Does allochthonous dissolved organic matter increase during summer algal bloom conditions in an agricultural reservoir?

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Abstract

Cyanobacterial harmful algal blooms (cyanoHABs) are increasing in frequency worldwide. CyanoHABs can produce toxins (e.g., microcystin), which can be a contaminant in recreational and drinking water reservoirs. Reservoirs have been increasing worldwide, highlighting the importance of understanding their biogeochemical processes. Dissolved organic matter (DOM) is a reactive and readily available source of nitrogen (N) and carbon (C) for microbes in aquatic systems, however, the relationships between DOM and cyanoHABs remain relatively unexplored in agricultural reservoirs. Our primary objective is to determine if an increase in allochthonous DOM leads to an increase in autochthonous DOM during a summer cyanobacterial bloom event in a warm monomictic agricultural reservoir. Water samples were collected two to three times per week from June 21st until October 5th, 2018 and analyzed for algal biomass and community composition, DOM quality and quantity. A variety of spectral parameters were used to determine DOM quality. One cyanobacterial bloom event was detected on July 16th. Maximum microcystin concentration for the sampling period was 0.68 μgL^{-1} which is well under the EPA recommended recreational limit (8 μgL^{-1}). Dissolved organic carbon (DOC) concentrations were positively correlated with high amounts of terrestrial DOM. DOC concentrations and a_{350} also correlated positively with microcystin concentrations. Specific UV absorbance at 254nm ($SUVA_{254}$) correlated positively with Chl-*a* (r=0.37, p=0.033). Our findings indicate that high DOM quantity has a significant relationship to microcystin concentration, which has negative implications for recreation and drinking water quality.

Introduction

Over the past several decades, cyanobacterial harmful algal blooms (cyanoHABs) have been increasing in frequency worldwide (Huisman et al. 2018). Reservoirs are a primary drinking water and recreation source which can be contaminated by cyanobacteria and lead to the deaths of fish, birds, and even mammals (Chen et al. 2016). As such, it is important that we fully understand the biogeochemical processes that may lead to the formation of toxin producing cyanoHABs.

Dissolved organic matter (DOM) is a reactive, readily available source of carbon (C) and nitrogen (N) for microbes in aquatic systems (Jaffé et al. 2008). Excessive nutrient inputs can lead to eutrophication in aquatic systems (Jones and Bachmann 1975). Previous studies have shown a relationship between nutrients such as phosphorus (P) and N and the formation of algal blooms (Jones et al., 2004; Paerl et al. 2011; Xu et al. 2015). Although there is extensive literature about the effects of N and P on algal blooms (Levine and Schindler 1998; Smith et al. 2006; Jankowiak et al. 2019,), the impacts of dissolved organic matter (DOM) cycling and its relationship to cyanoHABs and toxin concentrations in reservoirs remains relatively unexplored. High concentrations of DOM can lead to serious water quality issues including the formation of algal blooms and fish kills as a result of low oxygen concentrations (Creed et al. 2018). DOM may also be contributing to a shift in phytoplankton communities that favors potentially toxin producing cyanobacteria (Creed et al. 2018), though more research is needed to establish the relationship. Current knowledge about DOM and C cycling comes largely from studies in coastal and marine systems (Zhao et al. 2009, Osburn and Stedmon 2011, Dixon et al. 2014). Those conducted in freshwater have focused on natural systems such as large rivers and natural lakes (Green and Blough 1994, Cole et al. 2007). It is important to understand inland reservoir

biogeochemistry and C cycling, as reservoirs contribute significantly to the global C cycle (Downing et al. 2006) and have been increasing in number globally (Zarfl et al., 2014).

Small reservoirs have been identified as important sites for C burial (Cole et al. 2007) and efflux (Jones et al. 2016, Pittman et al. 2013); however, DOM cycling has not been thoroughly investigated in small agricultural reservoirs in regards to cyanotoxin concentrations. The water quality implications of DOM have been studied in a small subtropical reservoir (Liu et al. 2014); however, possible links with algal blooms, and more specifically with algal toxins, have not been thoroughly explored in small, agricultural reservoirs. Small farm reservoirs make up a significant portion of freshwater water bodies in the United States (Downing et al. 2006). Agricultural reservoirs are particularly vulnerable to eutrophication and cyanobacterial blooms (Downing et al. 1999, Wang et al. 2005). The state of Missouri, USA alone has over 190,000 reported small farm ponds (Smith et al. 2002). Missouri waterbodies are primarily man-made reservoirs and 63% of Missouri land use is classified as agricultural (Jones and Knowlton, 1993) which highlights the importance of understanding the biogeochemistry of these systems.

Previous research has established a positive relationship between high amounts of precipitation events and frequent bloom formation. This is largely due to the influx of nutrients (N and P) into water bodies during a rain event (Michalak et al., 2013). There is also a positive relationship between high amounts of terrestrial DOM and high amounts of precipitation Dixon et al., 2014). This research highlights the importance of understanding how rainfall may be affecting DOM influx into reservoirs.

The optical properties of DOM have been found to be useful in identifying DOM quality (Helms et al., 2008). Our study uses a range of spectrophotometric parameters to determine the source and reactivity of DOM in an agricultural reservoir. Our primary objective is to determine

if an increase in allochthonous DOM leads to an increase in autochthonous DOM during a summer cyanobacterial bloom event in a warm monomictic agricultural reservoir. Therefore, we also examine precipitation patterns during the sampling period to determine if changes in DOM are also impacted by precipitation in small agricultural systems.

