Ecological Indicators 60 (2016) 963–969

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Sediment cores from shallow lakes preserve reliable, informative paleoenvironmental archives despite hurricane-force winds

William F. Kenney[a,*], Mark Brenner[a,b], T. Elliott Arnold[b], Jason H. Curtis[b], Claire L. Schelske[b]

[a] Land Use and Environmental Change Institute, University of Florida, Gainesville, FL 32611-2120, USA
[b] Department of Geological Sciences, University of Florida, Gainesville, FL 32611-2120, USA

ARTICLE INFO

Article history:
Received 1 October 2014
Received in revised form 17 August 2015
Accepted 27 August 2015

Keywords:
Paleolimnology
Shallow lakes
Pb-210 dating
Hurricane impacts

ABSTRACT

Comparison of sediment cores collected in 1999 and 2013 from shallow Lake Harris, Florida, USA showed that the sediment maintained stratigraphic integrity despite multiple hurricanes passing through the area in 2004. Sediments less than 50 years old displayed small losses of organic matter (OM), total phosphorus (TP) and heat-extractable (HE-P) through time that are unrelated to hurricane impacts. Nevertheless, sediment that accumulated between the two core collection dates contained 4-fold more TP than was lost from the sediment over the 14-year period, indicating that sediments in Lake Harris are a net sink for water-column TP. Persistent, elevated ^{137}Cs activity in sediments deposited since the mid-1960s indicates protracted cesium input to the lake from this subtropical watershed. There is also evidence for downward transport of ^{137}Cs in the sediment profile between core collection dates. Prolonged export of ^{137}Cs from the watershed and downward mobility of the radionuclide in the sediment profile diminish the utility of ^{137}Cs as a dating tool in Lake Harris.

1. Introduction

Sediment cores from lakes possess valuable information about past environmental changes (Smol, 2009; Davidson and Jeppesen, 2013). Some have questioned the validity of paleolimnological studies in shallow lakes, despite an absence of empirical evidence to support their claim. Such skeptics often express concern that wind energy compromises the potential to preserve undisturbed stratigraphic sediment records in shallow lakes. In subtropical Florida, USA, this uncertainty is heightened by the potential influence of hurricanes on the integrity of the sediment record.

In the literature, these concerns may have originated in a speculative statement based on anecdotal accounts of a hurricane in 1947 that up-rooted extensive macrophyte beds in shallow Lake Apopka, Florida, USA and triggered a shift to a turbid-water, phytoplankton-dominated state (Schelske and Brezonik, 1992). Subsequently, however, it was discovered that the 1947 storm was not a hurricane at all (Lowe et al., 1999), that the storm never passed within 160 km of the water body (Neumann et al., 1981), and that it did not even produce strong winds on the lake. Despite this evidence to the contrary, the speculative suggestion that a stochastic mechanism, i.e. a hurricane, had triggered a state change in Lake Apopka, was cited repeatedly in the literature (Bachmann et al., 1999; Scheffer et al., 2001; Scheffer and van Nes, 2007; Janssen et al., 2014). Furthermore, even though the "hurricane hypothesis" was shown to be completely unfounded, it was apparently sufficiently enticing to inspire modeling exercises that purported to show that the lake became heterotrophic after the storm event (Bachmann et al., 2000). It was also suggested that since the 1947 storm, resuspension of wind-generated fluid mud has provided the major carbon source to the lake (Bachmann et al., 2000, 2005). One conclusion of these errant modeling exercises was that management approaches designed to reduce phosphorus in the lake would fail to restore the water body to its previous, clear-water, macrophyte-dominated state (Bachmann et al., 1999).

Ultimately, further studies in Lake Apopka showed that the water body is autotrophic (Gu et al., 2011) and that earlier models were flawed (Schelske and Kenney, 2001). Likewise, meta-data analysis indicated that sediment resuspension is unlikely to prevent the success of P-based management plans for phytoplankton-dominated shallow lakes (Jeppesen et al., 2003). A recent re-evaluation of Lake Apopka's trophic state history suggests that anthropogenic light attenuation in the water column (i.e. darkening), caused by pumping of stained, nutrient-rich waters from surrounding agricultural fields into the lake, likely triggered the shift to phytoplankton dominance (Schelske et al., 2010).

* Corresponding author. Tel.: +1 3523928664.
E-mail address: kenney@ufl.edu (W.F. Kenney).

http://dx.doi.org/10.1016/j.ecolind.2015.08.046
1470-160X/

Despite the advances in our understanding of Lake Apopka's recent trophic state history, some derived from paleolimnological analyses (Waters et al., 2005; Shumate et al., 2002; Kenney et al., 2002; Donar et al., 2009), wind-induced sediment disturbance is often raised as a factor that compromises sediment core studies in shallow lakes.

The potential for sediment cores from shallow lakes to preserve stratigraphic paleoenvironmental records, despite the influence of hurricane-force winds, can be evaluated using the "repeat-coring" technique of Blumentritt et al. (2013). The approach involves returning to a coring location (or locations) in a lake and taking new sediment sections, years after an initial paleolimnological study was completed. Such an investigation might be carried out using ^{210}Pb-dated cores from Lake Apopka, collected years apart. We were, however, concerned that diking and draining ~40% of the lake bed for intensive agriculture (Lowe et al., 1999) may have affected the delivery rate of unsupported (excess) ^{210}Pb to the lake sediments, thereby violating the fundamental assumption of the constant rate of supply (CRS) ^{210}Pb dating model (Appleby and Oldield, 1983; Oldfield and Appleby, 1984). Because this might preclude the ability to generate an accurate core chronology, thereby compromising effective comparison of data from sediment cores collected at different times in Lake Apopka, we chose to compare "old" and "new" cores collected from nearby (<10 km), but less disturbed Lake Harris (Fig. 1).

