J. Aquat. Plant Manage. 54: 87–94

Littoral sediment accumulation ten years after muck removal in Lake Tohopekaliga, Florida

MARK V. HOYER, MICHAEL D. NETHERLAND, AND DEAN JONES*

ABSTRACT

In 2004 a multimillion dollar muck removal program was completed that targeted an estimated average 46 cm of muck in 1,420 ha of littoral area in Lake Tohopekaliga, FL. In 2005 sediment cores were taken from 145 sites located throughout the scraped littoral area, showing an estimated 1.6 cm of organic sediment after the removal program. To address concerns about the longevity of this management activity, sediment cores were taken again at 130 of the original sites in August 2008 and January 2015 to estimate sediment accumulation rates. From 2005 to 2015 there was a whole-lake average of 2.2 cm of organic sediment accumulated, yielding a rate of 0.22 (0.18 to 0.24, 95% confidence interval) cm yr^{-1} for the decade. At that accumulation rate it would take approximately 210 yr (191 to 238, 95% confidence interval) to reach the original 46 cm of littoral muck, and these data suggest that the muck removal program will not have to be repeated for many years. Additionally, aquatic plants were identified at coring sites sampled in 2015 to determine if sediment accumulation rates were different in areas dominated by specific plant types and/or species, and no significant differences were found.

Key words: aquatic plant sedimentation, eutrophication, lake management, lake sediment.

INTRODUCTION

Many lakes in the world undergo increased lake succession caused by cultural eutrophication, water-level stabilization, and expansion of invasive aquatic macrophytes (Scheffer 1998, Cooke et al. 2005, Brenner et al. 2006). This littoral accumulation of sediments became such a problem in Lake Tohopekaliga that the Florida Fish and Wildlife Conservation Commission (FWC) spent several million dollars in 2004 to remove these sediments from 1,420 ha of the 9,800-ha lake (Hoyer et al. 2008). Project objectives included: 1) offset lake succession that resulted from cultural eutrophication, water-level stabilization, expansion of invasive aquatic macrophytes, and especially the accumulation of organic material from aquatic plant monocultures in the littoral zone; 2) improve lake access and aesthetics; and 3) restore fish and wildlife habitat toward historic plant community characteristics and improve sportfishing opportunities.

First, the lake water level was lowered to allow littoral sediments to dry out. Next, heavy equipment was used to scrape the plants and dead organic materials from 1,420 ha of the underlying sand substrates in the littoral zone over a period of 6 mo. Some of these materials were trucked out of the lake basin, but because of the high costs required to transport this material long distances and a lack of nearby disposal sites, most of the muck was heaped into large piles in shallow parts of the lake to form 29 artificial islands with basal areas from 0.4 to 3.3 ha each (Hoyer et al. 2008). The average depth of approximately 46 cm of organic matter in the littoral areas before the lake enhancement project was reduced to 1.6 cm in the scraped areas (Hoyer et al. 2006).

This was one of Florida's largest lake management actions ever taken and many representatives of major state and federal resource agencies had concerns about the utility of this management tool for other lakes in Florida, especially because of the large cost. One of the major concerns was how long this action would benefit the lake, and how long into the future before this disruptive management activity would be needed again. After the muck removal project was finished and water began to refill the lake, 145 sediment cores were taken in January 2005 to estimate thickness of organic sediment in scraped areas around and behind all islands created in Lake Tohopekaliga (1.6 cm; Hoyer et al. 2006). This was done to establish a baseline measurement of organic matter thickness for future examinations of sediment accumulation rates. An additional 145 cores were taken at the exact locations in January 2006 (Hoyer et al. 2006) and August 2008 (Hoyer et al. 2008). The 2006 postmanagement sediment measurements were variable and most likely the sediments were easy to move around during this time period because there was little or no aquatic vegetation present to reduce wave action and stabilize the sediments (Hoyer et al. 2008).

The postmanagement movement of sediments was likely exacerbated by hurricane impacts (Hoyer et al. 2008). At about the same time the lake was refilled with water, three strong hurricanes passed through central Florida, with direct impacts on Lake Tohopekaliga. In addition to extreme disturbance from hurricane-force winds, rainfall of 92 cm in August and September (compared with the average of 38 cm for the same 2 mo in 2000 through 2003) resulted in significant impacts. It took approximately 2 yr for water chemistry impacts of both hurricanes and management activities to stabilize to pre-2004 levels (Hoyer

---

*First author: Director, Florida LAKEWATCH, School of Forest Resources and Conservation, University of Florida, 7922 NW 71st Street, Gainesville, FL 32653. Second author: Research Biologist, U.S. Army Engineer Research and Development Center, 7922 NW 71st Street, Gainesville, FL 32653. Third author: Research Biologist, University of Florida Center for Aquatic and Invasive Plants, 700 Experiment Station Road, Lake Alfred, FL 33850. Corresponding author's E-mail: Michael.D.Netherland@usace.army.mil. Received for publication June 8, 2015 and in revised form January 6, 2016.

et al. 2008). Similarly, significant abundances of submersed aquatic plants such as Hydrilla verticillata (L. f.) Royle and American eelgrass Vallisneria americana Michx. took approximately 2 yr to become re-established because of the dark water conditions.