Methodology

Study Site

An observational study was conducted on Dairy Farm Lake #1, a reservoir in Boone County, Missouri, USA (38°99'38"N, 92°48'90"S). Dairy Farm Lake is located on the University of Missouri Experimental Foremost Dairy Farm and is in an agricultural watershed co-managed by the University of Missouri and the Missouri Department of Conservation (MDC). MDC manages the fish populations and the lake is open to the public for recreational fishing. Dairy Farm Lake has a surface area of 56,160 m^2 (~15 acres) and a total water volume of 123,920 m^3. The 639,997 m^2 watershed is 62.94% crop land and 31.85% pasture. The mean depth for Dairy Farm Lake is 2.21 m with a maximum of 4.62 m. All water samples were collected in front of the earthen dam at a depth of 4.3 m.

Dairy Farm Lake has been monitored annually by the University of Missouri Limnology Laboratory as part of the Statewide Lake Assessment Program since 2006, excluding 2015. Annual monitoring includes analysis of Total Phosphorus (TP), Total Nitrogen (TN), Total Suspended Solids (TSS), and Chlorophyll-*a* (Chl-*a*) concentrations (Table 1; Eaton et al. 1995). TP and TN are measured using a digestion and spectrophotometric method (APHA 4500-P E; Crumpton et al. 1992). Dairy Farm lake is hypereutrophic, based on nutrient criteria of Chl-*a* >40

117 μgL^{-1}, TP>100 $\mu g\ L^{-1}$, and TN>1200 $mg\ L^{-1}$ (Jones et al 1993). The average historical Chl-*a*
118 concentration for Dairy Farm Lake from 2006-2017 is 106.6 μgL^{-1} (9.2–772.6 μgL^{-1}; Table 1).

119 *Sampling*

120 Samples were collected three times per week from June 21st until October 5th, 2018.
121 Temperature profiles were measured each sampling day using a YSI EXO 3 temperature probe.
122 Profiles were examined in the field to determine the depth of the thermocline. Mixing depth was
123 later calculated using the Lake Analyzer package in R (Winslow et al., 2018); the lake was
124 stratified for the duration of the sampling season. Photosynthetically Active Radiation (PAR)
125 was measured using a Li-Cor LI-1500 cosine sensor in quarter meter increments at the water
126 collection site. The light attenuation coefficient (K_d) was later calculated as described in Kirk
127 (1994). Secchi disk depth and water level changes were also measured each sampling day. A
128 meter stick was placed in the water next to the dam and changes were monitored each sampling
129 day. Precipitation data was collected from the Sanborn Field Weather Station located in
130 Columbia, MO, USA.

131 Samples for analysis of DOM, DOC, and Chl-*a* were collected from both the epilimnion
132 and hypolimnion in 2L polycarbonate bottles. Bottles were previously acid washed and triple
133 rinsed with lake water at the sample site before sample collection. Epilimnetic samples were
134 collected using an integrated sampler from the surface to 0.5 m depth. Discrete hypolimnetic
135 samples were taken one meter off the bottom of the reservoir (~3 m from surface) using a Van
136 Dorn sampler. Whole water samples were stored away from light and taken back to the lab for
137 processing on the same day. Water samples to be used for cyanotoxin analysis were collected in
138 polyethylene terephthalate glycol (PETG) bottles to prevent contamination (Kamp et al. 2016).
139 *Chlorophyll-a, phytoplankton community composition and biovolumes, and cyanotoxin analyses*

Three freeze-thaw cycles were conducted on the toxin samples. Algal toxin samples were filtered through 0.45μm filters and concentrations were then analyzed using Abraxis® ELISA kits with a detection limit of 0.15 μgL^{-1} and an ELISA Microplate Reader (Carmichael and An, 1999). Phytoplankton samples were collected from the epilimnion and preserved with Lugols solution. Chlorophyll-*a* (Chl-*a*) concentrations were measured as a proxy for algal biomass. The seasonal mean for Dairy Farm Lake is based on annual samples collected four times per summer from 2006 to 2018 as part of the Statewide Lake Assessment program. Whole water samples were filtered through 0.7 μm GF/F filters. Chl-*a* concentration was determined via extraction with ethanol and fluorometry using a Turner Designs TD-700 Fluorometer and was corrected for pheophytin (Phe-*a*; Knowlton and Jones 1995).

Dissolved organic carbon

Whole-water samples from both the epilimnion and hypolimnion were filtered through pre-combusted 0.7 μm GF/F filters. The filtrate was used for DOM analysis and absorbance spectroscopy. To determine DOM quantity, we measured dissolved organic carbon concentration (DOC). Prior to analysis, water samples were acidified (pH < 3) with 1 M H_2SO_4 to convert inorganic carbon to CO_2 gas. DOC was measured using a high temperature combustion method (APHA 5310 B) on a Shimadzu TOC-V_{CPH}; detection limit 0.2 mgL^{-1}. Samples were air sparged for 7.5 minutes to remove the inorganic carbon. Each sample was measured in two pre-combusted vials, and each of the two vials were measured twice (quadruplicate). Reported DOC concentrations are the average of these four measurements. If the coefficient of variance (CV) of the four measurements was greater than 5, the sample was re-analyzed.

DOM absorbance spectra

An indicator of DOM quantity (a_{350}) was also determined using UV absorbance spectroscopy on an Agilent Cary 60 UV-Vis spectrophotometer. Each sample was scanned from 200 to 800 nm in a 1 cm quartz cuvette. All samples were blank corrected by subtracting the absorbance of UltraPure DI water. Absorption was converted to Napierian absorption coefficient with the equation $a_\lambda = 2.303 A_\lambda \ L^{-1}$ (Osburn and Stedmon, 2011), where a is the absorption coefficient, A is measured absorbance at wavelength λ, and L is the pathlength of the cuvette in meters.

