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PHYSICAL AND ALGAL CHARACTERISTICS OF LIBERTY PARK RESERVOIR IN CLARKSVILLE, TENNESSEE

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ABSTRACT

Physical and algal characteristics of Liberty Park Reservoir in Clarksville, Tennessee were evaluated to determine the reservoir's ecological status and to provide data needed to monitor changes. Water column characteristics of the reservoir include a high value for the light extinction coefficient, turbidity, concentration of total phosphorus, and concentration of chlorophyll *a*. The benthic characteristics include a high concentration of chlorophyll *a*, pheophytin *a,* benthic organics, inorganic sediments, and high values for algal trophic indices. The results demonstrate that Liberty Park Reservoir is ecologically impaired by nutrient enrichment and erosion which, in turn, results in unhealthy phytoplankton and periphyton communities.

Liberty Park Reservoir is located in Clarksville, Tennessee. The reservoir is approximately 25 ha and averages approximately 2 m deep. Clarksville, Tennessee is in the Lower Cumberland River Watershed which is part of the Western Pennyroyal Karst (71e) and Western Highland Rim (71f) Level IV Ecoregions. The geologic base is Mississippian-age limestone and includes chert, shale, siltstone, sandstone, and dolomite. The soils are a thin loess mantle, highly erodible, and fertile (Baskin et al. 1997). Forests are Western Mesophytic and consist largely of *Quercus* and *Carya* species. Most of the Lower Cumberland River Watershed is used to produce agriculture products including tobacco, corn, soybeans, and livestock (TDEC 2021). The cumulative effects of erosion, agricultural runoff, livestock access to streams, and poorly functioning sewage systems result in poor watershed water quality.

Phosphorus enrichment frequently increases primary production and is a major cause for the degradation of aquatic communities worldwide (Stancheva and Sheath 2016)). High rates of primary production, high concentrations of chlorophyll (chl) *a,* and changes of organism composition are hallmarks of eutrophication by phosphorus enrichment. For example, the biomass of phytoplankton and photoautotrophic periphyton are characteristically low in oligotrophic water bodies and may accumulate to nuisance levels in eutrophic waterbodies. The primary objectives of this research were to characterize the water quality and biological integrity of Liberty Park Reservoir such that changes can be monitored. We used multiple approaches to achieve the objectives including determinations of: (1) nutrient concentrations of water, (2) pigment concentrations of water and periphyton, (3) ash-free dry mass of benthic organic matter, (4) biochemical oxygen demand of water, and (5) composition of benthic soft-algae and diatom assemblages.

Methods

Sampling occurred the morning of September 9, 2021. Photosynthetic photon flux density (PPFD) was measured at the surface and at 0.25-m depths at 2 locations (2 replicates) with a spherical underwater quantum sensor coupled to a Li-Cor quantum meter (Li-Cor Cooperate, Lincoln, Nebraska). These data were used to calculate the vertical extinction coefficient of light (n"; Lind et al. 1992): $n'' = (\ln PPFD_{surface} - \ln PPFD_{depth})/depth$.

Specific conductance, temperature, and pH were determined at three different locations (three replicates) using a Multiparameter meter (Hana Instruments Incorporated, model HI 98194). Concentration of total phosphorus of one water sample collected with a Van Dorn sampler at 0.25-m depth was determined using a Lachat QuickChem 8500 Flow Injection Analyzer using the persulfate-digestion and the ascorbic-acid method (Baird et al. 2017).

Concentration of chlorophyll (chl) *a* and turbidity of the water at a 0.25-m depths at three different locations (three replicates) were determined using a portable fluorometer and nephelometer (AlgaeChek Ultra, model RS232, Modern Water Incorporated). The fluorometer measures the intensity of fluorescence at 685 nm emitted from chl *a* upon excitation by low emission diodes (470 nm). The nephelometer measures the concentration of suspended particulates expressed as nephelometric turbidity units calculated from the intensity of scattered light reflected from a source beam due to particles in the water.

The biochemical oxygen demand 5-day assay (BOD_5 assay) as described by Baird et al. (2017) was used to determine the effect of organic matter in the water column on oxygen consumption by microorganisms. Water samples were retrieved from a depth of 0.25 m using a Van Dorn sampler. Samples were transferred to two borosilicate-glass bottles with ground-glass stoppers. Initial dissolved oxygen (DO) concentration was determined using a portable DO meter (model MW600, Milwaukee Instruments Incorporated). The bottles were incubated for 5 days in darkness at 25 ^{O}C and the concentration of DO consumed recorded as BOD_5 (mg DO $\cdot$ L^{-1} $\cdot$ 5 d^{-1}).

