Aquatic Ecosystem Sciences LLC

TECHNICAL MEMORANDUM

Upper Klamath Lake 2012 Data Summary Report

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INTRODUCTION

The Klamath Tribes have been monitoring water quality in Upper Klamath Lake (UKL) since 1990. These data have been described and summarized to varying degrees in a series of reports and manuscripts (e.g., Kann 1998; Kann and Smith 1999; Kann and Welch 2005; Kann 2007 through Kann 2012). The UKL electronic water quality database was previously updated with 2012 data and appropriate quality assurance analyses (*see Excel spreadsheet: Klamath Tribes UKL Water Quality Data 1990-2012_ver_4-15-13.xls*). A recent report provides additional detail and more comprehensive analysis of the 1990-2009 database (Jassby and Kann 2010). The current 2012 data report is intended to serve as an annual update to the UKL water quality database, including a summary of 2012 data (basic summary statistics and graphical analysis), and limited comparison of inter- annual trends of UKL data collected for the 23 year period between 1990 and 2012.

METHODS

Methods followed the Klamath Tribes established procedures for field collection and laboratory analysis of water quality parameters (see Klamath Tribes 2013a,b for a complete description of these methods). Beginning in 2008 for nutrient parameters and 2009 for Chlorophyll-a (CHL), laboratory analyses transitioned from Aquatic Research, INC. in Seattle WA to the Sprague River Water Quality Laboratory in Chiloquin OR. During the transition period duplicate samples were analyzed by both laboratories to confirm parameter reproducibility. During the 2012 sampling season limnological data (Table 1) were collected biweekly from the end of April through October at 10 standardized stations in UKL and Agency Lake (Figure 1; Figure 2).

Table 1. Limnological parameters sampled in Upper Klamath Lake, 2011.

Parameter	Abbreviation/ Unit	Profile [a]	Grab [b]
Temperature	T (°C)	X	
Dissolved Oxygen	DO (mg/L)	X	
pH	pH	X	
Specific Conductivity	(µSiemens/cm)	X	
Secchi Transparency	Secchi (m)		
Light (Photosynthetically Active Radiation)	PAR ($uEm^{-2}s^{-1}$)	X	
Total Phosphorus	TP (µg/L)		X
Soluble Reactive phosphorus	SRP (µg/L)		X
Total Nitrogen	TN (µg/L)		X
Ammonia Nitrogen	NH_4-N (µg/L)		X
Nitrate-Nitrite Nitrogen	NO_3+ NO_2-N (µg/L)		X
Silica	SiO_2 (µg/L)		
Chlorophyll *a*	CHL (µg/L)		X
Phytoplankton Species Composition and Biomass[c]	(mm^3/L)		X
Zooplankton Species Composition and Biomass[c]	(mg/L)		X

a Profile = collected with multi-parameter WQ probe at multiple depths in water column
b Grab = integrated water column sample collected with "tube sampler" except for zooplankton which was collected with a Schindler-Patalis Trap
c. Phytoplankton and zooplankton data are compiled in spreadsheets provided separately and are not analyzed herein.

Site Code	Site Description	Coordinates	
AN	AGENCY NORTH	N 42° 33' 38.0	W 121° 56' 50.8
AS	AGENCY SOUTH	N 42° 31' 24.9	W121° 59' 03.4
CP	COON POINT	N 42° 26' 08.6	W 122° 01' 41.5
ER	EAGLE RIDGE	N 42° 25' 19.5	W 121° 56' 35.8
ML	MID LAKE	N 42° 22' 08.7	W 121° 50' 55.3
MN	MID NORTH	N 42° 26' 28.9	W 121° 59' 55.8
NB	NORTH BUCK IS.	N 42° 18' 30.2	W 121° 51' 22.4
PB	PELCIAN BAY	N42 27.593	W122 04.582
PM	PELICAN MARINA	N 42° 14' 16.892	W 121° 48' 37.341
SB	SHOALWATER BAY	N 42° 24' 26.1	W 121° 57' 47.1
WB	WOCUS BAY	N 42° 19' 35.0	W 121° 55' 11.9

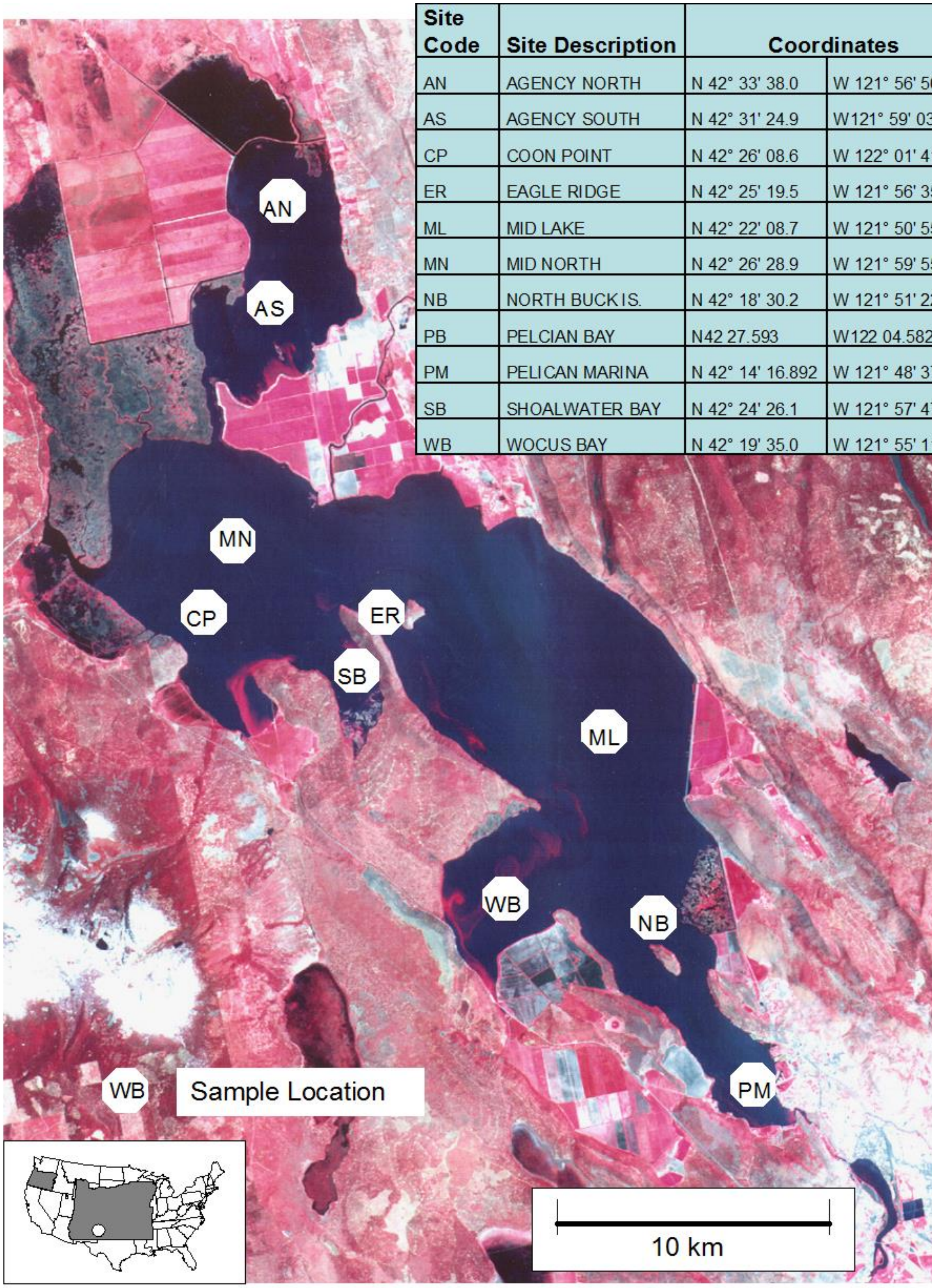

Figure 1. Location of Upper Klamath Lake sampling stations, 2012.

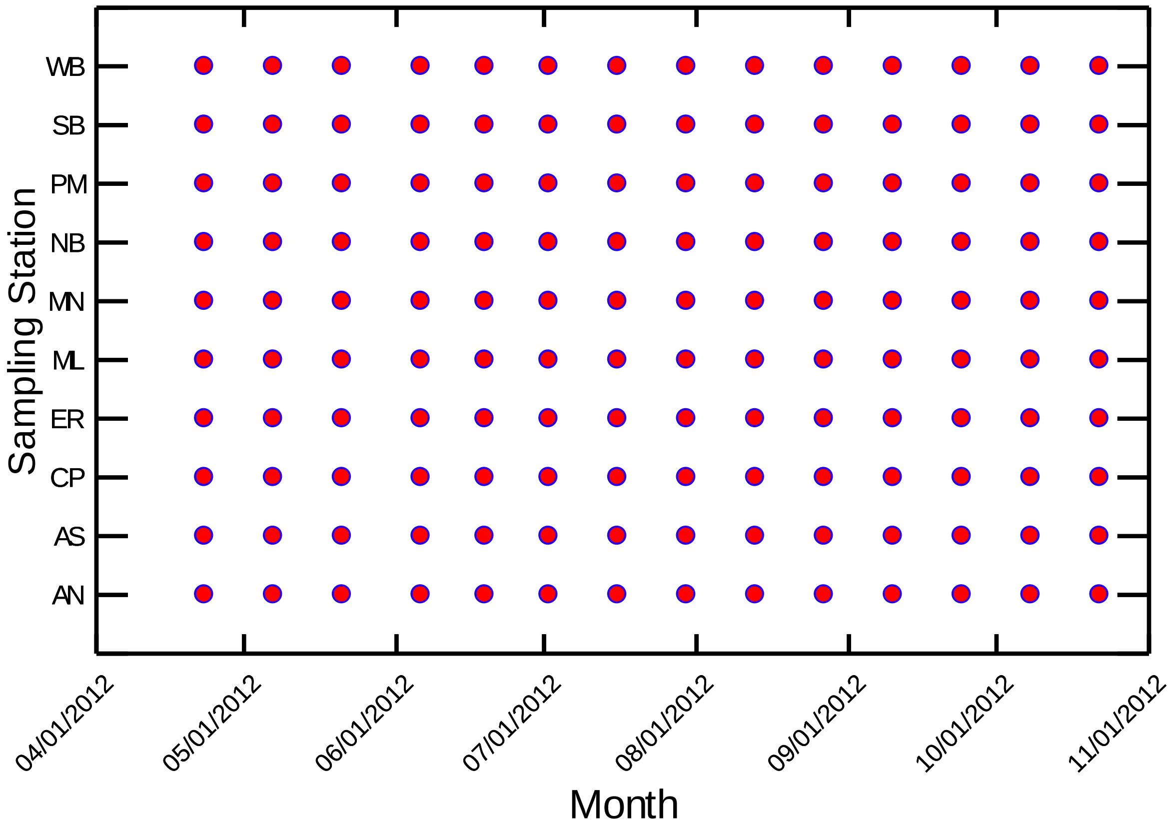

Figure 2. Spatial-temporal sampling matrix for Upper Klamath Lake, 2012.

Data reduction consisted of computation of both lake-wide means on a given sample date and of growing season (June-September sample dates) means. Because of bloom timing differences between Upper Klamath and Agency Lake (e.g., see Kann 1998), lake-wide means and analyses are shown separately for Upper Klamath Lake only and Agency Lake only. Chlorophyll and nutrient data tended to be either normally or log-normally distributed both within a date and seasonally. Based on a comparison of both log transformed ($\log_{10}$ or $\log_{10}(x+1)$) and non-transformed data with the normal distribution using Kolmogorov-Smirnov one-sample tests or the Shapiro-Wilk standard test for normality (*cf.* Systat® 2004), the geometric mean tended to provide the best estimate of lake-wide or seasonal central tendency. Lake-wide variability is shown via boxplots which convey the median, interquartile range and outliers. In addition to median and interquartile values, lake-wide central tendency may be portrayed as a mean and standard error.

Nutrient quality assurance/quality control analyses are shown in the accompanying data spreadsheet (*Klamath Tribes UKL Water Quality Data 1990-2012_ver_4-15-13.xls)*

RESULTS/DISCUSSION

Seasonal and Water Column Trends in Profile Water Quality Data (T, DO, and pH)

Water column and seasonal trends in T, DO, and pH are important aspects of water quality dynamics and fish habitat in UKL. Depth-time plots of isotherms and isopleths for these parameters allows both seasonal and depth distribution to be evaluated simultaneously. These are plotted below for two representative stations, ER located in the deep trench area, and MN located in an open-water area in the northern part of the lake (Figure 3; Figure 4). At both stations temperature ranged between 11-14 ^{o}C during late-April and early-May, with warming occurring in mid-May (~16 ^{o}C), with little additional warming into early-June (in fact Figure 7, below indicates an approximate 2 ^{o}C cooling in early-June). Overall this is in contrast to 2011 when temperatures generally remained below 12 ^{o}C into early-June. Warming continued to occur during the second half of June, although temperatures were still only ~18 ^{o}C, and only rose slightly to <20 ^{o}C through the 1st week in July. Water temperature then increased again in mid- to late-July, before peaking during the mid-August period (Figure 3; Figure 4). Maximum surface and water column temperatures occurred during the late-July to early- September period, with seasonal cooling beginning in late-August when a temperature drop of 2 ^{o}C occurred (from ~22 to <20 ^{o}C).

Unlike 2010 when water column pH initially increased (>9.0) in late-April and early-May (lake observations at that time indicated a massive diatom bloom and further confirmation showed very high biomass of the diatom *Asterionella formosa*), pH in 2012 was similar to 2011 and remained relatively low (<8.75) until late-June. A sharp increase to seasonal peak values then occurred by mid- to late-July with values ranging between 9.5-10.0 (Figure 3; Figure 4). UKL stations generally declined through the remainder of the season. Dissimilar to 2009-2011, pH maxima tended to be in more in sync with the period of maximum water column temperature.

Water column DO values were initially elevated in late-April and early-May (10-11 mg/L), and declined in mid-May (7-8 mg/L) at which time they continued to remain stable until late-June (7-9 mg/L). Surface DO then increased in late-June (10-12 mg/L; preceding the pH increase that occurred later in July), and DO at lower depths remained near 7 mg/L (Figure 3 and Figure 4). DO then declined during late-July (at ER) and early-August (MN) at deeper depths (<2-4 mg/L), especially at ER (Figure 3). Low DO at ER extended through much of the water column (Figure 3), as compared to MN where low DO only occurred near bottom (Figure 4). Lower DO conditions were present until early- to mid-September. As noted previously (e.g., Kann 2012), trends in pH and DO can be influenced by temperature and algal dynamics (cool late-spring and early-summer conditions were associated with low algal productivity, a delayed bloom, and moderate bloom decline in 2011). However, algal productivity remained low in May and June despite water temperatures that were substantially warmer than 2011 (see below), indicating that factors other than water temperature also influence algal productivity and subsequent DO and pH dynamics.

Similar depth-time plots were constructed for these stations for all years of data (1990-2011) and are shown in Appendix I. Although a comprehensive inter-annual analysis will not be performed here, unlike 2011 when water column temperatures showed a later peak than most years (early August as opposed to late-July), 2012 peak temperature timing was more typical of other years. However, DO tended to be low on a water column-wide basis at ER, showing more extreme lows

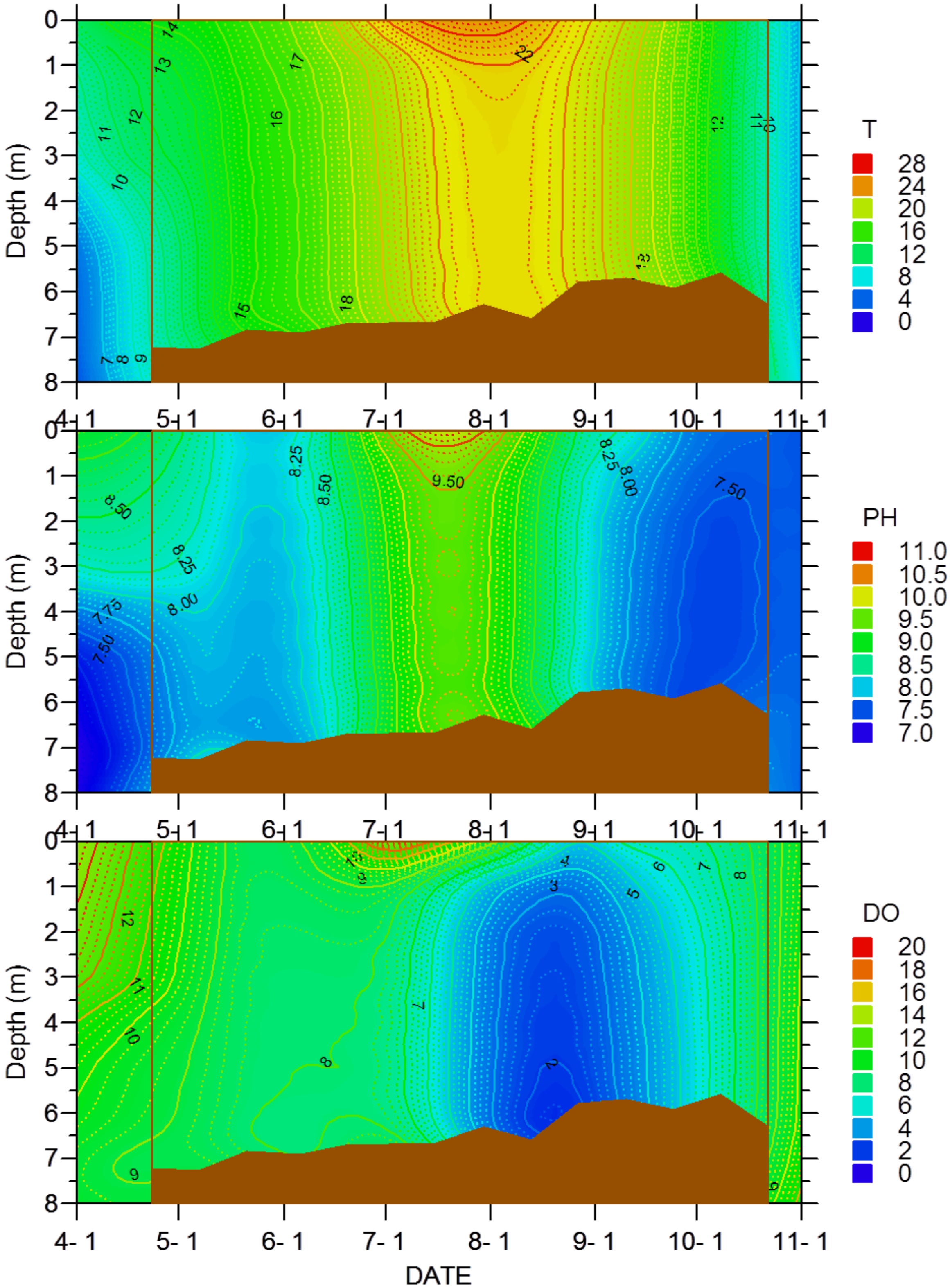

Figure 3. Depth-time distributions of isotherms of T (°C) and isopleths of D.O (mg/L) and pH at UKL station Eagle Ridge (ER), 2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

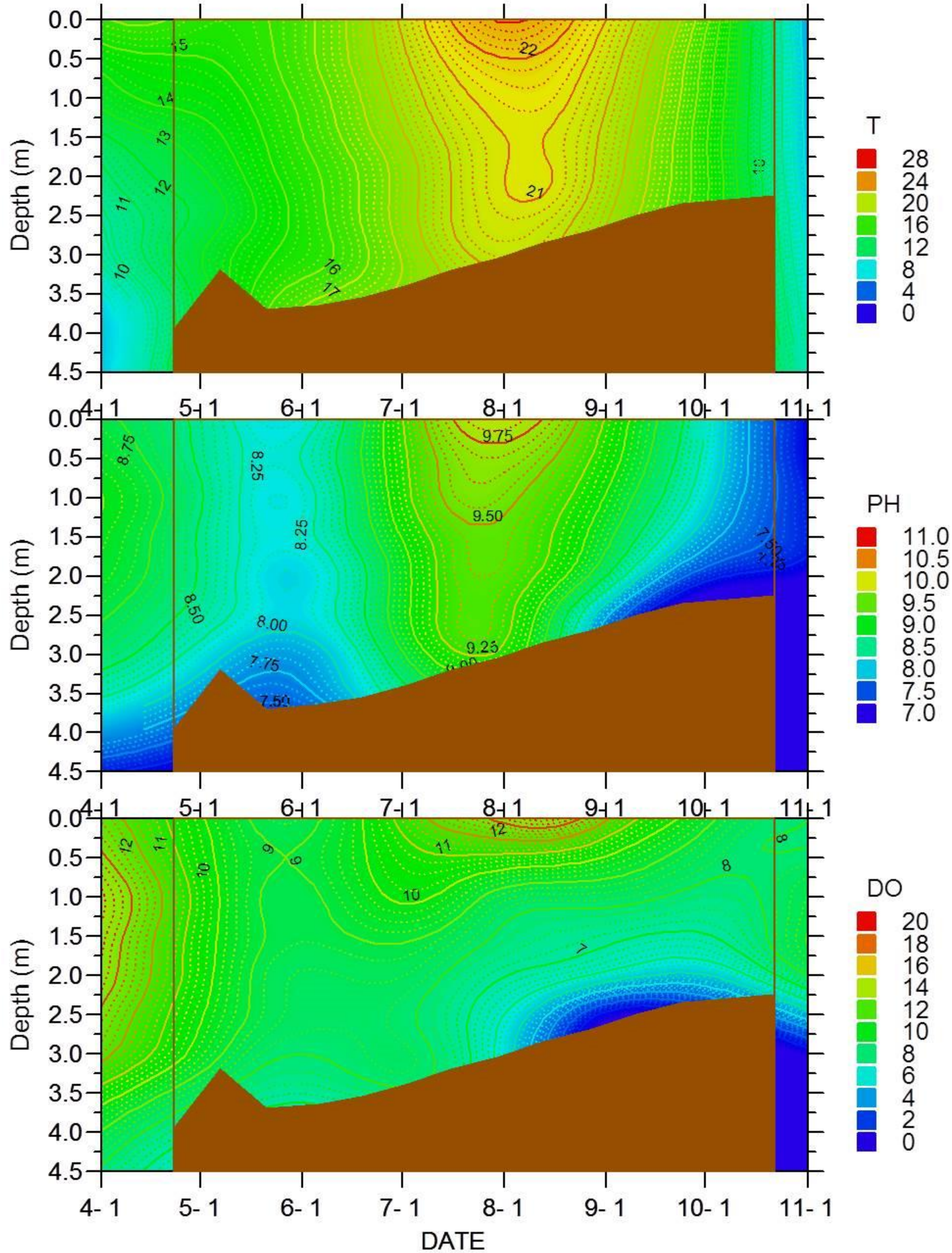

Figure 4. Depth-time distributions of isotherms of T (˚C) and isopleths of D.O (mg/L) and pH at UKL station Mid North (MN), 2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

than many previous years (indicative of a severe bloom decline). Low off-bottom DO was also apparent at MN relative to other years. The pH seasonal peak tended to be higher than the previous several years at MN, especially deeper in the water column (Appendix I). As shown below and in earlier data and analytical reports (e.g., Kann 2011; Jassby and Kann 2010), differences in pH and dissolved oxygen can be explained in part by the interaction of both climate and bloom dynamics, which can also be influenced by lake level.

2012 Station Distributions

The distribution of parameter values for each station for the June-September period (chosen here to encompass the major algal growing season in UKL) are shown in Figure 5 and Figure 6. Although the seasonal timing of water quality has been shown to vary among stations (see below analyses comparing individual stations by date), the season-wide distributions as indicated by the interquartile range (25^{th}-75^{th} percentiles or box hinges in the plots below) tend to overlap for most parameters. In addition, although the timing of sample collection can affect the distribution of these variables (particularly temperature, pH and dissolved oxygen—see Jassby and Kann 2010), the below plots reflect water column means which are less sensitive to the effect of sample timing than are surface values.

Nonetheless, as with previous years, certain stations tended to stand out on a seasonal basis. For example, the pH distribution (as indicated by the upper or lower quartile) was skewed higher for PM and NB (and to a lesser degree AS), and skewed lower for WB, ER, SM, and AN (most notable for AN; Figure 5). ER showed the lowest overall DO, closely followed by WB, while PM, NB, ML, AS, and AN tended to show higher overall distributions. Secchi depth (transparency) was somewhat lower at ER and WB and higher at AS and AN. These among-station comparisons were not necessarily consistent with wither 2010 or 2011 patterns (see Kann 2011; 2012), and among-station patterns are not always consistent from year-to-year.

Stations PM, SB, and MN were among the highest with respect to median CHL, while WB showed significantly higher upper quartile CHL. The distribution if CHL at stations ML, AS, and AN were among the lowest (Figure 6). However, the inter-quartile CHL range was similar among many other stations. Both AS and AN showed noticeably lower CHL in 2012, especially compared to previous years (Kann 2012). In contrast to 2010 and 2011 when the AS and AN stations stood out with noticeably higher upper quartile and median values for TP, values were similar to or somewhat lower (see AN) than other stations in 2012 (Figure 6). However, SRP values for AS and AN were skewed high relative to other stations. Both PM and WB were skewed low for SRP relative to other stations.

Similar to previous years, Agency Lake stations were among the lowest for nitrogen, particularly for NH_4-N, but also for NO_3-N, and TN (Figure 6; Table 2). The upper quartile value and interquartile range for TN were highest at WB. Similar to 2010 and 2011, ER, SB, and CP were among the highest for ammonia, but WB was also high in 2012 (NH_4-N; Figure 6; Table 2). Un-ionized ammonia also tended to be highest at WB, ER, SB, and CP in 2012 (Figure 6). Upper quartile NO_3-N was higher overall at NB.

Median silica values (~30,000 µg/L) were similar among stations, although the Agency Lake stations showed a narrower interquartile range (Figure 6). See below for a description of seasonal silica dynamics.

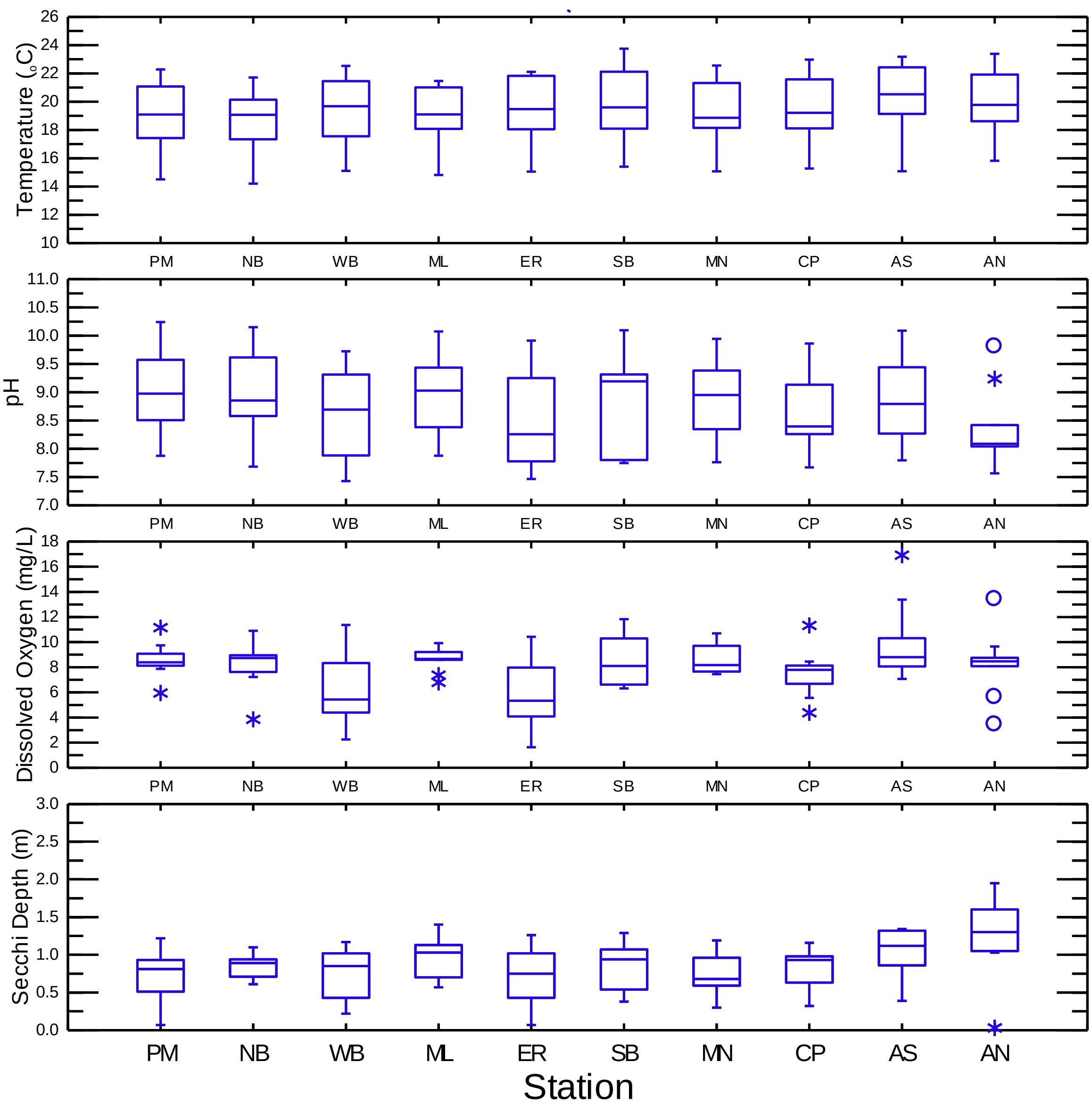

Figure 5. Station distributions of T (˚C), pH, D.O (mg/L), and Secchi depth, June-September, 2012.

