Available online at www.sciencedirect.com
ScienceDirect
Aquatic Botany 88 (2008) 247–255
Aquatic botany
www.elsevier.com/locate/aquabot

Primary producers and nutrient loading in Silver Springs, FL, USA

Erin L. Quinlan, Edward J. Phlips *, Karen A. Donnelly, Christina H. Jett, Peter Sleszynski, Stephanie Keller

University of Florida, Department of Fisheries and Aquatic Sciences, 7922 NW 71st Street, Gainesville, FL 32623, USA

Received 24 May 2007; received in revised form 25 October 2007; accepted 4 November 2007
Available online 19 November 2007

Abstract

The characteristics and dynamics of primary producer communities of Silver Springs was examined to compare with that observed by Odum [Odum, H.T., 1957. Trophic structure and productivity of Silver Springs, Florida. Ecol. Monogr. 27, 55–112.] as a means of evaluating the impacts of changes that have occurred over time. The Silver Springs ecosystem is considered an ecosystem at risk, where nitrate levels have more than doubled over the past 50 years. The spatial and temporal abundance and distribution of above-sediment primary producers in Silver Springs, FL, USA, was estimated on a system-wide basis using a GIS platform. The results of study suggest that while the *Sagittaria* component of Silver Springs has remained relatively stable, epiphyte and benthic algal mat community biomass has expanded, particularly benthic forms, like *Lyngbya*. However, we argue for caution in weighing the significance of long-term comparisons of system-wide biomass in light of considerable spatial heterogeneity in aquatic primary producer communities.

Keywords: *Sagittaria kurziana*; *Lyngbya*; Benthic algae; Epiphyton; Groundwater spring; Macrophyte

1. Introduction

The integrity of aquatic ecosystems throughout the world is under increasing pressures from human development in terms of accelerated rates of eutrophication, watershed alterations, recreational use, and pollutants. Even in putatively pristine artesian spring ecosystems, human impacts on groundwater chemistry have become apparent, such as dramatic increases in nutrient levels. Nutrient enrichment can shift a primary producer community from one dominated by macrophytes to one dominated by attached algae or benthic algae mats (Scheffer et al., 2001). From a management perspective, the presence of healthy benthic macrophyte communities is considered a desirable feature of freshwater ecosystems (Moss, 1990), providing habitat for fish and aquatic invertebrates, and stabilizing sediments against resuspension and erosion. The spatial distribution, abundance and physical condition of macrophytes are often used as indicators of biotic integrity in aquatic ecosystems (Dennison et al., 1993). Similarly, increases in the density of epiphytes and benthic algae have been used as indicators of excessive nutrient load (Dodds et al., 1997).

Silver Springs, FL, USA provided an opportunity to examine the spatial distribution of benthic primary producers in an ecosystem at risk, where nutrient loading has increased. The clarity of the water and the large stands of submerged aquatic vegetation in Silver Springs have been described in numerous scientific and lay publications (Brinton, 1859; Leconte, 1861; Ober, 1886). Among the scientific works, perhaps the most comprehensive is that of Odum (1957) who studied the productivity, trophic structure, and energy flow in Silver Springs, describing it as a unique chemostatic environment of remarkable temporal stability (Odum, 1957). Many of the physical conditions, such as temperature (23 °C), maximum boil depth (approximately 10 m), and discharge rate remain similar to those observed by Brinton (1859) and Odum (1957). In contrast, nitrate concentrations have doubled in the last 50 years, from a mean concentration of 0.50 mg nitrate-N L^{-1} in 1957 (Odum, 1957), to a mean concentration of 1.1 mg nitrate-N L^{-1} in 2004 (Phelps, 2004). These changes have been attributed to land-use alterations within the watershed and aquifer recharging areas. Karst sediments characterize much of the Silver Spring watershed and result in free transport of

* Corresponding author. Tel.: +1 352 392 9617x248.
E-mail address: phlips@ufl.edu (E.J. Phlips).

0304-3770/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.aquabot.2007.11.003

nitrate from surface sediments into groundwater reservoirs; the source waters for Silver Springs.