Concentrations of benthic chlorophyll (chl) *a* were determined using a portable fluorometer designed to determine benthic chl *a* concentrations *in situ* (Benthotorch, bbe Moldaenke). The fluorometer was pressed onto the surface of four replicate cobbles positioned at a depth of approximately 0.25 m. Optical density (OD) measurements of acetone pigment extracts were used to indicate the ratio of chl *a* to pheophytin *a* and thus the physiological condition of the periphyton. Chl *a* is degraded to pheophytin *a* as plants and algae senesce, thus high concentrations of pheophytin *a* reveal poor physiological condition. Because healthy algae may have no detectable pheophytin *a* determined by OD measurements, the chl *a* to pheophytin *a* ratio is indicated as the ratio of OD at 664 nm (OD_{664}) to OD at 665 nm (OD_{665}). OD_{664}/OD_{665} values, ash-free dry mass of benthic organics, and algal composition were determined from four cobbles removed from upper littoral zone (approximately 0.25 m depths) following the methods of Lebkuecher et al. (2015).

Phytoplankton was sampled with phytoplankton nets (120-µm pore size) and Van Dorn samplers. Phytoplankton were preserved in 1 % glutaraldehyde and concentrated by settling in darkness. Algae were identified to the lowest taxon possible using references listed in Grimmett and Lebkuecher (2017) and Lebkuecher and Mauney (2020). Trophic indices were used to infer the impact of trophic state on benthic algal assemblages and calculated as: index value = $[\Sigma_{j = 1\ taxon}\ n_j\ ti_j]/N$ where: n_j = number of taxon units j sampled at a site, ti_j = trophic-indicator value for taxon j, and N = total number of taxon units at the sampling site used to calculate the index. The trophic-indicator values are the normalized abundance-weighted averages of benthic [chl *a*] for algal taxa in reservoirs of Middle and East Tennessee (Lebkuecher, manuscript in preparation).

Results and Discussion

The near neutral pH of the water determined at 9:00 AM and other physical characteristics of Liberty Park Reservoir (Table 1) are typical of lentic environments in Middle Tennessee with poor quality water. For example, pH values of mesotrophic waterbodies in Middle Tennessee are basic due to the geologic base of largely limestone. Values of pH are typically slightly higher near sunset as a result of photosynthetic CO_2 uptake, thus lower concentrations of carbonic acid. Values of pH are typically slightly lower near sunrise as a result of nocturnal respiratory CO_2 emission, thus greater concentrations of carbonic acid. Nocturnal respiration in waterbodies with excessive biomass results in substantial changes in pH from basic to near neutral in the mornings.

Table 1. Physical characteristics (means $\pm$ S.E.) of Liberty Park Reservoir in Clarksville, Tennessee.

pH at 0.25 m depth at 9:00 AM	6.9 ± 0.8
Light extinction coefficient	3.6 ± 0.1
Turbidity (nephelometric units)	39 ± 9
Specific conductance (microsiemen $\cdot$ cm^{-1})	398 ± 0
Total phosphorus (µg $\cdot$ L^{-1})	127

The light-extinction and turbidity values demonstrate a high concentration of suspended particles. The majority of the light-extinction studies from a variety of natural freshwater lakes and reservoirs with different morphologies and chemistries report n" values near 1.3, a value that has been adopted as typical for purposes of comparison (Renolds 1990). Values of n" $\geq$ 1.8 indicate unusually high concentrations of suspended matter (Luettich et al. 1990). Turbidity values above 25 nephelometric units indicate the water column contains an unhealthy concentration of suspended particles (USEPA 1986).

Specific conductance of Liberty Park Reservoir is typical of lentic water bodies in Middle Tennessee. Water in areas with a limestone geologic base have higher specific conductivity relative to areas with a granite geologic base because of the presence of materials that ionize when washed into water. Mid-range conductivity (200 to 1000 microsiemen $\cdot$ cm^{-1}) is normal for most major rivers with hard water. The concentration of total phosphorus [TP] of water is well above the level suggested by Carlson and Simpson (1996) to designate lakes as eutrophic (> 25 µg TP $\cdot$ L^{-1}).

The low dissolved oxygen concentration in the morning (Table 2) is typical of eutrophic environments and is a result of nocturnal respiration by the large biomass. The high concentration of chl *a* of the water column (Table 2) indicates productivity of the water column is high, most likely due to the eutrophic [TP]. For example, concentration of the water column chl *a* of Liberty Park Reservoir is well above the value considered indicative of eutrophic conditions (> 7.3 µg $\cdot$ L^{-1}; Carlson and Simpson 1996). The value for the biochemical oxygen demand 5-day assay (BOD_5 assay) is typical for those determined from samples without excessive concentrations of organics. BOD_5 values from water without excessive concentrations of organics range from near 0 to 8 mg O_2 consumed $\cdot L^{-1} \cdot 5\ d^{-1}$, while values of wastewater from wastewater treatment plants are often above 19 mg consumed $\cdot L^{-1} \cdot 5\ d^{-1}$ (Delzer and McKenzie 2003, Yun and An 2016).