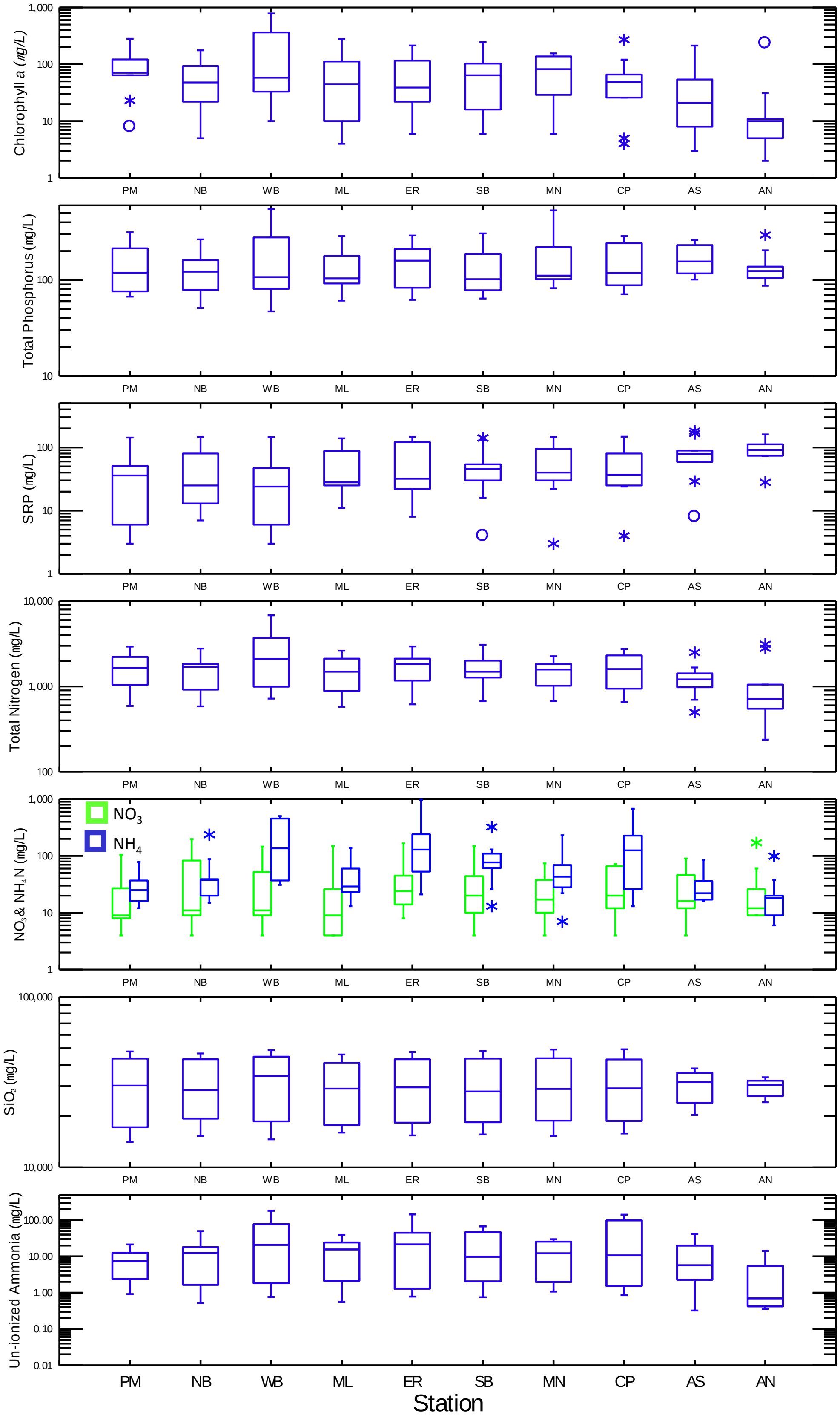

Figure 6. Station distributions of CHL, TP, SRP, TN, NO_3+ NO_2-N, NH_4-N, SiO_2 and un-ionized ammonia, June-September, 2012.

Table 2. Summary statistics for each UKL station for the June-September period, 2012 (LQ= Lower Quartile; UQ=Upper Quartile).

YEAR	Station	Parameter	Temperature (˚C)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chlorophyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	Silica (µg/L)	NO_3+NO_2 Nitrogen (µg/L)	NH_4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2012	AS	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	AS	Median	20.5	8.8	8.8	1.1	21.0	156.0	79.0	1210.0	31700.0	16.0	22.0	5.7
2012	AS	Arithmetic Mean	20.3	8.9	10.1	1.0	51.9	170.3	85.9	1281.7	30055.6	28.9	35.3	12.7
2012	AS	LQ	19.0	8.2	8.0	0.8	7.0	114.8	51.5	908.8	23000.0	11.5	16.8	1.8
2012	AS	UQ	22.5	9.5	11.1	1.3	65.8	236.5	108.3	1482.5	36000.0	46.3	45.3	22.6
2012	ER	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	ER	Median	19.5	8.3	5.3	0.8	39.0	159.0	32.0	1830.0	29500.0	24.0	129.0	21.4
2012	ER	Arithmetic Mean	19.6	8.5	5.8	0.8	77.4	156.6	61.8	1672.1	30622.2	49.7	256.0	43.5
2012	ER	LQ	18.0	7.8	3.7	0.4	20.0	80.3	19.5	1053.3	17675.0	12.8	53.0	1.3
2012	ER	UQ	21.9	9.3	8.0	1.1	135.5	216.3	126.3	2132.5	43850.0	65.5	317.0	68.4
2012	ML	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	ML	Median	19.1	9.0	8.7	1.0	45.0	104.0	28.0	1490.0	29000.0	9.0	29.0	15.6
2012	ML	Arithmetic Mean	19.0	9.0	8.6	0.9	88.2	147.0	55.6	1496.6	29333.3	31.3	49.6	16.0
2012	ML	LQ	17.8	8.3	8.3	0.7	10.0	87.0	22.3	860.0	17275.0	4.0	21.3	1.8
2012	ML	UQ	21.1	9.5	9.3	1.1	141.5	198.5	98.3	2175.0	41100.0	34.8	67.8	26.4
2012	MN	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	MN	Median	18.9	9.0	8.2	0.7	82.0	111.0	40.0	1580.0	28900.0	17.0	43.0	12.1
2012	MN	Arithmetic Mean	19.3	8.8	8.6	0.8	79.6	188.7	62.9	1492.7	30888.9	29.2	64.9	14.1
2012	MN	LQ	18.0	8.3	7.6	0.6	27.8	99.0	28.0	973.3	18025.0	9.8	26.5	1.9
2012	MN	UQ	21.3	9.4	9.7	1.0	141.3	237.8	105.5	1885.0	44850.0	46.5	76.0	26.0
2012	NB	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	NB	Median	19.1	8.9	8.7	0.9	48.0	122.0	25.0	1700.0	28400.0	11.0	38.0	12.3
2012	NB	Arithmetic Mean	18.3	9.0	8.2	0.9	68.1	134.4	50.2	1524.0	29855.6	53.9	57.9	15.3
2012	NB	LQ	16.9	8.4	7.5	0.7	19.3	78.3	12.0	867.3	18450.0	8.8	19.8	1.5
2012	NB	UQ	20.2	9.6	9.1	1.0	106.8	182.3	90.3	1947.5	43325.0	99.5	51.3	21.5
2012	PM	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	PM	Median	19.1	9.0	8.4	0.8	71.0	119.0	36.0	1650.0	30200.0	9.0	25.0	7.4
2012	PM	Arithmetic Mean	19.0	9.1	8.6	0.7	113.3	148.4	44.3	1647.4	30477.8	24.1	31.8	9.0
2012	PM	LQ	17.2	8.5	8.1	0.5	53.8	75.8	5.8	937.0	16600.0	7.0	15.8	2.3
2012	PM	UQ	21.2	9.7	9.2	1.0	160.0	217.5	58.5	2365.0	43825.0	30.5	39.5	14.5
2012	SB	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	SB	Median	19.6	9.2	8.1	0.9	64.0	102.0	46.0	1490.0	27900.0	20.0	77.0	9.8
2012	SB	Arithmetic Mean	19.8	8.8	8.5	0.8	85.8	147.4	55.8	1643.6	30522.2	41.1	100.4	24.1
2012	SB	LQ	18.0	7.8	6.6	0.5	14.5	76.5	26.5	1130.5	17825.0	9.8	52.3	1.9
2012	SB	UQ	22.2	9.4	10.3	1.1	136.0	201.0	73.0	2077.5	44625.0	56.8	115.0	47.8
2012	WB	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	WB	Median	19.7	8.7	5.4	0.9	58.0	107.0	24.0	2110.0	34400.0	11.0	136.0	20.9
2012	WB	Arithmetic Mean	19.1	8.6	6.3	0.8	200.9	186.3	37.1	2566.7	31944.4	34.2	211.3	44.8
2012	WB	LQ	17.1	7.8	4.3	0.4	28.5	79.0	6.0	961.8	17650.0	8.8	36.0	1.7
2012	WB	UQ	21.5	9.4	8.5	1.0	380.5	285.0	51.8	3892.5	45500.0	53.3	460.5	81.2
2012	AN	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	AN	Median	19.8	8.1	8.5	1.3	10.0	124.0	91.0	715.0	30500.0	12.0	18.0	0.7
2012	AN	Arithmetic Mean	20.1	8.4	8.3	1.2	34.9	144.4	93.3	1146.9	29644.4	35.6	25.4	3.4
2012	AN	LQ	18.4	8.0	7.5	1.0	4.5	103.5	73.8	475.3	26175.0	9.0	9.0	0.4
2012	AN	UQ	22.1	8.6	9.0	1.6	16.0	154.5	113.0	1487.5	32450.0	34.5	24.5	6.1
2012	CP	N of Cases	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
2012	CP	Median	19.2	8.4	7.8	0.9	49.0	118.0	37.0	1600.0	29100.0	20.0	125.0	10.6
2012	CP	Arithmetic Mean	19.6	8.7	7.6	0.8	70.3	157.6	61.1	1698.6	31044.4	33.0	178.7	45.9
2012	CP	LQ	18.1	8.3	6.4	0.6	20.8	86.3	24.8	893.0	18075.0	11.3	23.0	1.4
2012	CP	UQ	21.7	9.2	8.2	1.0	79.8	249.3	94.3	2417.5	44375.0	66.8	249.8	101.0

Seasonal Chlorophyll Pattern and Climate Interaction

Seasonal differences in algal biomass (CHL) among stations in 2012 show that, similar to the previous four years (2008-2011), but unlike 2006 (Kann 2011) and 2007 when AS and AN increased earlier and declined earlier in the season relative to UKL stations; early season CHL in Agency Lake was low in late-April and early-May and was then similar to UKL through the initial bloom peak (Figure 7). However, the Agency Lake bloom decline occurred much earlier than UKL in 2012 (and to a much greater degree than it did in 2011). The similarity between Agency and UKL Lakes in terms of the June algal biomass increase and seasonal maxima and decline in the later years may reflect greater connectivity between the two lakes due wetland restoration activities on the Williamson Delta Preserve (e.g., Wong et al. 2010; 2011). CHL concentration at the more southerly stations vs. northerly stations did not tend to show as distinct a seasonal pattern as previous years when relatively higher CHL occurred later in the bloom cycle (e.g., August) at the southerly stations.

As noted in previous annual data reports (Kann 2008 to 2012), water temperature partially explained the early season CHL patterns among the years. For example, low temperatures coincided with a depressed early-June bloom in 2006, and in 2008 much cooler lake-wide water temperature (median value <7 ^{o}C) in late April and early-May also coincided with low CHL levels. However, it was clear that factors other than temperature were also affecting bloom dynamics in those years (Figure 7).

For example, in 2010, late-April and early-May CHL was noticeably higher than the previous four years (generally >80 µg/L) due to an unusually large diatom bloom (*Asterionella formosa*) occurring at that time– despite temperatures in a range similar to many of the previous years (Kann 2011). The large 2010 diatom bloom then declined rapidly beginning in mid-May and by early-June chlorophyll levels were less than 10 µg/L. In contrast, CHL levels in 2011 were only slightly elevated in late-April and early-May (generally <20 µg/L), and except for a decline in mid-May (<7 µg/L), they remained generally less than 20 µg/L (often less than 10 µg/L at many stations) through the end of June (Figure 7). During this same period water column temperature remained very cool (<11 ^{o}C through early June) and although mid-June temperature increased to ~16 ^{o}C in UKL (they were 1-2 deg. warmer in Agency Lake), they only rose slightly, remaining <20 ^{o}C through most of July (Figure 7). In contrast, water temperatures during the previous five years generally exceeded 20 ^{o}C by early-July, if not sooner (Figure 7).

In 2012, the CHL pattern was more similar to 2010, although the spring levels ~30 µg/L were still substantially lower than the ~100 µg/L achieved in 2010. May-June levels were similar, as was the peak which occurred mid to late-July of both 2001 and 2012. Water temperature warmed more rapidly than 2011, and CHL also increased to levels >50 µg/L by early-July. CHL did not undergo a lake-wide decline in August as it did in 2011.

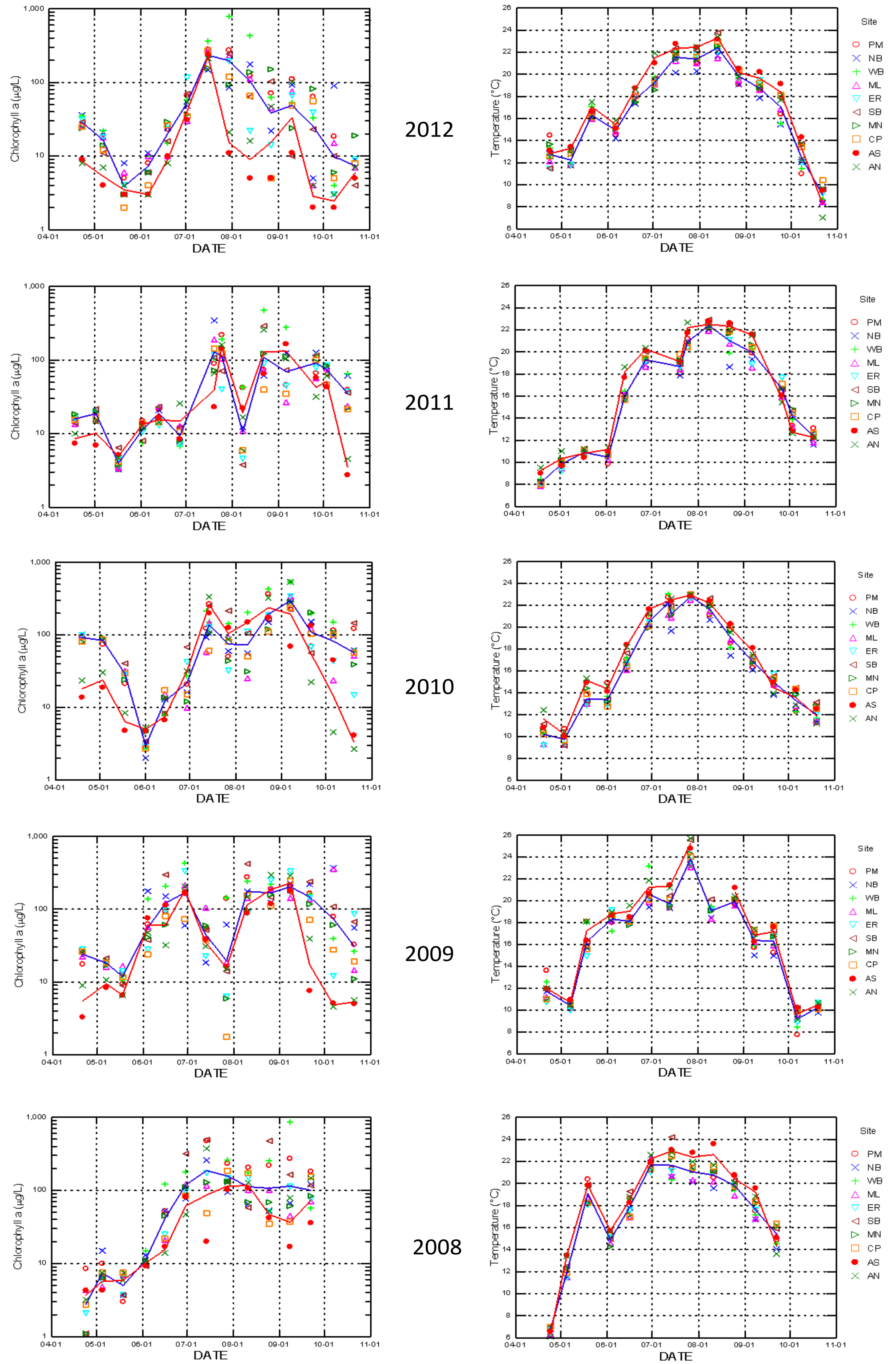

Figure 7. Seasonal CHL and temperature trends for UKL stations, 2008-2012 (blue line shows the median value for UKL-only, red line shows the median value for Agency Lake-only).

Because water temperature in the above plots is measured biweekly, and due to UKL's shallow depth a short lag-time is generally observed with respect to equilibrium with ambient air temperatures (e.g., Wood et al. 2006), it is also instructive to evaluate daily air temperatures as another indicator of water column warming.

Hourly data obtained from the USBR AgriMet station located near Agency Lake (Figure 13a) indicated at least partial tracking of May air temperature and CHL levels (Kann 2011; 2012). For example, temperature declines in mid-May of 2006 and 2008 that remained near or below 15 ^{o}C through mid-June were associated with suppressed CHL levels in early-June (Kann 2011). In 2007 and 2009, air temperatures warmed between mid- and late-May and were associated with elevated CHL levels in early June, and in 2010, when temperatures cooled substantially in mid-May and portions of June, CHL also remained suppressed during early and mid-June (Figure 7; Figure 8a)
.

Likewise, air temperature in 2011was similar to other years in the beginning of May, but unlike other years it remained relatively constant through May (it was also among the lowest when compared to previous years and showed further cooling towards the end of May) before increasing in June to levels similar to other years (Figure 8a). A significant departure from other years then occurred in July of 2011 when the upper quartile, median, and lower quartile values of daily mean air temperature were substantially lower than corresponding values for the previous 5 years (Figure 9).

In 2012, temperatures were intermediate to warmer in late-April, intermediate in early-May, with cyclical warming and cooling occurring through June, with mid-to late June temperatures tending to be lower than previous years (Figure 8a). July of 2012 was slightly higher than 2011, but like 2011 was lower than the 2006-2010 period. (Figure 9).

In general, previous analyses indicating a threshold temperature of ~15 for *Aphanizomenon* bloom development in Upper Klamath Lake (Kann 1998; Kann 2011) continue to be supported. However, as noted previously (Kann 2011) high CHL levels due to spring diatom blooms can be achieved even at temperatures much cooler than 15 ^{o}C. Furthermore, similar to 2011, based on 2012 patterns it appears that once the 15 ^{o}C threshold was reached, cool temperatures towards the end of June and into July also had an apparent effect on continuing algal biomass development.

Analysis of wind speed as an indicator of the extent of water column mixing showed that the periods directly preceding and during the typical period of June bloom development in 2006 and 2008 (which had relatively low CHL during that period) were characterized by generally higher wind speed relative to 2007 (Figure 8b), which had relatively higher CHL (Kann 2011). Wind speed during 2009 was more similar to 2007 (which had lower wind preceding and during development of the early June bloom), and also tended to have relatively higher CHL compared to 2006 or 2008, which were suppressed. The pattern for 2010 was less clear and may have been confounded by the massive diatom bloom which crashed immediately preceding the June period when *Aphanizomenon* typically begins to increase. Although wind was somewhat low to intermediate during the typical bloom initiation period in 2010 (late-May to early-June; Figure 8b), CHL still remained suppressed, possibly reflecting the unusually cool period occurring during late-May (Figure 8a). Likewise, in 2011 relatively high wind speeds in April and May were associated with relatively low algal biomass (Figure 8b).

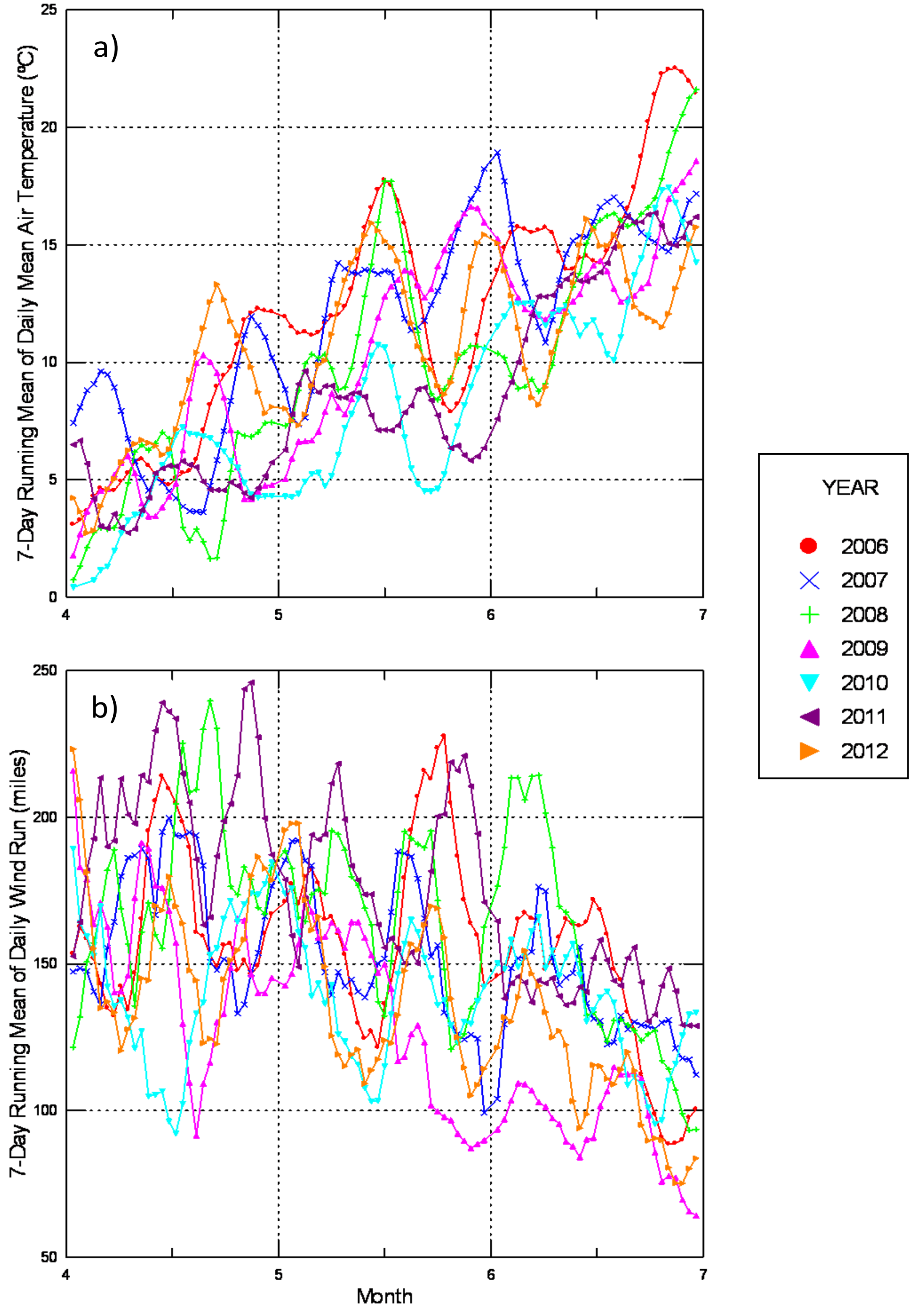

Figure 8. Time series of the 7-day running mean of daily air temperature (a) and 7-day running mean of the daily wind run in miles (b), April-June, 2006-2012. Data are from the Bureau of Reclamation AgriMet station located at Agency Lake (AGKO).

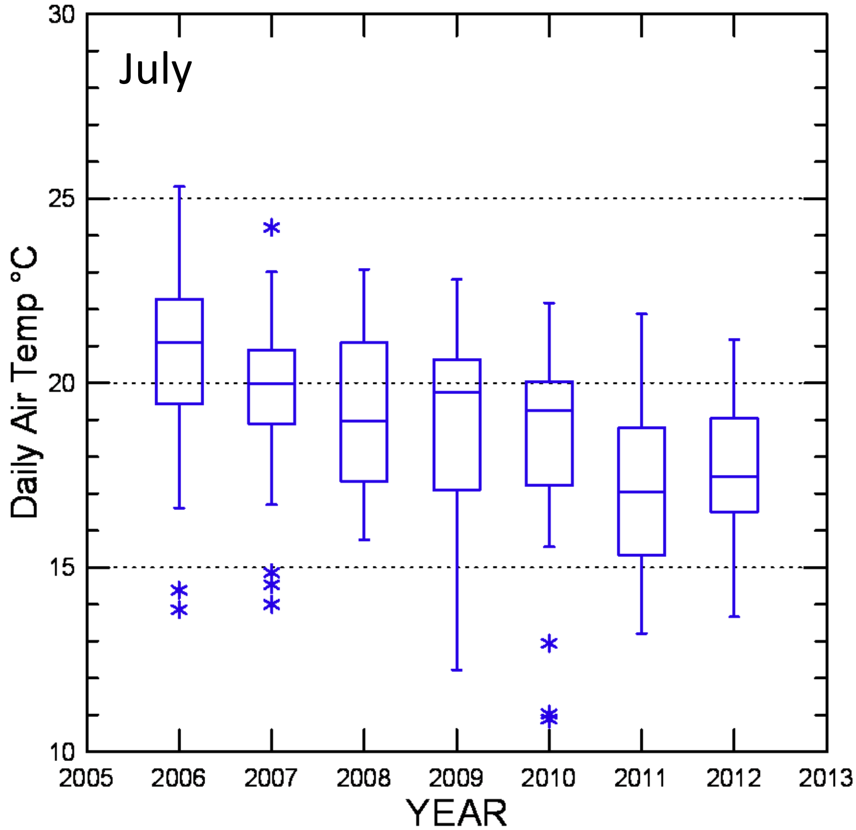

Figure 9. Annual distribution of Agency Lake AgriMet (AGKO) daily air temperatures during July, 2006-2012.

Wind speeds during the 2012 bloom development period (late-May to June) were on the low side relative to other years, which did not necessarily lead to enhanced CHL levels as expected, again indicating that factors other than climate also dictate bloom development.

Also similar to previous 2006-2011 analysis of air temperature and wind speed data that showed wind and temperature to be related such that warm/calm conditions co-occur and that cool/windy conditions co-occur (Kann 2012), these parameters also tended to co-occur in 2012 (Figure 10). Supporting observations from the above time-series graphs, confidence ellipses computed for the period encompassing 10 days prior to and subsequent to June 1st (the typical historical period of initial *Aphanizomenon* increase) show that both 2006 and 2008 (red and green ellipses in Figure 10) tended to be cooler and windier than during the same periods in 2007 and 2009 (blue and pink ellipses). 2009 showed the lowest wind speed of the four years (Figure 8b and Figure 10) and was associated with higher early- and mid-June CHL than the other years (Figure 7) (Kann 2010). Temperatures in 2010 were cooler overall than the other years and wind speeds were only intermediate (Figure 10). During 2011the late-May to early-June period was among the coolest and windiest of the six years portrayed (Figure 10), and as noted above also showed relatively low algal biomass levels. 2012 wind speeds were lower, and temperatures intermediate relative to other years.

These climate data indicate that cooler and well mixed conditions during the usual early season bloom development period (e.g., Kann and Welch 2005) contribute to variability in year-to-year bloom development. Multivariate analyses performed on the longer 1990-2009 data set also showed that wind and temperature, along with lake elevation were determinants of CHL levels in UKL (Jassby and Kann 2010). As noted below these factors also interact with varying year-to-year variability in nutrient concentrations.

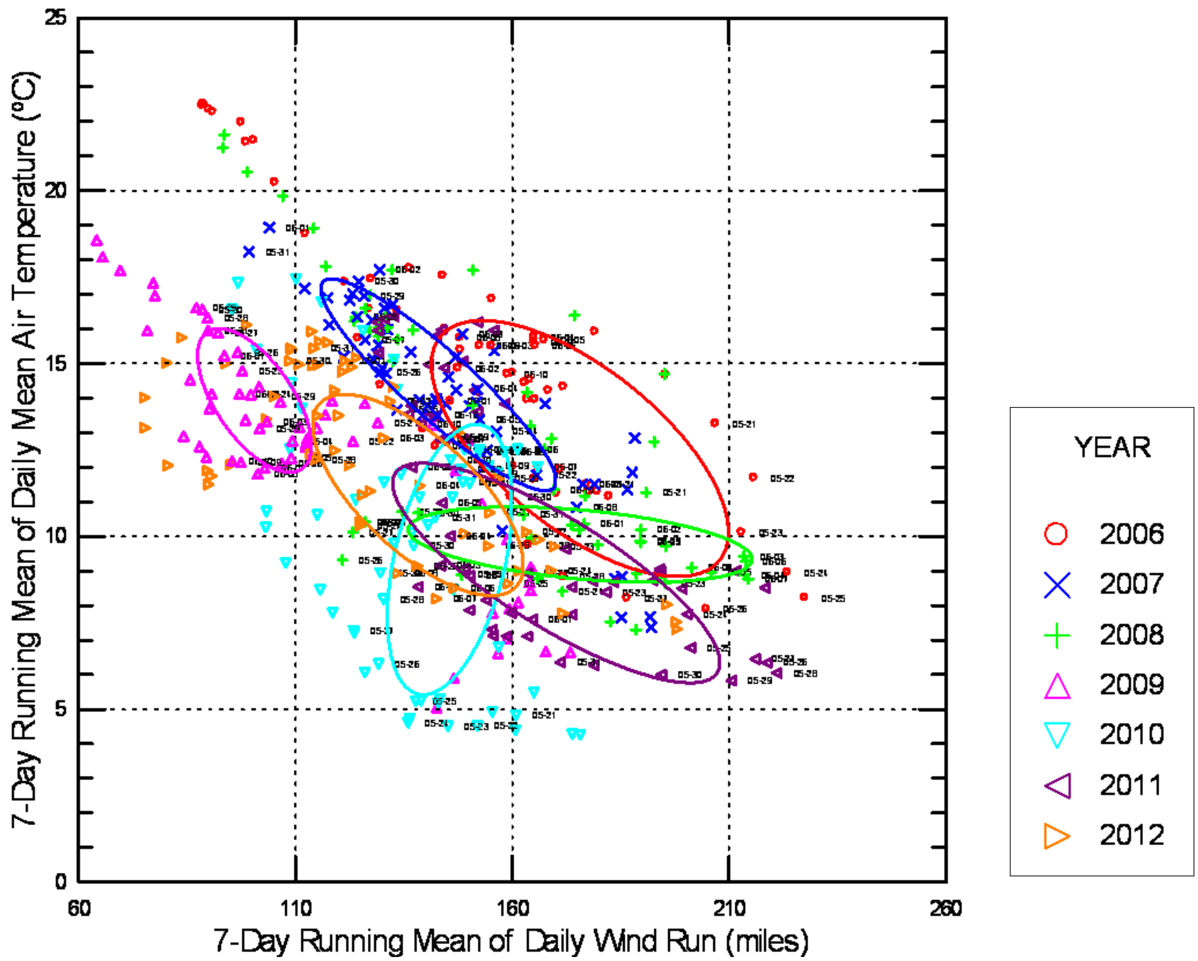

Figure 10. Scatter plot of the 7-day running mean of the daily wind run (miles) vs. 7-day running mean of daily air temperature (^{o}C) during May and June. Data are from the Bureau of Reclamation AgriMet station located at Agency Lake (AGKO). Data labels are day of the month. Confidence ellipses are drawn for dates occurring during the last 10 days of May and first 10 days of June; confidence ellipses are centered on the sample means of the x and y variables where the unbiased sample standard deviations of x and y determine its major axes and the sample covariance between x and y, its orientation (Systat 2013).