DOM quality (i.e., source and reactivity) was also determined using UV absorbance spectroscopy. Specific UV Absorbance (SUVA), normalized for DOC concentration, was calculated at 254nm (a_{254}/[DOC]). $SUVA_{254}$ provides an indication of molecular weight and aromaticity (Weishaar et al. 2003). Higher $SUVA_{254}$ values are associated with aromatic and allochthonous terrestrially derived DOM (Dixon et al. 2014). The spectral slope ratio was used to characterize both molecular weight and DOM source. Slope ratio (S_R) was calculated as the ratio of the slopes from wavelengths 275–295 to 350–400 nm ($S_{275\text{-}295}/S_{350\text{-}400}$ where S is the slope of the absorbance fitted to a single exponential decay function via non-linear regression; Helms et al. 2008). S_R values greater than one are indicative of autochthonous organic matter with a low molecular weight, while S_R values less than one indicate allochthonous organic matter with a high molecular weight (Helms et al. 2008). A definition of all measured parameters can be found in Table 2.

Statistics and Data Analysis

Prior to conducting parametric statistics, the data were confirmed to be normal using a Shapiro-Wilk Test (p>0.05; Base R). All parameters were analyzed for differences between the epilimnion and hypolimnion using a one-way analysis of variance test (ANOVA; multcomp)

with the data aggregated into weekly groups. ANOVA was also used to determine differences in each parameter between weeks. Correlation coefficients were calculated using the Pearson method (Hmisc). Correlations were determined to be significant at $p<0.05$.

Results

Limnological variables and precipitation

The reservoir was stratified for the duration of the sampling period (June 21st to October 5th) with an average mixing depth of 2.21 m (range 1.0–4.2). Mean Secchi disk depth for the sampling period was 0.4 m (range 0.3–0.7). The water level did not change during the sampling period as it was a relatively dry season with two significant precipitation events that preceded the detected algal blooms. There was 8.4 mm of rainfall two days before the first bloom occurred on July 16th. Similarly, there was 11.9 mm of rainfall four days before the second bloom on September 12th.

There were significant differences between the epilimnion and hypolimnion for all measured parameters excluding microcystin. The mean Chl-*a* for the epilimnion during the sampling season was 87.0 μg Chl-*a* L^{-1} (Table 3). Mean dissolved organic carbon (DOC) concentration in the epilimnion was 9.7 mg C L^{-1} with a maximum of 10.9 mg C $L^{-1}$and a minimum of 8.8 mg C L^{-1}. DOC concentration in the hypolimnion was significantly lower than that of the epilimnion (Table 4) with a mean 9.4 mg C L^{-1}, a maximum of 10.9 mg C $L^{-1}$and a minimum was 8.4 mg C L^{-1}.

Cyanobacterial bloom detection

We define a bloom as any deviation from established seasonal Chl-*a* means for the system (Carstensen and Henriksen 2007). The seasonal Chl-*a* mean for Dairy Farm Lake was

106.6 µg Chl-*a* L^{-1} (Table 1). We captured two bloom events during our sampling period which had significantly higher concentrations of Chl-*a* than the seasonal mean (Figure 1). The first occurred on July 16th, with a peak Chl-*a* value of 162.5 µg Chl-*a* L^{-1}. This bloom was dominated by cyanobacteria (counts; Figure 2) and had a peak microcystin concentration of 0.6 µg MC L^{-1}. A second bloom event occurred on September 12th with a peak Chl-*a* value of 135.6 µg Chl-*a* L^{-1}. This bloom had a microcystin concentrations half that of the first bloom (0.3) µg MC L^{-1} (Figure 3, A). Unlike the first bloom event, the second bloom (September 12th) was not dominated by cyanobacteria (counts; Figure 2). Microcystin concentrations in the hypolimnion were not significantly different than in the epilimnion, however, the mean for the sampling period was 0.4 µg MC L^{-1} (0.15 µg MC L^{-1} to 0.78 µg MC L^{-1}).

Algal community composition

Preliminary data from phytoplankton counts show that the initial bloom (July 16, 2019) was *Dolichospermum* (formerly known as *Anabaena*.). After this bloom collapsed, there was a second bloom of *Raphidiopsis* (formerly known as *Cylindrospermposis*). It is interesting that these genera were in such high abundance in the reservoir despite the microcystin concentration never being below the detection limit (0.15 µg MC L^{-1}) in any of our samples. It is suprprising that microcystin producing species were not the highest in abundance. Further study should include toxins produced by these genera of algae.

Relationship between DOM, Chl-a, and microcystin concentrations

There were significant correlations between the measured DOM parameters and Chl-*a* concentrations. There was no relationship between DOC and Chl-*a*; however, DOM quality assessed by a_{350} and $SUVA_{254}$ were positively correlated with Chl-*a* (Figure 4). The mean

229 microcystin concentration in the epilimnion was 0.3μg L^{-1} (0.15 μg MC L^{-1} to 0.68 μg MC L^{-1};
230 Table 3).

231 There were significant correlations between DOM quantity and quality and microcystin
232 concentrations. In the epilimnion, DOC correlated positively with microcystin concentrations
233 (Figure 5). A significant correlation between these two parameters was also found in the
234 hypolimnion, though the correlation in the hypolimnion was stronger (r=0.63, p<0.0005) than in
235 the epilimnion. Significant positive correlations were also found between a_{350} and microcystin;
236 however, it was stronger in the hypolimnion (r=0.49, p<0.003) than in the epilimnion (r=0.34,
237 p=0.047). There was no relationship between $SUVA_{254}$ and microcystin in the epilimnion;
238 however, there was a significant positive correlation between the two in the hypolimnion
239 (r=0.35, p=0.040). There were also significant correlations between S_R and a_{350} (r=0.65,
240 p<0.0005), and S_R and $SUVA_{254}$ (r=0.51, p=0.002). S_R was greater than one for the duration of
241 the sampling period indicating high amounts of algal DOM consistently throughout the summer.
242 S_R did not significantly change during the sampling period.

