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Back-pumping of agricultural runoff into a large shallow lake and concurrent changes in the macroinvertebrate assemblage

Andrew J. Rodusky[a,*], *Ryan P. Maki*[b], *Bruce Sharfstein*[a]

[a]*South Florida Water Management District, West Palm Beach, FL 33406, USA*
[b]*Voyageurs National Park, US National Park Service, International Falls, MN 56649, USA*

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ABSTRACT

Macroinvertebrates were monitored during the summer of 2001 at two paired reference and impact sites, to assess potential effects of agricultural runoff, which was back-pumped upstream into Lake Okeechobee, USA. Monitoring was conducted prior to back-pumping (Pre, April–May), during back-pumping (BP, June–September) and during the following year (Post, April–September, 2002, impact sites only). Prior to back-pumping, the macroinvertebrate communities at both impact sites differed from those at their respective reference sites. During back-pumping, differences in the macroinvertebrate communities were slightly less pronounced among the eastern pair of sites but were more pronounced at the western sites than they were prior to back-pumping. There also were marginal differences in the macroinvertebrate communities at both impact sites between the Pre and BP periods, while very little change was observed in the communities among the same periods at both reference sites. For the Post–Pre and Post–BP period comparisons, there were clear differences between the macroinvertebrate communities at the western impact site, while less pronounced differences were observed at the eastern impact site. This suggests that the Post back-pumping assemblage did not return to that observed prior to back-pumping activity. During BP, several water-quality variables appeared to be different among each of the paired sites and the correlation between water-quality variables and macroinvertebrate community structure was strong at the western sites but weaker at the eastern sites. This suggests that a combination of abiotic variables may have been influencing the community structure at the western sites while back-pumping was occurring. Macroinvertebrates at all sites reflected poor water quality, but more taxonomic changes during back-pumping were observed at the impact sites than at the reference sites. It is not known if these taxonomic changes resulted in impacts among the macroinvertebrate community or to higher-trophic-level predators such as fish. If lake restoration activities result in a shift to a less pollution-tolerant macroinvertebrate community, and the anticipated reduction in future back-pumping activity does not occur, the macroinvertebrate community may return to one that is dominated by pollution-tolerant taxa in affected portions of the lake.

*Corresponding author. Tel.: +1 561 681 2500x4566; fax: +1 561 681 6310.
E-mail address: arodusk@sfwmd.gov (A.J. Rodusky).
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1. Introduction

Non-point source runoff from agricultural and other watershed activities and the associated eutrophication of lakes is a cosmopolitan and widely reported phenomenon (Anderson, 1997; Ogutu-Ohwayo et al., 1997; Whitmore et al., 1997; Gulati and van Donk, 2002; Egertson et al., 2004). Less commonly reported are instances of eutrophication in lakes which are associated with agricultural point source discharges (Glenn et al., 1999; Bachmann et al., 1999; Bootsma et al., 1999). Especially uncommon appear to be those instances where an upstream lake receives agricultural runoff that is pumped from drainage canals, a practice sometimes termed "back-pumping" (BP) (James et al., 1995; Bachmann et al., 1999). When a watershed has intensive agricultural activity, BP water can contain high nutrient, pesticide and metals concentrations, high specific conductance (COND) and low dissolved oxygen (DO), which may have negative impacts on the biota of the receiving waters.