2012 Monthly and Seasonal Water Quality, Chlorophyll, and Nutrient Patterns

Basic statistics for monthly distributions for all sampling years are shown in Appendix 1. Peak water temperatures occurred in July and August of 2012, with the July median higher than August (this is in contrast to 2011 when the August median was higher) (Figure 11). Monthly distributions for pH in 2012 were similar to 2006-2008 and 2011 which showed a progressive seasonal increase with seasonal maxima occurring in July that coincided with the lowest Secchi depth (indicating reduced transparency) and highest CHL distributions (note that in 2010 high pH values occurred in April, declined in May and June and showed a bimodal peak in July and September). In contrast to 2011 CHL did not show a bimodal peak in 2012 (Figure 7 and Figure 12), and pH declined into September (Figure 11). Lower DO occurred during August in 2012, and although the timing of low DO was similar to other years, DO was relatively low compared to 2011 and other years despite the lack of a strong lake-wide bloom decline. As noted above, 2012 CHL peaked in July, and did not exhibit a second peak in September (Figure 12).

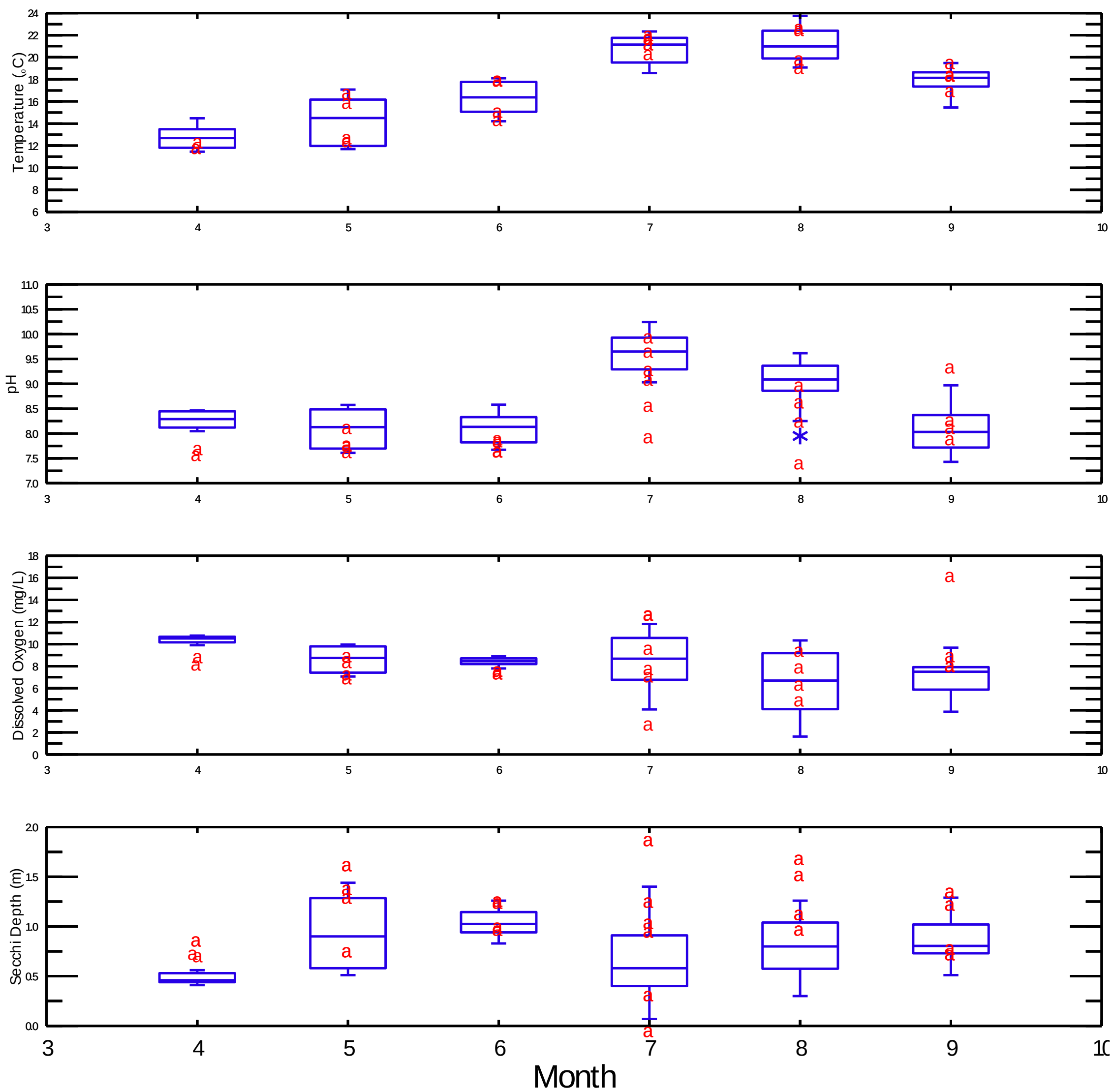

Figure 11. Monthly distributions of T (˚C), pH, D.O (mg/L), and Secchi depth, 2012 (symbol "a" denotes values for Agency Lake plotted separately from the box plot distribution).

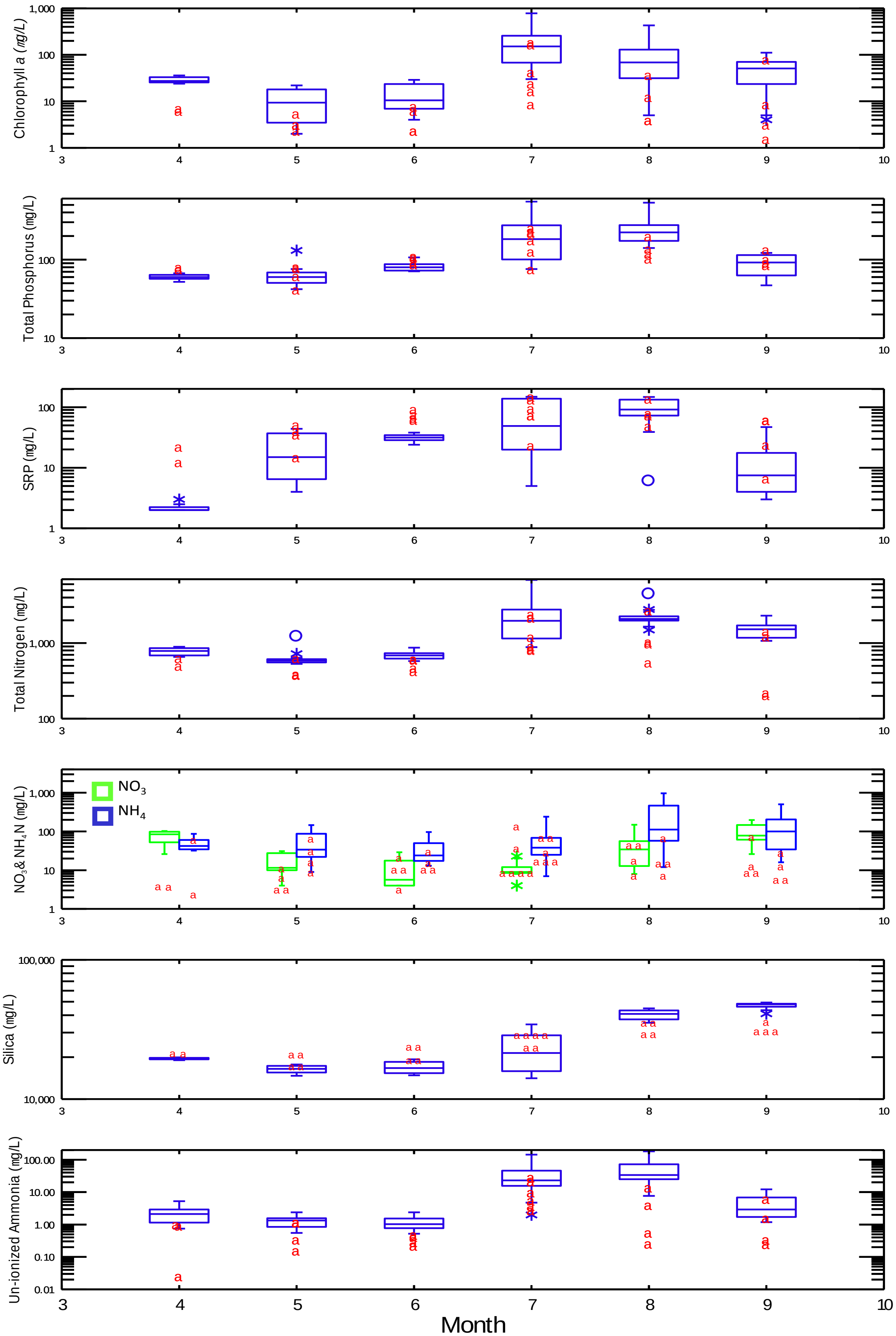

Figure 12. Monthly distributions of CHL, TP, SRP, TN, NO_3+ NO_2-N, NH_4-N, SiO_2 and un-ionized ammonia, 2012 (symbol "a" denotes values for Agency Lake plotted separately from the box plot distribution).

TP in 2012 remained low and relatively constant through June before increasing in July during the overall CHL increase (Figure 12). Unlike 2011 when SRP remained low and was depressed well into July, SRP in 2012 was elevated in May and June. Although TP and TN typically increase during June, values remained low for both parameters during June of 2012, with values then increasing during July when CHL increased with the initiation of the *Aphanizomenon* bloom. In contrast to 2011 when about a month delay was observed (when compared to the typical seasonal pattern), 2012 SRP increased in May and June, while 2012 $NH_{4,}$ increased in July (Figure 12).

A further look at the 2012 time-series with respect to CHL and dissolved nutrients shows that, as in other years, SRP at the UKL stations generally remained low through the initial July CHL peak before increasing during the algal biomass decline in early August (Figure 13). Also as in previous years (e.g., 2009-2011), this trend did not apply to the Agency Lake stations which showed elevated SRP in April (AN) and May (AN and AS), with levels then increasing and remaining high during the July CHL increase (Figure 13). As noted previously, there is an indication that SRP is limiting the early season bloom in UKL (as with 2011, the 2012 early season bloom also occurred in July), especially since internal sources of phosphorus are also increasing during that time period (Kann 2010; Walker et al. 2012).

In 2012 and most previous years TIN (the sum of NH_4-N and NO_3-N) levels were relatively low during the spring period, and because levels in 2011 tended to be somewhat elevated when compared to previous years, it was speculated that these relatively higher TIN levels (as well as climate) may play have played a role in suppressing the June to early-July *Aphanizomenon* bloom in 2011(Kann 2012). Elevated spring TIN levels in 2012 levels were also associated with a somewhat delayed bloom (although not as delayed as 2011) (Figure 14). Levels were notably lower on a lake-wide basis during the period leading up to the 2010 bloom (Kann 2012). Similar to SRP, TIN then increased substantially during the August CHL decline (Figure 13). As in earlier years, SRP in 2012 tended to decline into the fall months. However, unlike 2011 when TIN also declined in the fall, values continued to increase in 2012 (Figure 14). Spring and fall TIN tended to show an increased proportion of NO_3-N, while summer TIN was comprised predominantly of NH_4-N (Figure 13; Figure 14).

Both 2010 and 2011 showed ratios of TN:TP during April to be ~15, which in general would tend to favor the type of diatom blooms observed in spring (Kann 2012). However, unlike 2010 when the TN:TP and TIN:SRP ratios declined in May and June during the period preceding the rise of nitrogen-fixing Aphanizomenon in UKL (TN:TP ratios were generally lower than 12 and TIN:SRP<2.5), ratios increased substantially during Figure 14). This increase appears to be driven by the higher TIN values during his period, and as noted above may provide a partial explanation for the late onset of the nitrogen-fixing *Aphanizomenon* bloom. This is also supported by the relatively low April-June TN:TP and TIN:SRP ratios in 2012 (TN:TP ~10; TIN:SRP<2), which were associated with an earlier *Aphanizomenon*-associated algal biomass rise (Figure 14). The much lower 2012 TIN:SRP ratios are partially caused by higher SRP than occurred in 2011.

Similar to 2011, an apparent geographical grouping of stations occurred in 2012 (Figure 13); Agency Lake stations (higher early-season SRP and TP and higher SRP overall); northerly stations MN, CP, SB, ER (higher TIN during the August bloom decline and extending into October); and southerly stations ML, NB, PM (somewhat lower TIN during the August bloom decline, and increase in September). As noted above, differences in magnitude and timing of

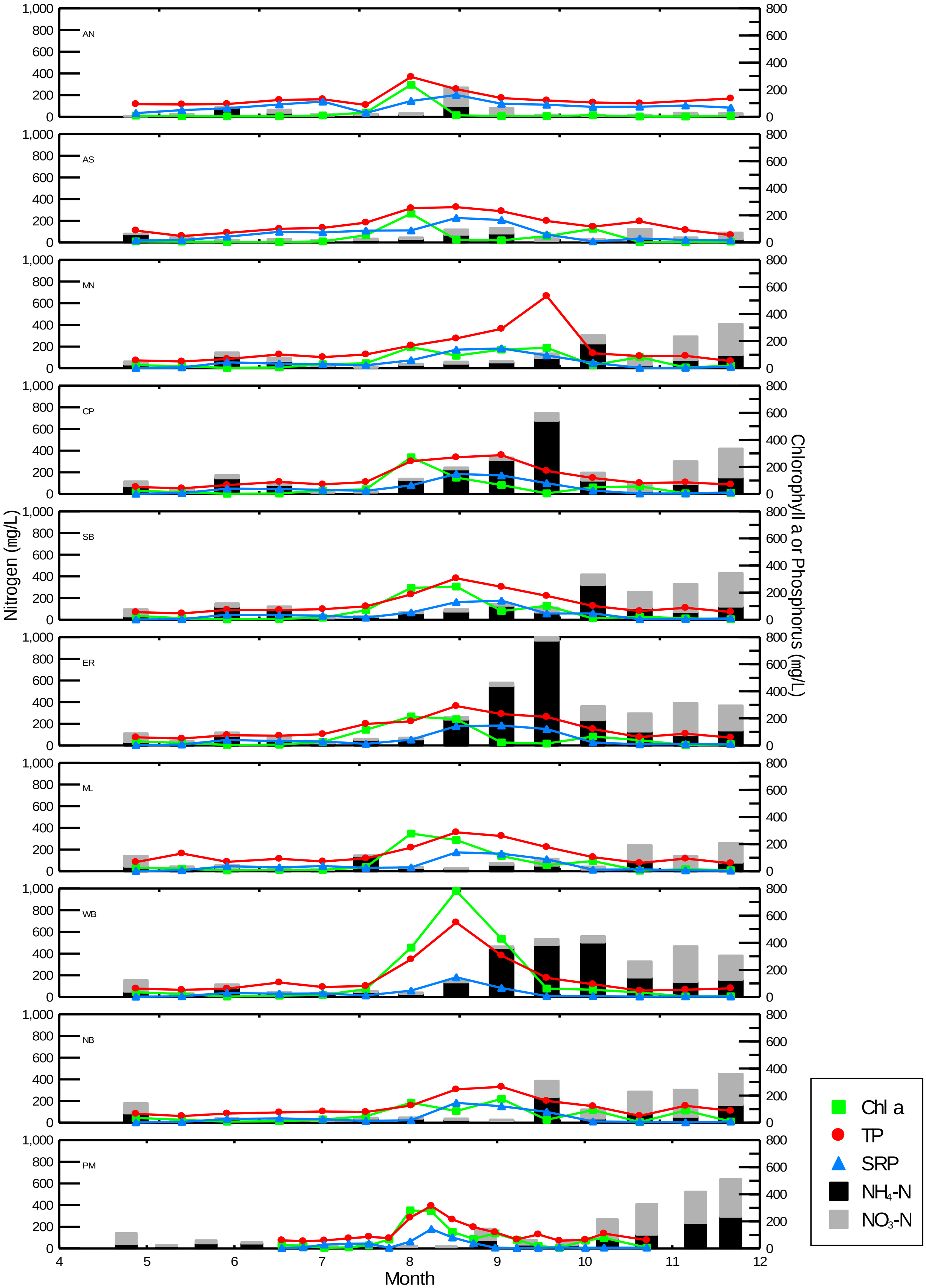

Figure 13. Chlorophyll, SRP, and TIN time-series for UKL and Agency Lake Stations, 2012.

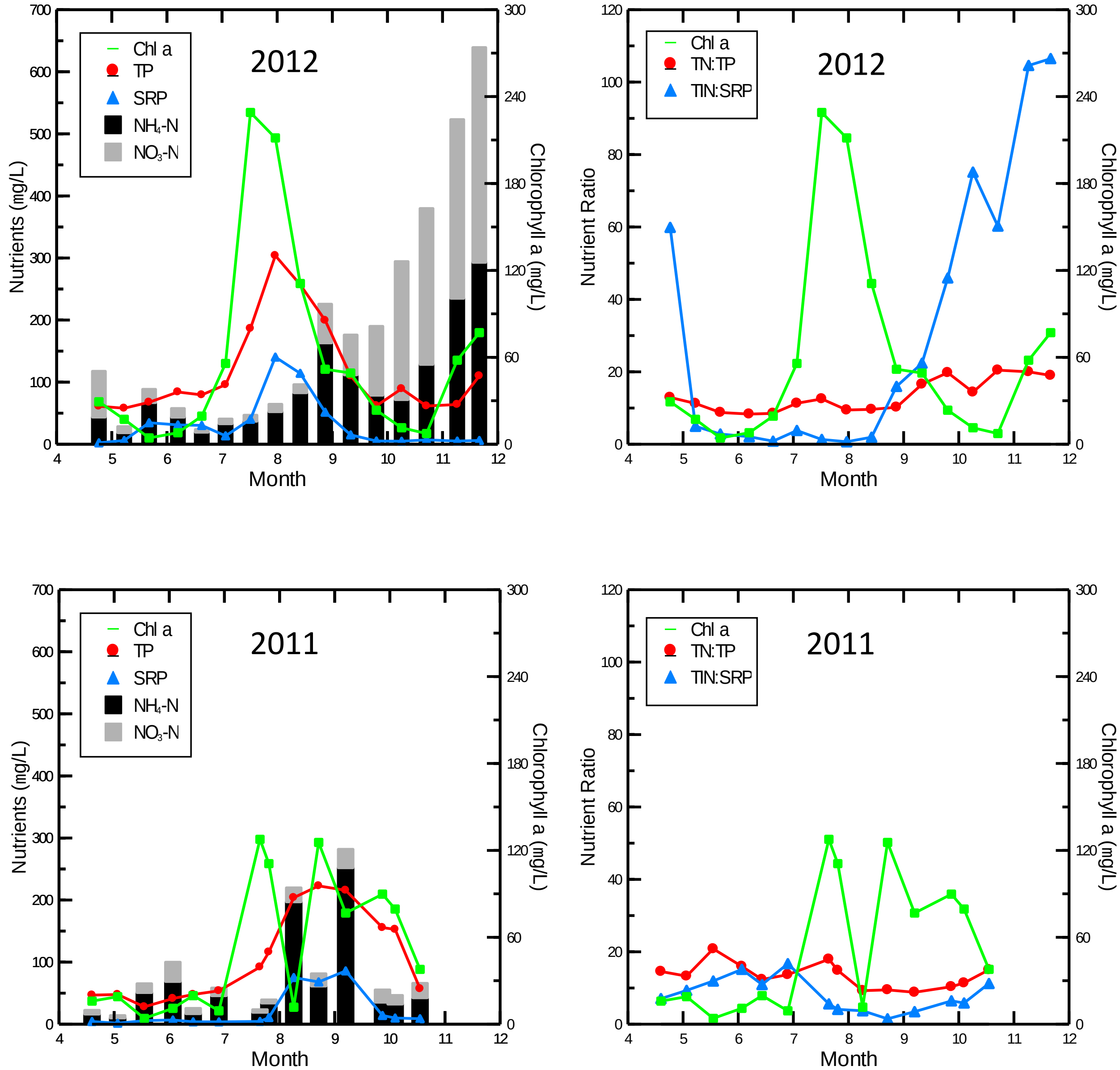

Figure 14. Lake-wide mean Chlorophyll, SRP, TIN, and nutrient ratio time-series for UKL Stations, 2011 and 2012.

CHL at the Agency Lake stations are not as apparent as in earlier years, possibly due to dike breaching and greater connectivity between the two lakes (Figure 12).

Silica (a parameter not previously reported in annual data reports) showed declining and lowest seasonal values in April and May, stable values in June, and a substantial increase beginning in July, with elevated values continuing through September (Figure 12). These trends are likely tied to silica uptake during spring diatom blooms, and subsequent summer sediment recycling and lack of uptake due to diatom decline during periods of *Aphanizomenon* dominance. More detailed silica trends along with algal biomass and nutrients are presented in Appendix III. These graphs indicate that the silica increase is concomitant with initial large CHL and TP increases in July, and that silica concentration increases (>40,500 µg/L) continue into September before gradually declining in the fall, and continue to decline to seasonal lows in the spring. The Agency Lake sites showed a more muted pattern with somewhat higher values in the spring compared to other stations, and the magnitude of summer increases were less pronounced, especially at AN (Appendix III).

In contrast to 2009 when chlorophyll to TP ratios greater than 1 (which indicate potential P limitation- see Kann 2010) were observed at a high frequency in June during the initial bloom increase, and to 2010 when CHL: TP ratios >1 occurred in April, part of May, July, and part of September (Kann 2011), the 2012 frequency of CHL: TP ratios >1 was similar to 2011, occurring at a high frequency only in July (Figure 15).

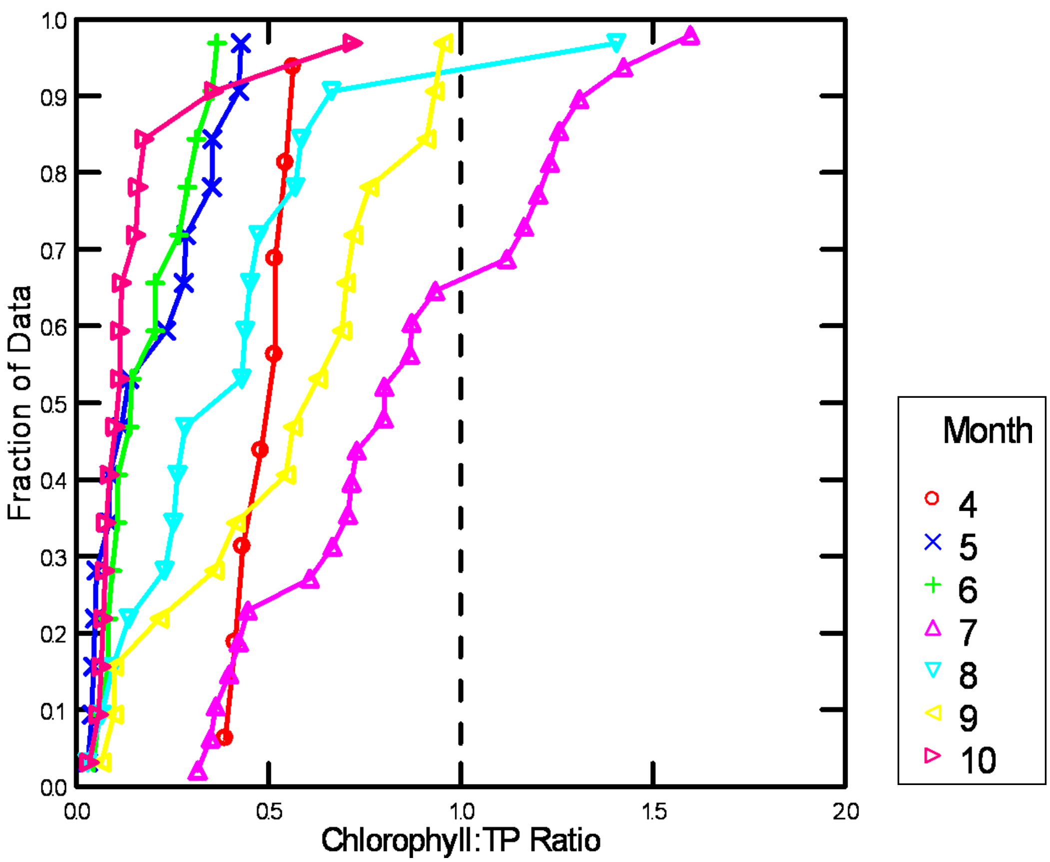

Figure 15. Quantile plot (cumulative frequency) of April-October chlorophyll to TP ratios in Upper Klamath Lake, 2012.

The underwater light environment is another factor that can influence both bloom dynamics and other water quality parameters, especially those that are photosynthetically driven. Although not discussed in detail here, a plot of photic zone depth (defined as the depth where 99% of incident light is absorbed as computed from extinction coefficients) relative to the maximum depth at UKL and Agency Lake stations shows that, as in other years, despite the shallow nature of the system that the photic zone depth was often shallower than maximum depth in 2012 (Figure 16; occurring when the blue line is above red line). The typical UKL pattern shows a relatively shallow photic zone during the spring diatom bloom, a deeper photic zone that extends the depth of the water column during much of May and early-June, a shallower photic zone during late-June to mid-July algal blooms, a decline (i.e., deeper photic zone- although not as extreme as the May decline) during August bloom declines, and finally another shallow photic zone period

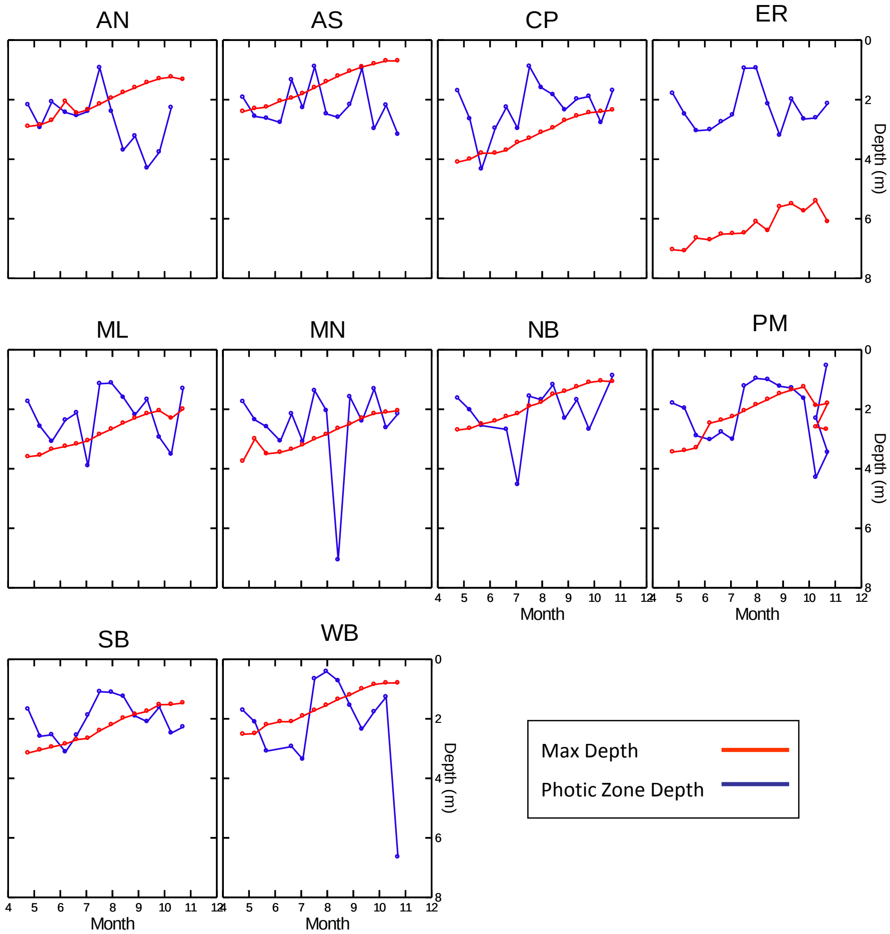

Figure 16. Photic zone depth and maximum depth at UKL and Agency Lake stations in 2012 (periods when the blue line is shallower than the red line indicate that a portion of the water column is not within the photic zone.

during bloom rebound in late-August and September (Kann 2010-2112). The 2012 pattern (Figure 16) was similar to other years, showing that at times a percentage of the water column is outside of the photic zone (e.g., does not have sufficient light for photosynthesis; Figure 17). Light limitation is more apparent at the deeper ER station which showed a greater percentage of the water column to be light limited.

