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PRIMARY PRODUCTION OF THE CUMBERLAND RIVER IN CLARKSVILLE, TENNESSEE

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ABSTRACT

The Cumberland River in the Lower Cumberland River Watershed in Middle Tennessee is listed as impaired by nutrient enrichment by the Tennessee Department of Environment and Conservation and the United States Environmental Protection Agency. We evaluated the impact of nutrient enrichment on habitat quality by examining biotic characteristics of periphyton growth and characteristics of the water column. Periphyton production on artificial substrate, rates of oxygen metabolism, and pigment concentrations of the water demonstrate the negative effects of nutrient enrichment. The results suggest that best management practices to reduce nutrient input within the Lower Cumberland River Watershed may improve habitat quality.

Knowledge of the effects of nutrient concentration on the biomass of phytoplankton is essential to understand the impact of eutrophication of lentic systems. Nutrient enrichment and sediments from nonpoint sources are most responsible for the biological impairment of United States waters (Irvine & Murphy 2009). Assessments of nutrient pollution are prerequisites to developing watershed management plans to monitor aquatic systems (Smucker & Vis 2013). Biological evaluations are required to characterize and quantify the influences of water quality. Water sampling for chemical analyses alone may not reveal the impact of nonpoint-source pollution because pollutants from nonpoint sources often enter waterways in pulses. In addition, chemical analyses do not reveal the impacts of pollution on biological integrity (Taylor et al. 2007).

Phytoplankton are the most important primary producers in the majority of lentic systems and large rivers. Nutrient enrichment changes primary production characteristics and affects whole-system ecological relationships. The biomass and production rates of phytoplankton are excellent indicators of water quality and are used universally to follow changes in the quality of aquatic environments (Lind et al. 1992). High concentrations of chlorophyll (chl) *a* and high rates of primary production in the euphotic zone are hallmarks of eutrophication (Harris & Piccinin 1977).

The reach of the Cumberland at Clarksville, Tennessee is part of the Lower Cumberland River Watershed. The Lower Cumberland River Watershed is in the Western Pennyroyal Karst (71e) and Western Highland Rim (71f) Level IV Ecoregions. The geologic base of the watershed is Mississippian-age limestone and includes some chert, shale, siltstone, sandstone, and dolomite. The soils are a thin loess mantle, highly erodible, and very fertile (Baskin et al. 1997). Forests are Western Mesophytic and consist largely of *Quercus* and *Carya* species (Baskin et al. 1997). The watershed encompasses approximately 2,338 square miles and has an estimated population of 155,000 people (TNCT 2015). Over 50% of the watershed is used to produce agriculture products including tobacco, corn, soybean, and livestock (TDEC 2012). The cumulative effects of erosion, agricultural runoff, livestock access to streams, and poorly functioning sewage systems result in poor quality water in the lower reaches of all the major tributaries in the watershed as well as the Cumberland River. The reach of the Cumberland River in Clarksville, Tennessee is listed as impaired

by nutrient enrichment by the Tennessee Department of Environment and Conservation and the United States Environmental Protection Agency (TDEC 2012). The primary objective of this research was to characterize the water quality of the reach of the Cumberland River at Clarksville, Tennessee such that changes in water quality can be followed. We used multiple approaches to document water quality including determinations of the light extinction coefficient, pigment concentrations of water, seston oxygen metabolism, and evaluations of primary production on artificial substrate.

Methods

Water-quality characteristics of the Cumberland River at Clarksville, Tennessee were determined on 25 September 2017. Photosynthetic photon flux density (PPFD) was measured with a spherical underwater quantum sensor coupled to a Li-Cor quantum meter (Li-Cor Cooperate, Lincoln, Nebraska). PPFD is a measurement of the amount of photosynthetically active radiation (PAR; light of wavelengths between 400 and 700 nm) that reaches a surface and is expressed as μmol photons·m^{-2}·s^{-1}. These data were used to determine the depth of the euphotic zone (defined here as the portion of the water column receiving $\geq$ 1% of the surface illumination) and the vertical extinction coefficient of light. The vertical extinction coefficient (n") was calculated using the equation (Kirk 1994): n" = (ln $PPFD_{surface}$ - ln $PPFD_{depth}$)/Depth.

