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Wading bird guano enrichment of soil nutrients in tree islands of the Florida Everglades

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HIGHLIGHTS

- Tree island soil P concentration and $\delta^{15}N$ values exceed other Everglades soils.
- Characteristics of Everglades tree island soil may indicate guano deposition.
- Deposition of stable guano P can exceed other P sources to tree island soil.

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ABSTRACT

Differential distribution of nutrients within an ecosystem can offer insight of ecological and physical processes that are otherwise unclear. This study was conducted to determine if enrichment of phosphorus (P) in tree island soils of the Florida Everglades can be explained by bird guano deposition. Concentrations of total carbon, nitrogen (N), and P, and N stable isotope ratio ($\delta^{15}N$) were determined on soil samples from 46 tree islands. Total elemental concentrations and $\delta^{15}N$ were determined on wading bird guano. Sequential chemical extraction of P pools was also performed on guano. Guano contained between 53.1 and 123.7 g-N kg^{-1} and 20.7 and 56.7 g-P kg^{-1}. Most of the P present in guano was extractable by HCl, which ranged from 82 to 97% of the total P. Total P of tree islands classified as having low or high P soils averaged 0.71 and 40.6 g kg^{-1}, respectively. Tree island soil with high total P concentration was found to have a similar $\delta^{15}N$ signature and total P concentration as bird guano. Phosphorus concentrations and $\delta^{15}N$ were positively correlated in tree island soils ($r = 0.83$, $p < 0.0001$). Potential input of guano with elevated concentrations of N and P, and ^{15}N enriched N, relative to other sources suggests that guano deposition in tree island soils is a mechanism contributing to this pattern.

1. Introduction

Determination of mechanisms controlling nutrient transport and transformations in soil is essential for wetland restoration planning and management. The Florida Everglades is a large (~10,000 km^2), primarily freshwater wetland (Wetzel et al., 2005). Drainage and flood control projects constructed within the region resulted in the conversion of wetland habitat to agriculture and urban land uses (Davis, 1994; Light and Dineen, 1994; DeBusk et al., 1994). These projects, and subsequent nutrient loading, altered historic nutrient and hydrologic regimes in the region (DeBusk et al., 1994). Restoration activities are ongoing throughout the Everglades and mostly focus on water delivery and control of phosphorus (P), a limiting nutrient in this highly oligotrophic ecosystem. An area of marsh is described as P-enriched when soil total P concentrations exceed 500 mg kg^{-1} (McCormick et al., 1999; Debusk et al., 2001).

The patches of trees and shrubs slightly elevated above the surrounding marsh are collectively described as tree islands (Sklar and van der Valk, 2002). Tree island soil P concentrations in the Everglades are reported to exceed the concentration of native marsh soil within the system, in some cases by two orders of magnitude or more (Orem et al., 2002; Wetzel et al., 2005; Ross and Sah, 2011).

Nutrient accumulation in tree island soil is primarily attributed to three mechanisms: evapotranspirational groundwater and surface water pumping by tree species, atmospheric deposition and deposition

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of animal waste (Wetzel et al., 2005; Ross et al., 2006). Accumulation of nutrients in tree island soils likely occurs at variable spatial and temporal scales among islands. If nutrient accumulation is variable among islands, differences could be attributable to the interactions between local surface and groundwater hydrologic gradients, differential vegetation patterns and wildlife distribution. Dramatic differences reported between tree island and marsh soils, and among tree island soils, may indicate that the mechanisms controlling P distribution between landforms may also influence distribution of P among islands. Soil P concentration of reconstructed tree islands, near the northern Everglades, was similar to marsh soil suggesting that tree island age may also play a role in soil nutrient accumulation (Rodriguez et al., 2014). Natural deposition or accumulation of P in high quantities may support an emerging theory for the ecology of the Everglades where high soil P and ecosystem health are no longer mutually exclusive (Wetzel et al., 2011).

Identification of P source is often challenging because of the complexity of P biogeochemistry. Wildlife species, particularly colonial nesting birds, have been described as potentially significant biovectors for nutrient transport, especially in the oligotrophic Everglades, and also in other wetland habitats (Bildstein et al., 1992; Frederick and Powell, 1994; Post et al., 1998). In the Everglades, wading birds generally forage in the emergent marshes and roost in patches of trees and shrubs dispersed throughout the ecosystem.

Spatial variation in foraging, and perching or nesting location within the ecosystem suggests a potential transport mechanism for nutrient redistribution (Frederick and Powell, 1994). Wading birds also seasonally nest in the Everglades in high density at many locations. Translocation of marine-derived nitrogen (N) and P to terrestrial island environments by seabirds, through guano deposition, is a mechanism for soil nutrient enrichment (Hutchison, 1950; Anderson and Polis, 1999; Wait et al., 2005). Similarly in the Everglades, transport of nutrients, particularly N and P, from marsh-derived prey items through bird guano deposition has been hypothesized to influence the distribution of soil P throughout the ecosystem resulting in elevated soil P concentration in tree island soils (Orem et al., 2002; Wetzel et al., 2005). For example, large nesting aggregations of birds may be capable of importing metric tonnes of P annually (Frederick and Powell, 1994). Nutrient transport alone does not comprise a mechanism for nutrient accumulation, unless the deposited nutrients have been transformed to a relatively stable form.

