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Biogeochemical changes during early development of restored calcareous wetland soils

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ABSTRACT

Preservation and restoration of wetlands is critical to maintain their key functional roles of improving water quality, carbon sequestration, and mitigation of greenhouse gas emissions. Restoration of former agricultural wetlands often requires severe measures including removal nutrient-enriched soil followed by natural succession involving changes in nutrient storages and transformations. The focus of this study was to assess changes in biogeochemical parameters during the early stages of soil development following complete soil removal in a calcareous subtropical wetland. Results indicated that significant changes occur in the first 16 years including increased soil depth, accumulation of organic matter, carbon (C), nitrogen (N), and phosphorus (P). Early development of soils showed a shift from initial N limitation towards a state of co-limitation by N and P after 16 years. Functional responses of these changes were determined by monitoring the microbe-driven processes (enzyme activities and soil oxygen demand) with respect to the nutrient changes. Soil β-glucosidase activity increased in the first few years and then declined with age of the soils. Alkaline phosphatase activity was inversely correlated to the P concentration in soils. When compared with an undisturbed reference site, these parameters indicate that N processes recover more rapidly than those of P and C, but functional attributes related to P limitation should begin to mimic restored conditions within the next century.

1. Introduction

While covering only 7% of the land surface, wetlands account for about one third of the total soil carbon, and thus remain one of the major reservoirs of biosphere carbon, (Bridgham et al., 2006; Matthews and Fung, 1987). Many wetlands have been lost or degraded through anthropogenic activities, and the loss of natural wetland systems is directly linked to the loss of their biogeochemical and ecological functions (Bridgham et al., 2006). For this reason, preservation and restoration of wetlands has become a critical need in meeting the challenges of maintaining carbon sequestration, mitigating greenhouse gas emissions, and protecting other functions and values of wetlands.

Restoration efforts seek to aid development of the natural ecosystem once a disturbance is removed. Wetland restoration frequently relies on two main approaches including hydrologic restoration (flooding duration intensity, etc.) and manipulation of species composition (e.g., removal of exotics, planting of natives). In systems affected by agriculture, however, restoration of hydrology and species composition is often inadequate as the agricultural disturbance of cultivation and elevated nutrients leave these wetlands susceptible to continued invasion by unwanted species. In these cases, elevated soil nutrients are frequently only addressed by drastic measures such as removal of the nutrient-enriched soil (e.g., Dalrymple et al., 2003; Tallowin and Smith, 2001). Following soil removal, native vegetation is then either planted or allowed to naturally reestablish.

In cases where soils are shallow and its removal leaves bedrock exposed, the revegetation process more closely resembles primary succession, beginning with the development of microbial communities (algal mats, lichens) and followed by the growth of macrophyte communities. This type of succession has been studied extensively in many systems such as volcanic ash or lava flows, receding glaciers, mud slides, and coastal dunes (Tscherko et al., 2003; Wookey et al., 2002). Succession in the early development of soils is mainly influenced by the parent material, colonizing biotic communities, and the accumulation of macronutrients such as carbon (C), phosphorus (P), and nitrogen (N).

A conceptual model presented by Walker and Syers (1976) describes changes in nutrients during soil development. According to this model, the combination of C and N accumulation with the conversion of available inorganic P to less available organic P forms results in younger systems being more N-limited while older systems with more developed soils being more limited by P. Studies from ecosystems including grasslands, soils derived from volcanic deposits, wetlands, and deserts have in general validated the shift from N to P limitation during soil development (Baer et al., 2002; Lajtha and Schlesinger, 1988; Meyer et al., 2008; Vitousek et al., 2010).

Nutrient limitation is a key regulator of ecosystem productivity as well as decomposition, and therefore, is also a direct determinant of potential

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macro-element storage in an ecosystem. In this manner, biogeochemical conditions (nutrient levels) and processes (e.g. soil enzyme activities) can serve as indicators of system function as well as the progress of restoration at a given site. Biogeochemical parameters are also frequently monitored in chronosequences of soil development to evaluate progress of restoration and observe changes in nutrient storage and nutrient limitation (Walker et al., 2010). Most chronosequence studies derive information from time periods that extend to thousands of years; however, a few studies have also examined changes over relatively short time periods (<50 years). While long-term studies may better demonstrate the final end-point of restoration, short-term changes are the primary determinant of the ability of a system to sequester macro-nutrients during the next few to several decades. In this manner, short-term studies may provide a better metric for establishing success criteria or mitigation credits.

The Hole-In-the-Donut (HID) region of the Florida Everglades is a recent example of restoration where complete soil removal was the only successful practice to alleviate the growth of invasive species following cessation of farming (Dalrymple et al., 2003; Inglett et al., 2006; Fig. 1). The HID is an isolated area (4000 ha) located within the Everglades National Park (ENP) of the Everglades ecosystem. Prior to purchase of this land by ENP during mid-70s, this area was intensively used for agriculture, resulting in enrichment of soils with nutrients, especially P. The HID restoration also offers a unique opportunity to study the process of calcareous soil development (primary succession) as it applies to the restoration success of these wetlands. The HID area has undergone periodic clearing (soil removal) since 1989 resulting in a short-term chronosequence of system development at sites ranging from 2 to 16 years after clearing. The main objectives of this study were (1) to investigate the biogeochemical changes during the early stages of primary succession in calcareous soils, and (2) compare the development of the restored sites to an undisturbed, reference, site with native vegetation. With the information from this study we examine trends of the changes in biogeochemical processes and present the recovery trajectory of the developing ecosystem.