To the extent that underwater light is influenced by seasonal algal dynamics (in concert with ambient light and the interaction with lake depth), decreases in available light during the early spring of 2010 (as they were in 2009) were likely influenced by diatom blooms (Kann 2011). However, unlike 2009 when a "clear water" phase occurred in May as the diatoms declined, in 2010 the "clear water' phase did not occur until later in May and extended to the end of June. A decline in available light did not occur until mid-July of 2010 (this occurred during June of 2009) as the *Aphanizomenon* bloom increased. In 2011 there was no apparent "clear water" phase until late-June, after which the algal bloom increased and water transparency declined (Kann 2012). In 2012, a reduced photic zone occurred in early-spring, with a "clear water" phase occurring in late-May, and although the photic zone was again reduced in early June, the lake was then relatively clear again in late-June prior to a sharp decrease in transparency in mid-July (Figure 17).

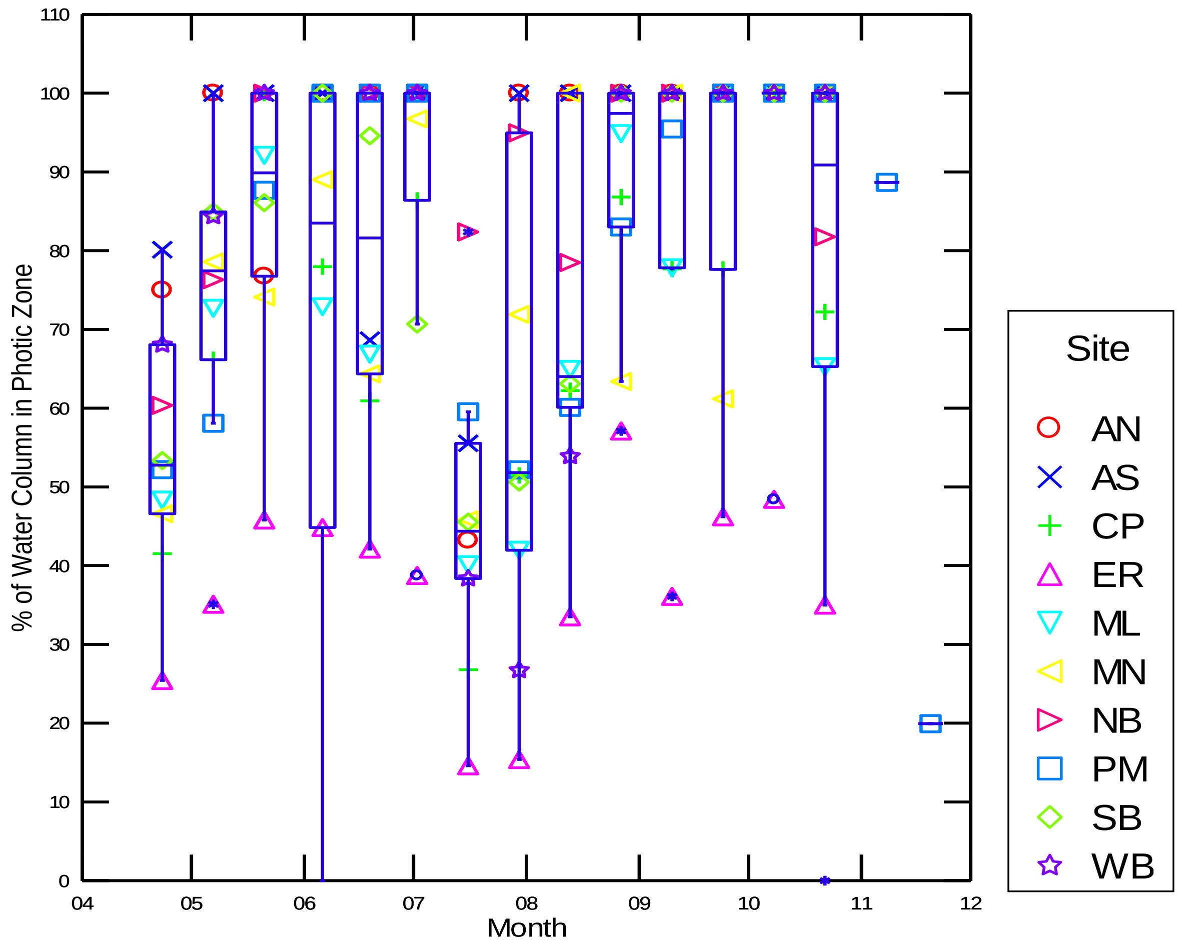

Figure 17. Percent of the water column in the photic zone for UKL and Agency Lake Stations, 2012.

As is typical for many shallow lake ecosystems, the concentration of nutrients, their ratios, the underwater light climate, and climatic variables (e.g., temperature and wind speed) are important determinants of annual bloom dynamics of *Aphanizomenon* in UKL. During the 2010 and 2009 growing seasons (see Kann 2010; 2011) it appears that the late-spring decline in TN:TP (indicating more nitrogen limiting conditions), a later (June as opposed to May) "clear water" phase (nitrogen fixation generally has a high energy/light requirement) and cooler May-June temperatures were important determinants of *Aphanizomenon* bloom timing. Likewise, relatively high TIN concentrations and high TIN:SRP ratios, a late "clear water" phase, generally cooler and windier conditions during late-May and early-June, and cool temperatures in July apparently influenced bloom dynamics in 2011. The bloom pattern in 2012 fell somewhere in between the 2009-2010 and 2011 pattern, with declining TIN:SRP ratios and a "clear water" phase also preceding the summer *Aphanizomenon* increase. The interaction of these variables as well as other controlling factors such as lake level and hydrodynamic patterns could be explored further with additional multivariate statistical analyses on the entire dataset. As shown by Jassby and Kann (2010), lake level and climate interact to determine bloom magnitude during the early season.

Comparison of 2012 to Previous 1990-2011 Data

To facilitate inter-annual comparisons of the major water quality variables, lake-wide means and medians were computed for UKL-only and Agency Lake-only. The distributions for the June-September period are shown in Figures 18-21 and summary statistics in Tables 3 and 4. Similar to 2010 and 2011, the June-Sep UKL-only pH distribution for 2012 was among the lowest for the period of record, with the median and lower quartile values similar to 1993 (Figure 18; Table 3).

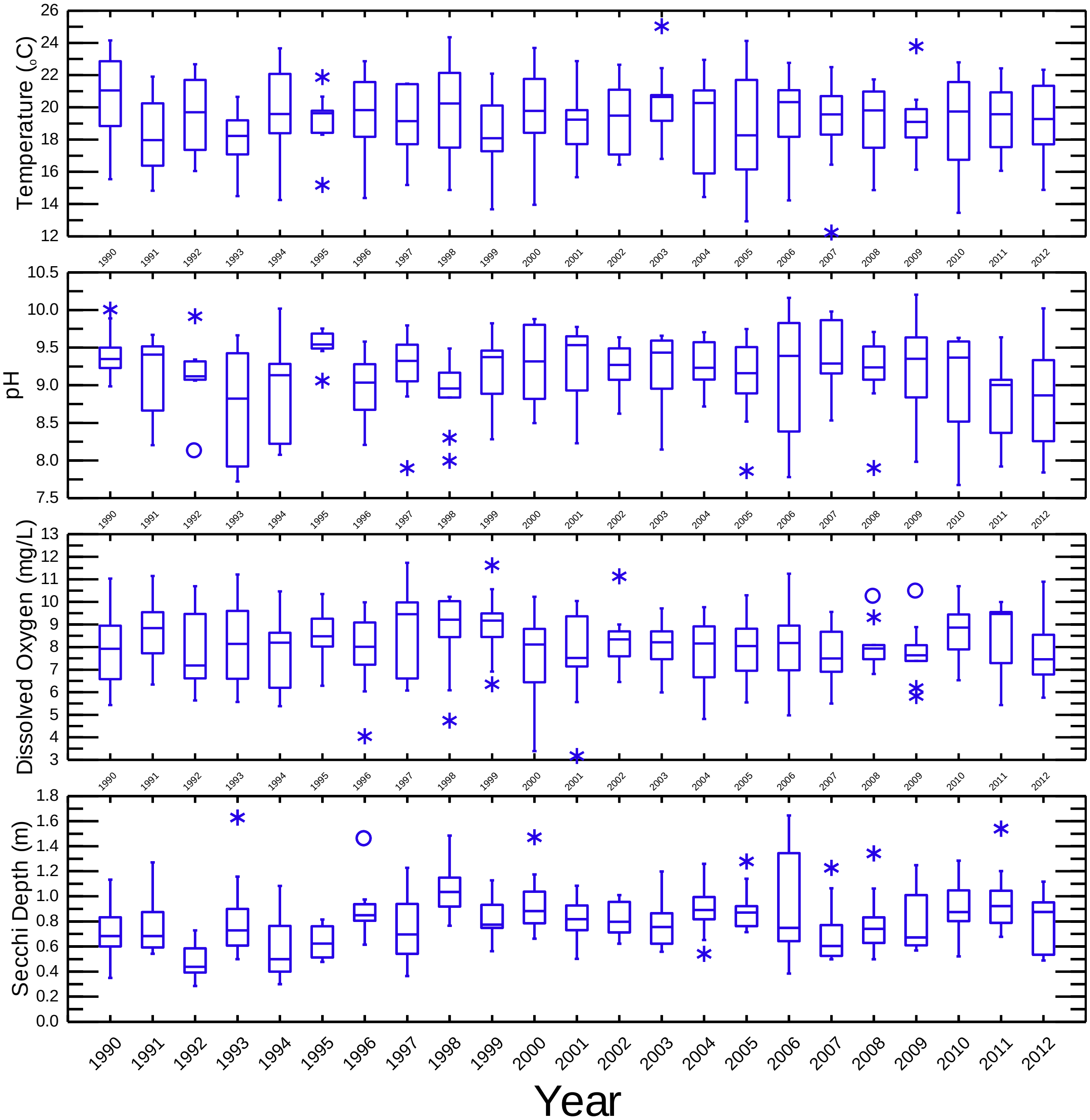

Figure 18. June-September distribution of UKL-only lake-wide means for T (˚C), pH, D.O (mg/L), and Secchi depth, 1990-2012.

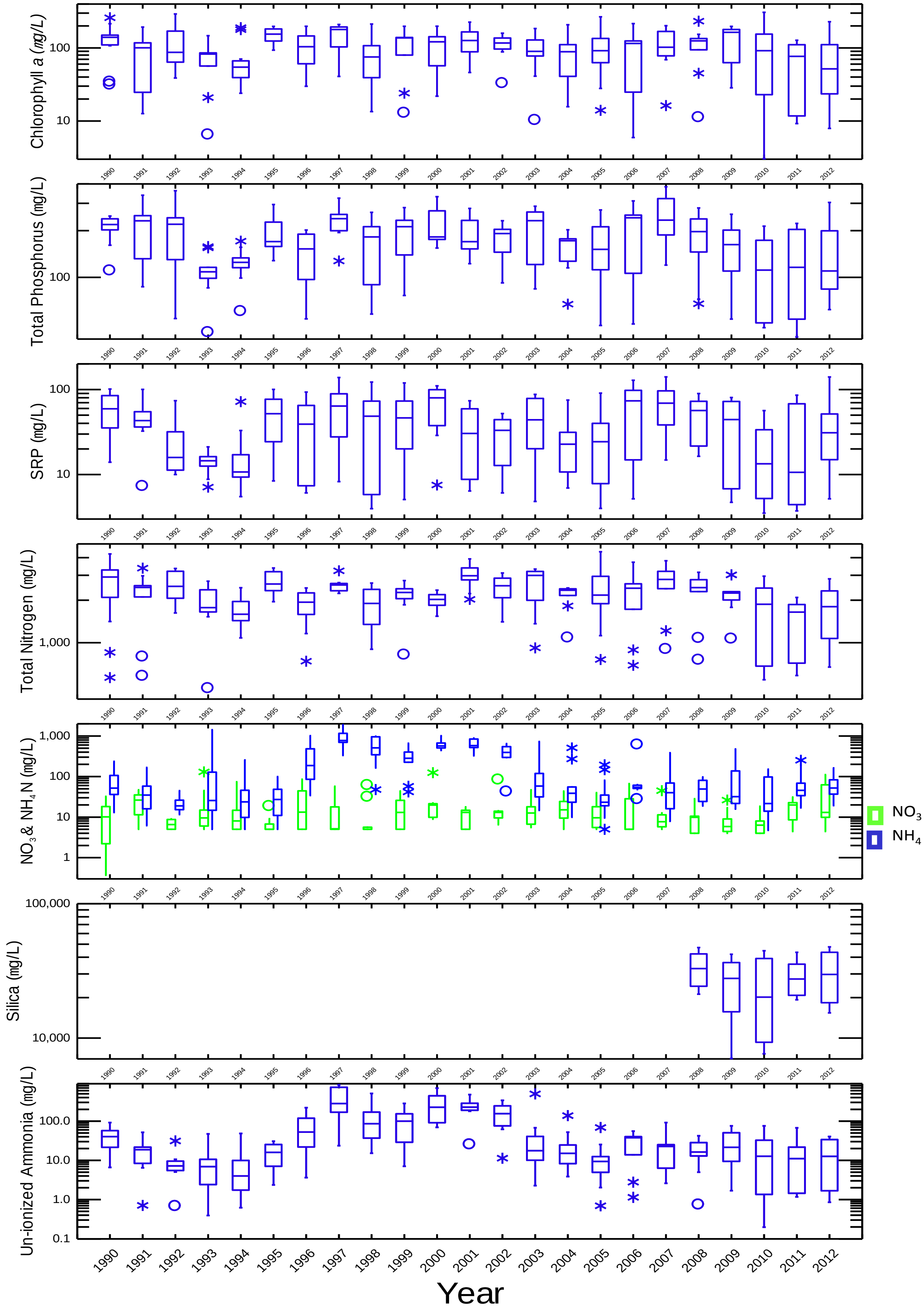

Figure 19. June-September distribution of UKL-only lake-wide means for CHL, TP, SRP, TN, NO_3+ NO_2-N and NH_4-N, 1990-2012.

Table 3. Summary statistics for June-September UKL-only lake-wide means, 1990-2011 (LQ= Lower Quartile; UQ=Upper Quartile).

YEAR	Parameter	Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chlorophyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	Silica (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1990	N of Cases	14.00	14.00	14.00	14.00	13	13	13	13	0	10	11	11
1990	Median	21.05	9.35	7.93	0.68	140	219	59	2916		9	52	50
1990	Arithmetic Mean	20.71	9.41	8.00	0.72	137	208	61	2643		11	85	54
1990	LQ	18.84	9.23	6.58	0.60	109	193	34	1923		2	34	37
1990	UQ	22.86	9.50	8.94	0.83	156	239	87	3379		18	124	73
1991	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	0	3	7	7
1991	Median	17.97	9.41	8.84	0.68	101	232	43	2459		26	35	29
1991	Arithmetic Mean	18.11	9.17	8.66	0.77	96	202	47	2172		26	52	35
1991	LQ	16.38	8.66	7.65	0.59	25	122	35	1780		10	14	13
1991	UQ	20.36	9.54	9.56	0.91	135	256	58	2643		42	73	57
1992	N of Cases	8.00	8.00	8.00	8.00	8	8	8	8	0	8	8	8
1992	Median	19.69	9.12	7.19	0.44	87	220	16	2531		7	19	10
1992	Arithmetic Mean	19.53	9.13	7.86	0.48	123	200	25	2571		7	22	13
1992	LQ	17.36	9.07	6.61	0.39	65	130	11	2066		5	15	7
1992	UQ	21.70	9.32	9.47	0.59	174	242	32	3202		9	26	20
1993	N of Cases	10.00	10.00	10.00	10.00	9	9	9	9	0	9	9	9
1993	Median	18.22	8.82	8.14	0.73	83	109	15	1772		10	26	15
1993	Arithmetic Mean	17.91	8.77	8.21	0.83	75	110	14	1841		26	235	38
1993	LQ	17.08	7.92	6.60	0.61	48	95	12	1620		6	13	2
1993	UQ	19.20	9.43	9.60	0.90	96	126	17	2375		23	211	20
1994	N of Cases	10.00	10.00	10.00	9.00	14	15	15	15	0	15	16	10
1994	Median	19.59	9.13	8.20	0.50	55	125	11	1590		8	24	5
1994	Arithmetic Mean	19.61	8.96	7.82	0.59	69	124	18	1705		15	49	11
1994	LQ	18.40	8.22	6.20	0.40	39	115	9	1421		5	10	2
1994	UQ	22.08	9.28	8.64	0.77	67	134	20	1984		15	46	10
1995	N of Cases	9.00	9.00	9.00	8.00	8	8	8	8	0	8	8	8
1995	Median	19.64	9.54	8.48	0.62	155	170	53	2608		5	28	30
1995	Arithmetic Mean	19.16	9.53	8.56	0.64	152	192	53	2698		7	35	31
1995	LQ	18.39	9.48	7.96	0.51	125	158	26	2336		5	11	17
1995	UQ	20.01	9.69	9.28	0.76	182	229	78	3183		7	49	47
1996	N of Cases	10.00	10.00	10.00	7.00	10	10	10	10	0	10	10	10
1996	Median	19.83	9.04	8.01	0.85	104	154	40	1936		14	196	54
1996	Arithmetic Mean	19.57	8.96	7.79	0.92	106	143	41	1819		27	331	84
1996	LQ	18.17	8.67	7.22	0.79	61	97	7	1584		5	85	23
1996	UQ	21.57	9.28	9.09	0.96	146	190	65	2252		44	483	130
1997	N of Cases	8.00	8.00	8.00	8.00	8	8	8	8	0	8	8	8
1997	Median	19.15	9.32	9.46	0.70	179	239	64	2563		5	778	327
1997	Arithmetic Mean	19.16	9.19	8.74	0.74	151	230	65	2562		17	941	500
1997	LQ	17.72	9.05	6.61	0.54	106	200	33	2332		5	699	238
1997	UQ	21.44	9.54	9.98	0.94	194	255	89	2624		25	1172	876

YEAR	Parameter	Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chlorophyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	Silica (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1998	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	0	9	9	9
1998	Median	20.24	8.96	9.21	1.04	75	182	49	1897		5	510	186
1998	Arithmetic Mean	19.88	8.89	8.61	1.09	87	163	47	1821		14	588	200
1998	LQ	16.96	8.70	7.85	0.91	39	85	6	1237		5	299	59
1998	UQ	22.35	9.22	10.08	1.23	120	218	76	2391		12	963	265
1999	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	0	9	9	9
1999	Median	18.09	9.37	9.18	0.77	137	212	46	2267		13	283	129
1999	Arithmetic Mean	18.16	9.15	8.92	0.83	111	193	52	2149		18	307	160
1999	LQ	16.54	8.74	8.06	0.73	66	139	17	2002		5	183	29
1999	UQ	20.24	9.54	9.76	0.97	151	240	76	2471		29	426	245
2000	N of Cases	8.00	8.00	8.00	8.00	8	8	8	8	0	8	8	8
2000	Median	19.78	9.32	8.11	0.88	122	182	80	2025		20	567	268
2000	Arithmetic Mean	19.70	9.28	7.54	0.94	111	217	69	2001		29	619	344
2000	LQ	18.42	8.82	6.44	0.79	71	176	39	1841		10	508	109
2000	UQ	21.76	9.80	8.81	1.04	143	268	100	2192		21	672	580
2001	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	0	9	9	9
2001	Median	19.24	9.53	7.52	0.82	126	170	30	2978		13	580	274
2001	Arithmetic Mean	18.76	9.26	7.49	0.81	133	194	33	2978		11	632	281
2001	LQ	17.28	8.91	6.75	0.71	85	152	8	2645		5	478	241
2001	UQ	19.85	9.66	9.43	0.93	179	243	60	3434		15	845	321
2002	N of Cases	8.00	8.00	7.00	8.00	8	8	8	8	0	8	8	8
2002	Median	19.49	9.27	8.34	0.80	117	192	34	2535		13	400	175
2002	Arithmetic Mean	19.30	9.24	8.36	0.82	112	176	31	2437		20	398	184
2002	LQ	17.08	9.07	7.41	0.71	97	148	16	2088		10	297	111
2002	UQ	21.10	9.49	8.85	0.96	137	204	45	2867		14	550	267
2003	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	0	9	9	9
2003	Median	20.65	9.43	8.21	0.76	90	232	44	2996		13	58	25
2003	Arithmetic Mean	20.29	9.20	8.01	0.80	94	206	47	2510		16	136	97
2003	LQ	18.65	8.89	7.34	0.61	68	119	18	1838		6	28	12
2003	UQ	21.18	9.61	8.70	0.92	131	268	79	3214		18	123	81
2004	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	0	9	9	9
2004	Median	20.27	9.23	8.16	0.89	89	172	23	2352		15	39	20
2004	Arithmetic Mean	19.31	9.24	7.80	0.88	88	152	28	2152		18	111	37
2004	LQ	15.89	9.03	6.61	0.78	38	124	10	2075		9	22	10
2004	UQ	21.41	9.58	8.92	1.00	117	178	37	2405		25	109	42
2005	N of Cases	18.00	18.00	18.00	9.00	16	18	18	18	0	18	18	18
2005	Median	18.26	9.16	8.05	0.87	92	152	24	2170		10	23	10
2005	Arithmetic Mean	18.80	9.13	8.02	0.90	101	159	29	2356		13	43	15
2005	LQ	16.15	8.89	6.95	0.76	63	112	8	1890		6	19	5
2005	UQ	21.71	9.51	8.82	0.98	136	212	40	2949		18	35	18
2006	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	0	9	9	9
2006	Median	20.32	9.39	8.18	0.75	115	242	74	2428		5	54	50

YEAR	Parameter	Temperature (°C)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chlorophyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	Silica (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2006	Arithmetic Mean	19.70	9.20	8.12	0.93	98	201	61	2269		19	114	52
2006	LQ	18.17	8.34	6.95	0.62	23	101	15	1516		5	50	24
2006	UQ	21.42	9.90	9.05	1.38	129	258	98	2883		30	62	83
2007	N of Cases	9.00	9.00	9.00	9.00	8	9	9	9	0	9	9	9
2007	Median	19.57	9.29	7.50	0.60	102	234	69	2804		8	40	35
2007	Arithmetic Mean	19.00	9.41	7.74	0.71	115	242	71	2568		12	77	36
2007	LQ	17.85	9.14	6.80	0.52	79	172	35	2114		6	14	7
2007	UQ	21.05	9.89	8.79	0.84	168	323	100	3196		12	71	47
2008	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	9	9	9	9
2008	Median	19.82	9.24	7.94	0.74	125	197	57	2452	32900	10	49	23
2008	Arithmetic Mean	18.93	9.16	8.12	0.80	114	185	52	2292	33630	10	51	29
2008	LQ	16.94	9.03	7.42	0.63	82	127	21	1994	23554	4	24	11
2008	UQ	21.12	9.53	8.40	0.89	140	240	76	2831	43161	11	81	50
2009	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	9	9	9	9
2009	Median	19.10	9.35	7.64	0.68	164	163	44	2245	27786	6	32	29
2009	Arithmetic Mean	19.08	9.24	7.77	0.91	131	158	42	2194	25786	9	120	50
2009	LQ	17.66	8.76	7.09	0.63	59	101	6	1950	14230	4	21	11
2009	UQ	20.04	9.70	8.29	1.09	183	211	74	2477	37036	11	166	75
2010	N of Cases	10.00	10.00	10.00	10.00	10	10	10	10	10	10	10	10
2010	Median	19.74	9.37	8.86	0.87	93	118	16	1883	20757	6	22	13
2010	Arithmetic Mean	18.92	9.08	8.74	0.90	108	119	21	1694	24231	8	51	24
2010	LQ	16.74	8.52	7.90	0.80	23	51	5	683	9309	4	14	1
2010	UQ	21.57	9.58	9.45	1.05	155	173	34	2435	39086	8	97	45
2011	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	9	9	9	9
2011	Median	19.26	9.00	9.47	0.92	77	116	11	1646	27514	20	46	12
2011	Arithmetic Mean	18.33	8.83	8.51	0.97	65	128	30	1417	29221	17	81	23
2011	LQ	16.43	8.28	7.23	0.77	12	52	4	702	20700	8	30	2
2011	UQ	20.91	9.21	9.65	1.08	115	207	70	1865	36404	24	101	33
2012	N of Cases	9.00	9.00	9.00	9.00	9	9	9	9	9	9	9	9
2012	Median	19.27	8.87	7.46	0.88	52	110	31	1799	29757	13	52	17
2012	Arithmetic Mean	19.15	8.83	7.80	0.80	84	153	49	1659	30521	33	69	24
2012	LQ	17.50	8.16	6.76	0.53	22	83	15	979	17593	9	36	2
2012	UQ	21.37	9.42	8.57	0.96	136	214	67	2346	43996	63	90	41

In contrast to 2011 when median DO concentration was higher than all other years for the period of record, median DO in 2012 was among the lowest despite the lack of a large bloom decline. As expected due to its controlling effect on pH, median CHL in 2012 tended to be among the lowest for the period of record (Figure 19). Although 2010 was also low (Kann 2011), overall values were noticeably lower than 2010 (Figure 19).

A similar pattern was shown for 2012 TP, although SRP was somewhat higher and more similar to values occurring in the early 2000's (Figure 19). However, similar to TP and Chl, TN was also among the lowest for the period of record. For the 23 years of record, the ammonia distribution was similar from 1990-1995, was elevated from 1996-2002, and then decreased to pre-1996 levels during the past 10 years (2003-2012). However, both 2009 and 2010 showed somewhat higher ammonia concentrations than the previous 5 years, and the lower-quartiles were higher in 2011 and 2012 than the previous 4 years (Figure 19). Inter-annual silica variability is indicated, with 2009 and 2010 showing reduced lower quartile values, possibly due to enhanced diatom blooms in spring of those years (Figure 19).

For Agency Lake, both pH and DO were also noticeably lower compared to previous years (Figure 20; Table 4). Lower quartile values of CHL, TP, and TN in Agency Lake were also among the lowest for the period of record (Figure 21; Table 4). In addition, the 2012 NO_3-NO_2-N distribution increased slightly from the previous 2 years, and NH_4-N tended to follow the overall 23 year cyclical pattern described above, and had similar median but high lower quartile value compared to 2011 (Figure 21). Both Agency and UKL Lakes continued to show several periods of apparent sub-decadal cyclical increases and decreases for nutrient parameters over the period of record (Figure 19 and Figure 21). Inter-annual silica variability in Agency Lake is low relative to UKL.

SUMMARY

With the addition of 2012 data, the UKL water quality/limnological database now includes 23 years of data and includes the years 1990-2012. Given the dynamic and variable nature of shallow, high productivity lakes such as UKL, a long-term monitoring program is essential for assessing change relative to management programs, as well as for understanding lake dynamics.

For example, as noted in earlier reports, ongoing wetland restoration is occurring in vast areas of the periphery of UKL (e.g., Wong et al. 2010; 2011), riparian and nutrient management plans (e.g., Oregon 1010 and TMDL plans) have been developed, and water use plans have been implemented (e.g., KBRT Wood River Valley programs).

Continued monitoring is recommended to accommodate the restoration time-frame (restoration of ecological function can be a multi-decade process) for Klamath Basin activities and to increase statistical power (sample size) for multi-variable analyses. Such a long-term database allows for statistical time series or trend analysis, as well as multi-variable assessment of the relationship between controlling variables (e.g., climate) and important water quality parameters (e.g., see Jassby and Kann 2010).

Further analysis (beyond the scope of the current data summary report) of the noticeable differences in CHL, as well as other water quality parameters among years will provide an opportunity to gain further insight into annual controlling factors of bloom dynamics. Additional multivariate analyses, time-series and trend analyses such as Seasonal Kendal Tests, as well as integration with current lake literature on shallow lakes and *Aphanizomenon* bloom dynamics are recommended. The analysis of the long-term Upper Klamath Lake phytoplankton and zooplankton datasets will also significantly aid in understanding annual water quality variability.

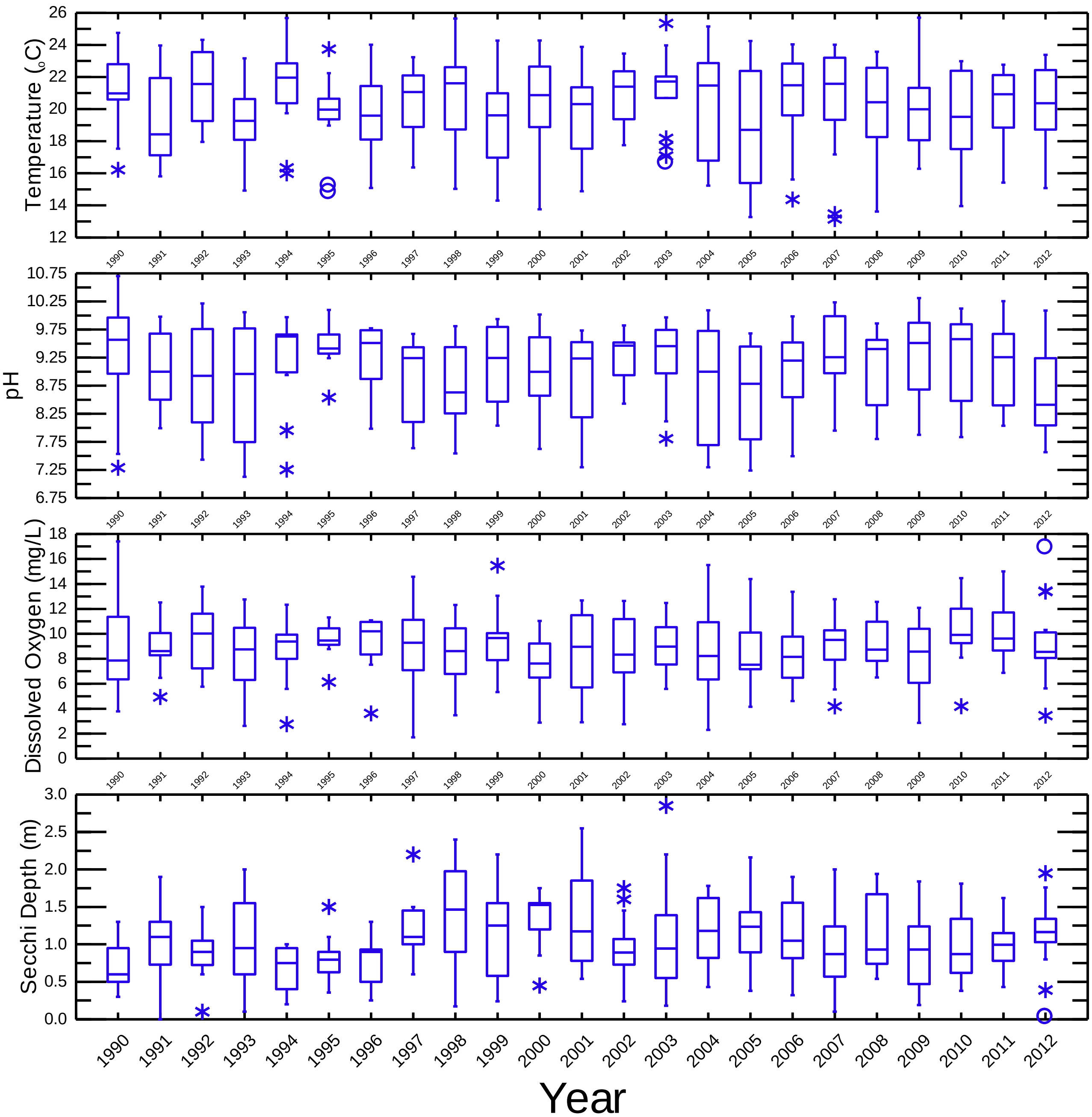

Figure 20. June-September distribution of Agency Lake means for T (˚C), pH, D.O (mg/L), and Secchi depth, 1990-2012.

