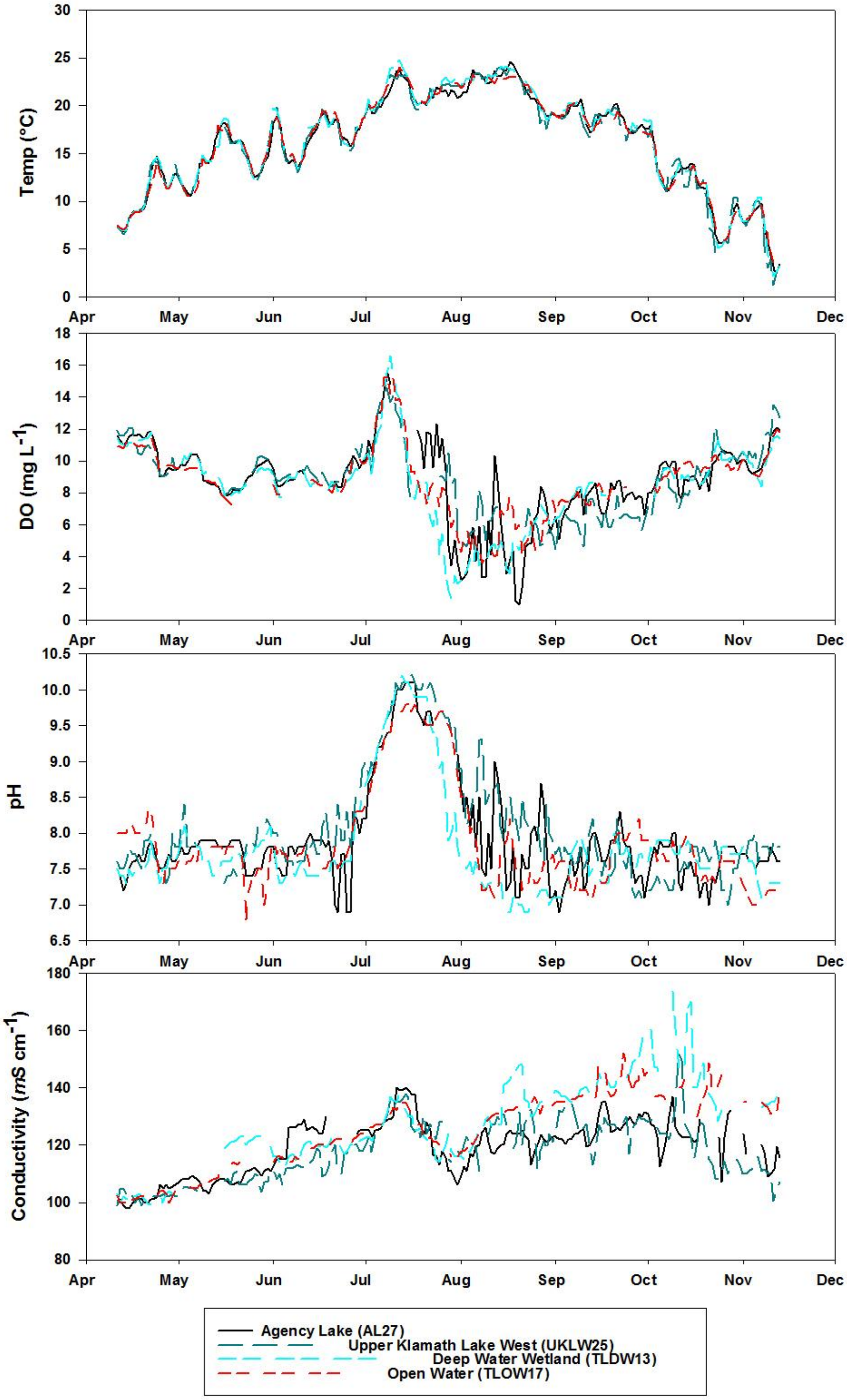


Figure 8a. Seasonal trends in continuous monitoring variables at lake and wetland sites, Williamson River Delta, OR, 2012. Shown as daily median by location/habitat and sampling event.