This study was initiated to examine how long the sediment removal program would benefit Lake Tohopekaliga, and when this management activity might be needed again in the future. Specifically, we sampled sediment at all but 15 of the original locations selected in 2005 and calculated a whole-lake sediment accumulation rate over a 10-yr period. Additionally, aquatic plants were identified at each sampling location to determine if current plant abundance and different plant types and/or species are related to local sediment accumulation rates.

METHODS AND MATERIALS

Study site and history

Lake Tohopekaliga is a large (surface area 9,800 ha), shallow (mean depth 2.1 m), natural lake located in the central part of the Florida peninsula south of Orlando (Osceola County). A major lake management problem started in the 1950s when the first municipal wastewater discharges reached the lake (Williams 2001). As a result, significant deterioration in water quality and aquatic habitat were evident by 1969. Annual phosphorus loading peaked in 1980 at 112,000 kg yr^{-1} (Jones et al. 1983). In 1982, it was estimated that 42–48% (60,000 kg) of the total phosphorus load and 41–49% of the total nitrogen load entering Lake Tohopekaliga came from wastewater treatment plants (Jones et al. 1983). By 1988 all wastewater discharges into Lake Tohopekaliga were eliminated, changing the annual phosphorus load from 87,000 kg in 1981 to 1,500 kg in 1988 (Dierberg et al. 1988, Williams 2001). Before the cleanup, however, culturally increased phosphorus concentrations in the lake caused increases in algal production, organic sedimentation, and accelerated lake succession.

Decreases in water-level fluctuations (water-level stabilization) led to other management problems at Lake Tohopekaliga. For the period of record from 1942 to 1964, Lake Tohopekaliga fluctuated between 59.40 and 48.93 ft mean sea level (MSL), a range of 10.47 ft vertical (U.S. Geological Survey, unpub. data). As a part of flood control programs, a lock-and-spillway structure (S-61) was completed on the outlet in January 1964 and a reduced fluctuation range was implemented. From 1964 to 1970 the elevation of Lake Tohopekaliga was controlled between 56.09 and 51.35 ft MSL, a difference of 4.74 ft (Wegener and Williams 1974). The regulation schedule was then revised, reducing fluctuations to 3.0 ft vertical (55.0 to 52 ft MSL), with a 1-in-3-yr drop to 51.5 ft MSL.

Reduced water-level fluctuations permitted development of formerly flooded lands around the lake, but had unintended consequences in the littoral areas. Limited water-level fluctuations in Florida allow expansive monocultures of emergent aquatic vegetation to develop in the littoral zone (Hoyer and Canfield 1997). These conditions are also favorable for some submersed and floating-leaved aquatic vegetation. Increases in aquatic vegetation result in accumulation of organic matter, especially from exotic aquatic plants like hydrilla and waterhyacinth Eichhornia crassipes (Mart.) Solms. Expansive monocultures of native emergent vegetation, such as pickerelweed (Pontederia cordata L.) and cattails (*Typha* spp.), also produce tremendous amounts of leaf litter (Hoyer and Canfield 1997). Organic matter trapped in stem and root structures of emergent and floating-leaved plants such as spatterdock Nuphar lutea ssp. advena (Ait.) Kartesz & Gandhi can create tussocks (floating plant islands with an organic base) when anaerobic gasses accumulate on the bottom, causing mats to break loose and float to the surface. The historical record of aquatic plants in Lake Tohopekaliga supports this mechanism of tussock formation (Hurkey 1957, Florida Department of Environmental Protection, Bureau of Invasive Plant Management 1982–1995).

High-water events in Lake Tohopekaliga possibly resulted in uprooting plants and sediment deposition on the normally dry floodplain, where they remained as water levels dropped. Conversely, organic sediments were exposed to drying and oxidation during drought conditions. Both mechanisms, which functioned to reduce the accumulation of organic matter and create a diverse, dynamic, aquatic plant community in the littoral zone, were lost when the range in water-level fluctuation was reduced from approximately 10 ft to 3 ft.

Measuring sediment depth

One hundred thirty of the original 145 sediment cores were taken once at each of five stations around 26 of the 29 wildlife islands to determine the depth (cm) of the organic material on the lake bottom. Because of difficulty in reaching the three islands in a small cove north of Highway 525, they were not sampled. All sediment cores for this project were taken between December 2014 and January 2015, yielding approximately 10 yr after the first 145 sediment cores were taken in January 2005. Latitude and longitude of all sediment core stations recorded using global positioning system equipment during the first sediment sampling (Hoyer et al. 2006) were again used to locate all stations (see Figure 1 and Appendix I). The stations were again labeled with a sediment core (SC), followed by the island letter, and ending with the sediment core station number (e.g., SCA1, sediment core for Island A at Station 1). Two cores (1 and 2 for each island) were taken behind each island between the island and the shoreline–water interface. The remaining three cores (3, 4, and 5 for each island) were taken along a transect set perpendicular to the shoreline approximately 300 m away from each island, and were separated by approximately 15 m.