243 **Discussion**

244 The goal of this project was to determine how DOM quantity and quality changes
245 summer algal bloom in an agricultural reservoir. While we saw significant decreases in
246 allochthonous DOM during bloom conditions, there were no significant increases in
247 autochthonous DOM during the bloom event. S_R, the index used for autochthonous DOM did not
248 significantly change during the bloom events; however, values were greater than 1 for the
249 duration of the sampling period, indicating consistently high amounts of autochthonous DOM
250 (Dixon et al. 2014).

Did terrestrial DOM quantity decrease during bloom conditions?

High a350 and $SUVA_{254}$ values for the duration of the study indicate that this reservoir contains high amounts of terrestrial and aromatic DOM. $SUVA_{254}$ was significantly lower in the hypolimnion during the cyanobacterial bloom than much of the sampling period (Figure 3B). Phytoplankton degradation is known to be a major source of DOM during algal blooms and terrestrially derived DOM has more influence on DOM composition during non-bloom conditions (Zhao et al. 2009). This seems to be the case in our data as well; however, the significant decrease in $SUVA_{254}$ during the bloom occurred only in the hypolimnion. There was also a significant increase in S_R in the hypolimnion, which may indicate phytoplankton degradation and accumulation in bottom waters. We would also expect to see a decrease in $SUVA_{254}$ in the epilimnion as well as the hypolimnion, since the bloom is occurring in the epilimnion. It is not clear what would cause such a sharp decrease in $SUVA_{254}$ only in the hypolimnion while there was no significant change in the epilimnion during the bloom.

Significant positive relationships were observed between DOC concentrations, Chl-*a*, and microcystin. This suggests that there is a relationship between the amount of DOM in an aquatic system and algal abundance. This is supported by previous research that has shown DOM to be a source of nitrogen and carbon for algae (Jaffé et al. 2008). However, research to support a relationship between DOM quantity and microcystin concentration is lacking.

There was a decrease in DOC from the beginning to the end of the sampling period in both the epilimnion and the hypolimnion. It is possible that this occurred because the algae were taking up C. In a mesocosm study, a decrease in DOC was documented during an algal bloom. The authors concluded that it was likely because algae were using the DOC which is likely what happened in this study as well. It is also possible that C assimilation by phytoplankton may have

played a role in sustaining the cyanobacterial bloom (Bai et al. 2017; Morales-Williams et al. 2017). At the beginning of the bloom, we saw an increase of allochthonous DOM. As the first bloom progressed, these values decreased, indicating that the algae were using this as a source of nutrients. As the bloom subsided, we saw allochthonous DOM increase again in both the epilimnion and hypolimnion. This suggests a sustained input of allochthonous DOM. This may be the result of runoff from precipitation events as such events were recorded several days before each bloom. Research from under ice algal blooms also supports a relationship between DOM quantity and cyanobacterial biomass (Roiha et al. 2016). It is possible that in this system as well that there is a positive relationship between DOM quantity and algal biomass.

Does DOM quality and quantity correlate with toxin concentration?

We found a significant positive relationship between DOM quantity and microcystin concentration. To our knowledge, no other studies have looked for a relationship between DOM and toxin concentrations. The relationship observed between DOM quantity and cyanobacterial biovolume suggests that there is an interesting dynamic between DOM and algal community structure. DOM has implications for microcystin concentration during bloom events as well. Microcystin concentrations during first the bloom event exceeded 0.3 μgL^{-1}, the EPA 10-day drinking water health advisory limit for young children (U.S. EPA 2015), but were well under 8.0 μgL^{-1}, the EPA recommended swimming advisory limit (U.S. EPA 2019). While our measurements come from raw water, this does highlight concern for the relationships between DOM and toxin concentrations. We did not find any indication of a relationship between DOM quality and toxin concentration. While we tested for relationships between all previously mentioned DOM quality parameters and microcystin, none of them were significant.

It is notable that there was no significant difference in microcystin concentrations between the epilimnion and hypolimnion. Since blooms occur in the epilimnion in shallow systems such as this one, it is interesting that microcystin in the hypolimnion were never below the detection limit. This may indicate that microcystin is accumulating in the bottom waters as the bloom crashes or that it is being released from sediments (Zastepa et al. 2015).

Conclusion

The results of this study show that there is a relationship between DOM quantity and quality, cyanobacterial bloom formation, and toxin concentration. However, it begs the question: are changes in DOM facilitating cyanobacteria bloom formation and toxin concentrations or did the bloom itself drive the changes in DOM? Unfortunately, we are unable to parse out this distinction with our data. To do this would likely require mesocosm experiments with additions of known quantities and known types of DOM (Rochelle-Newall et al. 1999).

Our results highlight the importance of understanding the relationships between DOM, cyanobacterial blooms, and toxin concentrations. There remains much to learn about DOM cycling and its relationship with toxin concentration, particularly in man-made systems. Harmful algal blooms and reservoirs are both increasing worldwide; however, to our knowledge no studies resolving the relationships between DOM and cyanotoxin concentration in reservoirs have been published. As cyanobacterial blooms and reservoirs continue to increase, the importance of understanding what factors cause increases in algal biomass and toxin concentration will become essential to finding potential solutions. Reservoirs are increasing worldwide and are an important source of freshwater for much of the population. As such, it is important that we fully understand the implications of DOM for cyanoHABs and algal toxicity.

