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The effect of water table decline on plant biomass and species composition in the Zoige peatland: A four-year *in situ* field experiment

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A B S T R A C T

The Zoige peatland is the largest alpine peatland in the world, and it is suffering the threat of water table decline. Plant productivity and species composition are important to ecosystem carbon sequestration and soil carbon input in peatlands. We examined the responses of plant community composition and biomass accumulation to water table decline to better understanding the responses of this peatland to environmental changes. A four-year *in situ* field experiment was conducted involving three treatments: deep, shallow, and control water tables, which were achieved by experimental drainage with 50 cm, 20 cm, and 0 cm deep ditches, respectively. Experimental drainage decreased the annual mean height of water table by ca. 12 cm and 15 cm (relative to the control) in the shallow and deep water table treatments, respectively, over the four years. The response of aboveground plant biomass (APB) to water table decline declined in the first year, remained unchanged in the second year and increased during the third and fourth years. However, water table decline had a non-significant effect on belowground plant biomass. This duration-dependent response of APB can be attributed to the changes in community species composition during the study years. Specifically, the negative effect of water table decline in the first year was due to the significant decrease in APB of hygrophytes (sedges and rushes). In the second year, although water table decline significantly increased APB of mesophytes (grasses and forbs), this increase was offset by the decrease in APB of hygrophytes, leading to a neutral effect. In both the third and fourth years, the extent of the increase in APB of mesophytes (typically the forb species *Anemone trullifolia* var. *linearis*) was greater than that of the decrease in APB of hygrophytes, leading to a positive effect. Our results indicate that short-term decline of the water table may increase the primary productivity by shifting dominant species of hygrophytes to mesophytes in the Zogie peatland.

1. Introduction

The Zoige peatland on the Tibetan Plateau is the largest alpine peatland in the world (Xiang et al., 2009). It covers 4 605 km^2, occupying about 1‰ of the world's peatland area (Chen et al., 2014). Soil organic carbon (SOC) in the Zoige peatland is estimated to be about 0.48 Pg (Chen et al., 2014), which is approximately 6.2% and 1‰ of the SOC storage in China and in the world, respectively (Cui et al., 2015). Considering its potential importance to national and global carbon dynamics, the responses of plant community composition and biomass accumulation to climate change and anthropogenic disturbance take on huge significance.

One major threat to the Zoige peatland is the decline of the water table due to climate change and human activity. This peatland has experienced significant warming with the temperature increase of 0.4 °C per decade since 1970 (Yang et al., 2014) and, because it is a high-altitude area, the Zoige peatland is predicted to have a greater than average increase in temperature in the near future (Stocker, 2014). In addition, precipitation has decreased by an average of 22–28 mm per decade (Dong et al., 2010; Yang et al., 2014), which must have resulted in a reduction of water input to the peatland. An additional concern is that this peatland has experienced intensive human activities since the 1960s, especially artificial drainage for pasture expansion (Dong et al., 2010; Xiang et al., 2009). A total length of 2 864 km of artificial drainage channels have drained nearly 41% of the total area of the Zoige peatland (Dong et al., 2010). Collectively, climate change and anthropogenic perturbation have resulted in a 5–15 cm reduction of water table from the 1970s to the 2000s (Xiang et al., 2009).

High water tables and associated saturated soils are critical to sustain peatland vegetation composition and productivity (Bakker et al., 2007; Blom and Voesenek, 1996). Even a brief decline of the water table can induce a significant change in species competitive rank

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(Maestre et al., 2005), species composition, and plant biomass accumulation (Garssen et al., 2014). Importantly, these changes in plant species composition and community structure further affect peatland SOC pools (De Deyn et al., 2008; Malmer et al., 1994; Potvin et al., 2015).

However, not all peatlands have similar responses to water table decline in plant species composition and biomass accumulation. For example, microcosm studies employing soil cores have reported that short-term (< 4 years) reduction of the water table can shift dominant species of bryophytes (e.g. *Sphagnum rubellum*) to vascular plants (e.g. Ericaceae and other graminoid species) and aboveground plant biomass decreases due to a significant reduction in moss biomass in the fens and bogs of Northern American (Potvin et al., 2015; Weltzin et al., 2000) and North Europe (Breeuwer et al., 2009). Nevertheless, contrasting positive effects have also been documented in field investigations. For example, long-term (40, 50, and 55 years) drainage converted bogs into forest ecosystems dominated by pine (*Pinus sylvestris*) and birch (*Betula pubescens*), accompanied by increases in aboveground plant biomass (Laine et al., 1995; Murphy et al., 2009; Straková et al., 2012). Likewise, in Canadian peatlands, decades of drainage increased shrub density at the expense of ground-layer mosses and vascular herbaceous species, accompanied by increased aboveground plant biomass (Miller et al., 2015; Munir et al., 2014). These studies collectively show that plant biomass and species composition may respond in complex ways to water table decline, depending on the duration of perturbation and original species composition.

In order to address the effect of water table decline on SOC in the Zoige peatland, several studies (Yang et al., 2014, 2017; Zeng and Gao, 2016) have treated soil cores with different levels of water table and measured the fluxes of greenhouse gases including CO_2, CH_4, and N_2O, as well as some other soil variables. Nevertheless, there is no detailed report regarding the response of the Zoige peatland in plant species composition and biomass accumulation. Therefore, we conducted an *in situ* field experiment and examined the response of the Zoige peatland plant community to water table decline over four consecutive years. The objectives of this study are to determine 1) whether water table decline changes plant community species composition and plant biomass accumulation, and 2) whether changes in species composition correlate with changes in aboveground plant biomass.