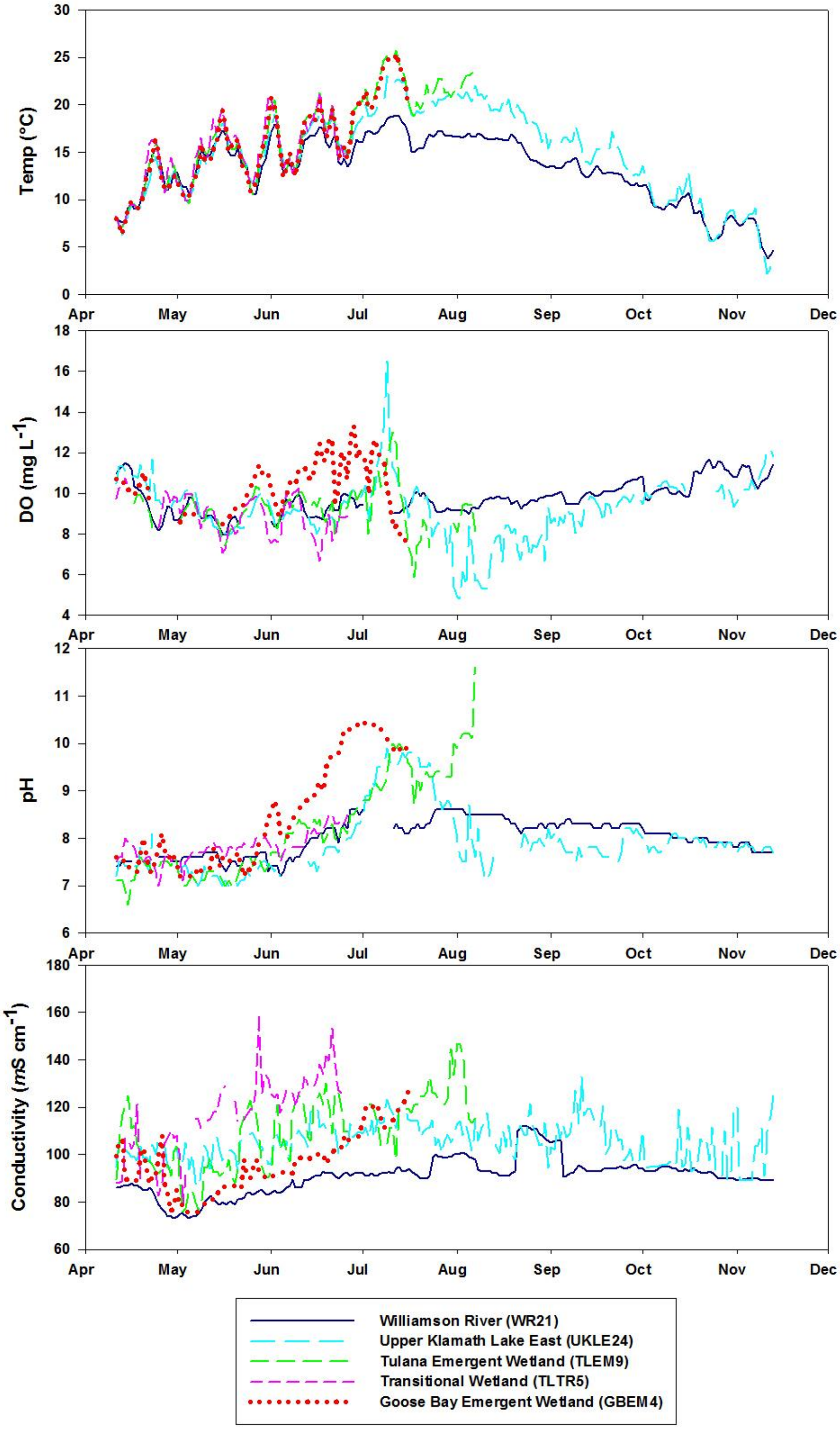


Figure 8b. Seasonal trends in continuous monitoring variables at lake, wetland, and river sites, Williamson River Delta, OR, 2012. Shown as daily median by location/habitat and sampling event.