The cores were taken with a sediment sampler that greatly enhanced the ease of sediment sampling (Davis and Steinman 1998). The sampler had a clear plastic tube 2 inches in diameter that was pushed into the sediment, sealed with a polyvinyl chloride check valve, and removed. The thickness of organic sediment above the sand base in the core was measured. At each coring location all aquatic

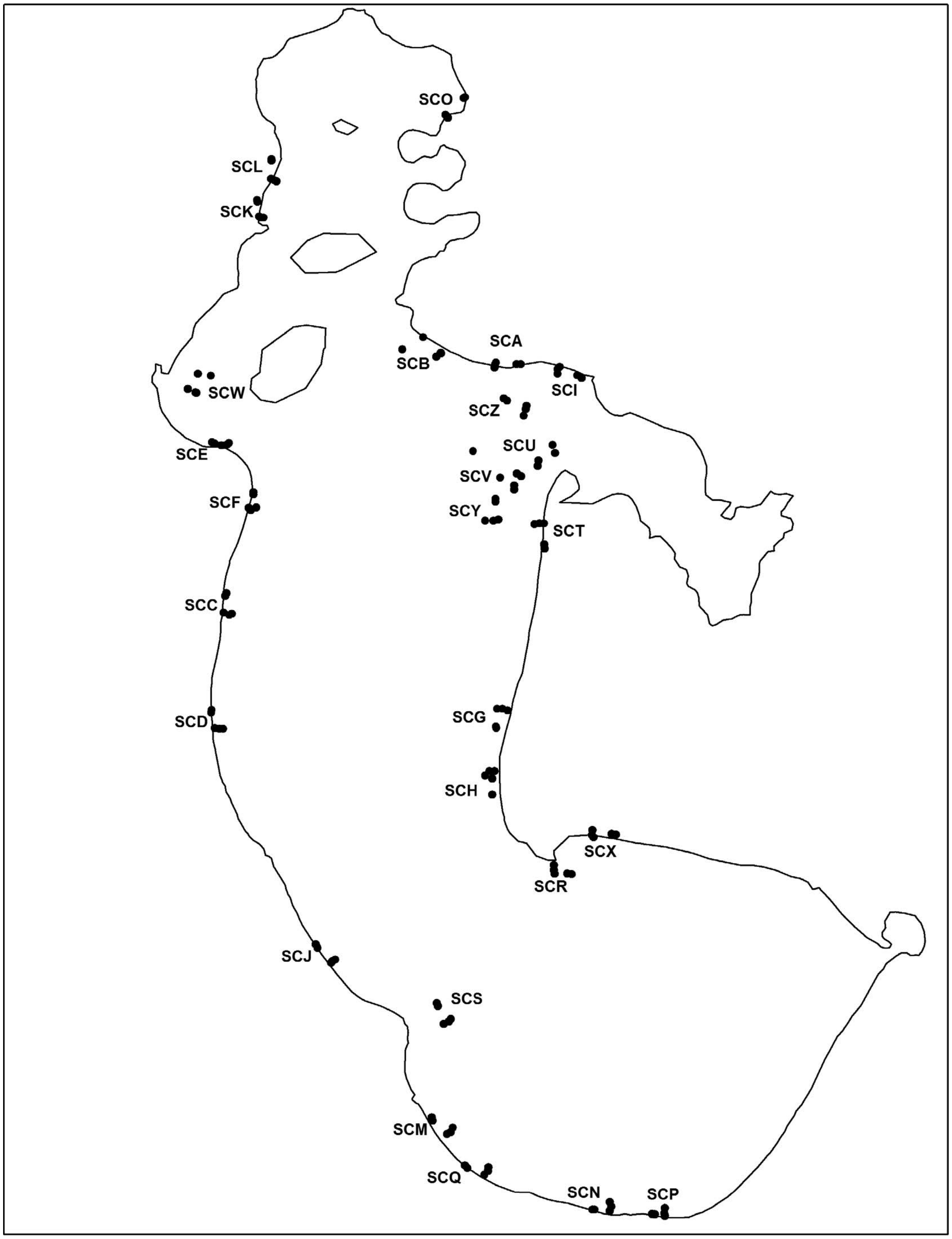

Figure 1. Map of 9,800-ha Lake Tohopekaliga with sediment measurement sites marked.

plant species within a 3-m radius of one side of the boat were identified and the abundance was classified as no plants (0), sparse (1), moderate (2), or abundant (3). The dominant plant species was identified as the one maintaining the most abundance. Sediment accumulation rates (cm yr^{-1}) at individual sites were determined by calculating the difference between core depth in 2015 and core depth in 2005 and dividing by 10 yr.

Individual sampling sites with high plant abundance (abundance of 3) were classified by plant type (e.g., emergent, floating, and submersed) using the plant type of the dominant plant species. When examining sediment accumulation rates in relation to plant type, or dominant species, only sites with abundant plants (abundance of 3) were used for analyses, and only if three or more sites had the plant type or species.