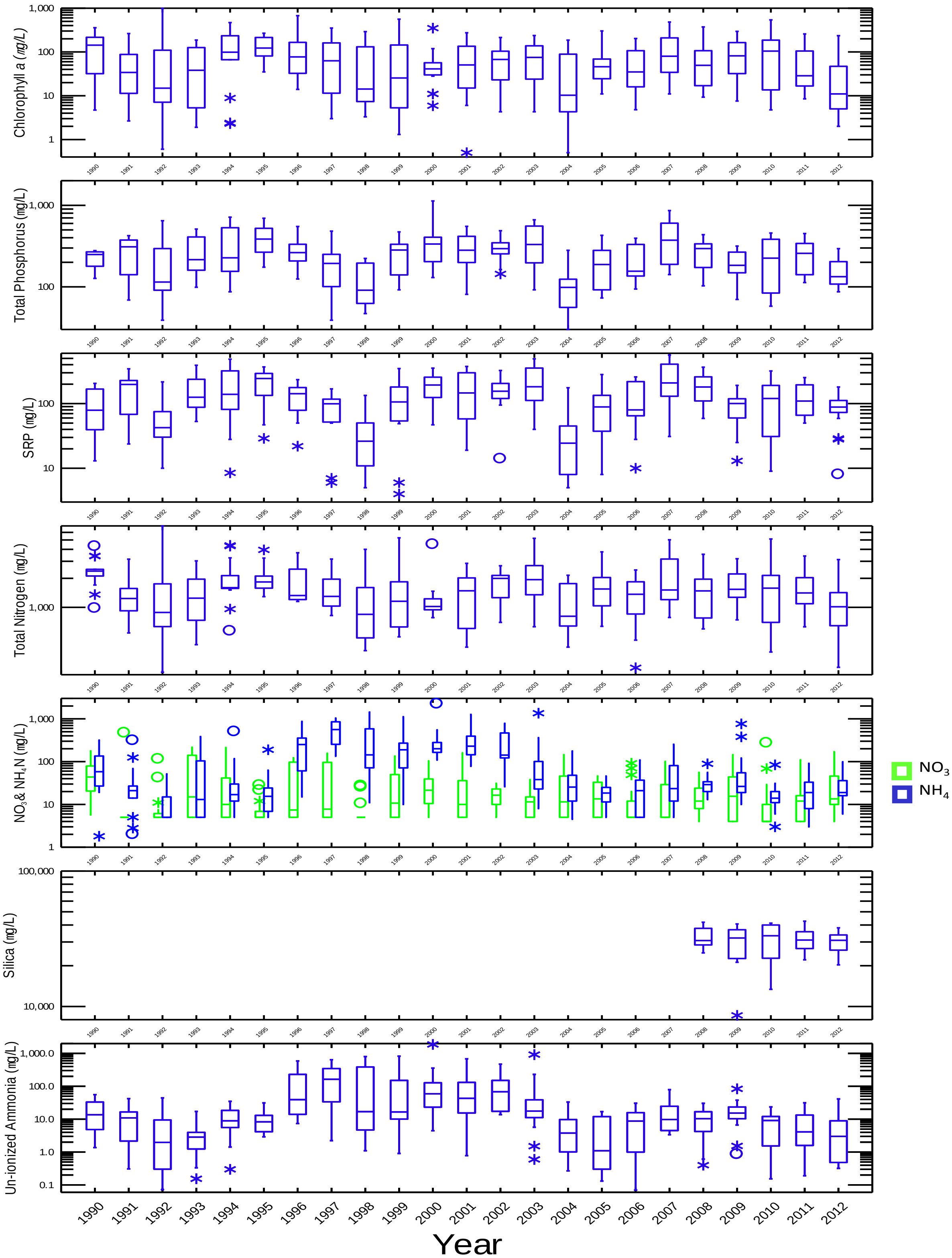

Figure 21. June-September distribution of Agency Lake means for CHL, TP, SRP, TN, NO3+ NO2-N, SiO2 and NH4-N, 1990-2012.

Table 4. Summary statistics for June-September Agency Lake means, 1990-2012 (LQ=Lower Quartile; UQ=Upper Quartile).

Year	Parameter	Temperature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chlorophyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	Silica (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1990	N of Cases	14.00	14.00	14.00	11.00	13	13	13	13	0	9	11	11
1990	Median	20.98	9.57	7.87	0.60	143	249	79	2374		21	58	14
1990	Arithmetic Mean	21.07	9.31	9.04	0.75	151	223	99	2411		41	95	20
1990	LQ	20.60	8.97	6.35	0.50	32	178	35	2009		0	26	5
1990	UQ	22.80	9.97	11.36	0.98	224	270	172	2706		55	136	34
1991	N of Cases	18.00	16.00	18.00	18.00	18	18	18	18	0	6	13	11
1991	Median	18.43	9.00	8.62	1.10	34	310	198	1234		5	21	11
1991	Arithmetic Mean	19.16	9.07	8.94	1.04	71	275	179	1395		82	51	13
1991	LQ	17.12	8.50	8.28	0.73	11	141	68	919		5	12	2
1991	UQ	21.94	9.68	10.07	1.30	88	375	228	1566		5	38	18
1992	N of Cases	16.00	16.00	16.00	16.00	16	14	16	14	0	16	16	16
1992	Median	21.57	8.93	10.03	0.90	15	115	43	889		5	5	2
1992	Arithmetic Mean	21.42	8.87	9.49	0.87	107	187	65	1533		15	12	7
1992	LQ	19.26	8.10	7.24	0.73	7	91	31	631		5	5	0
1992	UQ	23.55	9.76	11.62	1.05	111	295	76	1750		6	15	10
1993	N of Cases	20.00	20.00	20.00	20.00	18	18	18	18	0	18	18	18
1993	Median	19.27	8.96	8.75	0.95	45	216	126	1275		15	14	3
1993	Arithmetic Mean	19.20	8.78	8.30	1.05	68	261	165	1459		62	73	4
1993	LQ	18.09	7.75	6.30	0.60	5	160	88	733		5	5	1
1993	UQ	20.63	9.77	10.48	1.55	126	409	238	1960		141	104	4
1994	N of Cases	14.00	13.00	14.00	12.00	13	13	13	13	0	13	13	12
1994	Median	21.96	9.63	9.38	0.75	99	227	139	1600		10	17	9
1994	Arithmetic Mean	21.33	9.22	8.63	0.68	156	334	188	2080		33	62	12
1994	LQ	20.37	8.98	8.00	0.40	52	146	81	1555		5	11	6
1994	UQ	22.86	9.71	9.93	0.95	253	537	331	2416		42	32	18
1995	N of Cases	16.00	16.00	16.00	16.00	16	16	16	16	0	16	16	16
1995	Median	19.97	9.41	9.47	0.80	124	386	245	1835		5	16	8
1995	Arithmetic Mean	19.75	9.47	9.57	0.78	139	392	214	2057		8	29	10
1995	LQ	19.36	9.32	9.13	0.63	81	267	140	1580		5	7	4
1995	UQ	20.64	9.66	10.45	0.90	214	523	293	2110		7	24	13
1996	N of Cases	8.00	8.00	8.00	6.00	8	8	8	8	0	8	8	8
1996	Median	19.59	9.51	10.21	0.90	78	265	143	1325		8	255	39
1996	Arithmetic Mean	19.67	9.25	9.22	0.80	159	286	134	1872		44	280	146
1996	LQ	18.10	8.87	8.35	0.50	37	208	87	1203		5	61	14
1996	UQ	21.44	9.74	10.95	0.93	176	334	177	2545		99	360	233
1997	N of Cases	12.00	12.00	12.00	10.00	12	12	12	12	0	12	12	12
1997	Median	21.06	9.24	9.29	1.28	63	194	99	1305		9	565	165
1997	Arithmetic Mean	20.41	8.90	8.83	1.46	104	200	87	1560		49	582	210
1997	LQ	18.89	8.11	7.09	1.00	12	107	52	1030		5	257	34
1997	UQ	22.10	9.44	11.12	1.50	165	252	118	1960		100	854	346
1998	N of Cases	16.00	16.00	16.00	16.00	16	16	16	16	0	16	16	16

Year	Parameter	Temperature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chlorophyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	Silica (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1998	Median	21.67	8.63	8.62	1.47	14	90	26	845		5	144	17
1998	Arithmetic Mean	21.09	8.78	8.45	1.43	66	113	39	1187		8	355	183
1998	LQ	18.73	8.26	6.79	0.90	7	58	12	482		5	72	5
1998	UQ	23.35	9.44	10.44	1.98	131	196	50	1605		5	596	389
1999	N of Cases	18.00	18.00	18.00	18.00	18	18	18	18	0	18	18	18
1999	Median	19.61	9.25	9.67	1.25	27	283	107	1155		11	189	17
1999	Arithmetic Mean	19.10	9.11	9.52	1.21	103	259	127	1561		31	220	118
1999	LQ	16.98	8.47	7.89	0.58	5	140	54	626		5	71	10
1999	UQ	20.99	9.80	10.06	1.55	144	333	181	1840		50	271	151
2000	N of Cases	16.00	16.00	16.00	14.00	16	16	16	15	0	16	16	16
2000	Median	20.87	9.00	7.63	1.53	41	336	195	1020		22	200	59
2000	Arithmetic Mean	20.32	9.03	7.49	1.36	61	358	199	1293		32	360	192
2000	LQ	18.88	8.57	6.50	1.20	20	204	125	939		11	165	23
2000	UQ	22.66	9.61	9.22	1.55	58	407	257	1243		40	285	128
2001	N of Cases	18.00	18.00	18.00	18.00	18	18	18	18	0	18	18	18
2001	Median	20.31	9.24	8.97	1.18	52	282	147	1485		10	230	43
2001	Arithmetic Mean	19.69	8.81	8.13	1.34	77	297	175	1435		26	357	141
2001	LQ	17.54	8.19	5.70	0.78	15	199	58	603		5	145	15
2001	UQ	21.36	9.53	11.50	1.85	135	416	300	2020		36	393	131
2002	N of Cases	14.00	14.00	14.00	14.00	14	14	14	14	0	14	14	14
2002	Median	21.40	9.47	8.33	0.89	70	294	156	1998		17	143	69
2002	Arithmetic Mean	20.92	9.26	8.69	0.93	77	300	162	1773		17	264	132
2002	LQ	19.37	8.94	6.91	0.73	23	254	120	1260		10	122	17
2002	UQ	22.36	9.52	11.19	1.07	104	347	205	2140		23	468	151
2003	N of Cases	18.00	18.00	18.00	18.00	18	18	18	18	0	18	18	18
2003	Median	21.76	9.46	8.97	0.95	76	331	183	1935		12	40	18
2003	Arithmetic Mean	21.40	9.28	9.08	1.08	87	368	230	2112		15	149	84
2003	LQ	20.69	8.97	7.55	0.55	24	197	112	1350		5	23	11
2003	UQ	22.86	9.74	10.53	1.39	138	556	355	2710		15	101	39
2004	N of Cases	18.00	18.00	18.00	18.00	18	18	18	18	0	18	18	18
2004	Median	21.47	9.00	8.22	1.18	11	99	25	808		12	26	4
2004	Arithmetic Mean	20.44	8.79	8.35	1.21	51	108	41	1119		31	40	8
2004	LQ	16.78	7.69	6.34	0.82	4	56	8	639		5	12	1
2004	UQ	22.87	9.73	10.94	1.62	89	124	45	1760		46	48	10
2005	N of Cases	16.00	16.00	16.00	16.00	16	16	16	16	0	16	16	16
2005	Median	18.71	8.78	7.52	1.24	46	189	89	1555		14	19	1
2005	Arithmetic Mean	18.81	8.62	8.42	1.19	69	200	100	1741		19	19	5
2005	LQ	15.40	7.80	7.17	0.90	25	92	38	1035		5	12	0
2005	UQ	22.38	9.45	10.11	1.43	69	281	135	2045		33	25	12
2006	N of Cases	18.00	18.00	18.00	16.00	18	18	18	18	0	18	18	18
2006	Median	21.48	9.20	8.16	1.05	35	156	80	1365		5	21	9
2006	Arithmetic Mean	20.80	9.00	8.25	1.13	67	207	118	1354		18	28	10
2006	LQ	19.61	8.55	6.48	0.82	13	136	65	852		5	5	1

Year	Parameter	Temperature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chlorophyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	Silica (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2006	UQ	22.84	9.52	9.77	1.56	107	331	219	1840		12	37	16
2007	N of Cases	18.00	18.00	18.00	18.00	16	18	18	18	0	18	18	18
2007	Median	21.58	9.26	9.51	0.87	80	375	209	1520		5	24	10
2007	Arithmetic Mean	20.54	9.38	8.91	0.90	138	406	261	2171		20	58	17
2007	LQ	19.33	8.97	7.93	0.57	35	189	130	1200		5	12	5
2007	UQ	23.21	9.99	10.29	1.24	210	603	407	3170		29	81	25
2008	N of Cases	18.00	18.00	18.00	18.00	18	18	18	18	17	18	18	18
2008	Median	20.43	9.40	8.74	0.93	50	295	182	1480	30700	12	29	10
2008	Arithmetic Mean	19.82	9.07	9.22	1.12	78	266	184	1483	32982	17	32	11
2008	LQ	18.26	8.40	7.83	0.74	17	173	110	774	28475	8	20	4
2008	UQ	22.58	9.57	10.97	1.67	107	337	260	1960	37850	24	34	17
2009	N of Cases	16.00	16.00	16.00	18.00	18	18	18	18	18	18	18	16
2009	Median	19.99	9.51	8.58	0.93	82	184	101	1540	32150	16	27	15
2009	Arithmetic Mean	20.06	9.25	8.13	0.91	106	191	95	1698	30156	29	96	21
2009	LQ	18.06	8.68	6.08	0.47	32	149	60	1270	22600	4	19	10
2009	UQ	21.32	9.87	10.41	1.24	164	267	119	2220	36900	44	55	23
2010	N of Cases	17.00	17.00	17.00	17.00	16	17	17	17	17	17	17	17
2010	Median	19.52	9.58	9.92	0.87	107	225	120	1580	33300	4	14	9
2010	Arithmetic Mean	19.21	9.22	10.56	1.00	139	233	120	1840	31065	26	19	8
2010	LQ	16.87	8.46	9.18	0.62	15	82	31	660	22700	4	10	1
2010	UQ	22.39	9.89	12.10	1.38	187	386	192	2413	40150	11	21	12
2011	N of Cases	18.00	18.00	18.00	18.00	18	18	18	18	18	18	18	18
2011	Median	20.24	9.26	9.62	1.00	29	258	110	1410	30950	12	19	4
2011	Arithmetic Mean	19.22	9.08	10.18	0.97	67	254	132	1587	31150	18	24	8
2011	LQ	17.68	8.40	8.67	0.78	17	141	66	1090	26800	4	8	2
2011	UQ	22.02	9.67	11.72	1.15	105	341	195	2030	35700	16	33	13
2012	N of Cases	18.00	18.00	18.00	18.00	18	18	18	18	18	18	18	18
2012	Median	20.37	8.41	8.56	1.17	11	134	89	1015	30850	14	19	3
2012	Arithmetic Mean	20.21	8.62	9.18	1.15	43	157	90	1214	29850	32	30	8
2012	LQ	18.72	8.04	8.07	1.03	5	108	73	644	26100	10	16	0
2012	UQ	22.43	9.24	10.11	1.34	47	204	112	1420	33800	46	36	9

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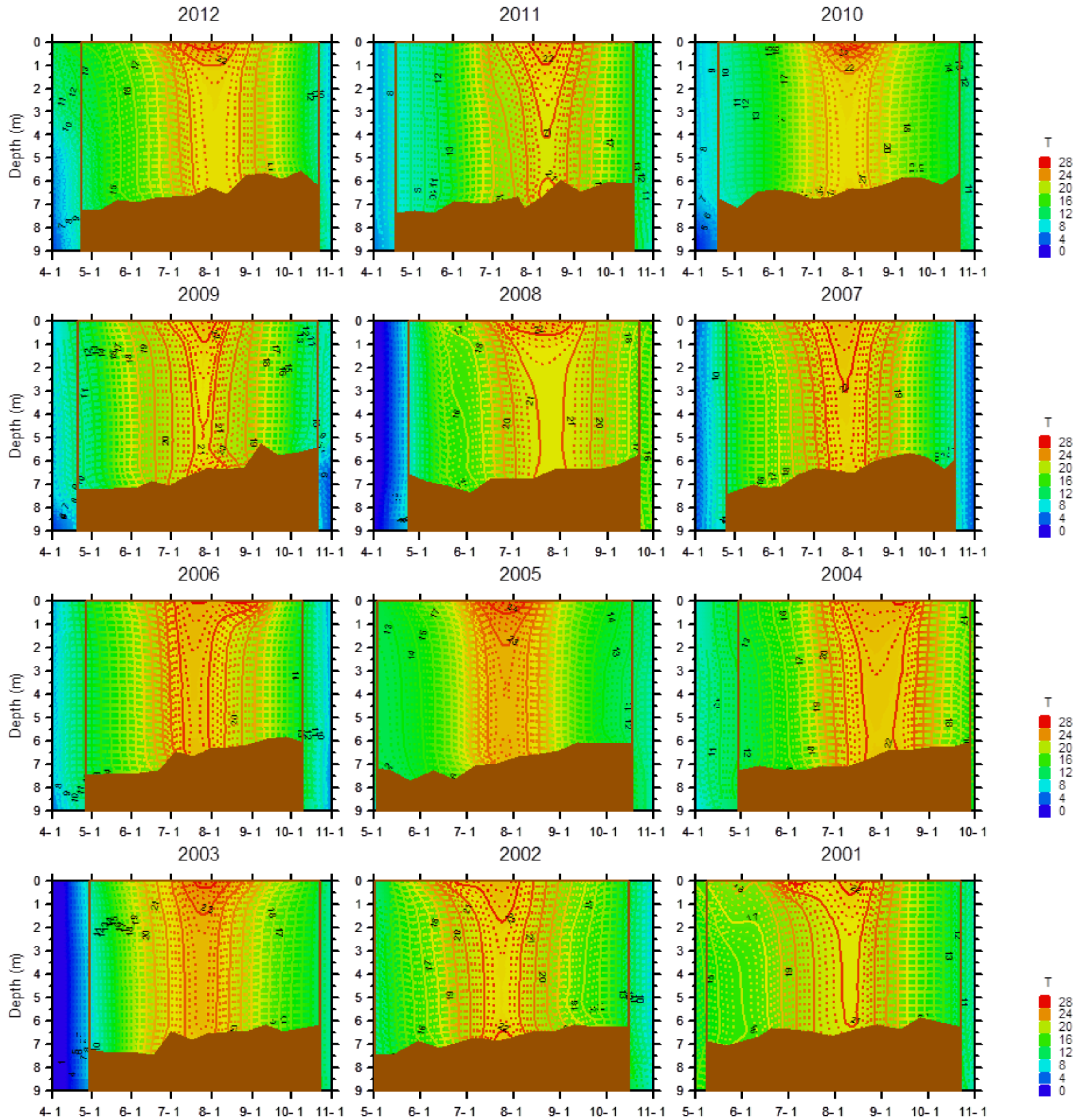
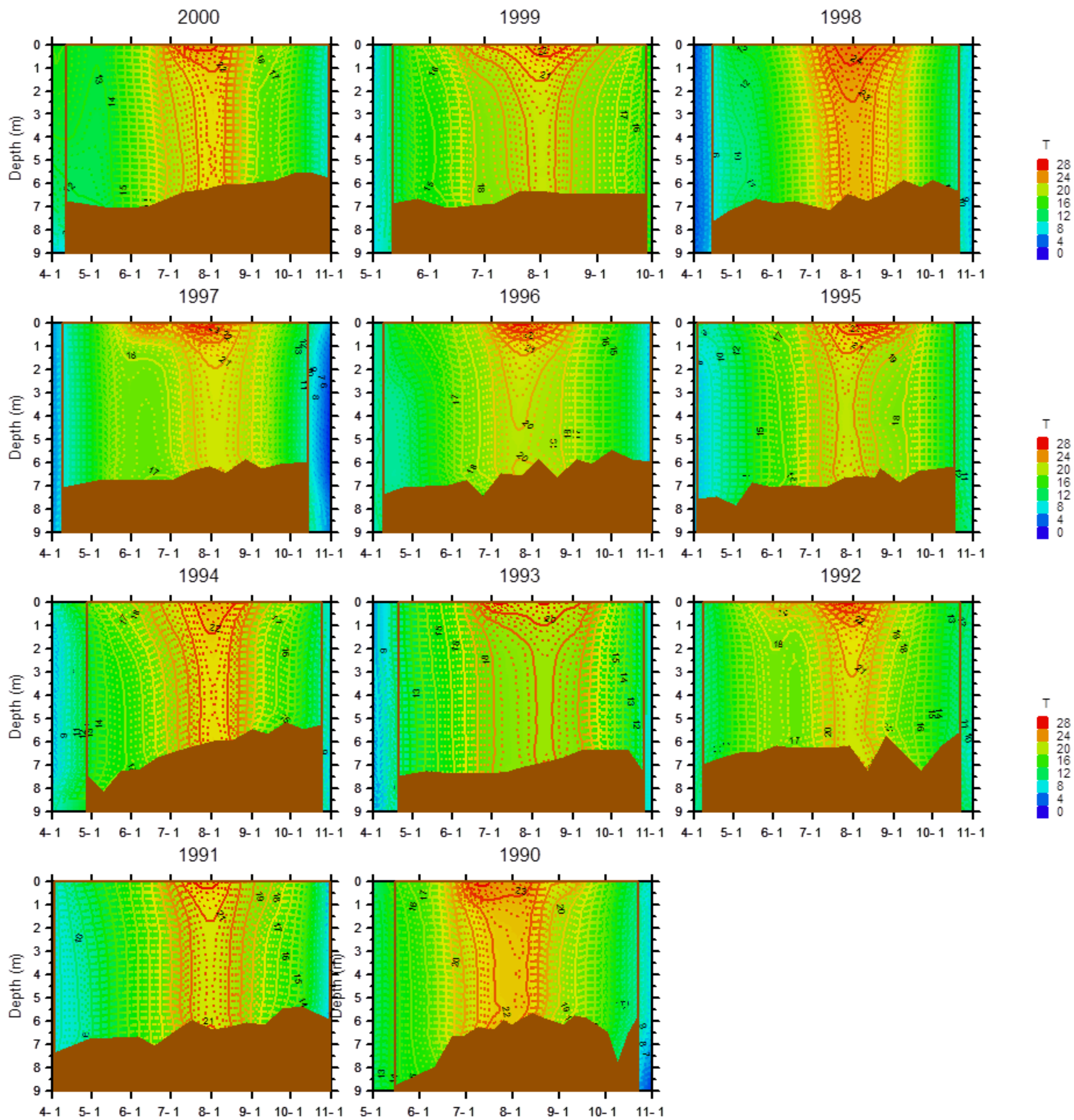
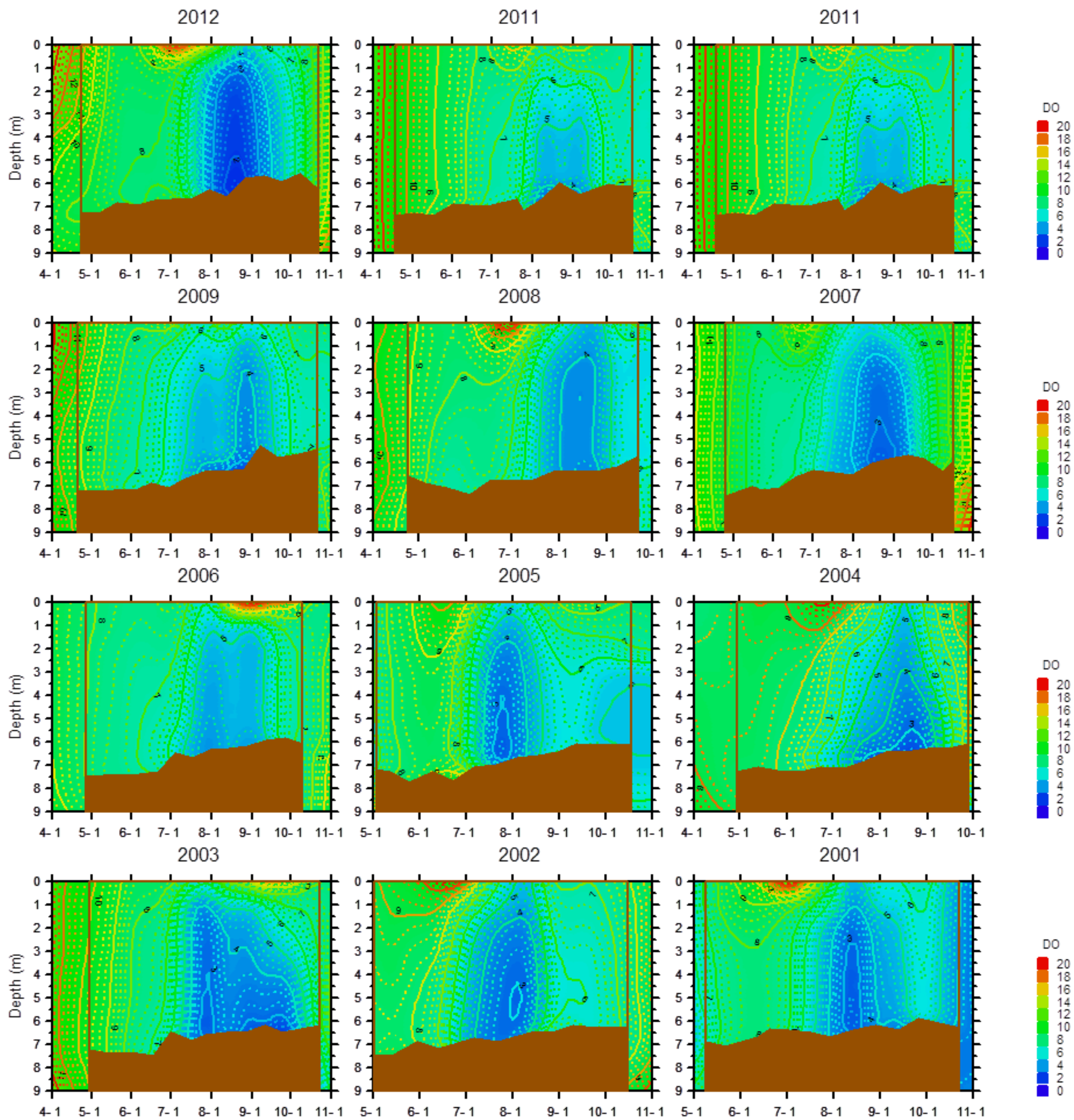
APPENDIX I: Seasonal and water column trends in water quality profile data (T, DO, and pH)