Lake Okeechobee, a naturally eutrophic lake which has become a highly managed, multiple-use and increasingly eutrophic system (Steinman et al., 2002a), has periodically received back-pumped runoff, primarily from agricultural land. Prior to 1979, back-pumping of drainage canal water into the southern portion of the lake for flood control was common, but since 1979 it has been conducted much less frequently (Havens et al., 1996). This reduction in BP activity since 1979 came about when the South Florida Water Management District (SFWMD) implemented an interim action plan in recognition of potential negative ecological impacts as a result of frequent BP activity. From 1979 to 2006, back-pumping also was conducted during periods of severe drought (1981, 1985, 1989 and 2001) for water-supply purposes (SFWMD, 2002). Water that is back-pumped into Lake Okeechobee is high in total nitrogen (TN, $>1.7\,mg\,l^{-1}$), total phosphorus (TP, $>0.15\,mg\,l^{-1}$) (Havens and East, 1997) and COND ($>1000\,\mu S\,cm^{-1}$), while containing relatively low ($<4\,mg\,l^{-1}$) DO concentrations (Dickson et al., 1978). This water often has a very high TN:TP ratio (>200:1), and it has been suggested that substantially increasing back-pumping of runoff water into Lake Okeechobee could result in ecological damage to the southern portion of the lake (Havens and East, 1997). Yet, only one study has assessed potential impacts of this water on the biota of the lake. During this study, experimental incubations using back-pumped water resulted in a significant increase in cyanobacterial biomass, suggesting that an increase in back-pumping could increase cyanobacteria blooms in the south end of the lake (Havens and East, 1997). No studies assessing the potential impacts of BP runoff on higher-trophic-level organisms, such as macroinvertebrates, have been previously conducted.

The macroinvertebrate community in Lake Okeechobee has received less study than other biotic communities in the lake, such as submerged aquatic vegetation (SAV) and phytoplankton (summarized in Havens and Schelske, 2001). Since the late 1960s, three macroinvertebrate studies have been reported. A synoptic study conducted during 1987–91 (Warren and Vogel, 1991; Warren et al., 1995), which repeated the first study (Joyner, 1974), revealed that all sites were dominated by organic enrichment-tolerant species. The relative abundance of Oligochaetes during the late 1980s had increased approximately 50% (to 74%), while taxa other than Oligochaetes and Chironomidae had decreased from 53% to 5% of the assemblage, when compared to the Joyner (1974) study. An assessment of epiphytic macroinvertebrates during the mid-1980s indicated that the majority of species were tolerant of low DO and were indicative of moderately eutrophic conditions (Rudolph and Strom, 1990). The macroinvertebrate community also has been characterized as being relatively poor in quality and is rapidly becoming dominated by undesirable species, which are indicative of highly eutrophic conditions. The community is similar in composition to those in hypereutrophic lakes in Florida. However, the shallowness of the lake and consequently frequent wind-driven resuspension of the sediments may partially explain the absence or rarity of other macroinvertebrate species (Warren et al., 1995).

The back-pumping that was conducted in Lake Okeechobee during the summer of 2001 presented an opportunity to examine whether back-pumped agricultural runoff might adversely influence the community structure of higher-trophic-level organisms. The potential impacts of back-pumped runoff were examined by characterizing and comparing the macroinvertebrate communities and water-quality variables at two paired impact (I) and reference (R) sites. The objectives of this study were to compare taxonomic changes among each pair of I and R sites and determine whether any significant taxonomic shifts correlated with differences in water quality among the paired sites. The macroinvertebrate community was assessed since it is often used as an index of biological impairment in lakes (Blocksom et al., 2002) and is thought to be a better lake health assessment metric than other biological communities, due to macroinvertebrates' relative lack of mobility and longer generational times (Warren et al., 1995).

2. Methods

2.1. Study site description

Lake Okeechobee is a large, shallow, eutrophic lake, which has been described in detail elsewhere (Aumen, 1995; Steinman et al., 2002a; Havens and Gawlik, 2005). Two I and two R sites were established near and offshore, respectively, from the two water conveyance structures at the south end of the lake, which were used to back-pump water between June and September 2001 (Fig. 1). The eastern and western I sites (EI and WI) were located approximately 1100 and 1400 m from their respective water conveyance structures. Both sites were located in channels just lake-ward of an intersection between the southern fringing deep-water navigation channel ("rim canal") and pelagic water to the north. The eastern and western R sites (ER and WR) were located approximately 6900 and 1750 m offshore from their respective I sites in the pelagic zone at similar depths to the I sites. The R sites were located far enough from the pump stations so they would not be subjected to BP water plumes, such as those observed during previous BP events. All four sites were located in areas without SAV.