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Drained coastal peatlands: A potential nitrogen source to marine ecosystems under prolonged drought and heavy storm events—A microcosm experiment

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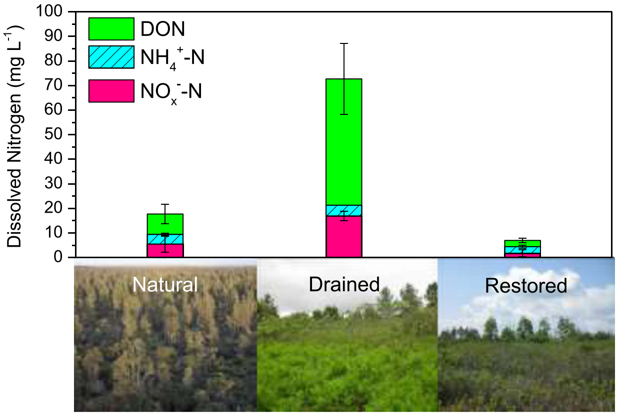
HIGHLIGHTS

- Drought duration significantly affects the rates of nitrogen mineralization in peat.
- Rewetting following drought triggers substantial nitrogen release from peatlands.
- Drainage/drought has long-lasting effects on nitrogen transformations in peatlands.
- Drought/drainage induced plant shift raises nitrogen mineralization in peatlands.

GRAPHICAL ABSTRACT



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ABSTRACT

Over the past several decades there has been a massive increase in coastal eutrophication, which is often caused by increased runoff input of nitrogen from landscape alterations. Peatlands, covering 3% of land area, have stored about 12–21% of global soil organic nitrogen (12–20 Pg N) around rivers, lakes and coasts over millennia and are now often drained and farmed. Their huge nitrogen pools may be released by intensified climate driven hydrologic events—prolonged droughts followed by heavy storms—and later transported to marine ecosystems. In this study, we collected peat monoliths from drained, natural, and restored coastal peatlands in the Southeastern U.S., and conducted a microcosm experiment simulating coupled prolonged-drought and storm events to (1) test whether storms could trigger a pulse of nitrogen export from drought-stressed peatlands and (2) assess how differentially hydrologic managements through shifting plant communities affect nitrogen export by combining an experiment of nitrogen release from litter.

During the drought phase, we observed a significant temporal variation in net nitrogen mineralization rate (NMR). NMR spiked in the third month and then decreased rapidly. This pattern indicates that drought duration significantly affects nitrogen mineralization in peat. NMR in the drained site reached up to 490 ± 110 kg ha^{-1}-year^{-1}, about 5 times higher than in the restored site. After the 14-month drought phase, we simulated a heavy storm by bringing peat monoliths to saturation. In the discharge waters, concentrations of total dissolved nitrogen in the monoliths from the drained site (72.7 ± 16.3 mg L^{-1}) was about ten times as high as from the restored site. Our results indicate that previously drained peatlands under prolonged drought are a potent source

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of nitrogen export. Moreover, drought-induced plant community shifts to herbaceous plants substantially raise nitrogen release with lasting effects by altering litter quality in peatlands.

1. Introduction

Massive volumes of chemical nitrogen production via the Haber-Bosch process have been applied to the landscape following the industrial revolution, causing many natural ecosystems which previously acted as nitrogen sinks to become nitrogen sources to downstream waters after saturation (Aber, 1992; Bragazza et al., 2006; Lamers et al., 2000). Overloading of nitrogen is a leading cause of impairment of coastal marine ecosystems around the world (Boesch et al., 2001; Compton et al., 2011; Diaz and Rosenberg, 2008; Paerl and Piehler, 2008). Currently, most studies focus on anthropogenic nitrogen sources, like fertilizer applied in farmlands and fossil-fuel derived atmospheric deposition (Cui et al., 2013; Liu et al., 2013; Paerl, 1997; Paerl, 2009; Robert, 2008). However, chronically accumulated organic nitrogen in natural ecosystems can potentially be quickly released and become a substantial source of nitrogen pollution, exacerbating degradation of aquatic ecosystems when environmental conditions, such as climatic warming and drought, change to favor nitrogen mineralization. Studies have shown large leaching losses of nitrogen from forests (Fang et al., 2009; Perakis and Hedin, 2002). But there is another important natural ecosystem—peatland that stores not only 1/3 of global soil carbon but also 12–21% of global soil organic nitrogen (12–20 Pg N) (Joosten, 2010; Limpens et al., 2006). Some peatlands have already lost their ability to absorb nitrogen due to an overload of nitrogen (Lamers et al., 2000; Qualls and Richardson, 2003). Moreover, most peatlands are located around rivers, lakes and coasts, where they may be a potentially significant nitrogen source to the adjacent aquatic ecosystems. To date, the internal cycle of nitrogen, which is sensitive to climate change, is still poorly understood in peatlands although its impact on adjacent downstream ecosystems may be substantial (Vassiljev and Blinova, 2012; Verhoeven et al., 1988; Wray and Bayley, 2008).