Chlorophyll (chl) *a* concentration, phycocyanin concentration, and turbidity at a 0.25-m depth were determined using a portable fluorometer and turbidity (nephelometry) probe (AlgaeChek Ultra portable fluorometer and nephelometer, model RS232, Modern Water Incorporated, New Castle, Delaware). The fluorometer measures the intensity of fluorescence at 685 nm emitted from chlorophyll (chl) *a* and phycocyanin upon excitation by low emission diodes. The excitation wavelengths for induction of chl-*a* and phycocyanin fluorescence is 470 nm and 530 nm, respectively. The intensity of fluorescence is directly proportional to the concentration of the pigments. The turbidity probe (nephelometer) component of the AlgaeChek meter measures the concentration of suspended particulates by employing a source beam (685 nm) and a light detector beam (685 nm). Particle density is a function of the intensity of the scattered light reflected from the particles into the detector and is displayed as nephelometric turbidity units.

The rate of colonization of photoautotrophic periphyton on glass microscope slides is a standard method for measurement of primary production because it provides standardization which allows comparisons among different studies (Lowe and Pan 1996). A periphytometer holding glass microscope slides (25- by 75-mm) vertically 5 cm below the surface was deployed on 18 September, 2017 and retrieved 25 September 2017. Periphyton was scraped from both sides of slides using a razor blade. The periphyton were suspended in water by swirling and concentrations of chl *a* and phycocyanin were determined using the AlgaeChek portable fluorometer probe described above.

Phytoplankton productivity was examined on 25 September 2017 using the bottle-oxygen method (APHA 2017). This method was chosen because it provides community metabolism estimates of gross-productivity, net-productivity, and the whole-sample respiration rates (including bacteria, zooplankton, and phytoplankton). Water samples were retrieved from a depth of 0.25 m using a Van Dorn sampler. Samples were transferred to three borosilicate-glass bottles with ground-glass stoppers: a clear bottle, a darkened bottle, and a bottle used to determine the initial dissolved-oxygen concentration using a portable dissolved oxygen meter (model MW600, Milwaukee Instruments Incorporated, Rocky Mount, North Carolina). Transfers utilized a rubber delivery tube to prevent aeration. Clear and darkened sample-containing bottles were suspended at 0.25 m, the same depth from which the samples were collected. At the end of the 6-h incubation period, concentrations of bottle dissolved oxygen were measured. The increase in concentration of dissolved oxygen in clear bottles was used to determine net-productivity rate. The reduction of dissolved-oxygen concentration during incubation of darkened bottles was used to determine whole-sample respiration

rate. Gross primary production was determined by adding the loss of dissolved oxygen resulting from whole-sample respiration to the net primary production rate. Rate calculations and conversions from oxygen to carbon used the equations of APHA (2017).

Results and Discussion

The physical characteristics of the Cumberland River at Clarksville, Tennessee (Table 1) are typical of large rivers and reservoirs in Tennessee. For example, the basic pH is similar to other aquatic systems in the ecoregion given the limestone geologic base. Measurements of the photosynthetic photon flux density at varying depths reveal a shallow euphotic zone (4.5 m) on 25 September 2017. The light extinction coefficient (n") is an expression of the PPFD-depth slope on a logarithmic axis: the higher the n" value, the greater the vertical extinction rate of light as it penetrates the water column. 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 which has been adopted as typical for purposes of comparison (Renolds, 1990). Although the rate of light extinction is affected by water chemistry, rates of extinction which are described as high (i.e., n" $\geq$ 1.8) are indicative of high concentrations of suspended matter (Luettich et al., 1990). The relatively low n" of the Cumberland River on September 25, 2018 most likely reflects the lack of significant precipitation, thus sediment runoff during the previous 2 weeks. The unusually low n" results in a relatively deep euphotic zone compared to many large rivers and reservoirs in the central region of the Interior Plateau Level III Ecoregion. For example, Kentucky Lake, considered to be mesotrophic to eutrophic, has euphotic-zone depths of approximatively 2.4 m in July and August (Lebkuecher et al. 1996). The low concentration of suspended particles is verified by the low turbidity of the water. For example, a clear mountain stream might have a turbidity near 1 nephelometric turbidity units (NTU), whereas a large river with good quality water may have a turbidity of approximately 10 NTUs. Values above 25 indicates the water column contains an unhealthy concentration of suspended particles (USEPA 1986).