Little is known about the magnitude of the hypothesized mechanisms that may control nutrient accumulation and distribution in tree island soil. Deposition of high P content animal wastes such as guano, dropped food or carcasses in natural ecosystem settings can occur in discrete locations such as nesting sites of avifauna. Frederick and Powell (1994) suggested that where Everglades wading birds nest in high density, P deposition by avifauna may approach 3000 times the atmospheric P deposition rate, thereby playing an important role in nutrient redistribution. Guano deposition by avian species is one of the primary hypotheses offered to explain high concentrations of P in Everglades tree islands (Wetzel et al., 2005, 2011). Birds have been associated with nutrient focusing in wetlands and on islands located in marine environments (Post et al., 1998; Anderson and Polis, 1999; Wait et al., 2005; Macek et al., 2009). Anderson and Polis (1999) reported seabird guano deposition elevated soil P concentration up to six times higher than unaffected soil. Although an investigation conducted by Wait et al. (2005) focused on N inputs from guano deposition, their data also indicated a ~18:1 difference in soil P observed in guano affected islands versus non-guano islands.

Determination of the P concentration and forms of P in wading bird guano from the Everglades may provide insight regarding a mechanism of P transportation, and fate of P, within the ecosystem. The transport of P by birds from marsh habitat to tree islands in the Everglades, and the subsequent accumulation of P in tree island soil have been suggested as a mechanism that contributes to the oligotrophic status of the marsh (Wetzel et al., 2005). Although nutrient transport by birds to islands in marine ecosystems has been well described, similar information for the Everglades is not widely available. Contribution of P derived from bird guano to tree islands may be reflected by similarities between chemical properties of soil and guano. The purposes of this study were to: (1) chemically characterize wading bird guano collected from the Everglades, (2) investigate tree island soil characteristics and correlations among properties, and (3) estimate mass deposition of nutrients at Everglades tree islands from guano.

2. Materials and methods

2.1. Site locations, descriptions and sample collection

Soil was collected from 46 tree islands between 2005 and 2011 in the central and southern Everglades, Florida, USA (Fig. 1). All soil samples were collected from the head region of the tree island, which is the location most likely to have the highest concentration of soil P (Wetzel et al., 2009). The samples were oven-dried, and passed through a 2 mm mesh sieve prior to analysis. Soil samples were collected from depths ranging from of 0–5 cm ($n = 17$) and 0–10 cm ($n = 29$). These sampling depths were selected because this study focused on investigating shallow surface soil from numerous tree island in the Everglades and to compare P concentrations reported in subsurface soil layers at two tree islands in the Everglades by Orem et al. (2002).

Information describing survey and mapping of tree island soil in the Everglades is limited, and often soil within tree island habitat is described as peat (Wetzel et al., 2009; Ross et al., 2003; Leighty and Henderson, 1958). Coultas et al. (1998) described mineral soils within two tree islands in the southern Everglades. The few tree island locations with available soil survey data, classify the soils as Histosols (USDA, 1996).

Vegetation varies among tree islands ranging from upland species intolerant of extended periods of soil saturation, to swamp forest species capable of persisting during stages of soil saturation and standing

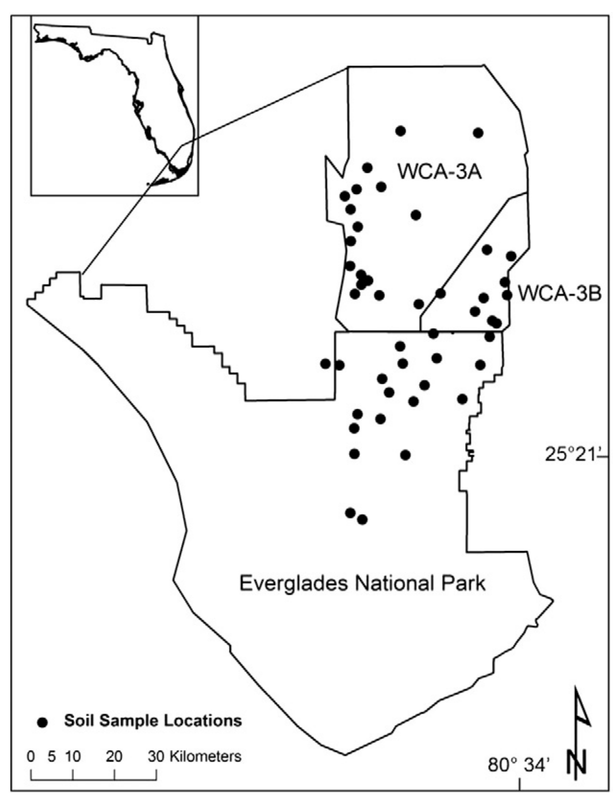

Fig. 1. Site map depicting tree island soil sample locations relative to the boundaries of Water Conservation Area 3A (WCA-3A), Water Conservation Area 3B (WCA-3B) and Everglades National Park, Florida, USA.