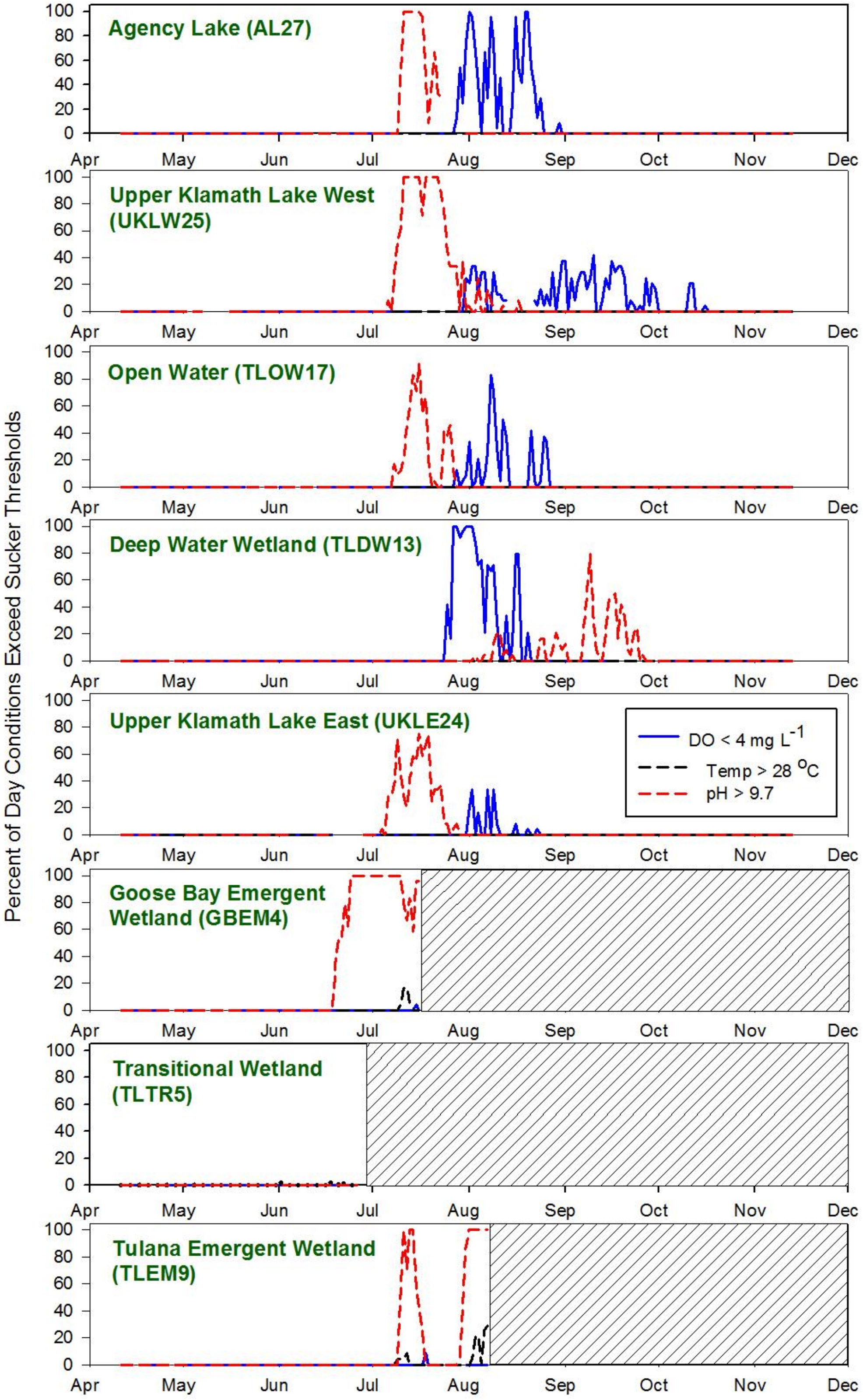


Figure 9. Location, timing, and duration of water quality conditions potentially harmful to Lost River and shortnose suckers (Loftus 2001), Williamson River Delta, OR, 2012. Hatched areas indicate discontinuation of monitoring.