2. Methods

2.1. Study site

This study was conducted in Hongyuan County (32°48′N, 102°33′E) of Sichuan Province in the Zoige peatland of the eastern Qinghai-Tibetan Plateau. The climate is cold and continental, and is characterized by a short and cool spring, summer, and autumn, and a long winter (Wu et al., 2014). The area of the Zoige peatland in Hongyuan County is about 492 km^2. According to the data collected at the Hongyuan County Climate Station (located 3 km from the study site and at the same altitude) from 1970 to 2016, the annual mean temperature was 1.73 °C, with an increase of 0.4 °C per decade. The maximum and minimum monthly mean was 11.1 and −9.4 °C in July and January, respectively. The annual mean temperature was 2.4 °C, 2.6 °C, 2.7 °C and 2.8 °C in 2013, 2014, 2015 and 2016, respectively (see Fig. S1). Data collected during the same time period show that the annual mean precipitation was 756 mm (80% of which occurs between May and August), with a decrease of 9.2 mm per decade. In particular, the annual mean precipitation was 753 mm, 908 mm, 719 mm and 710 mm in 2013, 2014, 2015 and 2016, respectively (Fig. S1). These indicate 2014 was a wet year, and 2013, and 2015 and 2016 seemed warmer and drier than 2013 and 2014.

The vegetation coverage in the study site is over 90% and consists mostly of sedge species including *Carex muliensis Kobresia humilis*, *Scirpus pumilus*, *Blysmus sinocompressus* and *Kobresia setchwanensis*. Rushes (*Juncus leucanthus* and *Juncus allioides*) are common but with relatively low abundance. Grasses, including *Deschampsia caespitosa* and *Agrostis matsumurae*, and forb species, including *Chamaesium paradoxum* and *Anemone trullifolia* var. *linearis*, are also abundant. Bryophyte is not apparent in our study site. Previous studies (Han and Yang, 2012; Yan and Wu, 2005) have shown that sedge and rush species are adapted to high-moisture habitats, whereas grasses and forbs are adapted to relative low-moisture habitats. Therefore, for the purpose of this study, we will refer to sedges and rushes as hygrophytes, and grasses and forbs as mesophytes. In addition, this peatland has been under intensive grazing for decades, and yaks (*Bos grunniens*) are the most important grazing livestock species (Yan and Wu, 2005).

2.2. Experimental designing and sampling

The experiment was set up as the one-factor, three-level block design, each block involving the deep, shallow, and control water table treatments. Each treatment replicated six times (six blocks), resulting in a total of 18 plots.

Before starting our experiment, we fenced a flat area of about 2 ha, where the vegetation evenness of the species distribution was so high that > 90% of plant species could be found in any 50 × 50 cm patch. In April of 2013, a 240 m long, 0.5 m wide, and 1 m deep drainage ditch (called hereafter the major ditch) connected to a small river was dug in the fenced area. Eighteen 6 × 6 m plots were deployed (with regular intervals of 30 m between two adjacent plots) approximately 30 m away from the major ditch, with nine plots distributing along each side of the major ditch. Six plots were drained by a 50 cm deep ditch and six plots by a 20 cm deep ditch, which served as deep and shallow water table treatments, respectively, and the remaining six plots were kept intact, serving as the control (see Fig. S2). Within each plot, one 1 m × 1 m subplot was randomly fenced using a steel wiring for plant sampling. The subplot was at least 1 m away from any ditch.

To record the height of the water table, polyvinyl chloride pipes (1.5 m in length and 5 cm in diameter) were driven into each plot. The height of the water table in each pipe was measured using a 1.5 m long ruler every three to ten days during the duration of the experiment, except for winter when the soil was frozen (from November to March). Water table depth was 15.3 cm, 13.1 cm, 8.7 cm and 11.8 cm in the shallow water table treatment, as well as 11.3 cm, 21.8 cm, 14.1 cm and 14.5 cm in the deep water table treatment lower than that in the control in 2013, 2014, 2015 and 2016, respectively. The annual mean height of the water table was 12 cm and 15 cm lower in the shallow and deep water table plots than that in the control plots, respectively, from 2013 to 2016 (Table S1; Fig. S3). We also measured soil moisture and temperature at the center of the subplots using data loggers (Watchdog 2000, Spectrum Technologies, Inc., USA) every 30 min over four years. During four years, the average daily soil moisture at 5 cm below the ground surface was 10% and 15% lower in the shallow and deep water table treatments than that in the control, respectively (Fig. S4). In addition, there were no significant differences in soil temperature at 5 cm belowground surface among the different treatments (Fig. S4).

The experimental monitoring covered four growing seasons, i.e. from 2013 to 2016. At the end of each growing season (August 18, 17, 20, and 15 in 2013, 2014, 2015, and 2016, respectively), we first harvested the aboveground plant parts of hygrophytes (including sedges and rushes) and grasses in each subplot. Then, we harvested the aboveground plant parts of the dominant forb species including *Anemone trullifolia* var. *linearis*, *Sanguisorba filiformis, Cremanthodium lineare*, *Ranunculus tanguticus, Chamaesium paradoxum* and *Potentilla anserina*. Other rare forb species were harvested together. After harvesting the aboveground plant parts we took three soil cores (5 cm in diameter and 30 cm in depth, respectively) beneath the harvested plants for each plot. The soil cores were manually mixed, sieved and all plant roots were picked out for the measurement of belowground plant biomass. Plant roots and the aboveground parts of plants were dried at