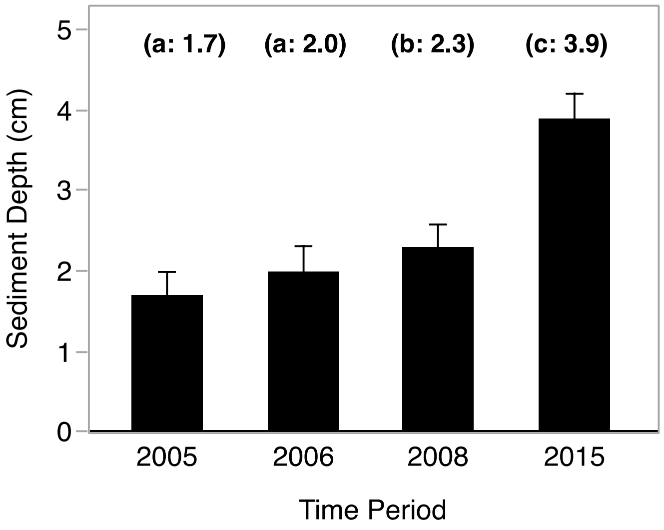

Figure 2. Sediment depths (cm) measured at 130 locations in Lake Tohopekaliga in January 2005, January 2006, August 2008, and January 2015. Bars represent mean values (± standard error) and different letters next to numeric values represent differences in sediment depths between sample years based on a Tukey–Kramer honestly significant difference test.

ANOVA was used to determine significance of dependent variables, and if significant, then a Tukey–Kramer honestly significant difference test was used to determine differences among all independent grouping variables (SAS 2000). When needed to accommodate heteroscedasticity of the data for parametric analyses (Sokal and Rohlf 1981), data were log10-tranformed (and if needed after adding 0.1 because some values were zero). When examining sedimentation rates in sites with different plant abundances, dominant plant types, and dominant plant species, samples sizes were different, so the data were examined for homogeneity of variance (Bartlett's homogeneity of variance test [SAS 2000]). If the variances were significantly different, then the significance of dependent variables was tested with a Welch ANOVA test (SAS, 2000). Data analyses were performed using JMP statistical package (SAS 2000) and all statements of significance are at the $P < 0.05$ level.

RESULTS

ANOVA showed that lake average organic sediment depth collected in 2005, 2006, 2008, and 2015 showed a significant increase through time: 1.7, 2.0, 2.3, and 3.9 cm, respectively. A Tukey–Kramer test showed that sediment depths in 2008 and 2015 were significantly different from all other years and that there was no difference between years 2005 and 2006 (Figure 2). The whole-lake difference between the 2015 (3.9 cm) and 2005 (1.7 cm) sediment depths divided by 10 yr shows that Lake Tohopekaliga averaged a sediment accumulation rate of 0.22 cm yr^{-1}.

To examine the variance in sediment measurements a variance components analysis was conducted with logarithmically transformed sediment depth plus 0.1 as the dependent variable and year, island within year, and site within island and year as the independent variables. The site data were from the three-site (3, 4, and 5) measured transects next to each island. In this analysis year accounted for 27%, island within year accounted for 38%, and site within island and year plus the remaining error accounted for 35% of the variation in sediment depth.

Table 1. Summary statistics for sediment accumulation rates (cm yr^{-1}) grouped by qualitative plant abundances. Bartlett's (SAS 2000) homogeneity of variance test showed that the variances across qualitative plant abundances were not equal and Welch ANOVA (SAS 2000, F ratio = 2.67, P = 0.09) showed that qualitative plant abundances did not account for significant variance in sediment accumulation rates.

Plant Abundance	Number	Mean	Standard Error
None	5	0.1	0.15
Low	7	0.2	0.13
Medium	63	0.2	0.04
High	55	0.3	0.05

Bartlett's homogeneity of variance test showed that the variances across qualitative plant abundances were not equal and Welch ANOVA (SAS 2000, F ratio = 2.67, P = 0.09) showed that qualitative plant abundances did not account for significant variance in sediment accumulation rates (Table 1). The average sediment accumulation rates at locations with qualitative plant abundances of 0, 1, 2, and 3, were 0.1, 0.2, 0.2, and 0.3 cm yr^{-1}, respectively. For all locations that had abundant aquatic plants (ranked with a 3) the dominant plant was classified by type: emergent, floating, and submersed. Bartlett's homogeneity of variance test showed that the variances across plant types were not equal and Welch ANOVA (SAS 2000, F ratio = 0.63, P = 0.55) showed that dominant plant type did not account for significant variance in sediment accumulation rates (Table 2). The average sediment accumulation rates at locations with the dominant plant type of emergent, floating, and submersed were 0.2, 0.2, and 0.4 cm yr^{-1}, respectively.

Sediment accumulation rates were also examined by dominant species in all locations that had abundant aquatic plants (ranked with a 3). Bartlett's homogeneity of variance test showed that the variances across plant types were not equal and Welch ANOVA (SAS 2000, F ratio = 0.78, P = 0.57) showed that dominant plant species did not account for significant variance in sediment accumulation rates (Table 3).

DISCUSSION

One of the major concerns about the sediment management activity conducted on Lake Tohopekaliga was how long the sediment removal program would benefit the lake and whether this management activity would be needed again in the near future. When the muck removal program

Table 2. Summary statistics for sediment accumulation rates (cm yr^{-1}) grouped by dominant plant type. Bartlett's (SAS 200) homogeneity of variance test showed that the variances across plant types were not equal and Welch ANOVA (SAS 2000, F ratio = 0.63, P = 0.55) showed that dominant plant type did not account for significant variance in sediment accumulation rates.