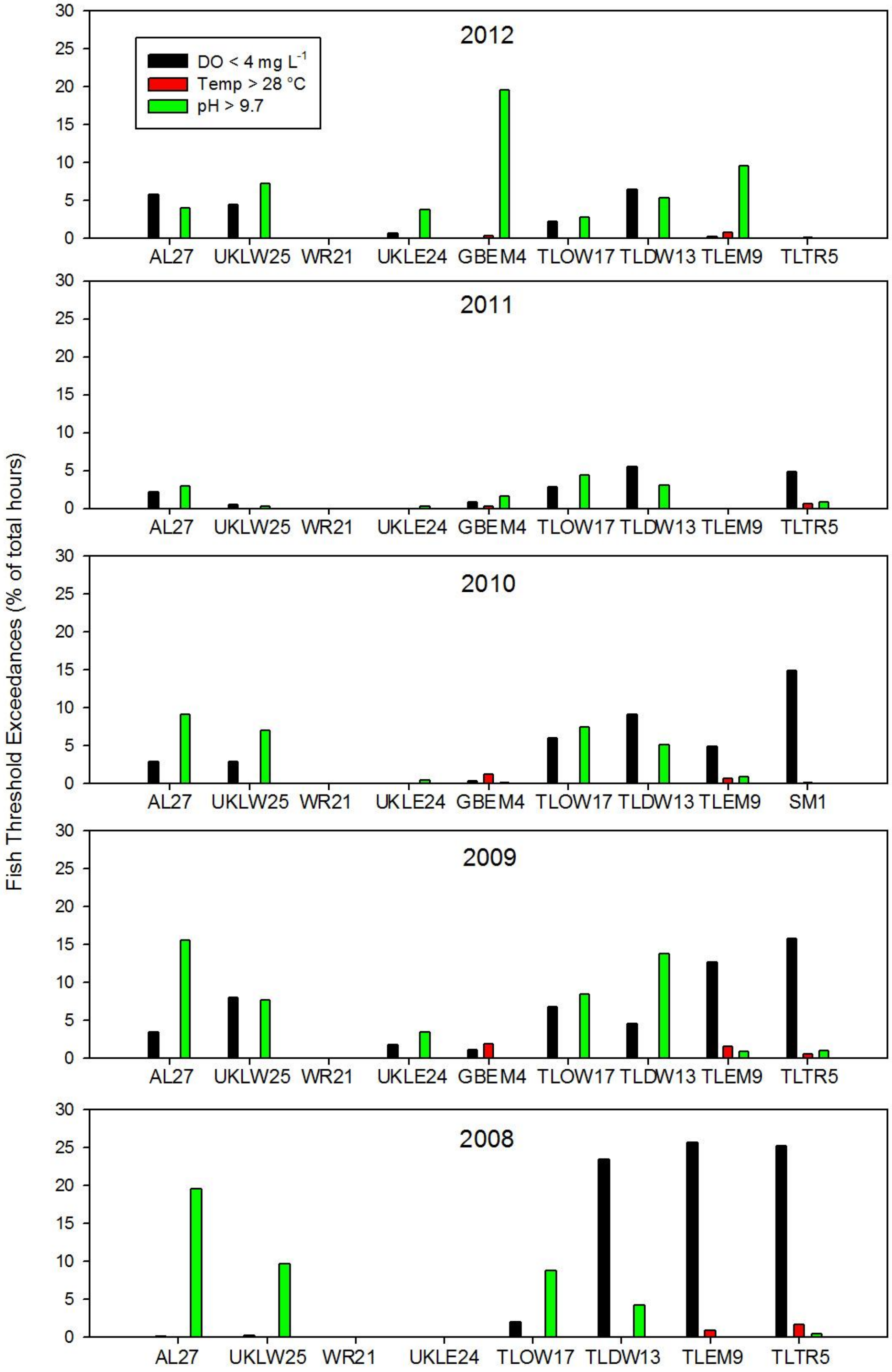


Figure 10. Comparison of the percent of total hours between April and November where conditions exceeded high stress threshold levels for suckers. Data is representative of different habitat types for five post-restoration years at the Williamson River Delta, OR.