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Tables and Figures

Table 1. Characterization table of Dairy Farm Lake #1 from 2006 to 2018 for Total Phosphorous (TP), Total Nitrogen (TN), Chlorophyll-*a* (Chl-*a*), Total Suspended Solids (TSS), and Secchi disk depth (Secchi Transparency).

Year	TP ($\mu g\ L^{-1}$)	TN ($\mu g\ L^{-1}$)	Chla ($\mu g\ L^{-1}$)	TSS ($mg\ L^{-1}$)	Secchi depth (m)
2006	118	2137	69.9	3.7	0.5
2007	105	1645	70.1	4.5	0.6
2008	249	1928	100.4	6.1	0.4
2009	191	2576	108.2	5.8	0.4
2010	218	2781	100.4	3.9	0.4
2011	291	2768	83.8	7.7	0.3
2012	127	1589	54.2	4.3	0.6
2013	148	1544	56.8	6.1	0.6
2014	100	1629	73.3	2.2	0.7
2016	103	1238	55.8	3.6	0.6
2017	95	1463	51.4	1.3	0.6
2018	101	1580	44.7	13.3	0.4

Table 2. Abbreviations, units, and definition of each parameter measured or calculated.

Parameter	Units	Definition
Chl-*a*	$\mu g\ L^{-1}$	Chlorophyll-*a* is used as an indicator of algal biomass.
Microcystin	$\mu g\ L^{-1}$	Hepatotoxin released by cyanobacteria and contained within their cells.
DOC	$Mg\ L^{-1}$	Dissolved organic carbon. Used as a measurement of DOM quantity.
a_{350}	m^{-1}	Napierian absorbance coefficient at 350 nm. a350 is an indicator of terrestrially derived dissolved organic matter.
$SUVA_{254}$	$Lmg^{-1}Cm^{-1}$	Specific UV absorbance (SUVA) at 254nm. SUVA is calculated as the Napierian absorption coefficient at 254nm divided by DOC concentration. High $SUVA_{254}$ indicates high molecular weight and high aromaticity.
S_R	unitless	Slope Ratio. S_R values lower than one are indicative of allochthonous organic matter with a high molecular weight. S_R values greater than one are indicative of autochthonous organic material with high molecular weight.

Table 3. Summary table of parameters from 2018 sampling season (June 21-October 5) of Dairy Farm Lake #1 including mean, minimum, and maximum values from the epilimnion and hypolimnion. Definitions of each parameter and units can be found in Table 2.

	Epilimnion			**Hypolimnion**		
	Mean	Minimum	Maximum	Mean	Minimum	Maximum
DOC	9.7	8.7	10.9	9.4	8.4	10.9
Chl-*a*	87.0	40.6	162.5	142.9	25.8	384.2
a_{254}	39.0	34.9	42.9	48.3	35.1	63.2
$SUVA_{254}$	4.0	3.8	4.4	5.1	3.9	6.7
S_R	23.1	4.7	168.5	12.0	3.1	32.2
Microcystin	0.3	0.2	0.7	0.4	0.2	0.8

Table 4. One-way ANOVA results for parameters grouped by week measured both in the epilimnion and hypolimnion. All parameters had significant changes ($p<0.05$) during the sampling period except for a_{350} in the epilimnion. A definition of each parameter can be found in Table 2.

	Epilimnion		Hypolimnion	
Parameter	$F_{(df1, df2)}$	*p*	$F_{(df1, df2)}$	*p*
Chl-a	$3.3_{(15,18)}$	0.0083	-	-
Microcystin	$5.24_{(15, 18)}$	0.0006	$4.5_{(15, 17)}$	0.002
DOC	$8.4_{(15, 19)}$	<0.0005	$3.6_{(15, 18)}$	0.0057
a350	$2.1_{(15, 19)}$	0.0657	$7.6_{(15, 18)}$	<0.0005
SUVA254	$5.4_{(15, 19)}$	<0.0005	$8.6_{(15, 18)}$	<0.0005
SR	$3.3_{(15, 17)}$	0.0101	$2.8_{(15, 16)}$	0.0253

Table 5: Correlation matrix for DOM quantity and quality parameters and their relation to the concentration of microcystin. Values represent correlation coefficients (r). Bolded values indicate correlations that were significant ($p<0.05$). Definitions for all parameters can be found in Table 2.

	DOC		a_{350}		$SUVA_{254}$		S_R		Chla	Microcystin
	Epi	Hypo	Epi	Hypo	Epi	Hypo	Epi	Hypo	Epi	Epi
DOC	1	1								
a_{350}	**0.51**	-0.27	1	1						
$SUVA_{254}$	**-0.51**	0.06	0.31	**0.91**	1	1				
S_R	-0.12	-0.12	**0.65**	**0.41**	**0.51**	0.18	1	1		
Chl-*a*	0.07	-	**0.44**	-	**0.37**	-	**0.36**	-	1	
Microcystin	**0.5**	**0.63**	**0.34**	**0.49**	0.12	**0.35**	0.04	-0.05	**0.6**	1

Figure 1: Epilimnetic chlorophyll-*a* concentrations from June 21st to October 5th divided into weekly aggregates. The first Chl-*a* peak (162.47 μg L^{-1}) occurred on July 16th, 2018. The second Chl-*a* peak (135.61 μg L^{-1}) occurred on September 12th, 2018. Both values were significantly higher than historical seasonal means indicating that our observational study included two distinct algal blooms. The dotted line represents the historical Chl-*a* mean in Dairy Farm Lake #1. The x-axis indicates the first day of each sampling week. Different letters indicate statistically significant differences between each week.

