Journal of Environmental Management 139 (2014) 217–226

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Effects of increased summer flooding on nitrogen dynamics in impounded mangroves

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ARTICLE INFO

Article history:
Received 25 July 2013
Received in revised form
31 January 2014
Accepted 23 February 2014
Available online

Keywords:
Mangrove
Nitrogen cycling
Hydroperiod
Water management
Mosquito control
Avicennia

ABSTRACT

Mangroves are important for coastal protection, carbon sequestration and habitat provision for plants and animals in the tropics and subtropics. Mangroves are threatened by habitat destruction and sea level rise, but management activities such as impounding for mosquito control can also have negative effects. We studied the effects of Rotational Impoundment Management (RIM) on nitrogen dynamics in impoundments dominated by three types of Black mangrove (*Avicennia germinans*) stands along the Indian River Lagoon (Florida). RIM, designed for noxious insect control, involves pumping estuarine water into impoundments in this area during spring and summer to raise water levels by 30 cm. We compared aspects of the nitrogen cycle before and after the start of the RIM and measured the same variables in an impoundment without RIM management.

RIM led to the accumulation of ammonium in the substrate which coincided with a lowering of nitrification rates and decreased denitrification rates. Salt pan habitats dominated by dwarf mangroves became less saline following RIM initiation. Shoot growth of mangroves increased in response to higher nitrogen availability and lower pore water salinity. Mangrove responses were greatest in areas with dwarf and sparse mangrove cover. Overall, RIM resulted in lower nitrification and denitrification leading to lower nitrogen losses and increased Black mangrove growth, all benefits of RIM beyond those associated with noxious insect control.

1. Introduction

Mangroves play an important role in the functioning of coastal ecosystems in the tropics and subtropics worldwide. Ecosystem services include food chain support, nursery habitat for fish, water quality enhancement and carbon sequestration (Bouillon et al., 2008). Ecosystem services are closely linked to biogeochemical cycling of nutrients, particularly coupling between carbon (primary production and decomposition), nitrogen and phosphorus cycles (Feller et al., 1999; Kristensen et al., 2008). Globally, mangrove growth has been found to be limited by either nitrogen or phosphorus availability depending on geographic location (Lovelock et al., 2007). Mangrove growth varies along local gradients from open water towards more inland locations, with N-limited growth closer to and P-limited growth further away from open water (Feller et al., 2003a; Twilley and Rivera-Monroy, 2005). Gradients in nutrient limitation are also associated with a gradient in the stature, primarily height, of mangroves (Feller et al., 2003a, 2010).

While mangroves are threatened by habitat destruction, climate change and pollution (Gilman et al., 2008; Halpern et al., 2007), there are examples of relatively minor disturbances which leave mangrove systems intact but modify their structure and function. One example is the creation of impoundments to manage noxious insects, a management system that is widespread in Florida; having started in the middle to late 20th Century. By the mid-1970s, more than 16,400 ha of mangroves had been impounded in the Indian River Lagoon (IRL), a 250-km long estuarine system located on the east-central coast of Florida (Rey et al., 2009; Rey and Kain, 1991).

Impounding almost always results in altered patterns of tidal exchange between the impoundment and the estuary and subsequent changes in mangrove structure and function. For example, mangrove impoundments cause changes in fish and bird

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http://dx.doi.org/10.1016/j.jenvman.2014.02.035
0301-4797/

communities (Harrington and Harrington, 1982; Provost, 1969) as well as vegetation (Rey et al., 1990). The impoundment of mangroves also produces significant changes in groundwater characteristics. Stringer et al. (2010) found, for example, that evapotranspiration caused a net influx of lagoon water into an impoundment, resulting in a thick layer of hypersaline groundwater. Changes in the hydrological regime also have the potential to influence soil redox conditions which, in turn, alter nitrogen and phosphorus availability which are controlled by microbial and geochemical processes (Verhoeven, 2009).

Clements and Rogers (1964) demonstrated that many of the negative impacts caused by passive (i.e., continuous) impounding can be avoided by seasonal flooding while also providing effective insect control. Rotational Impoundment Management (RIM) is a management approach that employs the concept of seasonal flooding to control insects and is widely implemented globally, including in the IRL (Rey and Connelly, 2012). RIM employs pumps to flood impoundments with estuarine water during spring and summer while, at the same time, culverts assure exchange of water between the impoundment and the estuary. RIM has resulted in vegetation changes and increased fish abundances (Brockmeyer et al., 1997; Rey et al., 1990, 1992) but little is known about the effects of RIM on nutrient cycling in mangrove-dominated impoundments. Our goal was to determine the effects of RIM on processes related to the nitrogen cycle and on mangrove growth in an impoundment where nitrogen-limited growth of mangroves had been documented (Feller et al., 2003a, 2003b). Whigham et al. (2009) found N limitations along a gradient from open water to the interior of the impoundments with the greatest limitations occurring in the interior where black mangroves were of low stature (i.e., dwarf). Areas with N limited dwarf black mangroves were also associated with hypersaline conditions.