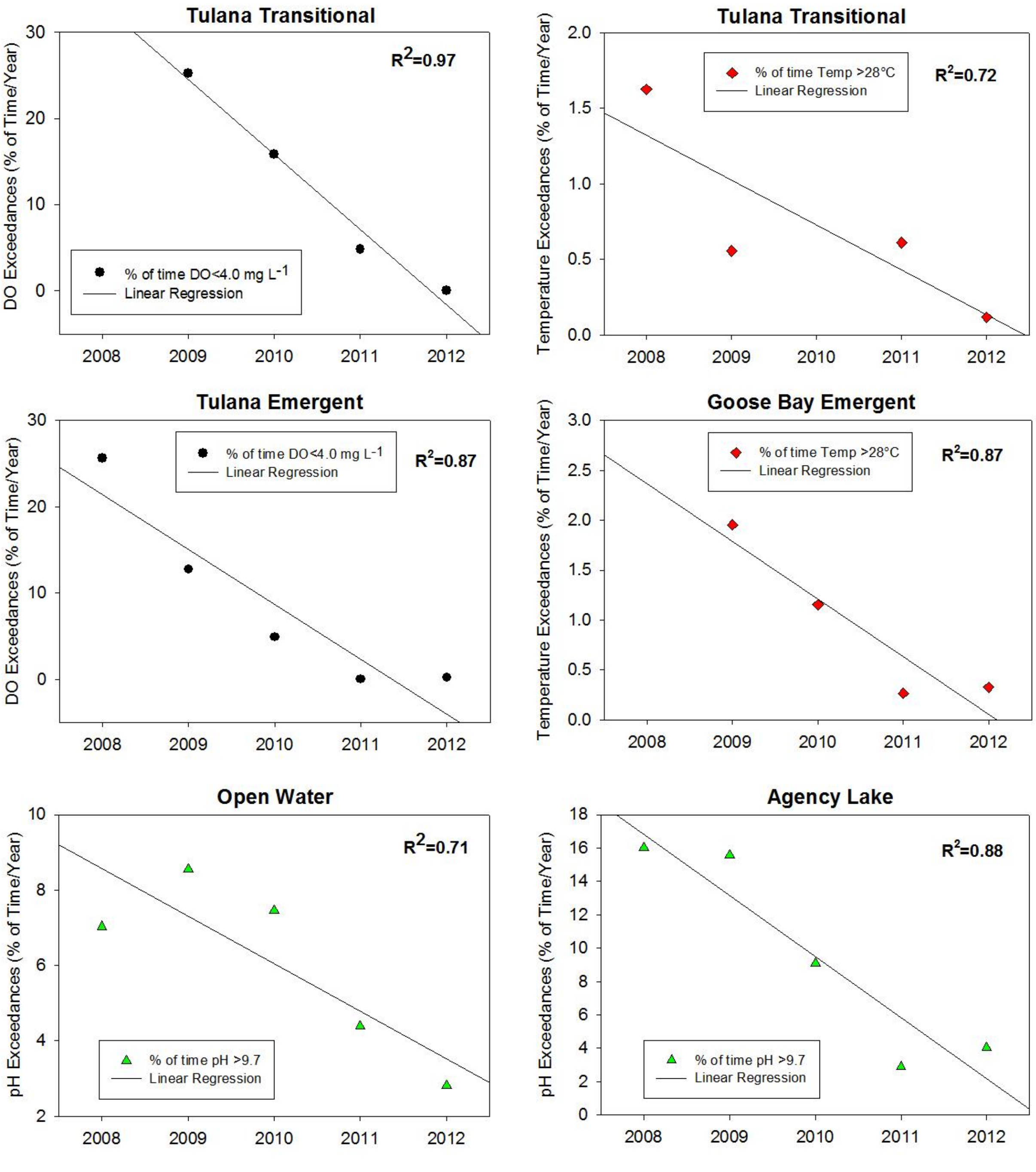


Figure 11. Linear regression showing correlation between proportion of annual time when DO<4.0 mg L^{-1}, pH>9.7, and temperature>28°C were exceeded plotted against time in post-restoration monitoring. Data is representative of different habitat types at the Williamson River Delta, OR. (Note: R^2 values <0.7 are not shown.)

CONCLUSION

Phosphorus has progressively decreased and become more stable with overall lower concentrations at lake and Tulana wetlands sites from 2009–2012 following an initial pulse of P released from newly flooded agriculture land in 2007 and 2008 (Aldous et al. 2007, Wong et al. 2011). During the time when peak algal blooms occur in UKL (mid-August) TP concentrations have decreased by 4 times in permanently flooded wetlands and by 3 times in lake sites from 2008 to 2012 (Figure 6a). Shallow water wetlands in Tulana have experienced a 2.4 times reduction in TP during June–August from 2008 to 2012. During monitoring efforts shallow water wetland habitats have exhibited the slowest rate of P decrease and levels may continue to taper off in the future. Overall, Goose Bay wetlands and Williamson River sites consistently had the lowest TP levels. Goose Bay emergent and transitional wetlands concentration has decreased by 2.8 times from June–July the year directly following reflooding (2009) to 2011 and 2012.

Tulana and Goose Bay emergent and transitional wetlands all experienced a significant reduction in stressful temperature and/or DO conditions to endangered suckers from early post-restoration to five years later (Figure 11). The reestablishment of emergent vegetation can play many critical roles in surface water chemistry including providing shade which helps reduce thermal load and more stable DO levels (Zedler 2000).

Trends in nutrient and chl-*a* concentrations in the permanently flooded wetlands exhibited seasonal variation typical of bloom and crash cycles of *A. flos-aquae,* while trends in the shallow emergent wetlands exhibited seasonal and spatial variation that may be associated with various factors, such as water depth, vegetation, soils, and hydrology. Particularly in the permanently flooded wetlands, algal dynamics (i.e., primary productivity and algal biomass as represented by chl-*a*) appeared to be a main factor exerting control on seasonal trends in water chemistry including DO and pH—trends typical of Upper Klamath and Agency Lakes (Lindenberg et al. 2009). However, some trends in physical water chemistry parameters have improved in deep water and open water wetlands, as well as lake sites in the past five years. Most notably, pH exceedances potentially harmful to the health of suckers have decreased in correlation to post-restoration time in open water habitats (R^2=0.71) and Agency Lake (R^2=0.88; Figure 11).