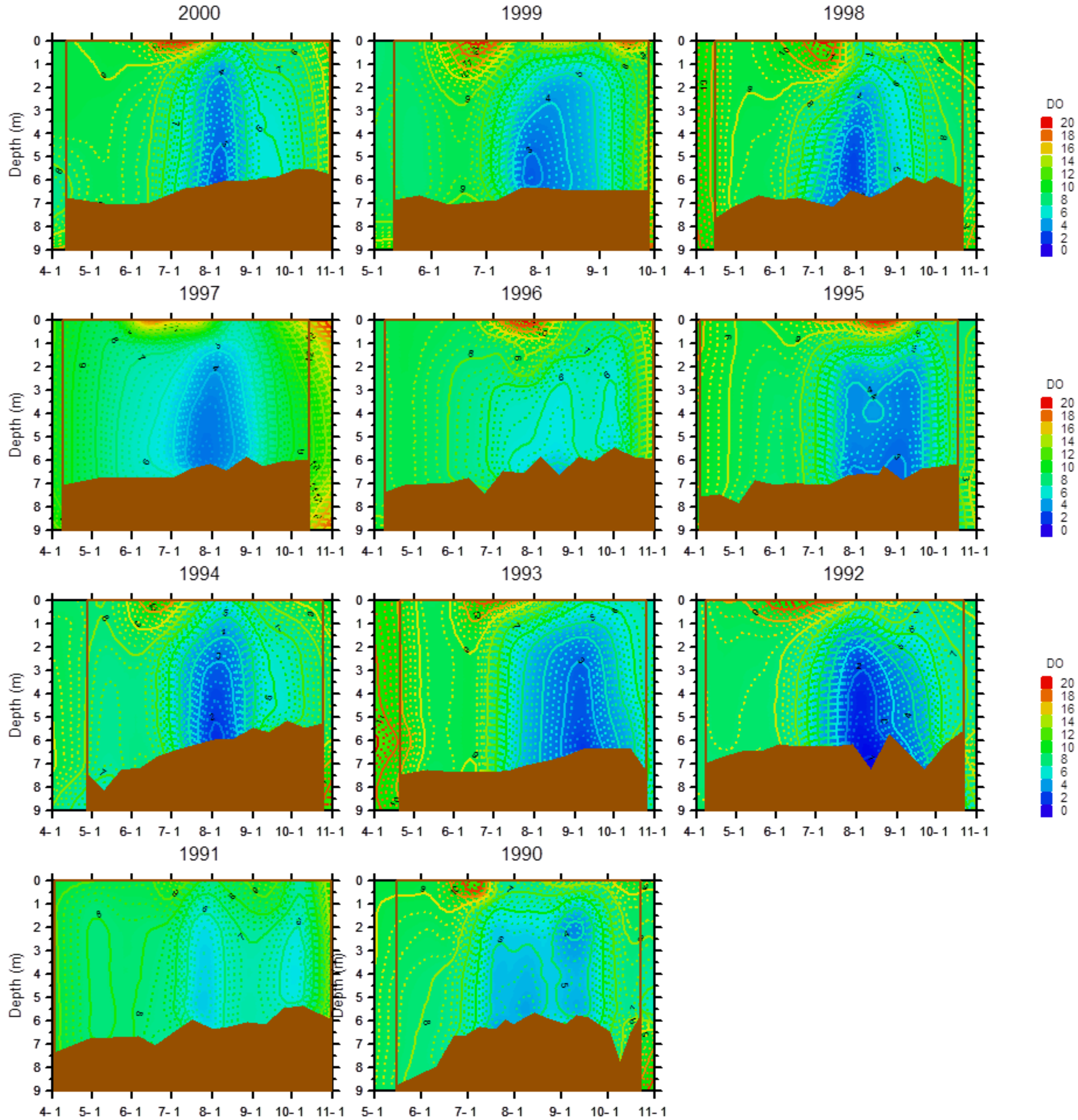
Depth-time distributions of isotherms of temperature (˚C) at UKL station Eagle Ridge (ER), 2001-2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



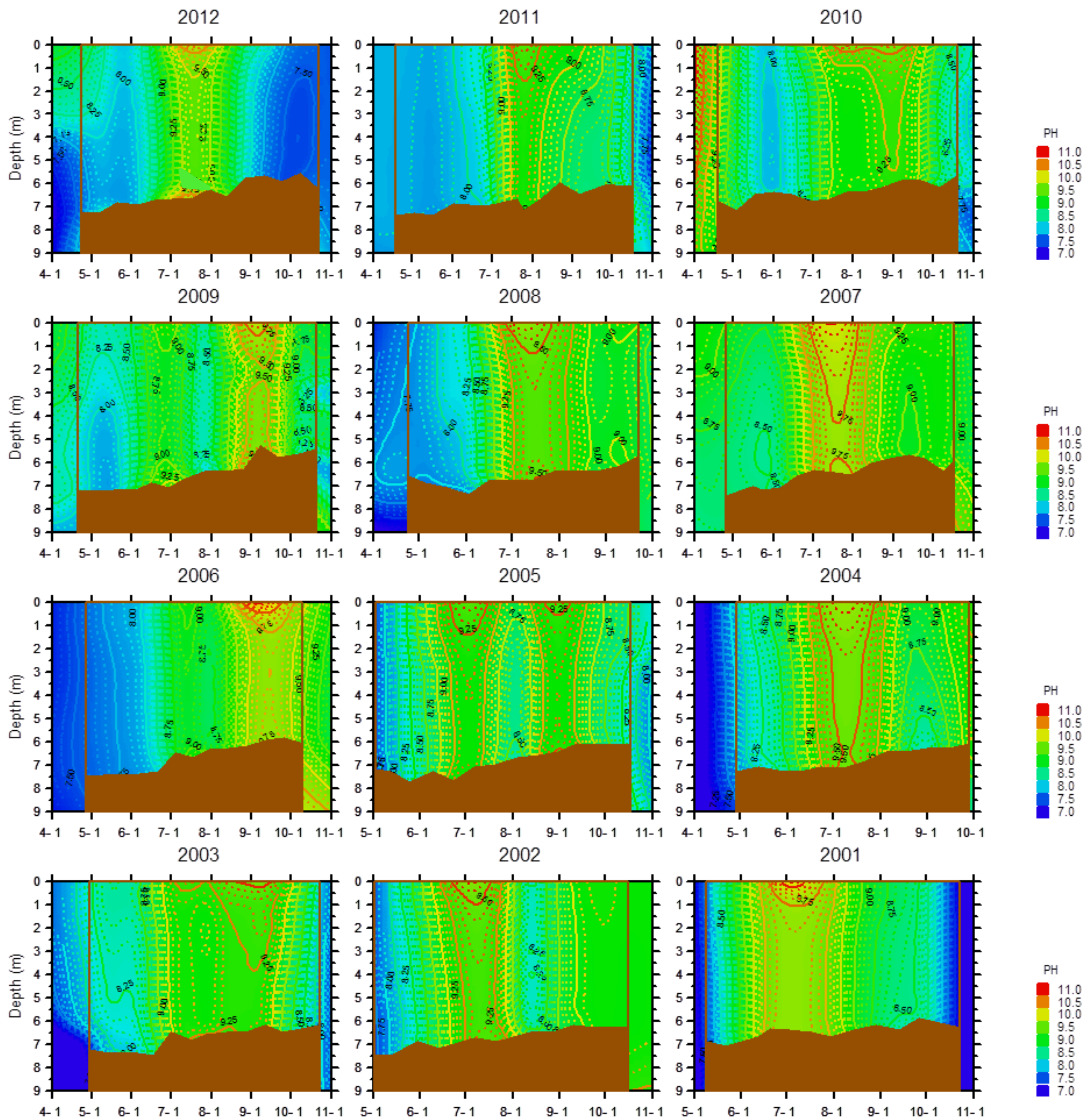
Depth-time distributions of isotherms of temperature (˚C) at UKL station Eagle Ridge (ER), 1990-2000. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



Depth-time distributions of isopleths of dissolved oxygen (mg/L) at UKL station Eagle Ridge (ER), 2001-2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



Depth-time distributions of isopleths of dissolved oxygen (mg/L) at UKL station Eagle Ridge (ER), 1990-2000. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



Depth-time distributions of isopleths of pH at UKL station Eagle Ridge (ER), 2001-2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

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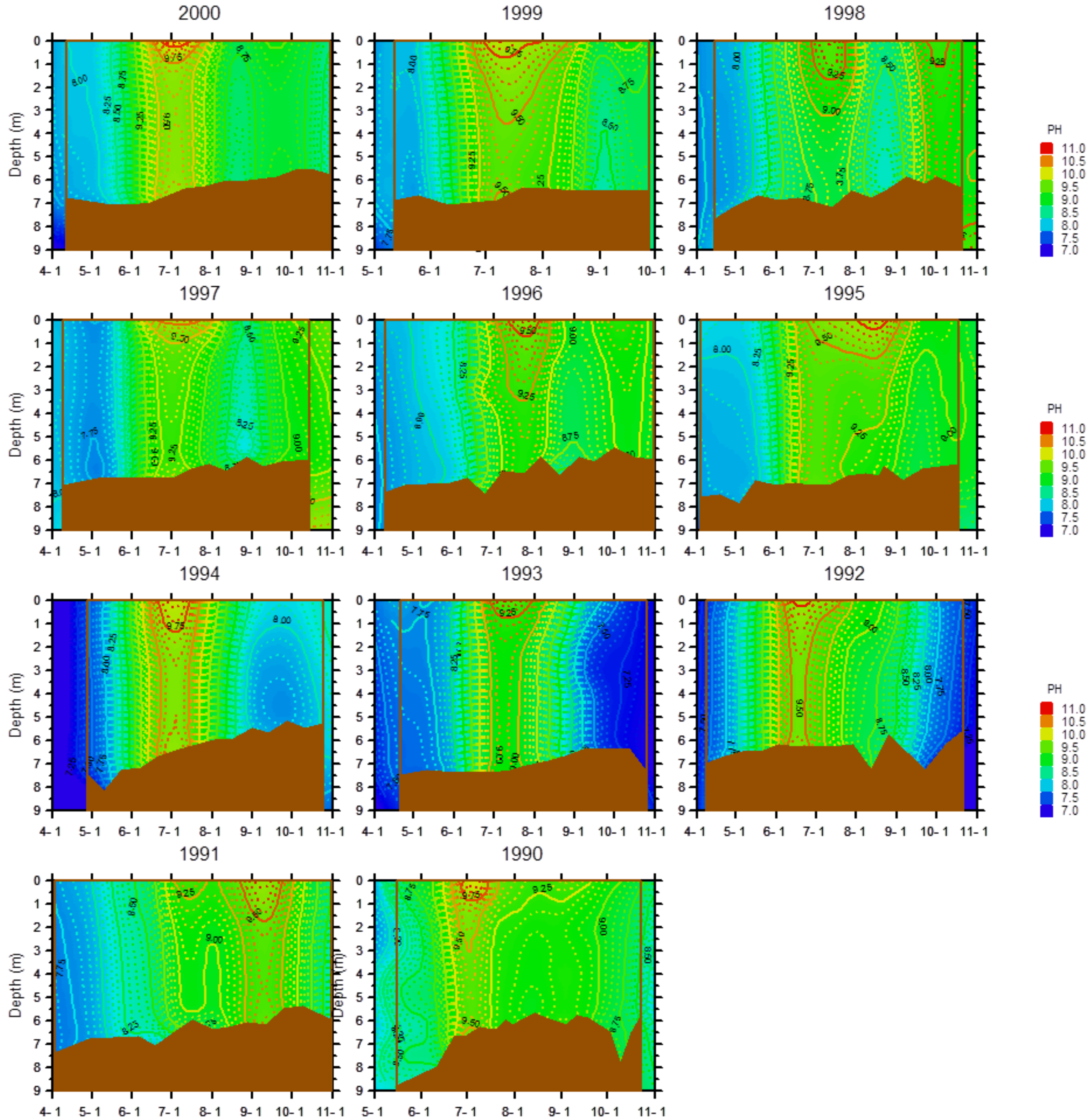
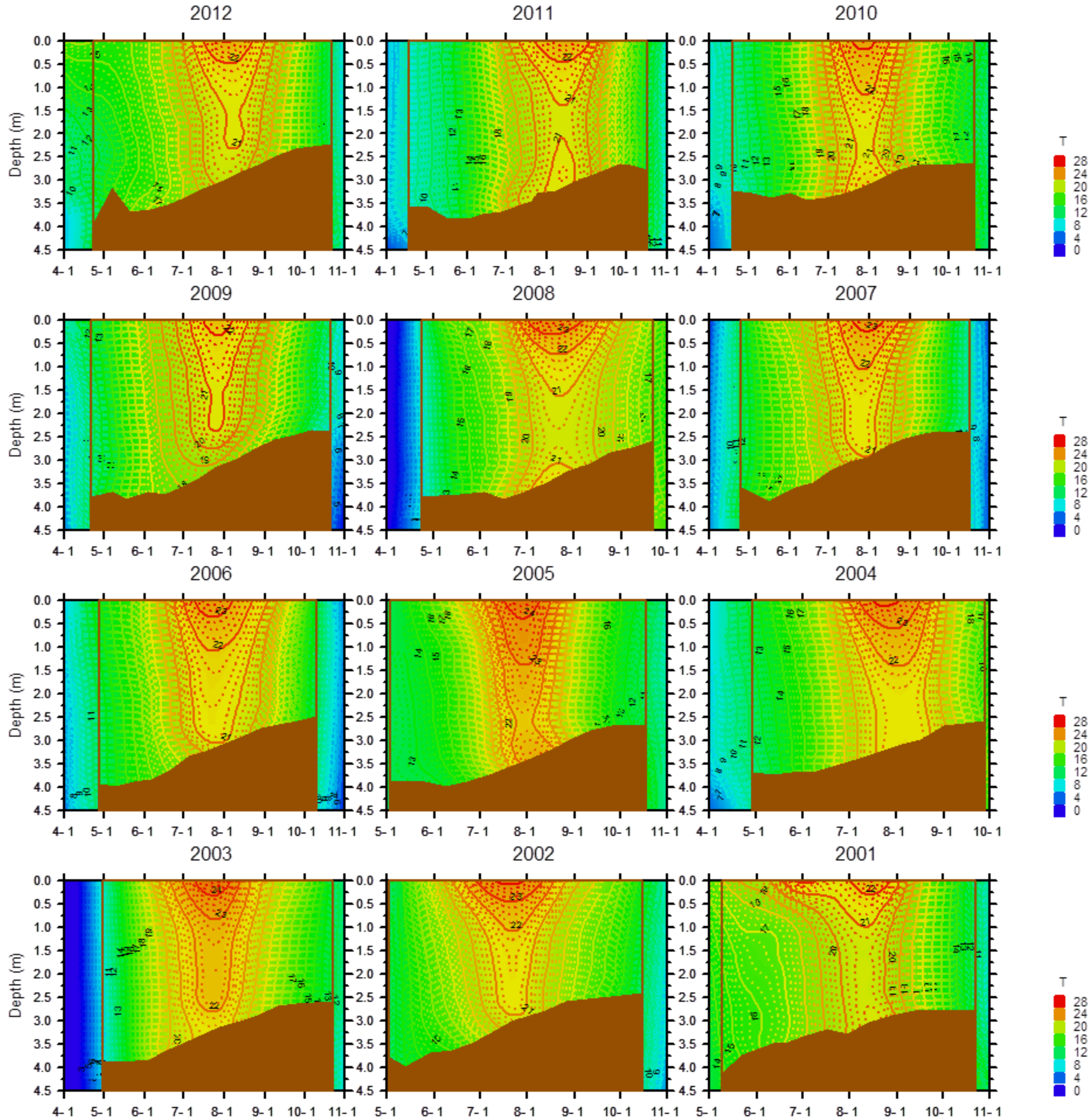
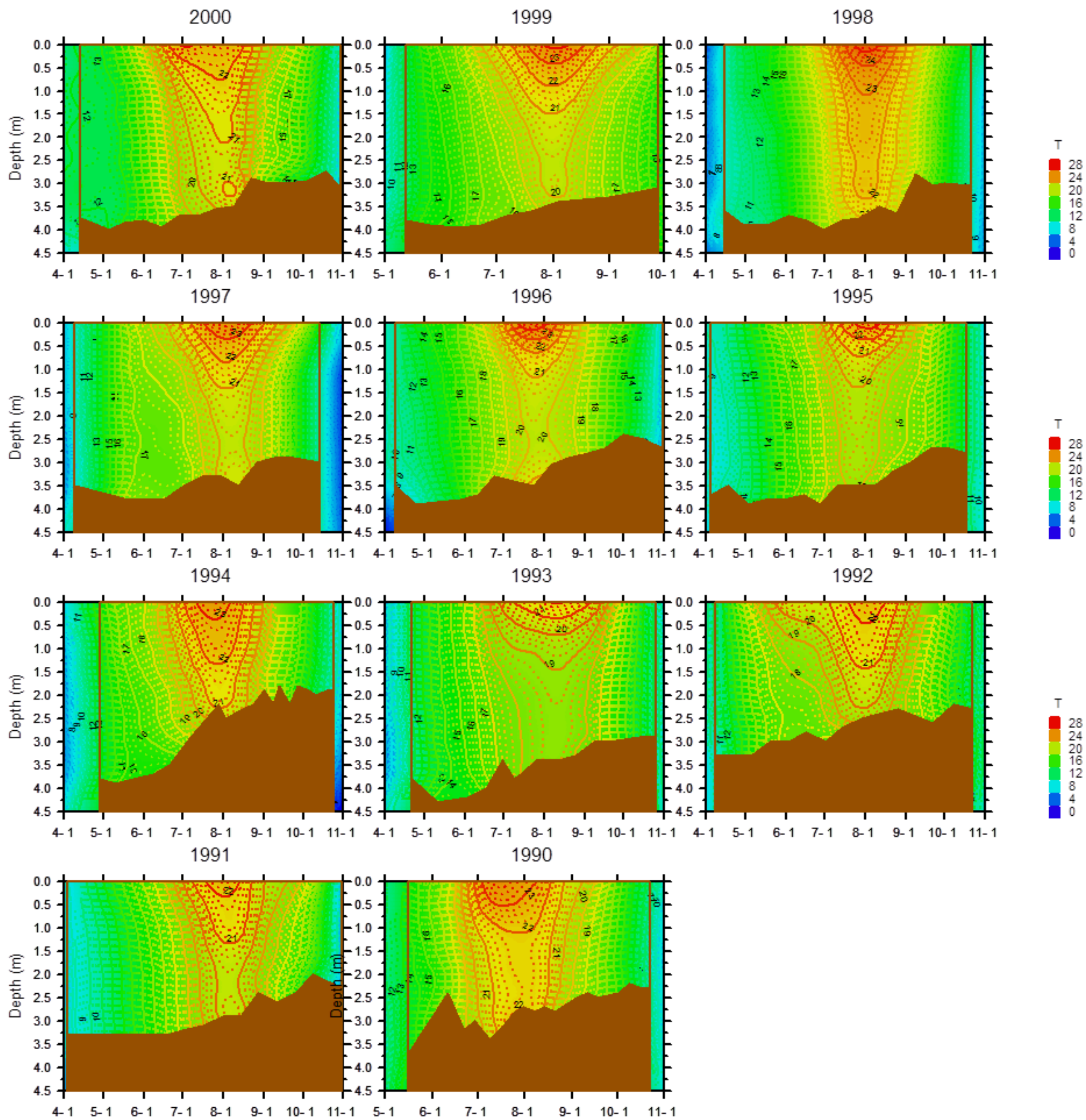


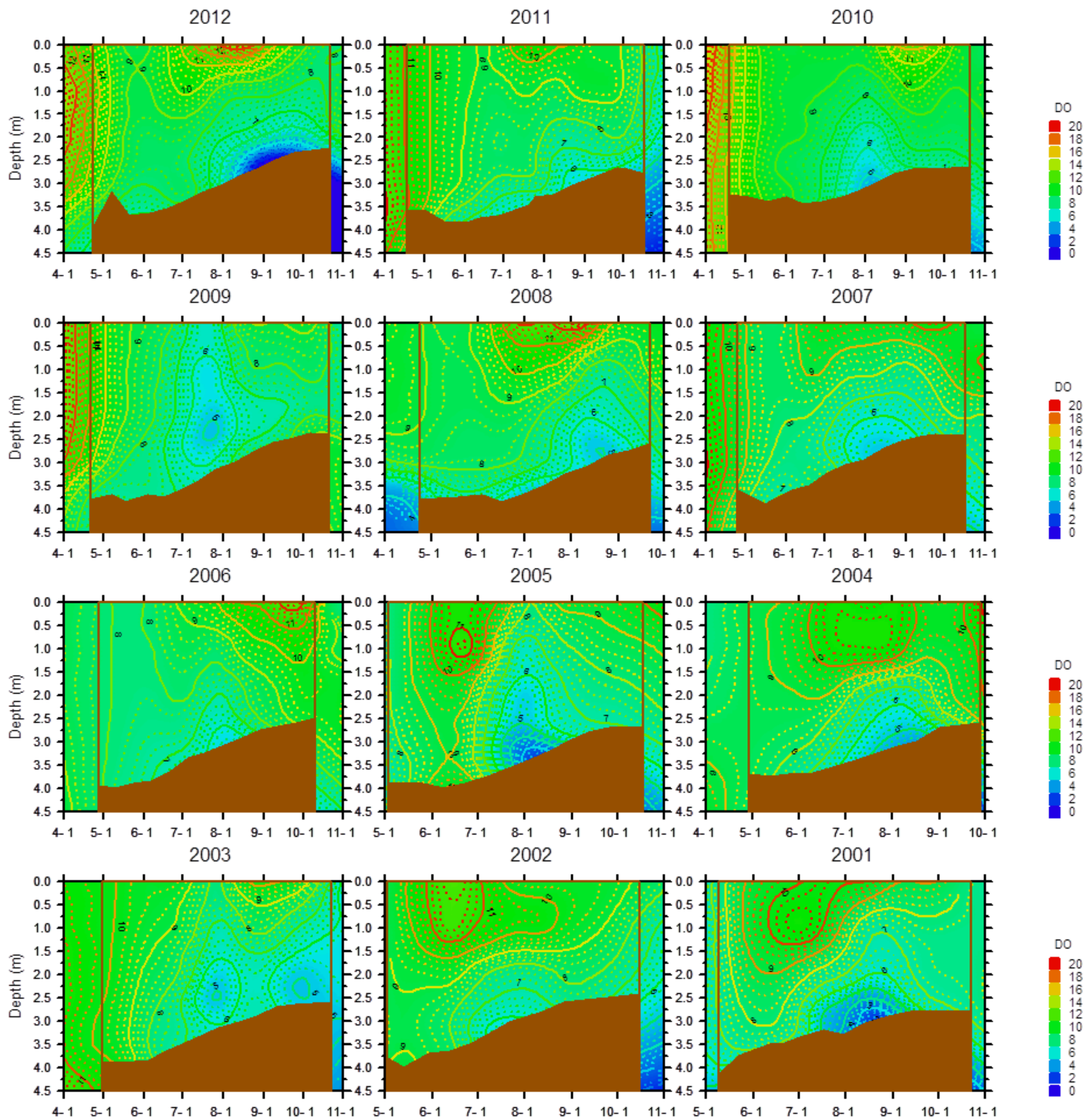
Depth-time distributions of isopleths of pH at UKL station Eagle Ridge (ER), 1990-2000. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



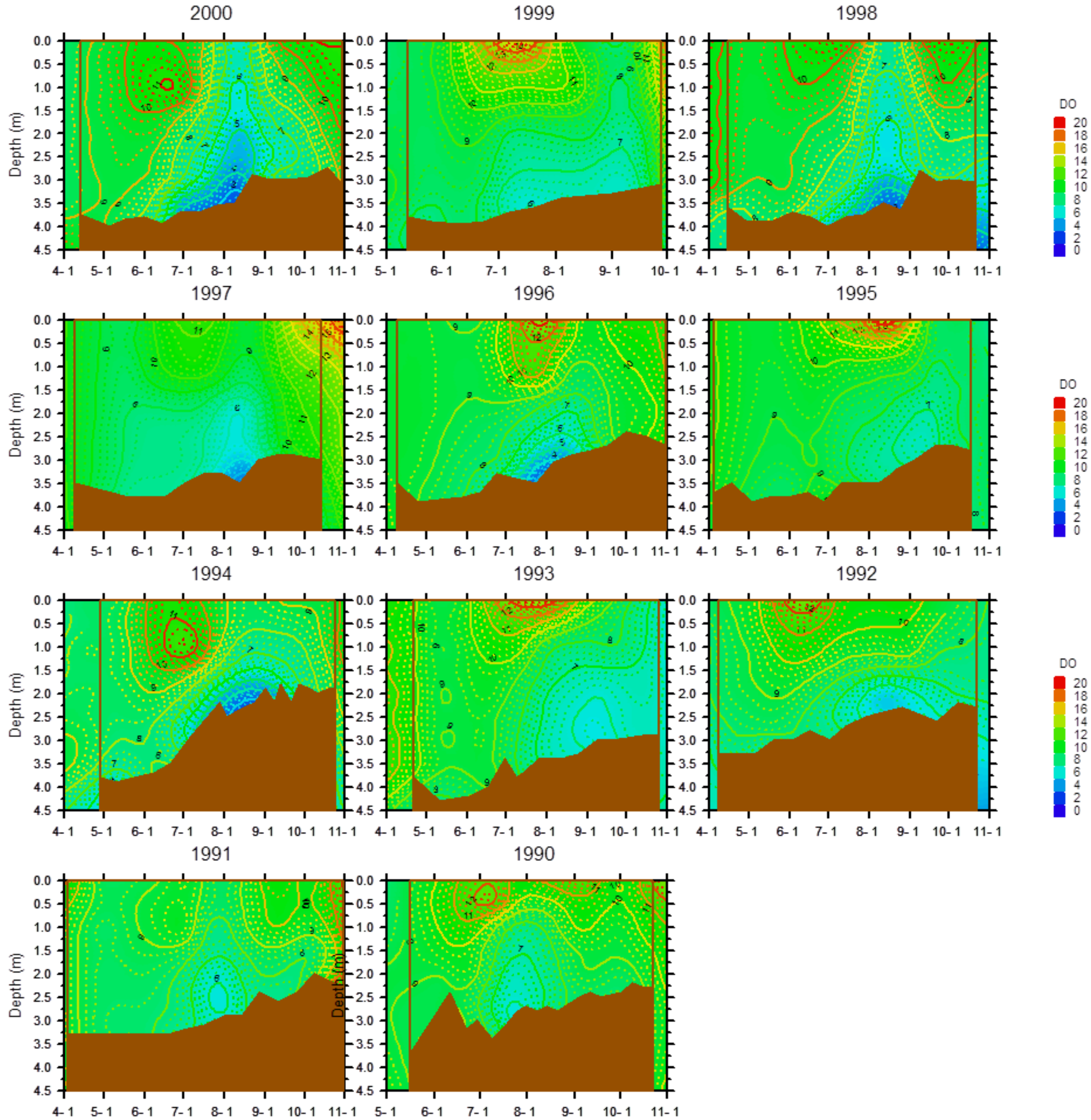
Depth-time distributions of isotherms of temperature (˚C) at UKL station Mid-North (MN), 2001-2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



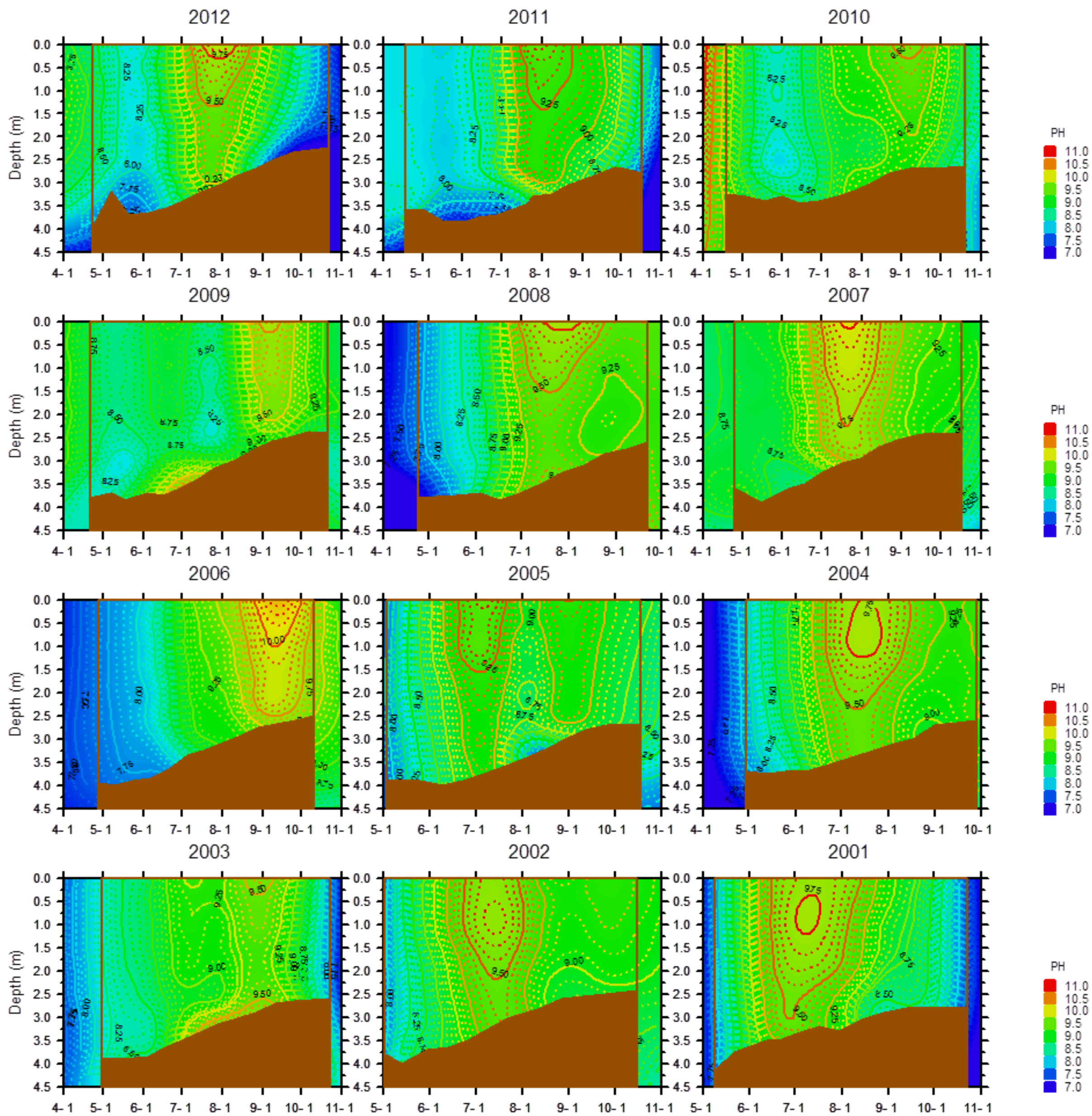
Depth-time distributions of isotherms of temperature (˚C) at UKL station Mid-North (MN), 1990-2000. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



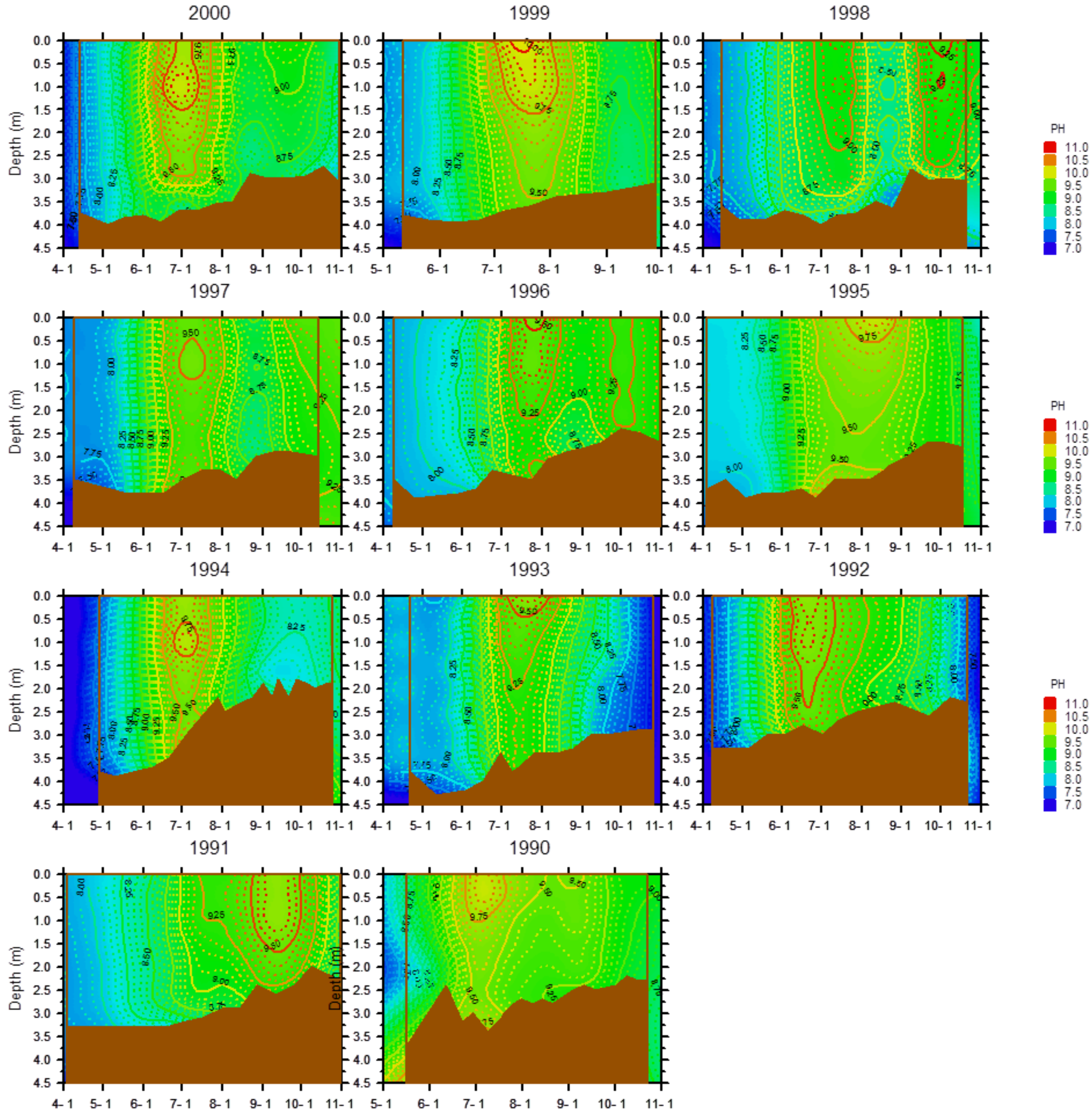
Depth-time distributions of isopleths of dissolved oxygen (mg/L) at UKL station Mid-North (MN), 2001-2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



Depth-time distributions of isopleths of dissolved oxygen (mg/L) at UKL station Mid-North (MN), 1990-2000. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



Depth-time distributions of isopleths of pH at UKL station Mid-North (MN), 2001-2012. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).