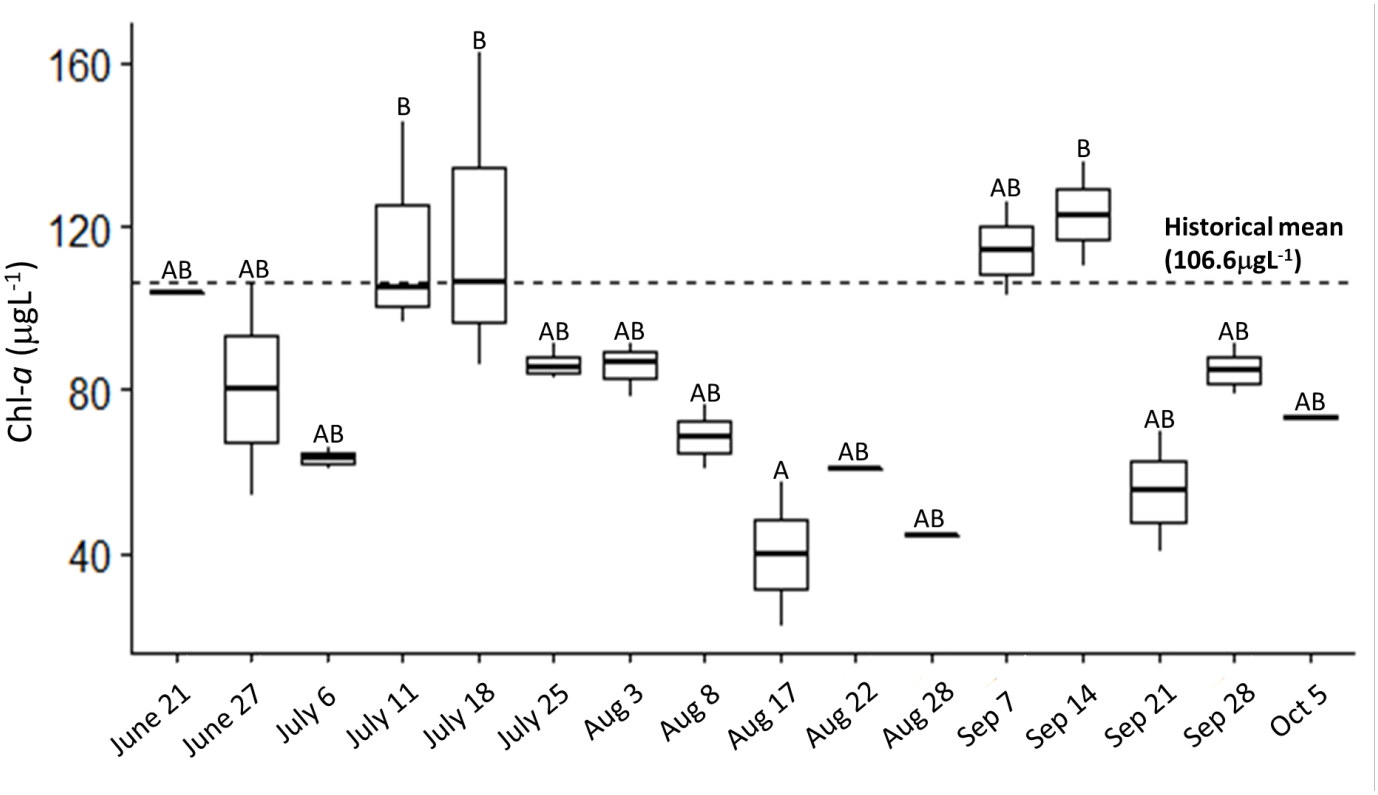
Figure 2: A: Cyanobacterial biovolume (mg/m^3) throughout the sampling period. B: Percent cyanobacteria during the sampling period. The highlighted portion in mid-July indicates where the algal community was dominated by cyanobacteria (>80% cyanobacteria).

Figure 3: Timeseries of microcystin, DOC concentration, $SUVA_{254}$, a_{350}, and S_R from June 21st to October 5th, 2018 in the epilimnion. A definition of each parameter can be found in Table 2. A: Microcystin concentration, B: DOC concentration, C: $SUVA_{254}$, D: a_{350}, E: S_R. The highlighted portion in mid-July indicates where the algal community was dominated by cyanobacteria. Each box represents one week of sampling. The x-axis indicates the first day of each sampling week. Different letters indicate statistically significant differences between each week.

Figure 4: Timeseries of measured parameters from June 21st to October 5th in the hypolimnion. A definition of each parameter can be found in Table 2. A: Microcystin concentration, B: DOC concentration, C: SUVA254, D: a350, E: SR. The highlighted portion in mid-July indicates where the algal community was dominated by cyanobacteria. Each box represents one week of sampling. The x-axis indicates the first day of each sampling week. Different letters indicate statistically significant differences between each week.

Figure 5: Correlations DOC and microcystin. A: DOC and microcystin in the epilimnion, r=0.50, p<0.05; B: DOC and microcystin in the hypolimnion, r=0.50, p<0.05.