Soil nitrogen in peat is highly concentrated and is about 10–40 times higher than concentrations found in mineral soils (Soper and Osbon, 1922). Generally, nitrogen mineralization is slow under waterlogged conditions and almost all mineralized nitrogen is recycled within peatlands (Lamers et al., 2000). However, if water level drops, making more oxygen available in the soil, nitrogen mineralization could be accelerated, and huge amounts of available nitrogen can be released (Qualls and Richardson, 2003). For example, nitrogen mineralization rate found in Histosols in New York was >500 kg N ha^{-1} year^{-1} (Guthrie and Duxbury, 1978), which is higher than the amount of chemical nitrogen fertilizer used in intensive farming (Ju et al., 2009). Such potentially high available nitrogen in soil is the main reason why large portions of peatlands were drained and reclaimed as farmlands for the past two hundred years (Richardson, 1983, 2008; Soper and Osbon, 1922). In Estonia, export of nitrogen from drained peatlands was >1.5-fold higher than from that of farmlands and was the major source of nitrogen export to the surface water (Vassiljev and Blinova, 2012).

Both climatic and human disturbance have been substantially lowering peatland water levels and already have driven over 11% of global peatlands into a degraded state (IPCC, 2007; Joosten, 2010). The altered hydrological conditions not only directly alter the rate of nitrogen mineralization by changing the availability of oxygen but also the composition of organic nitrogen for mineralization by gradually changing the dominant plant communities that may even have longer-lasting effects on the nitrogen cycle (Laiho et al., 2003). Importantly, drought durations are projected to increase in the future (IPCC, 2007), which could substantially increase the available nitrogen pool in peatlands. Therefore, large quantities of nitrogen in peatlands would likely be released to freshwater bodies during heavy storms and subsequently enter coastal estuarine and marine ecosystems with negative consequences (Boesch et al., 2001; Diaz and Rosenberg, 2008; Paerl and Piehler, 2008).

In this study, we collected peat monoliths from drained, natural and restored coastal peatlands in the Southeastern U.S. and conducted a microcosm experiment. We simulated prolonged drought and heavy storms in lab to test 1) whether intensive drought and storms can cause increased export of nitrogen from drought-stressed peatlands and 2) how drought duration and long-term hydrologic conditions (drainage and restoration versus natural hydrologic regimes) affect this process. We compared these outputs with measured regional estimates of nitrogen losses from peatlands from the same area.

2. Material and methods

2.1. Study sites

Along the south Atlantic coast, peatlands cover millions of hectares and store over 20% of peat in the continental USA (Richardson, 2012; Soper and Osbon, 1922). These temperate and subtropical peatlands, called pocosins, are generally dominated by shrubs and trees. Our study area is located at Pocosin Lakes National Wildlife Refuge (PLNWR) in North Carolina and is about 8 km away from estuarine and marine wetlands. This site has a warm, humid climate with an average annual temperature of 16.8 °C. Annul precipitation is around 1230 mm and about 800 mm is lost to evapotranspiration (ET). Generally, the lowest and highest water levels occur in summer and winter, respectively. Throughout the year, groundwater levels rarely rise above ground surface and often reach 20 cm below the surface, but fall to over 100 cm in depth in the summer (Wang et al., 2015).

Most of the pocosins were drained for farming between 1920s and 1940s (McMullan Jr., 1983). Currently, there are a series of distinct hydrologic units (800 m × 1600 m cells) divided by ditches that have been used by PLNWR to restore the water level since the 1990s. In this study natural, drained, and restored sites were selected for treatments. The natural site experiences natural hydrologic conditions. The water level ranges from 0 to 60 cm below the ground surface during the winter and over 100 cm during the summer. Mature canopy trees–including pond pine (*Pinus serotina* Michx.), loblolly bay (*Gordonia lasianthus* (L.) Ellis), fetterbush lyonia (*Lyonia lucida* (Lam.) K. Koch), and swamp bay (*Persea palustris* (Raf.) Sarg.)–cover about 80% of the natural site. The water level in the drained site is mostly below 50 cm depth and over 150 cm in summer. About 80% of the ground area in the drained site is covered by western brakenfern (*Pteridium aquilinum* (L.) Kuhn). In the restored site, the water level is 20–30 cm below ground surface and native shrubs are dominant species, including large gallberry (*Ilex coriacea* (Pursh) Chapm.), inkberry (*Ilex glabra* (L.) A. Gray), fetterbush lyonia, honeycup (*Zenobia pulverulenta* (W.·Bartram ex. Willd.) Pollard), and laurel greenbrier (*Smilax laurifolia* L.).

2.2. Microcosm experiment

We collected triplicate peat monoliths from the natural, drained, and restored pocosins in January 2011. In the field, peat monoliths (32 cm in diameter) were excavated in 10-cm increments to a depth of 40 cm and was transferred to a top-open plastic incubator (30-cm diameter, 37.5-cm depth). All vegetation, fresh litter, live roots and rhizomes (>1 mm diameter) were removed. We incubated these monoliths at a constant temperature of 25 °C in the lab creating a gradual loss