Depth-time distributions of isopleths of pH at UKL station Mid-North (MN), 1990-2000. Note: 1) brown shaded area on the abscissa denotes the bottom profile depth, and 2) contours are not valid outside of vertical brown lines (begin and end dates for seasonal sampling).

APPENDIX II: Summary statistics of monthly distributions for the June-September period, Upper Klamath Lake Stations; 1990-2011 (LQ= Lower Quartile; UQ=Upper Quartile).

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1990	6	n	13	13	13	12	11	11	12	11	2	2	2
1990	6	Median	16.1	9.18	8.9	1.00	60	119	17	795	25	62	50
1990	6	Mean	17.9	9.34	9.2	0.93	97	131	20	1111	25	62	50
1990	6	LQ	15.6	8.94	8.1	0.75	31	108	15	679	22	48	40
1990	6	UQ	20.8	9.64	9.8	1.20	117	141	20	1649	28	76	61
1990	7	n	17	17	17	15	15	15	15	15	8	15	15
1990	7	Median	22.2	9.42	7.1	0.50	138	215	67	2347	14	47	33
1990	7	Mean	22.4	9.48	7.3	0.61	170	222	66	2661	13	95	49
1990	7	LQ	21.7	9.27	6.3	0.40	95	194	53	2173	3	31	21
1990	7	UQ	23.1	9.65	8.9	0.86	278	247	81	3373	19	129	62
1990	8	n	9	9	9	9	9	9	9	9	9	9	9
1990	8	Median	23.3	9.28	7.8	0.50	191	241	95	3428	21	100	48
1990	8	Mean	22.1	9.24	7.4	0.73	201	243	94	3897	17	96	38
1990	8	LQ	19.1	9.04	5.3	0.35	82	171	87	2533	0	14	6
1990	8	UQ	23.5	9.37	9.1	1.00	276	307	104	4317	29	159	69
1990	9	n	15	15	15	15	13	13	13	13	13	13	13
1990	9	Median	18.2	9.37	9.6	0.60	147	228	59	3428	0	86	45
1990	9	Mean	18.5	9.41	8.9	0.71	164	236	68	3478	6	175	66
1990	9	LQ	17.7	9.24	6.8	0.43	76	201	52	2819	0	36	21
1990	9	UQ	19.1	9.60	10.9	0.98	235	251	73	3594	9	269	105
1991	6	n	16	16	16	16	14	14	14	14	14	7	7
1991	6	Median	15.9	8.43	8.1	0.85	17	89	19	681	47	5	1
1991	6	Mean	15.6	8.42	8.1	0.79	19	90	22	691	50	7	1
1991	6	LQ	14.9	8.17	7.4	0.35	12	83	7	593	16	5	0
1991	6	UQ	16.3	8.62	8.9	1.20	24	95	39	802	74	5	1
1991	7	n	12	12	12	12	10	10	10	10	3	10	10
1991	7	Median	19.9	9.43	8.9	0.68	107	155	40	2271	5	61	40
1991	7	Mean	19.5	9.49	8.8	0.70	118	162	37	2476	5	140	72
1991	7	LQ	18.4	9.37	7.6	0.50	77	141	24	2136	5	31	21
1991	7	UQ	20.3	9.67	10.5	0.80	139	176	49	2446	5	208	125
1991	8	n	22	18	22	24	21	21	21	21	0	21	18
1991	8	Median	20.3	9.28	9.2	0.66	126	241	55	2638		29	10
1991	8	Mean	20.0	9.14	8.6	0.71	140	257	65	2934		81	22
1991	8	LQ	18.3	8.71	6.7	0.46	39	212	41	2005		16	8
1991	8	UQ	21.8	9.59	10.1	1.05	196	297	99	3387		154	38
1991	9	n	15	15	15	15	14	14	13	14	0	7	7
1991	9	Median	16.3	9.59	9.0	0.72	134	272	57	2385		18	13
1991	9	Mean	16.6	9.57	8.8	0.75	187	312	63	2894		112	29
1991	9	LQ	15.9	9.47	7.7	0.51	88	219	47	2068		13	9
1991	9	UQ	17.5	9.77	9.9	1.00	173	334	79	3939		52	31
1992	6	n	14	14	14	14	14	14	14	14	14	14	14
1992	6	Median	18.2	9.61	10.1	0.40	248	162	15	2625	5	34	22
1992	6	Mean	18.2	9.63	10.1	0.51	258	195	14	2874	5	33	21
1992	6	LQ	16.0	9.34	9.2	0.30	96	121	10	1960	5	15	8
1992	6	UQ	20.3	9.94	10.9	0.60	378	271	18	3600	5	49	31

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1992	7	n	21	21	21	21	21	18	21	18	21	21	21
1992	7	Median	21.0	9.30	7.3	0.60	126	246	42	2835	5	12	6
1992	7	Mean	20.3	9.15	6.8	0.57	160	299	50	3096	9	147	17
1992	7	LQ	18.0	9.06	5.7	0.30	68	217	25	2420	5	5	2
1992	7	UQ	21.7	9.35	8.8	0.80	220	379	60	3635	8	50	18
1992	8	n	14	14	14	14	14	14	14	14	14	14	14
1992	8	Median	20.6	9.15	8.7	0.30	72	121	11	2363	6	19	6
1992	8	Mean	20.8	9.12	8.2	0.36	76	138	12	2444	8	21	7
1992	8	LQ	19.4	9.01	6.9	0.30	49	54	9	1980	5	5	2
1992	8	UQ	22.7	9.22	9.9	0.40	100	212	14	2880	11	23	11
1992	9	n	7	7	7	7	6	7	7	7	7	7	7
1992	9	Median	17.4	7.97	5.1	0.40	41	136	13	1620	5	13	0
1992	9	Mean	17.2	8.12	5.6	0.39	43	135	14	1639	16	13	1
1992	9	LQ	16.8	7.75	4.9	0.30	34	114	12	1483	5	7	0
1992	9	UQ	17.6	8.57	6.3	0.48	58	154	18	1811	16	17	1
1993	6	n	21	21	21	21	21	21	21	21	21	21	21
1993	6	Median	17.3	8.68	9.6	0.90	65	89	9	1660	5	5	1
1993	6	Mean	16.8	8.62	9.7	1.05	67	81	11	1498	6	13	1
1993	6	LQ	14.7	7.77	8.5	0.64	7	47	7	518	5	5	1
1993	6	UQ	18.4	9.35	10.9	1.40	114	102	12	2253	5	16	2
1993	7	n	15	15	15	15	14	14	14	14	14	14	14
1993	7	Median	18.2	9.31	8.4	0.80	109	121	14	1870	5	13	7
1993	7	Mean	18.3	9.38	8.4	0.65	140	139	13	2351	10	55	19
1993	7	LQ	17.8	9.16	7.8	0.50	71	97	11	1590	5	5	2
1993	7	UQ	18.8	9.65	9.4	0.80	150	175	15	2330	15	45	14
1993	8	n	14	14	14	14	14	14	14	14	14	14	14
1993	8	Median	18.9	8.93	7.6	0.73	85	137	19	1790	14	32	8
1993	8	Mean	18.9	8.80	7.0	0.67	100	141	19	1786	15	174	17
1993	8	LQ	17.4	8.55	5.1	0.50	72	100	14	1490	10	5	2
1993	8	UQ	20.7	9.12	8.7	0.80	125	159	22	2250	16	332	25
1993	9	n	14	14	14	14	14	14	14	14	14	14	14
1993	9	Median	18.1	7.99	6.2	1.05	34	105	18	1785	127	662	17
1993	9	Mean	17.7	7.92	5.9	0.99	63	114	18	2482	127	1254	131
1993	9	LQ	14.9	7.29	4.2	0.80	18	79	14	1595	35	473	6
1993	9	UQ	20.6	8.45	8.0	1.20	58	122	19	2740	178	1013	42
1994	6	n	14	14	14	14	14	14	14	14	14	14	14
1994	6	Median	16.9	9.55	9.8	0.73	103	86	5	1525	5	8	4
1994	6	Mean	17.0	9.55	10.0	0.71	134	81	6	1846	5	10	4
1994	6	LQ	15.7	9.25	9.5	0.60	69	60	5	1020	5	5	3
1994	6	UQ	18.1	9.92	10.9	0.80	187	94	7	2330	5	12	5
1994	7	n	11	11	11	10	11	11	11	11	11	11	11
1994	7	Median	20.8	9.93	8.4	1.03	109	159	33	2010	11	13	9
1994	7	Mean	21.1	9.71	7.7	0.86	149	150	44	2239	16	54	20
1994	7	LQ	19.2	9.29	6.7	0.50	68	117	26	1698	8	5	4
1994	7	UQ	23.3	10.04	8.6	1.10	212	181	68	2693	14	46	24
1994	8	n	15	15	15	14	15	15	15	15	15	15	14
1994	8	Median	21.4	8.72	6.2	0.40	56	143	12	1940	5	20	6
1994	8	Mean	21.3	8.82	5.9	0.44	61	152	14	1957	19	45	12

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1994	8	LQ	21.1	8.60	5.3	0.40	52	133	10	1740	5	10	2
1994	8	UQ	22.1	9.14	6.5	0.50	68	176	16	2185	22	45	9
1994	9	n	15	15	15	15	19	20	20	20	20	21	15
1994	9	Median	18.7	8.15	7.8	0.40	40	119	10	1435	5	19	1
1994	9	Mean	17.8	8.12	7.9	0.38	39	119	10	1471	9	44	1
1994	9	LQ	15.6	7.97	7.2	0.33	30	114	9	1370	5	15	1
1994	9	UQ	19.3	8.30	8.5	0.40	48	125	11	1580	8	44	2
1995	6	n	14	14	14	14	14	14	14	14	14	14	14
1995	6	Median	17.0	9.59	10.2	0.64	200	126	12	2110	10	9	6
1995	6	Mean	17.4	9.60	9.8	0.60	274	178	13	2870	12	27	16
1995	6	LQ	15.2	9.52	9.5	0.49	179	111	8	1850	5	5	2
1995	6	UQ	19.3	9.69	10.7	0.80	249	158	16	3020	17	25	17
1995	7	n	14	14	14	14	14	14	14	14	14	14	14
1995	7	Median	21.0	9.66	8.8	0.58	150	165	48	2300	5	5	4
1995	7	Mean	20.8	9.65	8.5	0.59	165	167	47	2404	21	43	21
1995	7	LQ	19.7	9.43	8.4	0.46	114	139	30	2005	5	5	3
1995	7	UQ	21.8	9.85	9.2	0.79	205	184	64	2580	5	14	7
1995	8	n	17	17	17	14	14	14	14	14	14	14	14
1995	8	Median	20.2	9.59	8.8	0.69	144	175	66	2623	5	29	17
1995	8	Mean	19.9	9.54	8.3	0.70	142	197	66	2716	5	84	41
1995	8	LQ	19.0	9.35	7.7	0.41	79	145	59	2200	5	11	8
1995	8	UQ	20.8	9.74	9.7	1.02	187	186	76	3115	5	146	66
1995	9	n	14	14	14	14	14	14	14	14	14	14	14
1995	9	Median	18.5	9.33	8.1	0.59	155	287	92	3393	5	42	19
1995	9	Mean	18.7	9.27	7.4	0.65	152	288	98	3337	5	189	47
1995	9	LQ	18.4	9.01	5.2	0.46	120	206	75	2555	5	18	9
1995	9	UQ	18.9	9.53	9.3	0.84	198	341	127	4220	5	330	75
1996	6	n	10	10	10	5	10	10	10	10	10	10	10
1996	6	Median	17.6	8.60	8.2	0.80	54	59	8	870	5	233	36
1996	6	Mean	17.9	8.63	8.4	0.83	61	63	8	972	8	274	67
1996	6	LQ	16.6	8.21	7.8	0.73	30	52	7	750	5	63	4
1996	6	UQ	19.3	9.09	9.1	0.94	95	66	8	1170	5	489	113
1996	7	n	10	10	10	8	10	10	10	10	10	10	10
1996	7	Median	21.7	9.42	9.0	0.84	139	115	6	1740	5	194	97
1996	7	Mean	22.2	9.43	9.2	0.80	155	118	7	1850	5	266	123
1996	7	LQ	21.0	9.31	8.5	0.57	100	102	6	1580	5	31	20
1996	7	UQ	23.5	9.50	9.7	1.05	199	124	7	1870	5	482	227
1996	8	n	10	10	10	7	10	10	10	10	10	10	10
1996	8	Median	20.3	8.94	7.0	0.76	94	189	59	2165	26	243	74
1996	8	Mean	20.2	9.00	7.2	0.83	107	181	66	2129	43	451	94
1996	8	LQ	19.5	8.70	6.0	0.64	60	166	50	1910	22	122	54
1996	8	UQ	20.5	9.37	8.8	1.09	154	202	89	2440	51	791	129
1996	9	n	10	10	10	8	10	10	10	10	10	10	10
1996	9	Median	15.8	8.80	7.9	1.13	84	183	71	2010	21	181	27
1996	9	Mean	16.3	8.81	8.1	1.15	116	190	74	2142	36	211	28
1996	9	LQ	14.8	8.65	7.1	0.80	69	165	61	1780	5	47	14
1996	9	UQ	18.7	9.05	9.2	1.34	119	214	78	2350	48	324	41
1997	6	n	7	7	7	6	7	7	7	7	7	7	7

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1997	6	Median	18.9	9.55	9.6	0.50	197	123	9	2190	5	298	164
1997	6	Mean	18.7	9.50	9.5	0.52	219	134	9	2312	5	395	219
1997	6	LQ	18.5	9.37	8.5	0.40	182	101	7	1984	5	272	154
1997	6	UQ	19.0	9.63	10.5	0.70	211	151	11	2463	5	518	240
1997	7	n	23	23	23	21	23	23	23	23	23	23	23
1997	7	Median	21.1	9.54	9.1	0.51	190	225	56	2240	5	1680	665
1997	7	Mean	20.0	9.53	8.5	0.54	267	271	57	2782	7	1666	912
1997	7	LQ	17.1	9.30	6.3	0.32	130	184	27	1895	5	774	401
1997	7	UQ	21.8	9.76	10.2	0.80	291	319	82	3248	5	1938	1452
1997	8	n	16	16	16	16	16	16	16	16	16	16	16
1997	8	Median	20.3	8.55	6.6	1.15	64	243	113	2650	47	854	73
1997	8	Mean	20.4	8.40	6.8	1.08	131	270	117	3277	55	836	144
1997	8	LQ	19.4	7.80	5.2	0.88	34	202	83	2355	23	619	20
1997	8	UQ	21.2	8.82	7.7	1.30	115	281	147	3170	85	980	139
1997	9	n	16	16	16	16	16	16	16	16	16	16	16
1997	9	Median	17.5	9.29	10.4	0.85	155	206	69	2065	5	597	233
1997	9	Mean	17.2	9.28	10.5	0.90	173	220	68	2337	6	758	302
1997	9	LQ	15.1	9.20	9.4	0.68	59	165	58	1665	5	472	151
1997	9	UQ	19.2	9.40	11.9	1.18	227	277	82	2945	5	902	396
1998	6	n	24	24	24	24	24	24	24	24	24	24	24
1998	6	Median	17.4	8.86	9.7	1.18	45	62	6	907	5	303	55
1998	6	Mean	17.3	8.87	9.6	1.13	63	83	8	1124	5	360	94
1998	6	LQ	15.6	8.71	9.2	0.93	35	50	5	828	5	187	30
1998	6	UQ	19.3	9.01	10.1	1.25	78	101	9	1323	5	454	103
1998	7	n	15	15	15	15	15	15	15	15	15	15	15
1998	7	Median	23.9	9.39	8.1	0.75	172	194	49	2330	5	963	451
1998	7	Mean	23.3	9.34	8.0	0.82	192	207	41	2501	5	957	499
1998	7	LQ	22.2	9.13	6.2	0.55	125	159	4	2071	5	648	353
1998	7	UQ	24.5	9.49	10.1	0.94	243	258	73	2663	5	1174	647
1998	8	n	16	16	16	16	16	16	16	16	16	16	16
1998	8	Median	21.7	8.15	6.8	1.82	13	225	112	2220	55	1005	59
1998	8	Mean	21.7	8.12	6.6	1.55	82	247	113	2556	62	1122	128
1998	8	LQ	20.4	7.79	3.5	1.14	6	191	80	2065	16	826	22
1998	8	UQ	23.2	8.23	8.5	2.00	50	249	147	2475	80	1090	71
1998	9	n	16	16	16	16	16	16	16	16	16	16	16
1998	9	Median	18.9	9.28	10.0	1.01	93	182	56	1848	5	288	89
1998	9	Mean	18.7	9.20	9.5	0.91	115	198	63	1884	6	280	107
1998	9	LQ	15.3	9.04	8.7	0.73	72	162	49	1490	5	24	8
1998	9	UQ	21.8	9.38	10.5	1.13	156	222	71	2230	5	501	183
1999	6	n	16	16	16	16	16	16	16	16	16	16	16
1999	6	Median	16.8	8.76	10.1	1.05	46	88	12	1113	5	239	33
1999	6	Mean	16.9	8.83	10.5	0.93	95	112	14	1361	5	275	89
1999	6	LQ	14.3	8.26	9.1	0.70	23	74	7	751	5	153	9
1999	6	UQ	19.4	9.39	11.4	1.09	127	119	21	1930	5	310	132
1999	7	n	15	15	15	15	15	15	15	15	15	15	15
1999	7	Median	20.1	9.82	9.1	0.57	223	178	29	2310	5	233	162
1999	7	Mean	19.5	9.80	9.1	0.63	224	194	28	2719	10	393	280
1999	7	LQ	18.3	9.65	8.7	0.32	125	138	5	1913	5	151	108

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
1999	7	UQ	20.8	9.90	10.3	0.87	299	223	49	3378	15	549	372
1999	8	n	16	16	16	16	16	16	16	16	16	16	16
1999	8	Median	21.1	9.42	7.6	0.74	143	235	81	2405	11	165	68
1999	8	Mean	21.1	9.43	7.6	0.74	183	285	80	2626	13	432	246
1999	8	LQ	20.1	9.30	6.1	0.53	76	187	75	1855	5	61	27
1999	8	UQ	22.3	9.58	8.9	1.02	233	358	85	3040	14	641	359
1999	9	n	24	24	24	24	24	24	24	24	24	24	24
1999	9	Median	17.1	8.74	8.6	1.15	47	191	67	2020	43	364	33
1999	9	Mean	16.4	8.70	8.5	0.99	74	209	79	2244	46	405	58
1999	9	LQ	14.7	8.42	6.9	0.65	24	152	52	1805	16	92	13
1999	9	UQ	18.0	9.00	10.4	1.30	98	216	114	2400	61	741	58
2000	6	n	16	16	16	16	16	16	16	16	16	16	16
2000	6	Median	20.5	9.81	9.4	0.61	183	173	9	2275	14	734	541
2000	6	Mean	20.1	9.77	9.1	0.66	203	185	22	2323	18	930	618
2000	6	LQ	17.6	9.60	8.0	0.43	106	124	7	1603	5	607	436
2000	6	UQ	21.9	9.98	10.2	0.88	271	227	33	2948	22	1355	718
2000	7	n	16	16	16	16	16	16	16	16	16	16	16
2000	7	Median	21.1	9.64	7.5	0.99	97	228	92	1605	10	521	315
2000	7	Mean	20.9	9.64	7.5	0.90	165	369	91	2012	10	707	477
2000	7	LQ	20.2	9.45	6.9	0.55	70	206	88	1390	10	368	229
2000	7	UQ	21.6	9.82	8.2	1.22	189	321	97	2295	10	927	481
2000	8	n	16	16	16	10	16	16	16	16	16	16	16
2000	8	Median	21.5	8.49	4.5	1.35	21	226	141	2278	67	870	79
2000	8	Mean	21.3	8.52	4.6	1.44	34	225	129	2240	76	778	92
2000	8	LQ	18.5	8.34	2.9	1.20	17	184	118	1920	19	570	58
2000	8	UQ	23.5	8.68	6.1	1.75	37	263	158	2460	134	971	125
2000	9	n	16	16	16	16	16	16	16	16	16	16	16
2000	9	Median	16.7	9.10	8.6	0.80	116	189	67	1680	18	484	116
2000	9	Mean	16.5	9.08	8.4	0.87	135	182	65	1900	24	496	150
2000	9	LQ	14.3	8.92	7.4	0.69	69	164	51	1445	13	358	80
2000	9	UQ	18.7	9.29	9.8	1.14	171	201	76	2160	29	605	188
2001	6	n	16	16	16	16	16	16	16	16	16	16	16
2001	6	Median	16.6	9.62	9.3	0.57	160	132	7	2490	5	502	258
2001	6	Mean	16.9	9.59	9.4	0.60	187	145	7	2566	5	499	270
2001	6	LQ	15.9	9.49	8.8	0.54	134	102	6	1900	5	254	161
2001	6	UQ	17.6	9.71	9.6	0.73	234	163	7	2943	5	645	333
2001	7	n	24	24	24	24	24	24	24	24	24	24	24
2001	7	Median	19.7	9.68	7.9	0.73	194	248	59	3340	13	623	356
2001	7	Mean	19.6	9.68	8.2	0.74	201	234	45	3330	13	614	384
2001	7	LQ	19.2	9.55	7.3	0.55	135	179	12	2545	12	348	268
2001	7	UQ	19.9	9.83	9.4	0.93	241	280	66	3890	15	716	482
2001	8	n	16	16	16	16	16	16	16	16	16	16	16
2001	8	Median	22.2	8.94	5.5	0.85	75	227	71	3120	8	861	231
2001	8	Mean	21.5	8.91	5.4	0.95	85	239	67	3388	11	934	253
2001	8	LQ	19.8	8.75	3.6	0.61	41	175	32	2863	5	677	138
2001	8	UQ	22.9	9.14	8.1	1.31	120	303	99	3820	15	1115	363
2001	9	n	16	16	16	16	16	16	16	16	16	16	16
2001	9	Median	16.7	8.74	6.7	1.09	83	165	31	2765	13	970	94

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2001	9	Mean	16.8	8.49	6.1	1.03	103	168	36	2894	18	879	142
2001	9	LQ	16.0	7.91	3.7	0.75	60	132	17	2285	12	420	20
2001	9	UQ	17.8	8.99	8.0	1.33	140	196	58	3690	25	1165	103
2002	6	n	16	16	16	16	16	16	16	16	16	16	16
2002	6	Median	19.5	9.25	9.2	0.72	142	101	7	1848	6	249	125
2002	6	Mean	19.4	9.23	9.7	0.76	168	122	7	1786	8	382	192
2002	6	LQ	17.5	9.08	8.5	0.56	90	74	6	1383	5	44	9
2002	6	UQ	20.7	9.43	11.2	1.04	209	128	9	2155	10	660	350
2002	7	n	16	16	16	16	16	16	16	16	16	16	16
2002	7	Median	21.8	9.61	7.3	0.75	148	178	41	2435	11	399	266
2002	7	Mean	21.7	9.58	7.2	0.78	139	190	42	2345	18	417	261
2002	7	LQ	21.0	9.50	6.0	0.59	82	160	30	2130	10	322	189
2002	7	UQ	22.7	9.69	8.4	0.97	186	208	55	2600	13	511	333
2002	8	n	16	16	16	16	16	16	16	16	16	16	16
2002	8	Median	19.6	8.96	8.4	0.85	77	174	39	2745	55	585	112
2002	8	Mean	19.8	8.85	8.0	0.96	90	206	47	2830	71	591	153
2002	8	LQ	18.6	8.59	6.7	0.69	40	158	31	2285	11	439	58
2002	8	UQ	20.8	9.21	9.7	1.21	135	250	62	2963	88	701	218
2002	9	n	16	16	8	16	16	16	16	16	16	16	16
2002	9	Median	16.5	9.27	8.9	0.89	98	190	46	2653	12	310	87
2002	9	Mean	16.5	9.24	8.1	0.93	111	214	45	2923	13	337	121
2002	9	LQ	15.9	9.12	6.9	0.69	78	151	32	2270	11	206	64
2002	9	UQ	17.1	9.43	9.0	1.10	136	267	58	3600	13	449	166
2003	6	n	16	16	16	16	16	16	16	16	16	16	16
2003	6	Median	20.1	8.40	8.0	1.24	16	91	19	1000	15	70	5
2003	6	Mean	20.0	8.40	8.2	1.16	29	102	17	1187	36	62	8
2003	6	LQ	19.1	8.15	7.7	0.99	12	69	12	794	12	54	2
2003	6	UQ	20.6	8.59	8.2	1.28	34	113	21	1508	63	76	10
2003	7	n	24	24	24	24	24	24	24	24	24	24	24
2003	7	Median	22.5	9.50	8.4	0.69	83	212	45	2785	9	380	73
2003	7	Mean	22.7	9.34	7.4	0.80	108	213	54	2844	9	449	218
2003	7	LQ	20.9	9.37	6.2	0.56	50	142	5	2235	5	24	14
2003	7	UQ	24.5	9.57	9.5	0.99	148	280	86	3325	12	720	285
2003	8	n	16	16	16	16	16	16	16	16	16	16	16
2003	8	Median	20.5	9.51	8.5	0.58	176	262	74	3045	14	16	8
2003	8	Mean	20.4	9.51	8.3	0.60	168	275	75	3124	14	43	17
2003	8	LQ	20.1	9.44	7.9	0.48	140	235	69	2870	5	11	7
2003	8	UQ	20.7	9.62	8.9	0.67	201	307	80	3505	19	23	13
2003	9	n	16	16	16	16	16	16	16	16	16	16	16
2003	9	Median	17.1	9.40	7.2	0.69	94	217	64	2480	17	151	30
2003	9	Mean	17.0	9.34	7.6	0.69	139	272	59	3065	29	178	70
2003	9	LQ	16.4	9.11	5.9	0.42	75	181	32	2048	12	34	15
2003	9	UQ	17.6	9.58	9.0	0.87	118	290	74	3060	42	241	109
2004	6	n	16	16	16	16	16	16	16	16	16	16	16
2004	6	Median	17.4	9.31	9.0	0.96	66	70	8	1325	5	22	4
2004	6	Mean	17.4	9.25	9.3	0.83	90	95	8	1448	7	27	11
2004	6	LQ	14.6	8.85	8.7	0.71	40	61	7	1035	5	13	3
2004	6	UQ	20.0	9.60	9.8	1.00	109	101	10	1570	10	36	8