Dominant Plant Type	Number	Mean (cm yr^{-1})	Standard Error
Emergent	30	0.2	0.06
Floating	11	0.2	0.096
Submersed	5	0.4	0.146

TABLE 3. SUMMARY STATISTICS FOR SEDIMENT ACCUMULATION RATES (CM YR^{-1}) GROUPED BY DOMINANT PLANT SPECIES. BARTLETT'S (SAS 2000) HOMOGENEITY OF VARIANCE TEST SHOWED THAT THE VARIANCES ACROSS PLANT TYPES WERE NOT EQUAL AND WELCH ANOVA (SAS 2000, F RATIO = 0.78, $P = 0.57$) SHOWED THAT DOMINANT PLANT SPECIES DID NOT ACCOUNT FOR SIGNIFICANT VARIANCE IN SEDIMENT ACCUMULATION RATES.

Dominant Plant Species	Number	Mean	Standard Error
Cattail	7	0.1	0.12
Torpedo grass	5	0.3	0.14
Primrose nonnative	12	0.2	0.09
Pickerelweed	6	0.4	0.13
Hydrilla	5	0.4	0.14
Luziola	11	0.2	0.10

began it was estimated that the average sediment depth in the 1,420 ha of littoral area targeted for management was 46 cm (Mann et al. 2004). Using our estimated accumulation rate of 0.22 cm yr^{-1} between 2005 and 2015, it would take approximately 210 yr (191 to 238, 95% confidence interval) to accumulate 46 cm of organic sediment. This would be a conservative estimate because over time organic sediments show compaction and oxidation, decreasing the total accumulation (Enriquez et al. 1993; Cooke et al. 2005). Thus, given the current status of Lake Tohopekaliga and current sediment accumulation rates, the muck removal program will not have to be repeated for several decades.

This estimate of 210 yr to accumulate the measured 46 cm seems unusually high considering anecdotal statements that the sediment in Lake Tohopekaliga only started to become a problem in the last few decades (Dierberg et al. 1988; Williams 2001). However in the 1950s significant municipal wastewater discharges dramatically increased the trophic status of the lake and discharges were not reduced until the late 1980s. Chlorophyll concentrations in 1979 to 1981 averaged 100 $\mu g\ L^{-1}$ (Williams 2001), whereas 2 yr after muck scraping they averaged around 30 $\mu g\ L^{-1}$ (Hoyer et al. 2008). These 30+ yr of cultural eutrophication could account for some of the discrepancy in our measured sediment accumulation rates. Indeed, several researchers have measured increased carbon and phosphorus sediment accumulation after increases in lakes trophic status (Brenner et al. 2006; Rose et al. 2010; Brothers et al. 2013; Anderson et al. 2014). Williams (2001) pointed out that when Lake Tohopekaliga's trophic state increased it became algal dominated and lost many of the submersed aquatic plants that provided habitat for sportfish. In similar situations, Brothers et al. (2013) measured a fourfold increase in carbon sedimentation in a eutrophic European lake that switched from aquatic plant dominated to an algal dominated system.

Early discussion regarding the muck removal program pointed to increases in aquatic plants, especially exotic plants (e.g., hydrilla), and large monocultures of native plants (e.g., pickerelweed) as culprits in the large accumulation of organic matter in Lake Tohopekaliga (Mann et al. 2004; Hoyer et al. 2008). Indeed, research in wetlands has shown that only a small amount of aquatic plant matter is consumed by grazers and that most of the material enters the detrital pool as litter, where it decomposes (Brock 1984; Wetzel 1990; Kuehn et al. 2000). It can also take months or years for the litter to decompose completely, making it possible for the litter to be buried and accumulate as organic sediment. Additionally, experimental evidence shows that different plant types/species show varying rates of sediment deposition (Reddy and Debusk 1991; Chimney and Pietro 2006). Contrary to these findings our data show no difference in sediment accumulation in areas currently occupied with few or abundant aquatic plants and in areas of abundant plants. Moreover, no differences in sediment accumulation were noted among areas currently occupied with varying plant types or species. The lack of organic debris associated with some of these areas of dense plant growth was unexpected; however, the FWC has maintained a rigorous management program to prevent long-term establishment of dense monocultures of plants such as pickerelweed, cattail, and more recently water primrose (*Ludwigia* spp.). The contribution of active management in reducing organic matter accumulation may therefore provide a prolonged life to the scraping project.

Even though a 10-yr span seems considerable, this discrepancy in the primary literature and our results may be due to the shortness of time for accumulation rates we measured in this study. With a rough estimate of 0.22 cm yr^{-1} whole-lake sediment accumulation rate, it may take a much longer time (> 10 yr) to separate accumulation rates in areas with varying plant abundances and species compositions. As noted above, plant abundances and species compositions were recorded at the time the cores were taken in 2015 and we did not access records regarding various management activities over the past decade. To facilitate future investigations of this large-scale management effort, we have included the data, latitude, and longitude for all the stations used in this study (Appendix I). Although reduced nutrient loads and active plant management to prevent formation of rank monocultures have likely played a significant role in reducing the rate of organic matter accumulation, our study did not directly address these variables. Nonetheless, it is clear that current rates of sediment accumulation are much lower than predicted, and they suggest that the need for planning any additional organic muck removal projects are far into the future.

