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Importance of water source in controlling leaf leaching losses in a dwarf red mangrove (*Rhizophora mangle* L.) wetland

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Abstract

The southern Everglades mangrove ecotone is characterized by extensive dwarf *Rhizophora mangle* L. shrub forests with a seasonally variable water source (Everglades − NE Florida Bay) and residence times ranging from short to long. We conducted a leaf leaching experiment to understand the influence that water source and its corresponding water quality have on (1) the early decay of *R. mangle* leaves and (2) the early exchange of total organic carbon (TOC) and total phosphorus (TP) between leaves and the water column. Newly senesced leaves collected from lower Taylor River (FL) were incubated in bottles containing water from one of three sources (Everglades, ambient mangrove, and Florida Bay) that spanned a range of salinity from 0 to 32‰, [TOC] from 710 to 1400 μM, and [TP] from 0.17 to 0.33 μM. We poisoned half the bottles in order to quantify abiotic processes (i.e., leaching) and assumed that non-poisoned bottles represented both biotic (i.e., microbial) and abiotic processes. We sacrificed bottles after 1,2, 5, 10, and 21 days of incubation and quantified changes in leaf mass and changes in water column [TOC] and [TP]. We saw 10–20% loss of leaf mass after 24 h—independent of water treatment—that leveled off by Day 21. After 3 weeks, non-poisoned leaves lost more mass than poisoned leaves, and there was only an effect of salinity on mass loss in poisoned incubations—with greatest leaching-associated losses in Everglades freshwater. Normalized concentrations of TOC in the water column increased by more than two orders of magnitude after 21 days with no effect of salinity and no difference between poisoned and non-poisoned treatments. However, normalized [TP] was lower in non-poisoned incubations as a result of immobilization by epiphytic microbes. This immobilization was greatest in Everglades freshwater and reflects the high P demand in this ecosystem. Immobilization of leached P in mangrove water and Florida Bay water was delayed by several days and may indicate an initial microbial limitation by labile C during the dry season.

Keywords: hydraulic residence time; organic carbon; phosphorus; limiting factor; salinity; Everglades

1. Introduction

Leaf litter fall and decomposition is an important recycling pathway for nutrients and fixed carbon in forested aquatic ecosystems (Fisher and Likens, 1973; Brinson, 1977; Tam et al., 1990). Although biological processes are important in governing the ultimate fate of leaf litter, evidence from numerous field and lab studies indicates that physical leaching is largely responsible for initial losses of these materials (Brinson, 1977; Rice and Tenore, 1981; Middleton and McKee, 2001 among others). Rates of leaf litter leaching are sensitive to environmental factors such as temperature, sunlight, water availability, and salinity (Nykvist, 1959, 1961; Parsons et al., 1990; Chale, 1993; Steinke et al., 1993). Some researchers have suggested that the biotic contributions in this early stage of decomposition are minimal and most often limited to microbial conditioning of the litter (Nykvist, 1959; Cundell et al., 1979; France et al., 1997). Other studies, however, have shown a significant microbial response on fixed carbon and nutrients within the first 24 h of exposure of leaf material (Lock and Hynes, 1976; Benner et al., 1986; Davis et al., 2006).

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In tropical mangrove ecosystems, leaf litter leaching rates decline after a few days of immersion in water, yet this process is responsible for substantial losses of elements to the water column and soil (Rice and Tenore, 1981; Chale, 1993; Steinke et al., 1993; Davis et al., 2003a). On a regional scale, the coupled process of mangrove leaf litter fall and leaching contributes to intra-annual patterns in water quality and materials flux unique to these coastal wetlands (Twilley, 1985; Davis et al., 2003b; Maie et al., 2005). This may be particularly important in nutrient-poor, dwarf mangrove wetlands where hydraulic residence times are often high and herbivory rates are very low (Twilley, 1995; Feller and Mathis, 1997). This combination of ecosystem properties leads to more reliance on internal recycling (i.e., detrital pathways) as a means of controlling nutrient availability and productivity.

The estuarine ecotone of the southern Everglades, FL, USA, supports an oligotrophic, P-limited wetland dominated by a dwarf red mangrove (*Rhizophora mangle* L.) forest (Koch and Snedaker, 1997). Unlike the Shark River estuary that drains much of the Everglades directly to the Gulf of Mexico, southern Everglades mangrove wetlands are subjected to very low tidal influence (<5 cm), relatively long hydrologic residence times, and seasonally variable influences of the Everglades and Florida Bay (as described in Chen and Twilley, 1999; Davis et al., 2001; Sutula et al., 2003). This leads to different surface water quality signatures in the southern Everglades mangrove ecotone during the dry season (Childers et al., 2006)—when salinity is high and concentrations of dissolved organic carbon (DOC) and total nitrogen (TN) are low—vs. the wet season—when salinity is low and [DOC] and [TN] are high (Davis et al., 2003b).