DISSEMINATION OF DATA

Data collected from this project will be available to all project partners as well as other organizations conducting water quality assessments in the watershed. Specifically a copy of this report will be made available to USGS, the Klamath Tribes, and US Bureau of Reclamation to provide valuable information to enhance their characterization of water quality in Upper Klamath Lake. The Nature Conservancy will be initiating data-sharing with Lower

Klamath Basin partners through uploading monitoring data to the California Environmental Data Exchange Network (CEDEN). Results will also be presented at conferences, including Klamath Basin Monitoring Program and Oregon chapter of the American Fisheries Society.

ACKNOWLEDGMENTS

The Oregon Watershed Enhancement Board (grant agreement #209-4040), the US Bureau of Reclamation (grant agreement # 07FG200081), and the National Fish and Wildlife Foundation (agreement # 2009-0075-000) graciously provided funding and support for this monitoring project. Many individuals contributed to the planning and development of this monitoring project including Mark Stern, Matt Barry, Jason Cameron, Mary Lindenberg, and Tamara Wood. We gratefully acknowledge Allison Aldous and Leslie Bach at The Nature Conservancy for providing thoughtful guidance and analytical support for this project; the Klamath Tribes' Sprague River Water Quality Laboratory for providing laboratory space and support; Jessica Asbill, Mariah Tilman, and JR Schanzenbacher at the US Bureau of Reclamation for providing technical support for YSI instruments; and Melody Warner, Joanna Long, Alix Lee, and Kellen Watson for assistance with field work. This work is a continuation of the monitoring and analysis efforts put forth by Siana Wong and Carolyn Doehring.

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APPENDICES

Appendix A. Quality assurance results for nutrient samples collected in 2012.

Split Samples	Number of Samples		% Total Samples	Difference between splits	
Analyte	Splits	Total		Median (mg L^{-1})	Median (Relative Percent Difference)
Total Phosphorus	28	266	11%	0.121	0.61
Soluble Reactive P	28	266	11%	0.071	0
Total Nitrogen	28	266	11%	0.722	2.04
Ammonia	28	266	11%	0.024	4.55
Nitrate + Nitrite	28	266	11%	0.011	0

Duplicate Samples	Number of Samples		% Total Samples	Difference between duplicates	
Analyte	Duplicates	Total		Median (mg L^{-1})	Median (Relative Percent Difference)
Total Phosphorus	14	266	5%	0.101	0.01
Soluble Reactive P	14	266	5%	0.063	0
Total Nitrogen	14	266	5%	0.608	0.91
Ammonia	14	266	5%	0.031	10.35
Nitrate + Nitrite	14	266	5%	0.014	0

Lab Blanks	Number of Samples		% Total Samples	Minimum Reporting Level (mg L^{-1})	Value of blank samples greater than reporting limit
Analyte	Blank	Total			Maximum (mg L^{-1})
Total Phosphorus	2	266	1%	0.036	NA*
Soluble Reactive P	2	266	1%	0.006	NA
Total Nitrogen	2	266	1%	0.06	NA
Ammonia	2	266	1%	0.012	NA
Nitrate + Nitrite	2	266	1%	0.016	NA

*NA=Not applicable, values below RL

Appendix A, continued.

Equipment Blanks **Analyte**	**Number of Samples** **Blank**	 **Total**	**% Total Samples**	**Minimum Reporting Level (mg L^{-1})**	**Value of blank samples greater than reporting limit** **Maximum (mg L^{-1})**
Total Phosphorus	1	266	0.4%	0.036	NA*
Soluble Reactive P	1	266	0.4%	0.006	0.149
Total Nitrogen	1	266	0.4%	0.060	NA
Ammonia	1	266	0.4%	0.012	0.059
Nitrate + Nitrite	1	266	0.4%	0.016	NA

*NA=not applicable, values below RL

Rinsate Blanks **Analyte**	**Number of Samples** **Blank**	 **Total**	**% Total Samples**	**Minimum Reporting Level (mg L^{-1})**	**Value of blank samples greater than reporting limit** **Maximum (mg L^{-1})**
Total Phosphorus	2	266	1%	0.036	NA*
Soluble Reactive P	2	266	1%	0.006	NA
Total Nitrogen	2	266	1%	0.060	NA
Ammonia	2	266	1%	0.012	0.036
Nitrate + Nitrite	2	266	1%	0.016	NA