Figure 1


160
120
80
40
Chl-a (µgL-1)
AB
AB
AB
B
B
AB
AB
AB
A
AB
AB
AB
B
AB
AB
AB
Historical mean
(106.6µgL-1)
June 21
June 27
July 6
July 11
July 18
July 25
Aug 3
Aug 8
Aug 17
Aug 22
Aug 28
Sep 7
Sep 14
Sep 21
Sep 28
Oct 5

595 Figure 2

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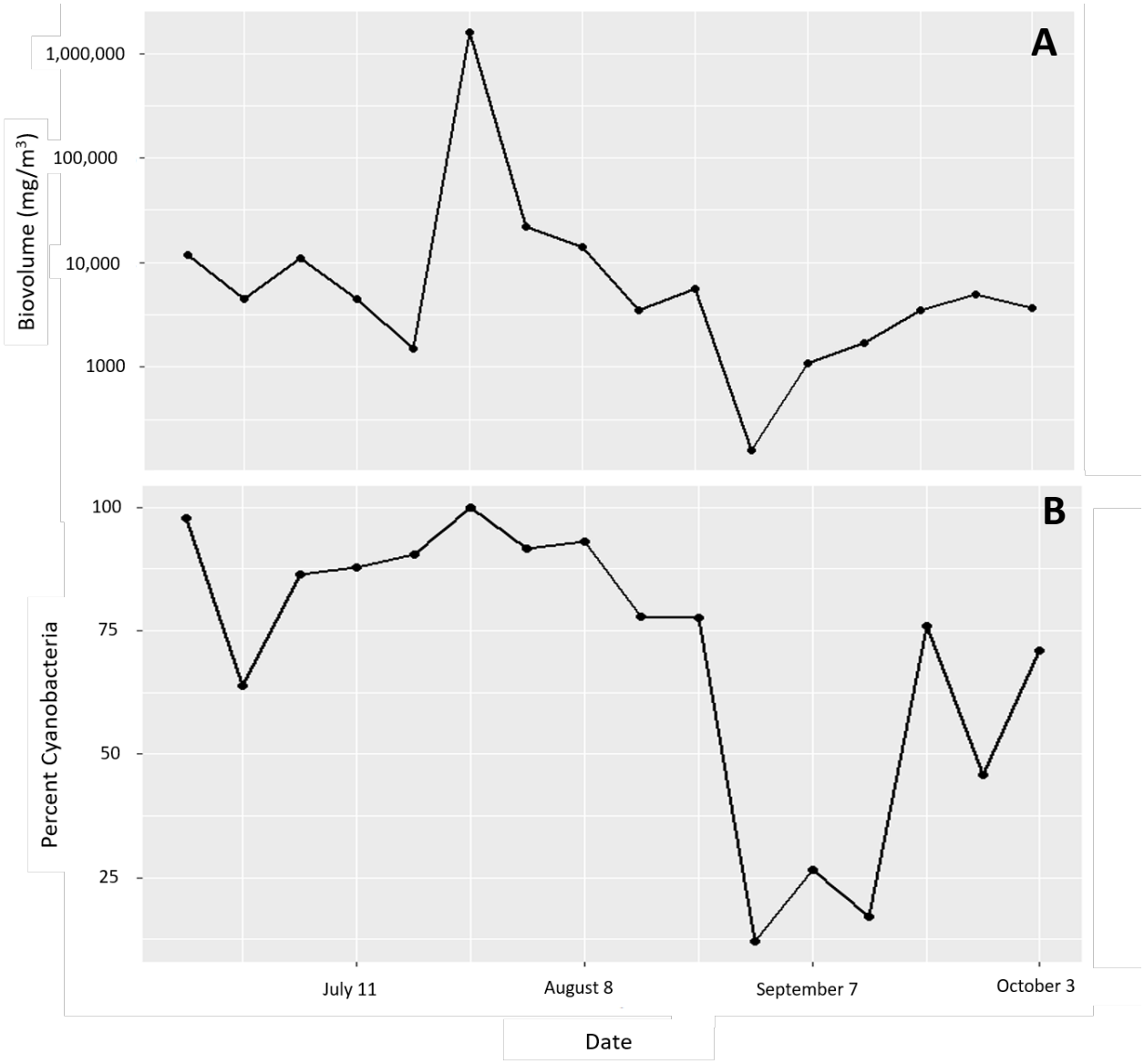