The availability of extensive information on the structure of the Silver Springs ecosystem in the 1950s by Odum (1957) allowed us to examine changes in the primary producer community over time and after significant changes in nutrient loading. We hypothesized that the increases in nutrient loading reduced the abundance and spatial extent of the macrophyte community due to excessive algae growth. The objective of this study was to re-examine the characteristics and dynamics of primary producer communities of Silver Springs to compare the existing structure of the community with that observed by Odum (1957), as a means of evaluating the impacts of changes that have occurred over time, and gain a better understanding of the factors that may drive future changes in the system. In order to quantify changes in the primary producer community, it is necessary to deal with the inherent spatial heterogeneity and temporal variability of the various primary producer groups, including aquatic plants, epiphytes, and benthic algal mats. We utilized a GIS platform to interpret and estimate the distribution and abundance of primary producers in Silver Springs and compared these findings to the observations of Odum (1957). The results of the study provide valuable insights into both the resilience of parts of the ecosystem to change and possible areas of sensitivity.

2. Materials and methods

2.1. Study area

Silver Springs, located in north central Florida (N 29° 12′ 57.3″, W 83° 3′10.5″), consists of numerous groundwater springs, with a mean daily discharge of $21.9 \pm 3.6\ m^3\ s^{-1}$ (1960–2005, USGS, 2006). Water temperature is relatively constant with a mean daily temperature of 23.1 ± 0.7 °C (USGS, 2006). Although groundwater inflow occurs along the entire length of the Silver River (8.3 km), most of the spring inflow is concentrated within 1200 m of the main spring boil. The depth of the run ranges from 1.5 to 10 m, with the maximum depths near the spring boils.

2.2. Macrophyte biomass

In the winter of 2003–2004 and summer of 2004, above-sediment macrophyte biomass was determined at sampling sites ($n = 111$) by counting blades or stems within a $0.25\ m^2$ quadrat via underwater survey. Six blades from each quadrat were collected for determination of dry weight (DW), ash-free dry weight (AFDW), and blade length.

The spatial and temporal distribution of aquatic vegetation was determined from high density transects using a Raytheon DE-719 fathometer with a 200 kHz transducer, according to the methods of Maceina and Shireman (1980) in February 2004 (104 transects) and August 2004 (98 transects). Macrophyte percent coverage was determined visually within a $0.25\ m^2$ quadrat on a percent coverage scale (PCS) (Braun-Blanquet, 1932) divided into 0, 10, 25, 50, 75 and 100% from georeferenced sampling sites ($n = 107$). PCS coverages were converted to blade density per square meter by counting the number of blades per $0.25\ m^2$ quadrat from each of the PCS divisions ($n = 50$) using SCUBA divers.

2.3. Epiphyte biomass

In the winter of 2003–2004 and summer of 2005, epiphytes were sampled from the macrophyte blades ($n = 252$) and analyzed for DW, AFDW, and for chlorophyll *a*, a proxy for algae biomass (g chlorophyll *a* g^{-1} AFDW macrophyte) according to methods described by Sartory and Grobbelaar (1984). The spatial distribution of epiphytes was characterized using the PCS coverages described for macrophyte coverage ($n = 607$ in summer and $n = 73$ in winter). From each of these divisions, ten blades were collected and the epiphytes were processed for chlorophyll *a* per blade biomass (g).

2.4. Benthic algae mat biomass

In the winter months of 2003–2004, benthic algae mat samples were collected in the Silver River using $0.25\ m^2$ quadrats ($n = 111$). An additional 124 summer and 43 winter sites were used to characterize the algae mat coverage (PCS). Algal mat thickness was determined to the nearest centimeter by divers at each site. Selected sites ($n = 20$) were used to quantify the biomass per volume of the mat ($g\ m^{-3}$) using a coring device (6.34 cm diameter for summer and 7.3 cm diameter winter). Sediments and foreign materials (i.e. invertebrates, leaves, fish etc.) were removed by rinsing with deionized water and then analyzed for DW and AFDW.

2.5. Gravimetric analysis

For determination of DW and AFDW, epiphytic material was removed from macrophyte blades/stems using methods described by Moulton et al. (2002). Cleaned blades were measured for length and width before placing them in individual pre-washed, pre-fired, tared crucibles and dried to constant weight at 105 °C for DW determination, then ignited for 1 h at 500 °C for ash determination. After combustion, samples were re-wet with deionized water and dried to a constant weight at 105 °C. The ash weight was measured and subtracted from the DW to determine AFDW. The same procedure was used to determine the epiphyte and benthic algae mat biomass, with the exception of the benthic algae mat samples, which were combusted for 3 h. The relationships between blade length (collected from fathometry charts) and blade biomass (DW and AFDW) were performed using regression analysis (SAS, 2004).

2.6. Microscopic analysis

The epiphytic and benthic algae mat community was characterized microscopically using the Utermohl method (Utermohl, 1958), based upon samples collected adjacent to the sampling quadrats and preserved with Lugol's solution. Both