*NA=not applicable, values below RL

Spike Samples **Analyte**	**Number of Samples** **Spikes**	 **Total**	**% Total Samples**	**Recovery < 80% (% Spike Samples)**	**Recovery>120% (% Spike Samples)**
Total Phosphorus	26	266	10%	31%	12%
Soluble Reactive P	26	266	10%	8%	8%
Total Nitrogen	26	266	10%	35%	15%
Ammonia	26	266	10%	8%	4%
Nitrate + Nitrite	26	266	10%	0%	0%

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

Constituents	Detection Limit (mg/L)	Reporting Limit (mg/L)	Standard Method	Laboratory
Total Phosphorus	0.018	0.036	SM4500-P H	Sprague River Water Quality Laboratory, OR
Soluble reactive phosphorus	0.003	0.006	SM4500- PF	
Ammonia	0.006	0.012	MD Krom methods	
Nitrate + Nitrite	0.008	0.016	Enzymatic NO3; SM4500-NO2	
Total Nitrogen	0.03	0.06	Enzymatic NO3	
Total Organic Carbon	0.2	0.5	SM 5310	Basic Laboratory, CA
Dissolved Organic Carbon	0.2	0.5	SM5310C	
Chlorophyll-a	0.0001	NA	SM10200H	Aquatic Research, WA

Appendix C. Quality assurance criteria for continuous monitoring data. Level A criteria represent the highest quality data as defined in TNC's Quality Assurance Project Plan. Level B criteria represent data outside Level A criteria, but deemed acceptable for statistical analysis. Level C criteria represent data deemed unacceptable and omitted prior to analysis.

Data Quality Level	Quality Assurance Plan & Action Steps	Water Temperature	pH	Dissolved Oxygen Concentration	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 continuous monitoring in 2012. Data meeting Level A quality assurance criteria are not shown.

Continuous Monitor Site	Data Quality Level	Parameter	Dates
AL27	B	SpC	04/10/12 - 04/17/12
AL27	B	DO	04/17/12 - 04/24/12
AL27	B	DO	05/01/12 - 05/08/12
AL27	B	pH	05/08/12 - 05/15/12
AL27	B	pH	06/05/12 - 06/12/12
AL27	C	DO	06/12/12 - 06/19/12
AL27	B	DO	06/19/12 - 06/27/12
AL27	C	SpC	06/19/12 - 06/27/12
AL27	B	DO	07/02/12 - 07/10/12
AL27	C	DO	07/10/12 - 07/17/12
AL27	B	DO	07/24/12 - 07/30/12
AL27	C	pH	07/24/12 - 07/30/12
AL27	B	DO	08/14/12 - 08/21/12
AL27	B	DO	08/21/12 - 08/28/12
AL27	B	DO	09/18/12 - 09/25/12
AL27	B	DO	10/24/12 - 10/31/12
AL27	B	DO	11/06/12 - 11/14/12
UKLW25	B	DO	04/10/12 - 04/17/12
UKLW25	C	DO	05/01/12 - 05/08/12
UKLW25	B	DO	05/31/12 - 06/05/12
UKLW25	B	DO	06/12/12 - 06/19/12
UKLW25	B	DO	06/27/12 - 07/02/12
UKLW25	B	DO, pH	07/02/12 - 07/10/12
UKLW25	C	DO	07/17/12 - 07/24/12
UKLW25	B	DO	07/24/12 - 07/30/12
UKLW25	C	DO	08/14/12 - 08/21/12
UKLW25	B	DO	09/18/12 - 09/25/12
UKLW25	B	DO	10/16/12 - 10/24/12
UKLW25	B	DO	10/24/12 - 10/31/12
UKLW25	B	DO	11/06/12 - 11/14-12
UKLE24	B	DO	04/17/12 - 04/24/12
UKLE24	C	pH	04/24/12 - 05/01/12
UKLE24	B	DO	05/01/12 - 05/08/12
UKLE24	B	DO	05/31/12 - 06/05/12
UKLE24	C	pH	06/05/12 - 06/12/12
UKLE24	B	DO	06/27/12 - 07/02/12
UKLE24	B	DO	07/30/12 - 08/08/12

Appendix D, continued.