ACKNOWLEDGEMENTS

Partial support and funding for this project was provided by the U.S. Army Engineer Aquatic Plant Control Research Program and the Florida FWC, Invasive Plant Management Section. Permission was granted by the Chief of Engineers to publish this research.

LITERATURE CITED

Anderson NJ, Bennion H, Lotter AF. 2014. Lake eutrophication and its implications from organic carbon sequestration in Europe. Global Change Biol. 20:2741–2751.

Brenner M, Hodell DA, Leyden BW, Curtis JH, Kenney WF, Gu B, Newman JM. 2006. Mechanisms for organic matter and phosphorus burial in sediments of a shallow, subtropical, macrophyte dominated lake. J. Paleolimnol. 35:129–148.

Brock TCM. 1984. Aspects of the decomposition of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae). Aquat. Bot. 19:131–156.

Brothers SM, Hilt S, Attermeyer K, Grossart HP, Kosten S, Lischke B, Mehner T, Meyer N, Scharnweber K, Kojler J. 2013. A regime shift from macrophyte to phytoplankton dominance enhances carbon burial in a shallow, eutrophic lake. Ecosphere 4:137.http://dx.doi.org/10.1890/ES13-00247.1.

Chimney MJ, Pietro KC. 2006. Decomposition of macrophyte litter in a subtropical constructed wetland in south Florida (USA). Ecol. Eng. 27:301–321.

Cooke GD, Welch EB, Peterson SP, Newroth PR. 2005. Restoration and management of lakes and reservoirs. 3rd ed, Lewis Publishers, Boca Raton, FL. 548 pp.

Davis WP, Steinman AD. 1998. A lightweight inexpensive benthic core sampler for use in shallow water. J. Freshw. Ecol. 13:475–479.

Dierberg FE, Williams VP, Schneider WH. 1988. Evaluating water quality effects of lake management in Florida. Lake Reserv. Manage. 4:101–111.

Enriquez S, Duarte CM, Sandjensen K. 1993. Patterns in decomposition rates among photosynthetic organisms—The importance of detritus C–N–P contents. Oecologia 94:457–471.

Hoyer MV, Bachmann RW, Canfield DE Jr. 2008. Lake management (muck removal) and hurricane impacts to the trophic state of Lake Tohopekaliga, Florida. Lake Reservoir Manage. 24:1-12.

Hoyer MV, Canfield DE, Jr. (*eds.*). 1997. Aquatic plant management in lakes and reservoirs. Prepared by the North American Lake Management Society (P.O. Box 5443, Madison, WI 53705) and the Aquatic Plant Management Society (P.O. Box 1477, Lehigh, FL 33970) for U.S. Environmental Protection Agency, Washington, DC.

Hoyer MV, Canfield DE, Jr., Bachmann RW. 2006. Evaluation of Lake Tohopekaliga habitat enhancement project. Annual Report. Florida Fish and Wildlife Conservation Commission, Fresh Water Fisheries Division, Tallahassee, FL.

Hurkey WH. 1957. Recommended program for the Kissimmee River Basin. Florida Game and Freshwater Fish Commission, Kissimmee, FL.

Jones BL, Milar PS, Miller TH, Swift DR, Federico AC. 1983. Preliminary water quality and trophic state assessment of the Upper Kissimmee Chain of Lakes, Florida. 1981–982. First Annual Report. South Florida Water Management District, West Palm Beach, FL.

Kuehn KA, Lemke MJ, Suberkropp K, Wetzel RG. 2000. Microbial biomass and production associated with decaying leaf litter of emergent macrophyte *Juncus effusus*. Limnol. Oceangr. 45:862–870.

Mann MJ, McDaniel CK, Michael CS, Landrum AS, Bonvechio TF, Penfield TS, Jasent AC. 2004. Lakes Tohopekaliga, Cypress, Hatchineha, Kissimmee, East Lake Tohopekaliga, Tiger, and Alligator Chain of Lakes. Study 6301. Kissimmee Chain of Lakes Annual Progress Report, Florida Fish and Wildlife Conservation Commission, Tallahassee, FL.

Reddy KR, Debusk WF. 1991. Decomposition of water hyacinth detritus in eutrophic water. Hydrobiologia 211:101–109.

Rose NL, Morley D, Appleby PG, Batterbee RW, Allikasaar T, Guilizzoni P, Jeppesen E, Korhola A, Punning JM. 2010. Sediment accumulation rates in European lakes since AD 1850: Trends, reference conditions and exceedance. J. Paleolimnol. 45:447–468.

SAS. 2000. JMP Statistics and graphics guide. SAS Institute, Inc., Cary, NC.

Scheffer M. 1998. Ecology of shallow lakes. Chapman and Hall, New York.

Sokal RR, Rohlf FJ. 1981. The principles and practice of statistics in biological research. 2nd ed. W. H. Freeman and Co., San Francisco, CA. 593 pp.