2. Methods

2.1. Site description and sample collection

Our site of interest is in the Hole-in-the-Donut region of the Everglades National Park, Florida (Fig. 1). This region of formerly marl prairies was used for farmland for over 30 years until it was abandoned around 1970. Fallow fields were quickly infested with *Schinus terebenthifolius* (Brazilian pepper). In an effort to restore the ecology of this region and to eradicate *Schinus*, soils were mechanically scraped to bedrock (limestone, calcium carbonate) beginning in 1989 and continuing through the present day (Dalrymple et al., 2003). Cleared regions were left to revegetate with native species from adjacent non-impacted areas. Sites for this study were cleared in 2003, 1997, and 1989 which placed them at 2, 8, and 16 years of age after restoration. In addition to the restored

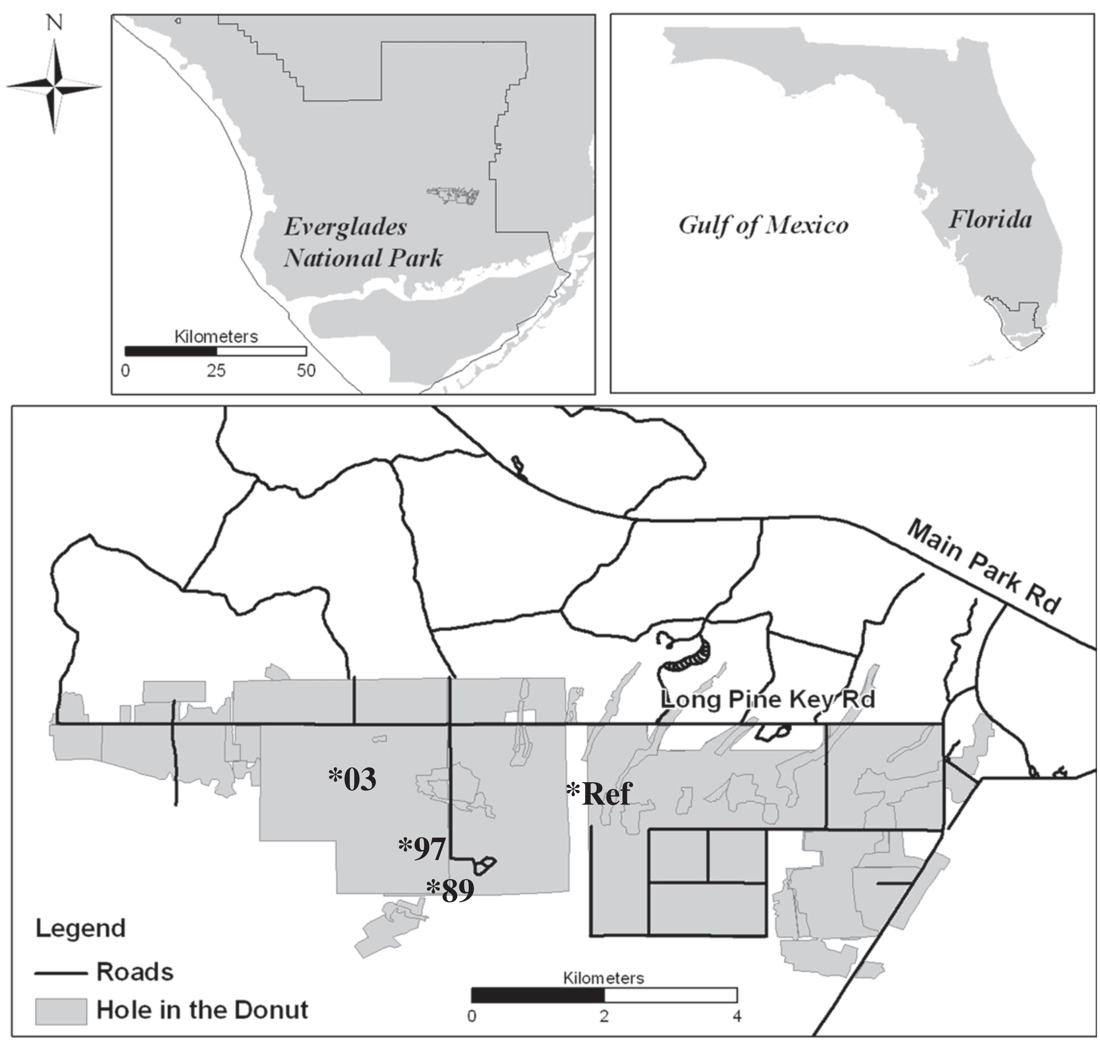

Fig. 1. Location of the Hole-in-the-Donut region in the Everglades National Park, FL showing areas of farming impact or restoration (shaded areas) and locations of sampling locations of sites restored in 2003 (03), restored in 1997 (97), restored in 1989 (89), and unfarmed reference site (Ref).