Concentrations of benthic chl *a* were > 10 mg $\cdot m^{-2}$, a value suggested to designate lentic aquatic systems in Tennessee as eutrophic. Benthic concentrations of mesotrophic reservoirs in Tennessee have chl *a* concentrations that range from 6 to 9 mg $\cdot$ cm^{-2}, while eutrophic reservoirs in Tennessee typically have of benthic chl *a* concentrations $\geq$ 10 mg $\cdot$ m^{-2} (Lebkuecher, manuscript in preparation). The excessive periphyton biomass is also indicated by the concentrations of ash-free dry mass of benthic organic matter of > 10 g $\cdot$ m^{-2}, a threshold value indicative of eutrophic environments (O'Brien and Wehr 2010).

The OD_{664} to OD_{665} ratio of pigment extracts indicate the photoautotrophic periphyton were in poor physiological condition. A OD_{664} to OD_{665} ratio of 1.7 is interpreted as no detectable pheophytin *a* present and ratios < 1.5 indicate the algae contain high concentrations of pheophytin *a* (Baird et al. 2017). The poor physiological condition of the photoautotrophic periphyton are most likely due to the high concentration of benthic sediments that may smother periphyton that are epilithic (live on rock surfaces).

Table 2. Biological characteristics and concentration of benthic sediments (means $\pm$ S.E.) of Liberty Park Reservoir.

Dissolved oxygen ($mg \cdot L^{-1}$) at 0.25 m depth at 9:00 AM	4.1 ± 0.1
Water column chlorophyll *a* ($\mu g \cdot L^{-1}$)	59.2 ± 3.5
Biochemical oxygen demand ($mg\ 0_2 \cdot L^{-1} \cdot 5\ days^{-1}$)	2.7 ± 0.05
Benthic (cobble) chlorophyll *a* ($mg \cdot m^{-2}$)	16.6 ± 4.2
Ash-free dry mass of benthic organics ($g \cdot m^{-2}$)	24.0 ± 4.7
OD_{664} to OD_{665} ratio	1.1 ± 0.2
Benthic sediment and ash mass ($g \cdot m^{-2}$)	121 ± 42
Soft algae trophic state index	82
Diatom trophic state index	66

We identified 30 taxa of soft algae (Appendix 1) and 49 taxa of diatoms (Appendix 2). The most abundant benthic soft alga sampled was the filamentous cyanobacterium *Anabaena* sp. (34.6 %) followed by *Rhizoclonium* sp. (21.8 %), and *Cladophora glomerata* (L.) Kütz. (14.6 %). The most abundant diatom sampled was the centric diatom *Aulacoseira pusilla* (Meister) Tuji and Houk (8 %), followed by *Gomphonema parvulum* Kütz. (5.1 %), and *Cymbella tumida* (Bréb.) Van Heurck (4.4 %). The *Nitzschia* small sp. complex (Kahlert et al. 2012) was 5.1 % of the diatom assemblage. The *Nitzschia* small sp. complex was created to decrease inconsistency of water-quality analyses using diatom composition within the European Union given these taxa are morphologically similar. The complex includes *N. frustulum* (Kütz) Grun., *N. inconspicua* Grun., *N. liebetruthii* Rabenh., all of which are indicators of eutrophic conditions (KDOW 2008).

The high values for the soft algae trophic state index and diatom trophic index indicate that the soft algae and diatom assemblages have high relative abundances of taxa common in eutrophic environments (Table 2). Trophic state indices are based on the abundance of algae known to be indicators of mesotrophic or eutrophic habitats. Algae taxa are assigned trophic indicator values based on previous studies. For example, algae taxa in Tennessee reservoirs are assigned trophic indicator values between 0 and 100. Taxa with values below 50 are more common in mesotrophic habitats and taxa with values above 50 are more common in eutrophic habitats. A waterbody with a high abundance of taxa with indicator values above 50 will have a trophic index value above 50. The > 50 values for both the soft algae trophic state index and diatom trophic index indicate that the excessive concentration of phosphorus in Liberty Park Reservoir negatively impacts the composition of the periphyton community.