We used repeat coring to test the sustained stratigraphic integrity of sediment cores from Lake Harris, which was impacted by three hurricanes in 2004. We used ^{210}Pb-dated sediment cores that were collected in 1999 and then again in 2013 and compared the stratigraphic distributions in the two cores, of ^{210}Pb and ^{137}Cs activities, bulk sediment mass, organic matter content (OM), total phosphorus (TP) and heat-extractable P (HE-P). If hurricane force winds disturbed the sediment, we would expect to find significant discrepancies in ^{210}Pb activity (1900–1999) between the 1999 and 2013 cores, possibly caused by homogenization of the recent sediments or large-scale movement and deposition of lake sediments and terrestrial materials. In the two ^{210}Pb-dated cores, we found high fidelity among stratigraphic profiles of ^{210}Pb activity (1900–1999). These findings show that shallow Florida lakes have the potential to contain sediment records that maintain stratigrahic integrity despite multiple hurricane impacts. Because the sediments maintained stratigraphic integrity, we were able to use the repeat-coring data to evaluate P and ^{137}Cs mobility in the sediment.

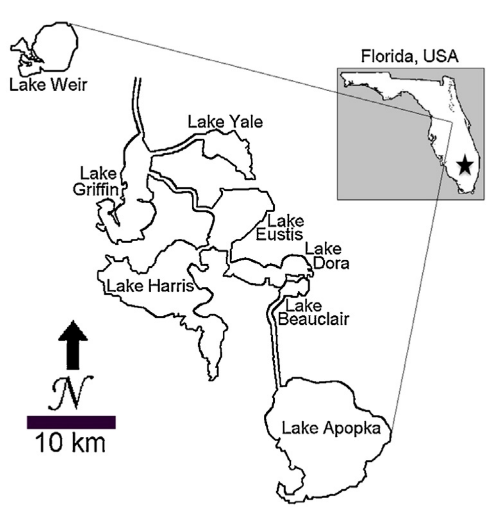

Fig. 1. The location of Lake Harris within the Harris Chain of Lakes is shown on the map of the study area (widths of canals and rivers are exaggerated). A star identifies the approximate location of Lake Okeechobee on the map of Florida.

2. Methods

2.1. Study site

Lake Harris (Fig. 1) is a subtropical, eutrophic, shallow water body located 50 km NW of Orlando, FL, USA (Fulton and Smith, 2008). The lake has a surface area of 75 km^2, a mean depth of 3.5 m and is considered naturally productive (Fulton and Smith, 2008). Sediment records show progressive increases in TP concentration and greater phytoplankton contributions to sediment OM since ~1950 (Kenney et al., 2010). These changes correspond temporally to a 6-fold increase in the local population between 1950 and 2000 (FDEP, 2001).

2.2. Methods for sediment core retrieval and sectioning

The two sediment/water interface cores were collected with a piston corer (Fisher et al., 1992), one in 1999 and one in 2013. We attempted to collect these cores at nearly identical locations, but because of logistical limitations, we suspect that these coring locations were less than 50 m apart. Cores were extruded vertically and sectioned in the field at 4-cm intervals. Samples were stored in low-density polyethylene cups in ice chests for transport to the laboratory. Subsamples of wet sediment were removed to determine heat-extractable P (HE-P). Remaining sediment in each section was frozen, freeze-dried and ground to a fine powder in the laboratory before analyses.

2.3. Methods for sediment chronology and geochemistry

The 1999 and 2013 sediment cores were dated by ^{210}Pb, each shortly after the date of core collection. Radiometric measurements (^{210}Pb, ^{226}Ra and ^{137}Cs) were made using low-background gamma counting with well-type intrinsic germanium detectors (Appleby et al., 1986; Schelske et al., 1994). Sediment ages were calculated using the CRS model (Appleby and Oldield, 1983; Oldfield and Appleby, 1984). Age errors were propagated using first-order approximations and calculated according to Binford (1990). Activity errors were calculated from the square root of the total counts and confidence intervals are the average activity ± twice the activity error. Activities in the 1999 core were adjusted (downward) to account for decay that occurred between the collection dates of the two cores, enabling comparison of activities in the two sequences for roughly equivalent time intervals.

Sediment bulk density (g dry cm^{-3} wet) was determined from the proportion of dry matter in wet sediment and proportions of inorganic and organic matter in dry sediment, using the equation of Binford (1990). Organic matter content was determined by weight loss on ignition at 550 °C for 2 h. The colorimetric procedure for HE-P determination is presented in Kenney et al. (2001) and TP was also measured by colorimetry according to Schelske et al. (1986). Kenney et al. (2001) referred to the HE-P fraction as equivalent to polyphosphate, but HE-P may also include other organic components of sediment P (Torres et al., 2014). To avoid confusion, we use the operationally defined term HE-P here. Because the HE-P fraction may include polyphosphate in intact, sedimented phytoplankton (Kenney et al., 2015) and HE-P was strongly correlated to phytoplankton indicators such as native chlorophyll (Waters et al., 2005) and diatom biogenic silica (Kenney et al., 2015), we consider HE-P to be an indicator of high phytoplankton deposition. Error terms for gravimetric and geochemical characteristics were calculated as the average of the relative percent difference of replicate analyses. Confidence intervals represent the measured value ± twice the replicate error.