Wegener W, Williams VP. 1974. Water level manipulation project completion report for Lake Tohopekaliga drawdown study. Florida Game and Freshwater Fish Commission, Kissimmee, FL.

Wetzel RG. 1990. Land-use interfaces: Metabolic and limnological regulators. Verh. Int. Verein. Limnol. 24:6–24.

Williams VP. 2001. Effects of point-source removal on lake water quality: A case History of Lake Tohopekaliga, Florida. Lake Reserv. Manage. 17:315–329.

APPENDIX I Location (Datum__WGS__1984) and sediment depth (cm) for each site located in Lake Tohopekaliga and sampled in January 2005, January 2006, August 2008, and January 2015.

Station	Latitude (°)	Longitude (°)	Sediment 2005	Sediment 2006	Sediment 2008	Sediment 2015
SCA1	28.24783	81.37375	1.7	1	1.5	5
SCA2	28.24783	81.37433	2.3	0.6	0.5	6
SCA3	28.24750	81.37744	0.7	0.2	0.2	3
SCA4	28.24789	81.37736	0	0.2	0.2	3
SCA5	28.24808	81.37722	0	0.3	0.2	4
SCB1	28.25003	81.39061	14.5	0	3.1	21
SCB2	28.25150	81.38758	9.5	11.4	13	7
SCB3	28.24903	81.38578	4.4	20.3	12	13
SCB4	28.24944	81.38517	16.5	19.1	20	14
SCB5	28.24944	81.38506	0.7	3.8	3	14
SCC1	28.21981	81.41642	0	0.2	1.5	3.5
SCC2	28.21947	81.41656	0.3	0.3	1	5.9
SCC3	28.21739	81.41683	0	0.2	0.5	0.8
SCC4	28.21708	81.41600	0.51	0.6	0.8	1.3
SCC5	28.21722	81.41567	0	0.6	0.8	2.4
SCD1	28.20517	81.41883	10.41	11.4	12	5.1
SCD2	28.20483	81.41889	0	1.3	3.5	10.1
SCD3	28.20281	81.41844	0	0.3	1.5	3
SCD4	28.20272	81.41781	0	0.3	2.1	2.6
SCD5	28.20272	81.41722	0.25	12.1	3.5	1.8
SCE1	28.23883	81.41797	1.27	0.6	0.8	6
SCE2	28.23867	81.41764	0	4.1	3.5	5.5
SCE3	28.23842	81.41667	0	1.3	0.9	6.5
SCE4	28.23853	81.41583	0	0.2	0.8	3
SCE5	28.23869	81.41558	0	0.2	0.7	2.5
SCF1	28.23242	81.41225	0	0.2	1	7.5
SCF2	28.23214	81.41228	0.25	1.9	3	5.5
SCF3	28.23050	81.41294	0	10.8	12	2.5
SCF4	28.23022	81.41261	0	0.2	0.2	4.5
SCF5	28.23053	81.41186	0	0.2	1.3	4.5
SCG1	28.20208	81.37828	1.11	0.2	0.5	3.7
SCG2	28.20225	81.37836	2.22	0.3	0.4	1.4
SCG3	28.20456	81.37814	0.64	3.2	2.1	1.6
SCG4	28.20453	81.37733	0.64	0	0.1	1.6
SCG5	28.20431	81.37664	0	0	0.2	4.3
SCH1	28.19572	81.37906	6.35	5.1	5.9	5
SCH2	28.19369	81.37911	0.76	0	2.1	0.7
SCH3	28.19614	81.38003	5.71	7.6	8.1	1.8
SCH4	28.19669	81.37942	3.81	6.3	5	1.4
SCH5	28.19667	81.37869	0	1.3	2	3.3
SCI1	28.24592	81.36508	7.4	0.2	1	6
SCI2	28.24631	81.36569	8.5	5.2	2.3	5
SCI3	28.24656	81.36850	1.1	0.6	2.1	8
SCI4	28.24711	81.36844	0	0	0.2	11
SCI5	28.24739	81.36817	0	0.2	0.2	7
SCJ1	28.17536	81.40475	3.81	0.2	0.5	0.5
SCJ2	28.17492	81.40447	0	1.3	0.7	0.2
SCJ3	28.17297	81.40261	0	3.2	1	1.7
SCJ4	28.17317	81.40239	0	0	0.5	2.9
SCJ5	28.17339	81.40197	0	0.2	0.5	1.8
SCK1	28.26928	81.41083	10.16	6.4	5.4	10
SCK2	28.26903	81.41078	2.54	4.4	6	6
SCK3	28.26719	81.41058	0.25	0	0.3	5.5
SCK4	28.26703	81.41031	1.91	0	0.2	5.5
SCK5	28.26700	81.41003	2.54	0	0.1	2.5
SCL1	28.27433	81.40869	0.25	0.6	1.5	5
SCL2	28.27417	81.40869	0	2.5	2.3	6
SCL3	28.27186	81.40878	0.25	0.6	1.2	5
SCL4	28.27167	81.40828	0.63	0.5	1	13
SCL5	28.27158	81.40800	0.25	0.5	3	3
SCM1	28.15328	81.38872	0	0.6	0.5	0.5
SCM2	28.15283	81.38864	0	3.2	2.8	0.1
SCM3	28.15117	81.38661	0	0.2	1.5	5
SCM4	28.15139	81.38606	0	0.6	1.4	1.4
SCM5	28.15192	81.38575	0	0.2	1.1	0.1
SCN1	28.14117	81.36581	5.71	6.4	6.9	8.2
SCN2	28.14117	81.36608	5.08	8.9	10	8.3
SCN3	28.14097	81.36361	0	0.2	1.8	2.8

APPENDIX I Continued.