Microbial processes in wetland nitrogen dynamics are strongly dependent on soil redox. Nitrification only occurs under oxic conditions, whereas denitrification, dissimilative reduction of nitrate to ammonium (DNRA) and anaerobic ammonia oxidation (Anammox) occur under anoxic conditions (Groffman et al., 2002). The effects of redox conditions on mineralization of organic nitrogen are less clear. Although microbial decomposition of organic matter is faster in oxic conditions, the high degree of microbial immobilization of nitrogen often prevents ammonification. In addition, if the frequency and duration of flooding increases, more nitrogen might enter the system with flood water.

The overall effects of RIM management on soil nitrogen dynamics could be lower nitrification and associated accumulation of ammonium (Patrick and Reddy, 1976). Conditions for denitrification would improve but the rate would depend on nitrate concentrations in the flood water due to decreased nitrification in the soil. Moreover, competition with the DNRA process may increase (Fernandes et al., 2012). As has been demonstrated in laboratory conditions (Patrick and DeLaune, 1977), altered impoundment hydrology might lead to lower gaseous losses of nitrogen and, eventually, to higher nitrogen availability to mangroves. The increase in RIM associated flooding might also decrease the incidence of hypersaline soils to the benefit of plants and animals.

Our research questions were (1) would the application of RIM affect N mineralization, nitrification and denitrification; (2) to what extent would RIM lead to changes in pore water salinity, soil pH and extractable nutrient pools and (3) would mangrove growth change and the changes vary among different types of black mangrove stands. The study was designed to compare process rates and soil and plant characteristics before and after the beginning of RIM in one impoundment. For comparative purposes all of the variables were also measured in an adjacent impoundment in which RIM was not implemented.

In anticipation that substrates in the impoundment managed with RIM would become less hypersaline in spring and summer, we hypothesized that a decrease in soil redox potentials would lead to a decrease in rates of nitrification and coupled denitrification. We expected that RIM would lead to higher N availability and increased plant growth, especially in areas where shorter and sparser mangroves had been shown to be N limited.

1.1. Study site

The study was conducted in two adjacent impoundments (SLC-23 and SLC-24) located at N27°33′, W80°33′ on the east side of the Indian River Lagoon (IRL) on North Hutchinson Island between Vero Beach and Fort Pierce, Florida. The impoundments were created around 1970 by enclosing mangrove-dominated areas with dikes (Rey et al., 1990). The impoundments have sandy soils with a high concentration of shell debris and low organic matter content (less than 5%; Feller et al., 2003b).

Initially, dikes around both impoundments lacked culverts, isolating them from tidal circulation. The dike around Impoundment 23 was breached in 1979, resulting in enhanced tidal circulation. Impoundment 24 remained isolated until 1985, during which time vegetation cover decreased from 75% to 30% (Rey et al., 1990). Culverts were installed in Impoundment 24 in 1985 and 1987 but tidal exchange remained limited because of the small number and size of the culverts. Mangrove cover increased after the culverts were installed (Rey et al., 1990). All mangroves trees in both impoundments died from frost in 1989 but both have been recolonized (Rey et al., 2009). Until RIM was instituted in Impoundment 24, water levels in the impoundments were passively controlled by tidal exchange with the IRL through the culverts (Impoundment 24) or culverts and a breach in the dike (Impoundment 23). In 2009, RIM was instituted in Impoundment 24 following the establishment of a water control structure (i.e. pumps with supporting pipes). Pumping in Impoundment 24 began in March 2009 and it has been annually flooded between March–September with water being pumped in and allowed to drain back to the IRL through the open culverts. The RIM target is for water levels of 10–30 cm above the soil surface (Jim David, St. Lucie County Mosquito Control District, personal communication). Management of Impoundment 23 has not changed; thus serving as a control for the measurements made in Impoundment 24.

Vegetation in both impoundments is dominated by Black mangrove (*Avicennia germinans*). Red mangrove (*Rhizophora mangle)* is abundant and, at times, dominant near the fringe of the impoundments bordering the open water ditch that occurs immediately adjacent to the dike. White mangrove (*Laguncularia racemosa)* and Buttonbush (*Conocarpus erectus*) are also present and typically occur on higher elevation locations within the impoundments and at the wetland-upland border.

The structural characteristics of the black mangroves vary from dense stands of taller trees near open water areas to dwarf plants in interior areas. A complete description of the zonation with three height categories (i.e., tall, intermediate, dwarf) is given in Feller et al. (2003b). Dwarf mangrove are typically associated with salt pans where there is no vegetation or scattered individuals or patches of Black mangroves, often with combinations of Saltwort (*Batis maritima*), Virginia glasswort, (*Salicornia virginica)* and Dwarf glasswort (*Salicornia bigelovii)*.

We selected replicate locations of three different black mangrove cover types in both impoundments: (a) dwarf mangrove locations had less than 30% cover and tree heights <1 m; (b) sparse mangrove locations had cover that varied from 30 to 80% and tree height 1–3 m; and (c) dense mangrove locations had cover >80% and tree height >3 m. In terms of the zonation as described by