Table 1. Physical characteristics of the Cumberland River at Clarksville, Tennessee.

Temperature (^{o}C) at 0.25 m at 8:00 AM CST	23.5
pH at 0.25 m at 8:00 AM CST	7.7
Photosynthetic photon flux density$_{surface}$ at 8:00 AM (μmol photons$\cdot$m$^{-2}\cdot$s^{-1})	450
Photosynthetic photon flux density$_{surface}$ at 12:30 PM (μmol photons$\cdot$m$^{-2}\cdot$s^{-1})	1820
Photosynthetic photon flux density$_{0.25\ m}$ at 8:00 AM (μmol photons$\cdot$m$^{-2}\cdot$s^{-1})	381
Photosynthetic photon flux densit$_{0.25\ m}$ at 12:30 PM (μmol photons$\cdot$m$^{-2}\cdot$s^{-1})	1350
Euphotic zone depth (m)	4.5
Light extinction coefficient (n")	1.00
Nephelometric turbidity units	5.3

The rate of colonization of photoautotrophic periphyton on glass microscope slides is a routine method for measurement of primary production because it provides standardization which allows comparisons among different studies and accurately portrays trophic state (Lowe and Pan. 1996). Values $\leq$ 0.3 mg chlorophyll (chl) a $\cdot$ m$^{-2}\cdot$ day are typical of rivers with good quality water in Middle Tennessee (Flynt et al. 2001, Lebkuecher et al. 2009). The rates of photoautotrophic periphyton production of the Cumberland River (Table 2) are substantially greater than rates considered healthy and demonstrate the river is eutrophic.

The high rates of phytoplankton production and community respiration measured using the bottle-oxygen method (Table 2) support the conclusions from the evaluations of primary production measured using a periphytometer that the river is eutrophic. In Kentucky Lake, rates of gross primary production and community respiration during the middle of the day may be as high as 116 mg C $\cdot$ m^{-3} $\cdot$ h^{-1}, and 19 mg C $\cdot$ m^{-3} $\cdot$ h^{-1}, respectively (Lebkuecher et al. 1996). The high value for the ratio of gross primary production to respiration in the Cumberland River indicate a high concentration of heterotrophs, thus a high concentration of dissolved organics typical of poor-quality water (Atkinson et al. 2008).

Table 2. Biological characteristics of the Cumberland River at Clarksville, Tennessee.

Chlorophyll *a* (mg $\cdot$ m^{-2} $\cdot$ day^{-1})	1.14
Phycocyanin (mg $\cdot$ m^{-2} $\cdot$ day^{-1})	0.52
Gross primary production (mg O_2 $\cdot$ m^{-3} $\cdot$ h^{-1})	375 ± 0.00
Gross primary production (mg C $\cdot$ m^{-3} $\cdot$ h^{-1})	140.63 ± 0.00
Respiration (mg O_2 $\cdot$ m^{-3} $\cdot$ h^{-1})	100 ± 25
Respiration (mg C $\cdot$ m^{-3} $\cdot$ h^{-1})	37.5 ± 9.375
Net primary production (mg O_2 $\cdot$ m^{-3} $\cdot$ h^{-1})	275 ± 25
Net primary production (mg C $\cdot$ m^{-3} $\cdot$ h^{-1})	103.125 ± 9.375
Ratio of gross primary production to respiration	4.0 ± 1.0
Chlorophyll *a* (µg $\cdot$ L^{-1})	25.0
Phycocyanin (µg $\cdot$ L^{-1})	5.3

Seston refers to particles suspended in the water column including phytoplankton. Concentrations of seston chlorophyll *a* > 8 µg/L are indicative of eutrophic conditions in large rivers and lakes (Dodds 2006). The concentration of seston phycocyanin is indicative of the concentration of cyanobacteria. The eutrophic concentration of seston chl *a* of the Cumberland River (Table 2) support conclusions from analyses of photoautotrophic periphyton production and oxygen metabolism that the Cumberland River at Clarksville, Tennessee is eutrophic. The results suggest that best management practices which reduce nutrient enrichment of water in the Lower Cumberland River Watershed may improve habitat quality.

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