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Figure 3

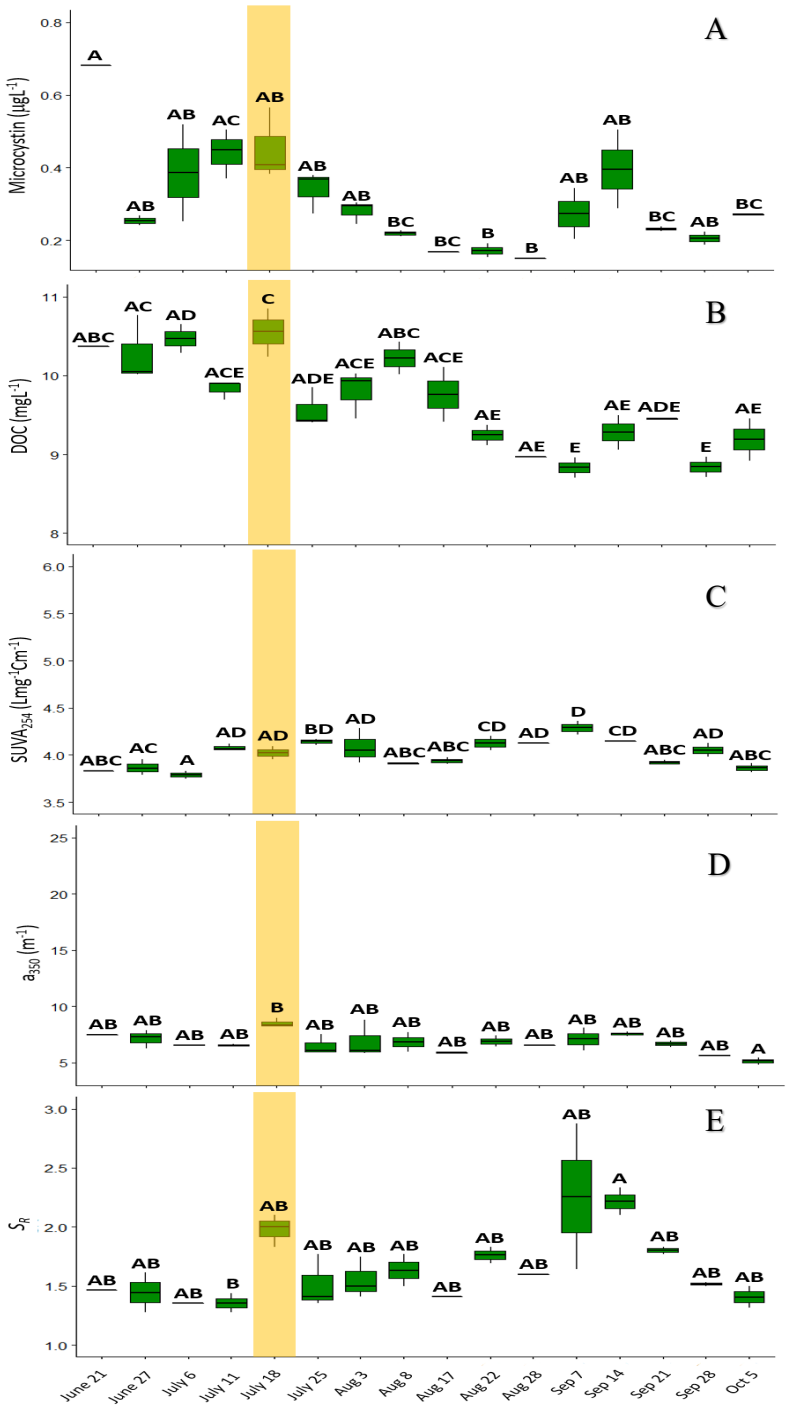
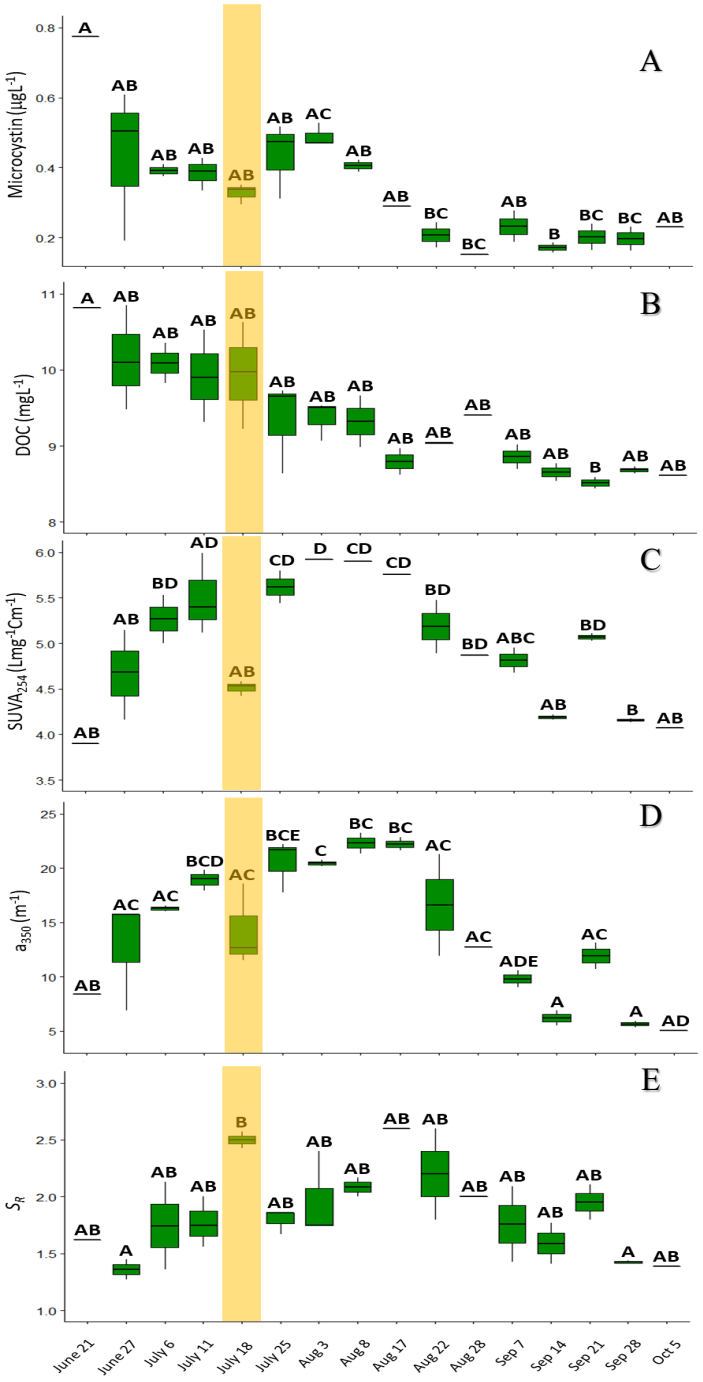

A
Microcystin (µgL-1)
B
DOC (mgL-1)
C
SUVA254 (Lmg-1Cm-1)
D
a350 (m-1)
E
SR
June 21
June 27
July 6
July 11
July 18
July 25
Aug 3
Aug 8
Aug 17
Aug 22
Aug 28
Sep 7
Sep 14
Sep 21
Sep 28
Oct 5

Figure 4


A
B
C
D
E
Microcystin (µgL-1)
DOC (mgL-1)
SUVA254 (Lmg-1Cm-1)
a350 (m-1)
SR
June 21
June 27
July 6
July 11
July 18
July 25
Aug 3
Aug 8
Aug 17
Aug 22
Aug 28
Sep 7
Sep 14
Sep 21
Sep 28
Oct 5

661 Figure 5

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