This study provides baseline data needed to monitor changes of water quality in Liberty Park Reservoir and highlights the negative impacts of nutrient enrichment on the ecological integrity of aquatic habitats within the Lower Cumberland River Watershed. Although continued urban development is inevitable in the watershed, this study indicates that better control of nutrient runoff may improve habitat quality.

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Appendix 1. Percent composition of soft-algae taxa sampled from cobbles and additional phytoplankton taxa present (P) in Liberty Park Reservoir listed in alphabetical order by phylum.

Chlorophyta	**Percent composition of benthic soft-algal taxa and additional phytoplankton taxa present (P)**
Bulbochaete sp.	0.1
Chlamydomonas sp.	1.2
Carteria fritschi Talkeda	P
Cladophora glomerata (L.) Kütz.	14.6
Closterium sp.	0.2
Cosmarium sp.	2.7
Gloeocystis vesiculosa Nägeli	0.1
Oocystis lacustris Chodat.	0.2
Pediastrum sp.	0.1
Rhizoclonium sp.	21.8
Scenedesmus sp.	0.6
Spirogyra sp.	5.9
Staurastrum sp.	0.1
Tetraselmis sp.	P
Cercozoa	
Paulownia chromatophora Lauterborn	1.5
Cyanobacteria	
Anabaena sp.	34.6
Borzia trilocularis Cohn.	0.3
Komvophoron constrictum (Szafer) Anagn. and Komárek	0.3
Komvophoron schmidlei (Jaag) Anagn. and Komárek	0.1
Komvophoron sp.	0.3
Limnothrix planktonica (Woloszynska) Meffert	2.1
Merismopedia glauca (Ehrenb.) Kütz.	0.1
Merispodedia tenuissima Lemmerm.	P
Oscillatoria limosa (Dylwin) C. Agardh	P
Oscillatoria princeps Vaucher	2.4
Oscillatoria sp.	4.1
Synechococcus aeruginosus Nägeli	0.1
Synechococcus sp.	0.6
Euglenophyta	
Euglena sp.	0.2
Trachelomonas sp.	0.2

Appendix 2. Percent composition of diatom taxa sampled from cobbles in Liberty Park Reservoir listed in alphabetical order.

Taxon name	Percent Composition
Achnanthidium exiguum (Grun.) Czarnecki	2.2
Achnanthidium minutissimum (Kütz.) Czarn.	0.7
Achnanthidium sp.	2.2
Aulacoseira pusilla (Meister) Tuji and Houk	8.0
Cyclotella meneghiniana Kütz.	2.9
Cyclotella distinguenda Hust.	0.7
Cymbella affinis Kütz.	2.2
Cymbella sp.	0.7
Cymbella tumida (Bréb.) Van Heurck	4.4
Cymbella turgidula Grun.	0.7
Diatoma hiemale (Roth) Heib.	0.7
Encyonema minutum (Hilse) Mann	2.9
Encyonema silesiacum (Bleisch) Mann	0.7
Encyonema sp.	1.5
Gomphonema affine Reichardt	2.9
Gomphonema affine var. *rhombicom* Reichardt	0.7
Gomphonema angustatum (Kütz.) Rabenh.	2.2
Gomphonema gracile Ehrenb.	2.2
Gomphonema minutum Ag.	0.7
Gomphonema olivaceum Rabenh	0.7
Gomphonema parvulum Kütz.	5.1
Gomphonema pseudoaugur Lange-Bert.	1.5
Gomphonema sp.	2.2
Gyrosigma acuminatum (Kütz.) Rabenh.	1.5
Gyrosigma attentuatum (Kütz.) Rabenh.	0.7
Karayeva clevei (Grun.)	1.5
Navicula antonii Lange-Bert.	0.7
Navicula cryptocephala Kutz.	0.7
Navicula sp. (> 12 µm length)	4.4
Navicula tripunctata (O. F. Müll.) Bory	0.7
Navicula trivialis Lange-Bert.	0.7
Nitzschia acicularis (Kütz.) W. Sm.	0.7
Nitzschia amphibia Grun.	2.9
Nitzschia fonticola Grun.	3.0
Nitzschia frustulum (Kütz.) Grun.	2.2
Nitzschia inconspicua Grun.	3.7
Nitzschia nana Grun.	1.5
Nitzschia palea var. *debilis* (Kutz.) Grun._	1.5
Nitzschia semirobusta Lange-Bert.	0.7
Nitzschia sinuata var. *tabellaria* Grun.	2.2
Nitzschia sp. small complex	5.1
Nupela sp.	2.2
Placoneis sp.	3.7
Planothidium frequentissimum Lange-Bert.	0.7
Sellaphora sp.	0.7

Stephanodiscus minutulus (Kütz.) Round	3.7
Ulnaria acus (Kütz.) Aboal	0.7