Continuous Monitor Site	Data Quality Level	Parameter	Dates
UKLE24	B	SpC	08/08/12 - 08/14/12
UKLE24	B	DO	08/14/12 - 08/21/12
UKLE24	C	pH	08/14/12 - 08/21/12
UKLE24	B	DO	08/28/12 - 09/05/12
UKLE24	B	SpC	09/05/12 - 09/18/12
UKLE24	B	DO	09/18/12 - 09/25/12
UKLE24	C	DO	10/16/12 - 10/24/12
WR21	B	DO	04/10/12 - 04/17/12
WR21	C	pH	04/17/12 - 04/24/12
WR21	B	DO	04/24/12 - 05/01/12
WR21	B	DO	05/ 08/12 - 05/15/12
WR21	C	DO	05/22/12 - 05/31/12
WR21	C	DO, pH	07/02/12 - 07/10/12
WR21	B	DO	07/17/12 - 07/24/12
WR21	B	DO	07/30/12 - 08/08/12
WR21	B	DO	08/14/12 - 08/21/12
WR21	B	SpC, DO	08/28/12 - 09/05/12
WR21	B	DO	09/25/12 - 10/02/12
WR21	B	DO	10/ 16/12 - 10/24/12
WR21	B	DO	11/06/12 - 11/14/12
TLOW17	B	DO	04/17/12 - 04/24/12
TLOW17	B	DO	05/15/12 - 05/22/12
TLOW17	C	DO, SpC	05/22/12 - 05/31/12
TLOW17	C	DO	06/05/12 - 06/12/12
TLOW17	B	DO	06/12/12 - 06/19/12
TLOW17	B	DO	06/19/12 - 06/27/12
TLOW17	B	DO	07/02/12 - 07/10/12
TLOW17	B	DO, pH	08/14/12 - 08/21/12
TLOW17	B	DO	08/28/12 - 09/05/12
TLOW17	B	DO	09/11/12 - 09/18/12
TLOW17	C	DO	09/25/12 - 10/02/12
TLOW17	B	DO	10/12/12 - 10/16/12
TLOW17	B	DO	10/16/12 - 10/24/12
TLOW17	B	DO	11/06/12 - 11/14/12
TLDW13	B	DO	04/17/12 - 04/24/12
TLDW13	C	DO	04/24/12 - 05/01/12
TLDW13	B	DO	05/01/12 - 05/15/12
TLDW13	C	SpC	05/01/12 - 05/15/12
TLDW13	B	DO	06/05/12 - 06/12/12

Appendix D, continued.

Continuous Monitor Site	Data Quality Level	Parameter	Dates
TLDW13	B	DO	06/12/12 - 06/19/12
TLDW13	B	DO	06/19/12 - 06/27/12
TLDW13	B	DO	07/17/12 - 07/24/12
TLDW13	B	DO	08/14/12 - 08/21/12
TLDW13	B	SpC	08/14/12 - 08/21/12
TLDW13	B	DO	08/21/12 - 09/18/12
TLDW13	C	DO	09/18/12 - 09/25/15
TLDW13	C	DO	09/25/12 - 10/02/12
TLDW13	B	DO	10/16/12 - 10/24/12
TLDW13	B	DO	10/31/12 - 11/06/12
TLEM9	B	pH	04/17/12- 04/24/12
TLEM9	B	DO	04/17/12 - 04/24/12
TLEM9	C	DO	04/24/12 - 05/01/12
TLEM9	B	DO	05/08/12 - 05/15/12
TLEM9	B	DO	05/31/12 - 06/05/12
TLEM9	B	DO	06/12/12 - 06/19/12
TLEM9	C	SpC	06/27/12 - 07/02/12
TLEM9	B	DO	06/27/12 - 07/02/12
TLEM9	C	DO	07/24/12 - 07/30/12
TLTR5	C	DO	04/17/12 - 04/24/12
TLTR5	B	DO	04/24/12 - 05/01/12
TLTR5	B	pH	05/08/12 - 05/15/12
TLTR5	B	DO	05/15/12 - 05/31/12
TLTR5	B	DO	05/31/12 - 06/12/12
GBEM4	B	DO	04/17/12 - 04/24/12
GBEM4	C	DO	04/24/12 - 05/01/12
GBEM4	C	DO	05/08/12 - 05/15/12
GBEM4	B	DO	05/22/12 - 05/31/12
GBEM4	B	DO	06/05/12 - 06/12/12
GBEM4	B	DO	06/27/12 - 07/02/12
GBEM4	B	DO	07/10/12 - 07/17/12