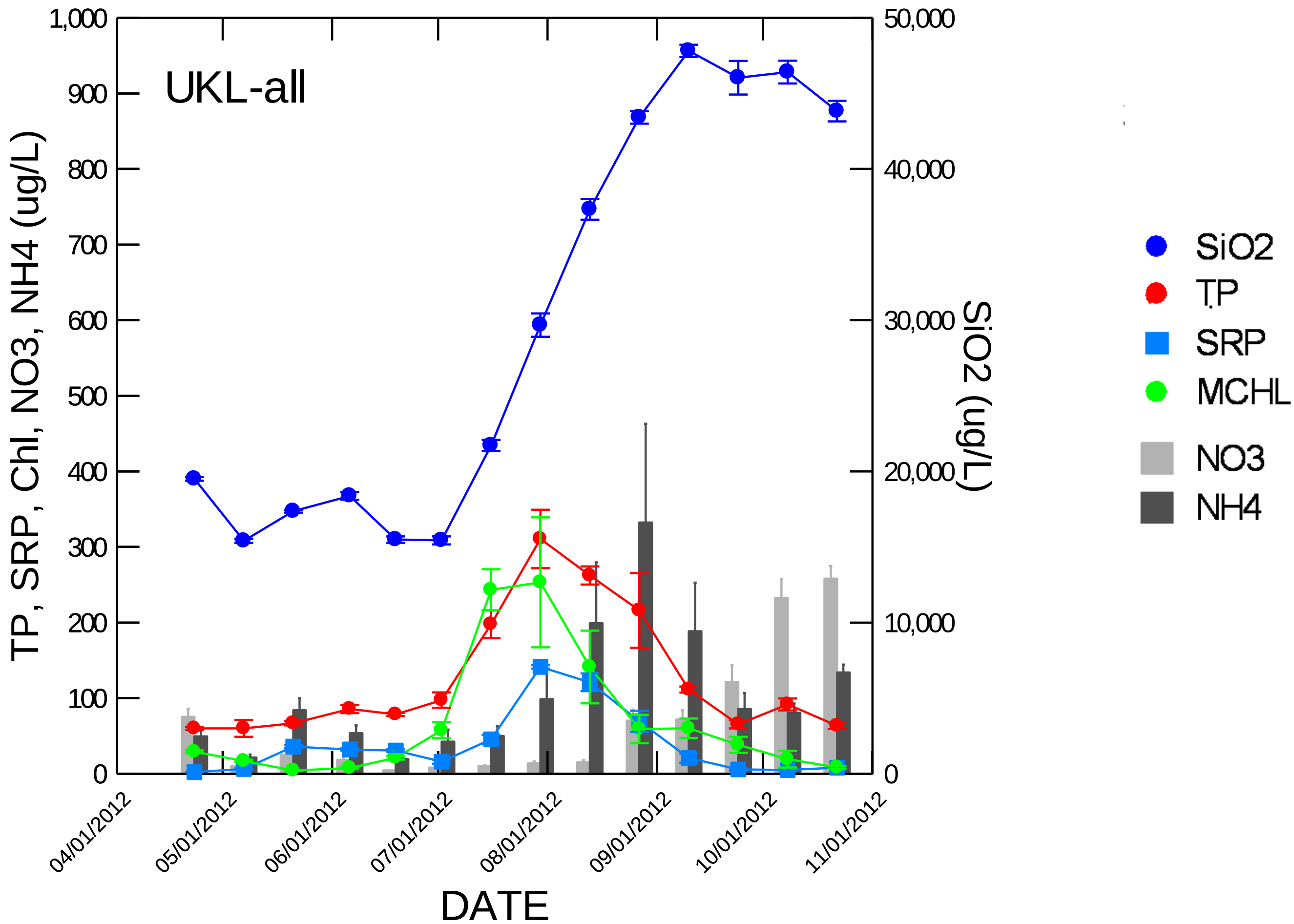
Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2004	7	n	16	16	16	16	16	16	16	16	16	16	16
2004	7	Median	21.7	9.63	7.4	0.66	132	173	31	2120	16	22	13
2004	7	Mean	21.7	9.63	7.1	0.72	188	188	29	2457	26	33	20
2004	7	LQ	21.0	9.54	6.4	0.49	104	132	14	1745	10	12	9
2004	7	UQ	22.7	9.72	8.1	0.76	211	195	41	2525	41	38	24
2004	8	n	16	16	16	16	16	16	16	16	16	16	16
2004	8	Median	21.9	9.03	5.9	0.95	81	178	56	2450	30	159	37
2004	8	Mean	22.0	9.03	5.7	1.02	77	191	66	2410	35	206	49
2004	8	LQ	21.2	8.86	4.2	0.76	29	170	48	2130	20	43	19
2004	8	UQ	23.0	9.35	6.8	1.26	108	195	89	2660	42	342	82
2004	9	n	24	24	24	24	24	24	24	24	24	24	24
2004	9	Median	16.2	9.14	8.5	1.04	51	141	25	2030	15	105	25
2004	9	Mean	17.2	9.11	8.5	0.96	82	155	27	2447	17	227	59
2004	9	LQ	15.6	8.99	7.8	0.84	16	122	11	1860	9	23	9
2004	9	UQ	19.4	9.26	9.2	1.13	74	178	33	2575	20	418	107
2005	6	n	19	19	19	16	19	19	19	19	19	19	19
2005	6	Median	15.9	9.07	9.7	0.97	61	84	6	1410	5	27	4
2005	6	Mean	15.7	8.96	9.7	0.87	59	93	7	1404	9	25	6
2005	6	LQ	14.5	8.73	9.5	0.75	29	63	5	990	5	15	2
2005	6	UQ	16.7	9.22	10.2	1.11	72	114	7	1815	11	33	11
2005	7	n	18	18	18	16	17	18	18	18	18	18	18
2005	7	Median	22.0	9.45	7.2	1.02	59	176	36	2090	8	69	37
2005	7	Mean	22.4	9.41	6.8	1.04	76	184	37	2432	10	111	49
2005	7	LQ	21.1	9.23	5.8	0.58	20	124	8	1890	5	15	10
2005	7	UQ	23.7	9.60	8.1	1.40	102	260	53	3150	14	137	74
2005	8	n	25	25	25	23	24	25	25	25	25	25	25
2005	8	Median	21.1	9.33	7.6	0.88	108	195	52	2470	13	19	9
2005	8	Mean	20.9	9.16	7.3	0.94	131	205	56	2836	18	128	21
2005	8	LQ	19.2	9.06	6.6	0.64	55	151	33	2048	5	9	5
2005	8	UQ	22.4	9.48	8.6	1.22	172	228	71	3418	26	133	31
2005	9	n	18	18	18	16	18	18	18	18	18	18	18
2005	9	Median	14.1	8.90	8.1	0.72	140	194	41	2870	10	58	8
2005	9	Mean	14.2	8.92	8.1	0.79	137	198	40	2978	11	92	14
2005	9	LQ	13.2	8.79	7.3	0.67	89	162	27	2510	5	23	5
2005	9	UQ	15.1	9.07	8.8	0.97	169	237	52	3290	14	113	19
2006	6	n	16	16	16	16	16	16	16	16	16	16	16
2006	6	Median	18.3	7.99	7.2	1.61	12	54	15	715	23	53	2
2006	6	Mean	18.1	7.99	7.3	1.59	13	74	15	793	23	58	2
2006	6	LQ	17.5	7.75	7.0	1.46	6	50	13	674	19	47	1
2006	6	UQ	18.7	8.22	7.8	1.73	20	59	18	919	27	73	3
2006	7	n	24	24	24	24	24	24	24	24	24	24	24
2006	7	Median	22.2	9.33	7.4	0.88	112	188	48	2065	20	102	32
2006	7	Mean	22.2	9.11	7.1	0.94	111	212	60	2192	41	289	56
2006	7	LQ	21.6	8.81	5.3	0.73	37	135	7	1825	5	41	25
2006	7	UQ	22.8	9.53	9.2	1.21	137	243	116	2340	62	534	66
2006	8	n	16	16	16	16	16	16	16	16	16	16	16
2006	8	Median	20.7	9.71	8.3	0.71	99	246	95	3160	5	30	18
2006	8	Mean	20.7	9.75	8.5	0.66	147	269	90	3386	5	119	71

Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2006	8	LQ	20.1	9.37	7.7	0.40	76	198	69	1975	5	14	9
2006	8	UQ	21.2	10.17	9.7	0.91	177	293	105	4565	5	79	55
2006	9	n	16	16	16	12	16	16	16	16	16	16	16
2006	9	Median	16.9	9.98	10.0	0.60	143	255	94	2500	5	62	37
2006	9	Mean	16.7	9.99	9.8	0.58	200	287	94	3389	5	95	71
2006	9	LQ	14.1	9.80	8.3	0.32	89	231	77	2385	5	27	17
2006	9	UQ	19.0	10.16	11.3	0.84	224	300	100	3515	5	147	100
2007	6	n	16	16	16	16	16	16	16	16	16	16	16
2007	6	Median	17.8	8.93	8.6	1.19	28	116	36	899	5	20	3
2007	6	Mean	17.9	8.81	8.4	1.18	51	127	33	1101	30	28	4
2007	6	LQ	16.6	8.58	7.4	1.01	13	92	16	800	5	9	2
2007	6	UQ	19.0	9.04	9.6	1.46	57	123	48	1070	63	45	5
2007	7	n	24	24	24	24	24	24	24	24	24	24	24
2007	7	Median	21.8	9.92	7.3	0.62	141	303	111	3065	5	23	18
2007	7	Mean	21.5	9.92	7.3	0.60	160	312	94	3013	8	52	40
2007	7	LQ	20.1	9.88	5.9	0.40	101	255	28	2355	5	5	4
2007	7	UQ	22.6	10.01	8.7	0.75	223	361	134	3660	13	69	51
2007	8	n	16	16	16	16	16	16	16	16	16	16	16
2007	8	Median	20.3	9.39	7.3	0.61	122	256	106	2660	5	32	20
2007	8	Mean	20.2	9.41	6.5	0.62	135	293	101	3244	9	100	43
2007	8	LQ	19.5	9.26	5.0	0.44	68	236	88	2415	5	20	12
2007	8	UQ	21.0	9.57	7.7	0.84	203	304	116	3935	12	198	77
2007	9	n	16	16	16	16	8	16	16	16	16	16	16
2007	9	Median	15.0	9.23	9.2	0.66	88	199	50	2666	13	295	74
2007	9	Mean	15.4	9.18	8.4	0.63	123	209	63	2873	16	343	75
2007	9	LQ	12.5	9.04	7.4	0.51	85	178	39	2414	5	77	33
2007	9	UQ	18.5	9.34	9.5	0.74	151	245	84	3172	20	482	116
2008	6	n	23	23	23	23	23	23	23	23	23	23	23
2008	6	Median	17.8	8.95	9.2	1.03	48	77	18	1120	4	25	5
2008	6	Mean	18.3	8.82	9.2	1.00	67	102	19	1488	13	30	8
2008	6	LQ	15.2	8.05	8.2	0.71	14	59	17	737	4	20	1
2008	6	UQ	21.3	9.51	10.2	1.34	94	121	22	1903	18	36	14
2008	7	n	16	16	16	16	16	16	16	16	16	16	16
2008	7	Median	21.2	9.61	8.0	0.73	160	200	54	2600	7	20	14
2008	7	Mean	21.3	9.60	8.0	0.66	261	200	58	2604	7	93	43
2008	7	LQ	20.6	9.43	6.8	0.50	131	164	42	1855	4	17	12
2008	7	UQ	21.4	9.79	9.2	0.89	260	231	69	3035	10	77	49
2008	8	n	16	16	16	16	16	16	16	16	16	16	16
2008	8	Median	20.2	9.27	7.2	0.80	102	230	94	2870	9	153	68
2008	8	Mean	20.3	9.26	7.2	0.78	141	268	93	2892	10	190	61
2008	8	LQ	19.6	9.15	6.6	0.70	62	210	82	2070	4	25	12
2008	8	UQ	21.0	9.44	8.4	0.94	191	298	109	3405	13	287	100
2008	9	n	16	16	16	16	16	16	16	16	16	16	16
2008	9	Median	16.6	9.31	8.4	0.70	98	198	66	2475	10	35	12
2008	9	Mean	16.5	9.16	7.4	0.71	155	253	72	3116	11	314	30
2008	9	LQ	15.6	9.04	6.0	0.62	64	181	54	2055	9	23	10
2008	9	UQ	17.5	9.48	9.1	0.89	159	267	85	3255	12	152	32
2009	6	n	24	24	24	24	23	24	24	24	24	24	24

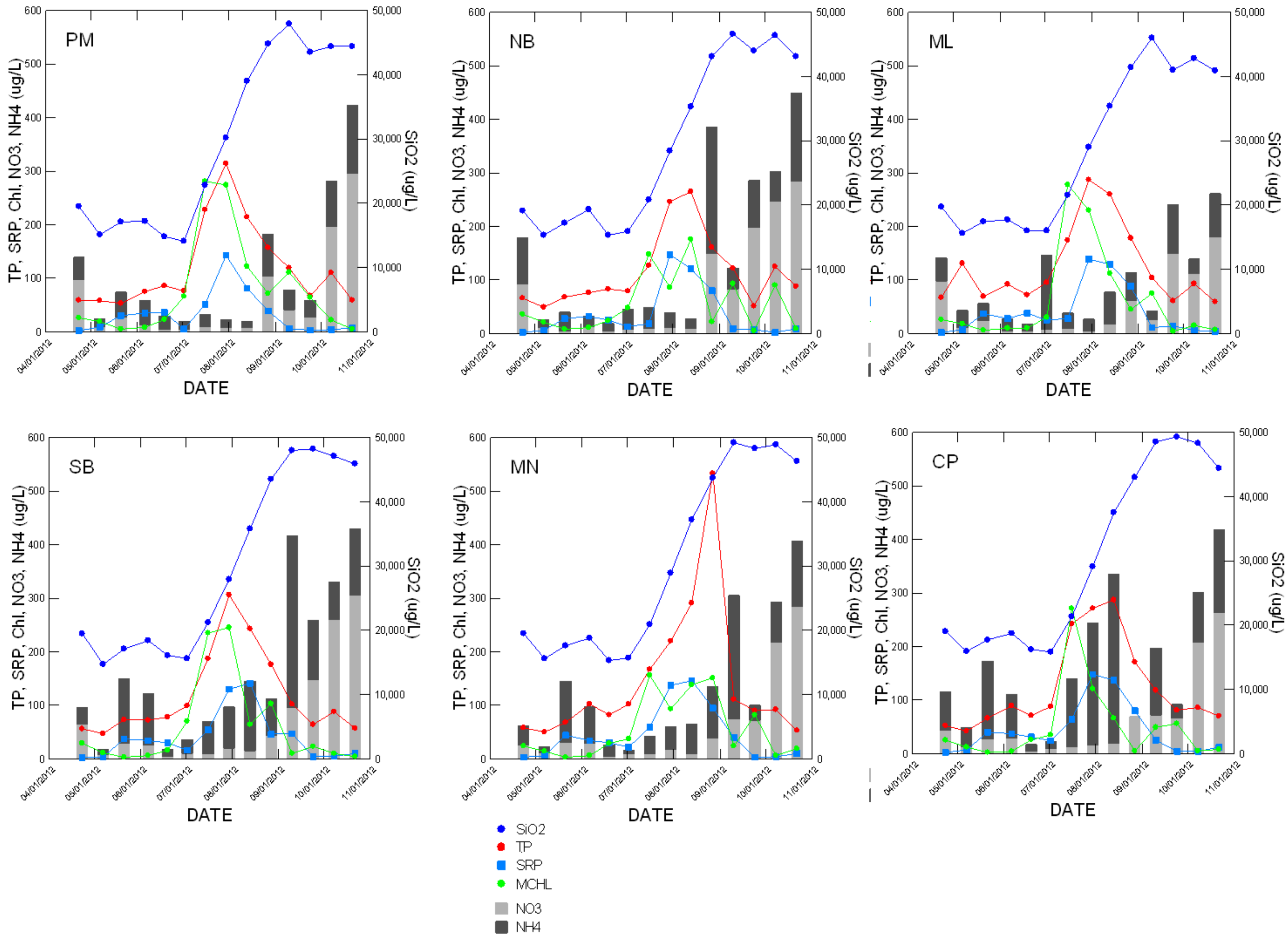
Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2009	6	Median	18.4	9.29	8.4	0.86	95	68	6	1670	4	19	8
2009	6	Mean	19.0	9.09	8.3	0.90	136	82	6	1735	5	26	9
2009	6	LQ	18.1	8.77	7.5	0.74	60	46	4	987	4	13	2
2009	6	UQ	19.7	9.42	9.0	1.10	176	99	7	1990	4	29	11
2009	7	n	16	16	16	16	16	16	16	16	16	16	16
2009	7	Median	21.8	8.47	5.7	1.51	45	160	60	2175	21	456	36
2009	7	Mean	21.8	8.34	5.7	1.61	50	157	72	2081	29	559	41
2009	7	LQ	19.7	7.63	4.6	1.09	16	136	41	1740	13	248	14
2009	7	UQ	23.6	8.92	7.0	2.04	60	171	97	2330	39	903	58
2009	8	n	15	15	15	16	16	16	16	16	16	16	15
2009	8	Median	19.6	9.69	8.9	0.68	167	192	41	2115	6	22	12
2009	8	Mean	19.5	9.74	8.9	0.62	186	195	48	2353	7	68	47
2009	8	LQ	19.1	9.20	7.9	0.48	132	155	27	1855	4	17	8
2009	8	UQ	20.1	10.25	10.8	0.80	230	213	69	2800	9	35	23
2009	9	n	16	16	16	16	16	16	16	16	16	16	16
2009	9	Median	16.5	9.81	7.8	0.57	175	241	91	2810	4	121	86
2009	9	Mean	16.4	9.77	7.4	0.62	183	251	82	3103	8	266	137
2009	9	LQ	15.8	9.66	6.6	0.48	143	218	69	2470	4	33	23
2009	9	UQ	17.0	9.92	8.2	0.77	223	280	96	3670	10	380	231
2010	6	n	24	24	24	24	24	24	24	24	24	24	24
2010	6	Median	16.6	8.35	8.5	1.07	12	48	4	603	4	10	0
2010	6	Mean	16.9	8.22	8.7	1.10	14	50	5	624	5	12	1
2010	6	LQ	13.5	7.70	8.1	0.98	3	44	3	547	4	7	0
2010	6	UQ	20.1	8.55	9.2	1.20	16	55	6	642	8	17	1
2010	7	n	20	20	20	20	20	20	20	20	20	20	20
2010	7	Median	22.3	9.51	9.1	0.99	107	82	8	1660	4	29	15
2010	7	Mean	22.1	9.51	8.4	0.92	121	108	20	1779	6	83	43
2010	7	LQ	21.3	9.40	6.8	0.64	60	67	6	1370	4	14	9
2010	7	UQ	22.9	9.67	9.6	1.14	149	153	27	2125	4	153	87
2010	8	n	16	16	16	16	16	16	16	16	16	16	16
2010	8	Median	20.4	9.42	8.6	0.71	135	181	46	2120	10	43	22
2010	8	Mean	20.4	9.23	8.5	0.81	153	184	53	2305	18	175	37
2010	8	LQ	19.2	8.93	7.7	0.52	81	163	39	1920	4	25	14
2010	8	UQ	21.7	9.58	9.8	0.96	190	200	71	2640	20	289	66
2010	9	n	16	16	16	16	16	16	16	16	16	16	16
2010	9	Median	15.9	9.50	9.0	0.74	215	176	31	2420	9	31	18
2010	9	Mean	15.9	9.46	9.0	0.69	216	206	34	2852	11	124	32
2010	9	LQ	15.0	9.37	7.8	0.56	112	147	26	2225	4	27	14
2010	9	UQ	16.9	9.64	10.9	0.81	284	221	37	2905	12	99	40
2011	6	N of Cases	24	24	24	24	24	24	24	24	24	24	24
2011	6	Median	16.1	8.06	8.4	1.05	13	48	5	655	14	50	1
2011	6	Arithmetic Mean	15.2	8.10	8.4	1.17	14	49	5	666	18	49	1
2011	6	LQ	10.6	7.98	7.9	0.95	9	42	4	605	10	36	1
2011	6	UQ	19.0	8.26	9.3	1.50	16	52	7	698	27	68	2
2011	7	N of Cases	16	16	16	16	16	16	16	16	16	16	16
2011	7	Median	20.1	9.59	10.2	0.77	115	97	7	1665	4	23	14
2011	7	Arithmetic Mean	19.8	9.63	9.8	0.76	136	107	8	1743	5	33	19
2011	7	LQ	18.6	9.49	8.9	0.71	97	88	4	1500	4	17	12

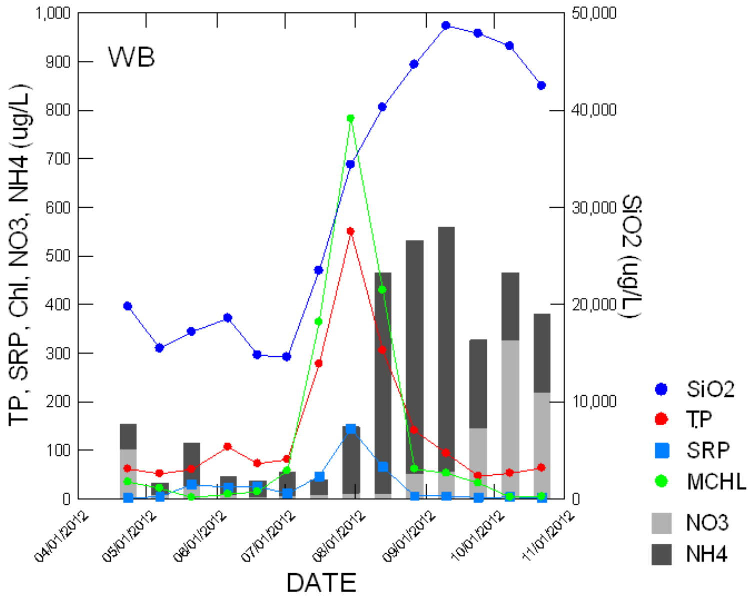
Year	Month	Parameter	Temp-erature (oC)	pH	Dissolved Oxygen (mg/L)	Secchi Depth (m)	Chloro-phyll a (µg/L)	Total Phosphorus (µg/L)	Soluble Reactive Phosphorus (µg/L)	Total Nitrogen (µg/L)	NO3+NO2 Nitrogen (µg/L)	NH4 Nitrogen (µg/L)	Un-ionized Ammonia (µg/L)
2011	7	UQ	20.8	9.73	10.5	0.83	167	122	10	1805	4	36	22
2011	8	N of Cases	16	16	16	16	16	16	16	16	16	16	16
2011	8	Median	22.0	9.05	7.4	1.03	43	206	71	1870	19	114	47
2011	8	Arithmetic Mean	21.7	9.03	7.3	1.01	85	218	75	2092	25	200	55
2011	8	LQ	21.4	8.85	5.5	0.78	8	184	64	1525	16	49	19
2011	8	UQ	22.5	9.28	9.6	1.41	81	228	83	2285	26	292	74
2011	9	N of Cases	16	16	16	16	16	16	16	16	16	16	16
2011	9	Median	18.1	8.98	8.8	0.79	87	187	35	1660	24	166	28
2011	9	Arithmetic Mean	18.3	8.91	8.4	0.89	93	186	52	1772	31	172	35
2011	9	LQ	16.7	8.72	6.4	0.65	51	145	14	1525	14	40	10
2011	9	UQ	20.1	9.11	10.3	1.01	116	211	96	1890	43	279	62
2012	6	N of Cases	16.0	16.00	16.0	16.00	16	16	16	16	16	16	16
2012	6	Median	16.4	8.13	8.5	1.03	11	80	32	687	6	24	1
2012	6	Arithmetic Mean	16.3	8.10	8.4	1.04	14	82	31	692	11	36	1
2012	6	LQ	15.1	7.82	8.2	0.94	7	73	29	622	4	18	1
2012	6	UQ	17.8	8.33	8.7	1.15	24	88	35	734	19	50	2
2012	7	N of Cases	24.0	24.00	24.0	24.00	24	24	24	24	24	24	24
2012	7	Median	21.1	9.65	8.7	0.58	152	183	49	1975	9	38	23
2012	7	Arithmetic Mean	20.7	9.62	8.7	0.63	185	202	68	2180	11	64	39
2012	7	LQ	19.5	9.29	6.8	0.40	68	101	20	1155	9	25	16
2012	7	UQ	21.8	9.93	10.6	0.91	258	275	138	2770	12	69	46
2012	8	N of Cases	16.0	16.00	16.0	16.00	16	16	16	16	16	16	16
2012	8	Median	21.0	9.09	6.7	0.80	69	223	92	2085	35	114	34
2012	8	Arithmetic Mean	21.1	9.04	6.4	0.78	100	239	95	2243	43	266	55
2012	8	LQ	19.9	8.86	4.1	0.58	34	174	73	1980	13	58	25
2012	8	UQ	22.4	9.37	9.2	1.04	130	276	133	2260	57	467	72
2012	9	N of Cases	16.0	16.00	16.0	16.00	16	16	16	16	16	16	16
2012	9	Median	18.1	8.03	7.5	0.81	51	92	8	1520	79	101	3
2012	9	Arithmetic Mean	17.9	8.08	7.0	0.85	49	88	13	1524	97	137	4
2012	9	LQ	17.3	7.72	5.9	0.73	24	63	4	1175	62	35	2
2012	9	UQ	18.6	8.37	7.9	1.02	71	115	18	1715	147	206	7

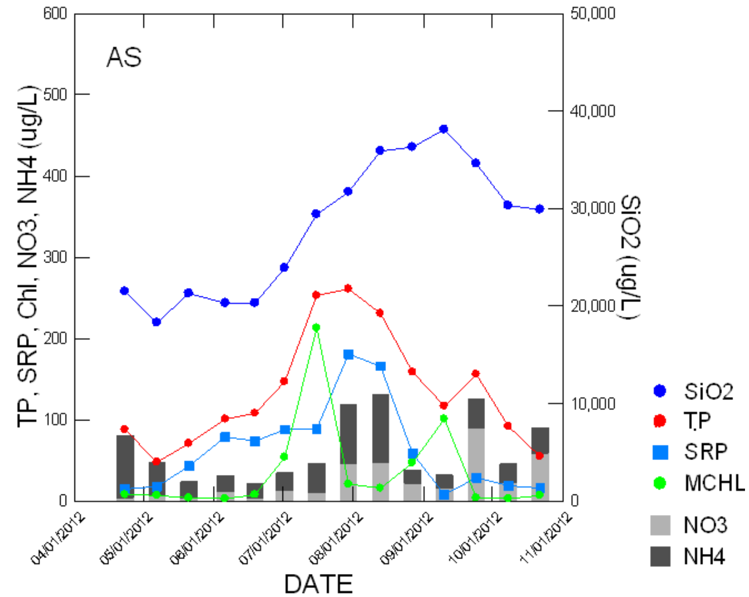
APPENDIX III: 2012 Seasonal trends in silica and other nutrient parameters in UKL (lake-wide mean shown with standard error).

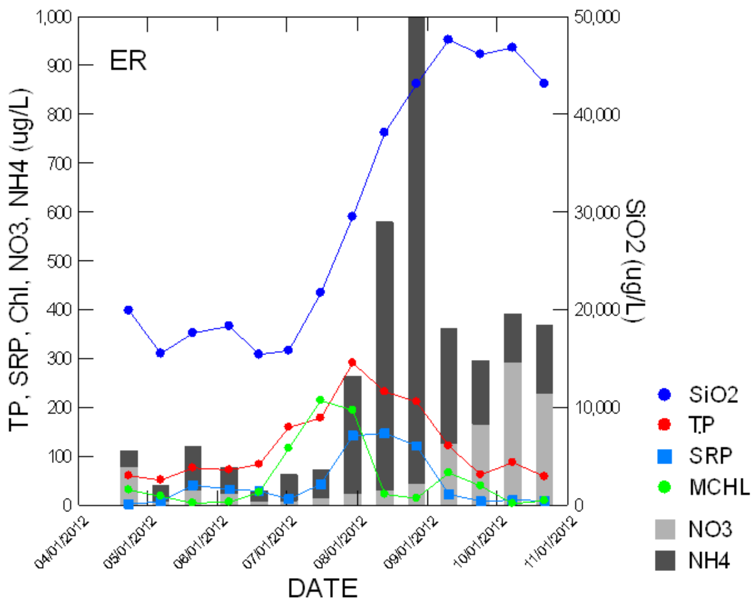


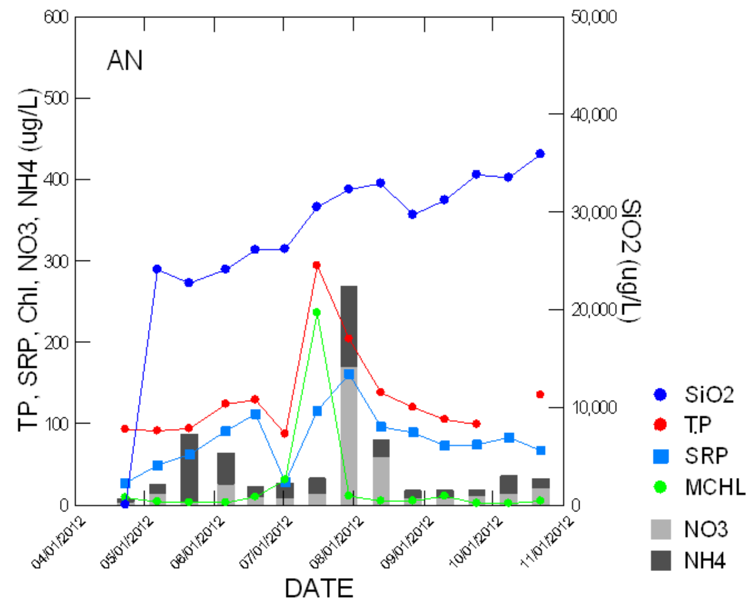
2012 Seasonal trends in silica and other nutrient parameters by station in UKL




WB
TP, SRP, Chl, NO3, NH4 (ug/L)
SiO2 (ug/L)
DATE
SiO2
TP
SRP
MCHL
NO3
NH4


AS
TP, SRP, Chl, NO3, NH4 (ug/L)
SiO2 (ug/L)
DATE
SiO2
TP
SRP
MCHL
NO3
NH4


ER
TP, SRP, Chl, NO3, NH4 (ug/L)
SiO2 (ug/L)
DATE
SiO2
TP
SRP
MCHL
NO3
NH4


AN
TP, SRP, Chl, NO3, NH4 (ug/L)
SiO2 (ug/L)
DATE
SiO2
TP
SRP
MCHL
NO3
NH4