Station	Latitude (°)	Longitude (°)	Sediment 2005	Sediment 2006	Sediment 2008	Sediment 2015
SCN4	28.14153	81.36339	0	0.2	1.5	0.5
SCN5	28.14208	81.36358	0	0.2	1.4	0.8
SCO1	28.28153	81.38108	0.7	3.2	4.4	13.5
SCO2	28.28164	81.38094	0	1.9	3.1	5.5
SCO3	28.27911	81.38342	1.91	0	1.1	6
SCO4	28.27931	81.38353	1.27	0	0.7	2.5
SCO5	28.27950	81.38375	1.27	0	0.7	0
SCP1	28.14047	81.35758	0.63	0	0	1
SCP2	28.14042	81.35725	0	0	0	0
SCP3	28.14022	81.35581	0	0	0.5	3.5
SCP4	28.14053	81.35586	0	0	0.5	0.5
SCP5	28.14117	81.35581	0	3.2	2	0.2
SCQ1	28.14711	81.38414	0	0.6	1.1	2.2
SCQ2	28.14681	81.38378	0	4.4	4.8	2.4
SCQ3	28.14592	81.38133	13.33	11.4	7.5	5.2
SCQ4	28.14633	81.38083	10.16	9.5	9	8.7
SCQ5	28.14683	81.38075	3.56	2.9	6.1	6.9
SCR1	28.18347	81.36806	1.27	2.5	3.8	0.2
SCR2	28.18361	81.36864	1.91	0.3	3.2	0.1
SCR3	28.18467	81.37056	0	0	1	0.3
SCR4	28.18406	81.37056	0	0	0.5	0.5
SCR5	28.18358	81.37047	0	0.2	0.5	0.1
SCS1	28.16761	81.38767	0.25	0.3	0.4	0
SCS2	28.16722	81.38750	3.56	5.1	3.1	0
SCS3	28.16497	81.38678	0	0	1	2.4
SCS4	28.16528	81.38606	0.76	0.2	1.2	2.7
SCS5	28.16561	81.38569	0	0	0.5	1.7
SCT1	28.22461	81.37089	0.95	0.6	0.9	4.8
SCT2	28.22514	81.37092	0.48	0.6	1	1.2
SCT3	28.22769	81.37222	2.54	0.2	0.2	0.9
SCT4	28.22778	81.37153	0	0	0.4	0.3
SCT5	28.22772	81.37092	0	0.2	0.5	2.7
SCU1	28.23503	81.37164	0	0.2	2.1	2
SCU2	28.23569	81.37147	0.4	0.2	1.9	4
SCU3	28.23656	81.36908	0	0.6	1.5	6
SCU4	28.23703	81.38078	0.6	1.9	2	11
SCU5	28.23758	81.36939	0.3	12.1	10.1	6
SCV1	28.23208	81.37503	0.32	1.9	2.1	3
SCV2	28.23261	81.37500	0.07	0.2	0.5	2
SCV3	28.23364	81.37697	0.07	0.2	1.1	3
SCV4	28.23411	81.37461	0.63	0.2	2.1	1
SCV5	28.23378	81.37403	0.63	0.6	2	1
SCW1	28.24747	81.41981	0.63	0.3	1	2.5
SCW2	28.24719	81.41794	0.25	0.6	0.6	3.5
SCW3	28.24511	81.42008	3.81	0.2	0.2	2.5
SCW4	28.24519	81.42017	1.27	0.2	0.2	4.5
SCW5	28.24561	81.42125	2.54	0.3	0.4	2.5
SCX1	28.18836	81.36161	0	1.3	2.1	5.6
SCX2	28.18847	81.36222	0.63	1.3	1.6	2.4
SCX3	28.18806	81.36481	0	0	1.1	3.5
SCX4	28.18836	81.36503	0	0	1.1	1.6
SCX5	28.18897	81.36492	1.27	1.3	1.8	1.3
SCY1	28.23097	81.37772	0	0.2	0.1	0.3
SCY2	28.23061	81.37772	0	0.2	0.1	1.1
SCY3	28.22822	81.37925	0	0.2	1.1	0.1
SCY4	28.22819	81.37811	0	0.2	0.3	0.1
SCY5	28.22833	81.37739	0	0.6	0.3	0.7
SCZ1	28.24356	81.37622	9.5	2.5	2.4	7
SCZ2	28.24328	81.37575	2.7	0.6	1	5
SCZ3	28.24261	81.37303	0.9	3.5	2.5	2
SCZ4	28.24217	81.37314	0.6	0.2	0.3	4
SCZ5	28.24136	81.37344	13	3.2	3.1	7