We conducted an experiment to determine how intra-annual patterns of salinity and water source in this dwarf *Rhizophora mangle* wetland affect early leaf decomposition and the release and recycling of leached phosphorus and organic carbon. A similar study looking at the effects of salinity on leaching showed that losses of mass and nutrients were greater in *Avicennia* leaves immersed in water with a salinity of 16‰ vs. 32‰ (Steinke et al., 1993). Based on these findings, we hypothesized that leaching losses from *R. mangle* leaf litter would be affected by surface water salinity. However, we also expected that source-specific water quality and respective microbial composition would affect leaf–water column exchanges.

Strong phosphorus-limitation across the southern Everglades mangrove ecotone results in low aboveground primary productivity and extremely low litter production (Koch and Snedaker, 1997; Coronado-Molina, 2000; Ewe et al., 2006). In spite of this, the initial leaching phase of *Rhizophora mangle* leaves has been shown to result in a significant release of P and labile organic matter during the first few days of immersion in water (Benner et al., 1986; Davis et al., 2003a). Considering the high degree of P-limitation that exists across the Everglades and into NE Florida Bay (Fourqurean et al., 1992; Amador and Jones, 1993; Noe et al., 2001), we expected a rapid microbial response to leached P regardless of the water source and quality experienced by this mangrove wetland.

2. Materials and methods

In May 1998, we collected newly senesced, yellow leaves from dwarf red mangrove trees along lower Taylor River, Everglades National Park, FL, USA, for use in this experiment. The exact location of the site (FCE-LTER site TS/Ph 7b) is longitude −80.649 and latitude 25.214. We conducted the incubations in glass bottles under ambient temperature and sunlight conditions. Following incubation, leaves were removed from the bottles, rinsed with de-ionized water to remove any superficial bacterial layer, and dried to a constant weight at 70 °C. The methods for leaf collection and for the leaching experiment are the same used in Davis et al. (2003a).

Since we used fresh leaf material, an accurate means of estimating initial dry weight was needed in order to determine mass loss and to normalize the quantity of total phosphorus (TP) and total organic carbon (TOC) released from each leaf. To accomplish this, we collected an additional batch of newly senesced leaves ($n = 75$) from the same site and at the same time to develop a linear regression model that could be used to estimate initial dry mass for each leaf from its initial fresh mass. This model showed that dry mass was consistently 34% of initial fresh mass ($p < 0.0001$; adjusted $r^2 = 0.99$; see Davis et al., 2003a).

Following initial leaf measurements, 100 fresh experimental leaves were individually stored in sterile plastic bags at 4 °C for no more than 24 h. Ninety individual leaves were randomly assigned to treatment combinations according to the experimental design. The three treatments included water treatment (2 levels: with and without poison), water salinity (3 levels: 0, 16, and 32), and collection day (5 levels: 1, 2, 5, 10, and 21 days). All treatment combinations (water treatment × salinity × collection day) had three replicates.

We added 2 ml of a 1% NaN_3 (sodium azide) solution to half of the experimental units as a poison to inhibit biotic respiration. The remaining bottles received 2 ml of de-ionized water. The effect of salinity on the early phase of leaf decomposition was determined by incubating leaves in waters of different salinity. The fixed levels of this treatment were chosen to represent the annual range of salinity and water source common to this dwarf mangrove wetland, as described below. All water was pre-filtered (Whatman GF/F) to reduce variability in large particles (>0.7 μm) between different waters.

To mimic typical wet season conditions in this dwarf *Rhizophora mangle* wetland, we used freshwater collected from a southern Everglades sawgrass (*Cladium jamaicense*) marsh. To get 16‰ water, we collected surface water from within the dwarf *R. mangle* wetland. Water representing the high salinity end member (32‰) was collected from NE Florida Bay. The latter two salinities were intended to reflect surface water conditions found in the dwarf mangrove zone during the dry season or associated with wind/storm events that would bring high salinity water into the dwarf mangrove ecotone from Florida Bay (see Fig. 1). We consider the different salinities (0, 16, and 32) of these different sources in our analyses, but also refer to these waters by their respective source (i.e., "Everglades", "mangrove", and "Florida Bay").