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Research article

Land management influences trade-offs and the total supply of ecosystem services in alpine grassland in Tibet, China

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ABSTRACT

Developing sustainable use patterns for alpine grassland in Tibet is the primary challenge related to conserving these vulnerable ecosystems of the 'world's third pole' and guaranteeing the well-being of local inhabitants. This challenge requires researchers to think beyond the methods of most current studies that are limited to a single aspect of conservation or productivity, and focus on balancing various needs. An analysis of trade-offs involving ecosystem services provides a framework that can be used to quantify the type of balancing needed. In this study, we measured variations in four types of ecosystem services under five types of grassland management including grazing exclusion, sowing, combined plowing and grazing exclusion, combined plowing and sowing, and natural grassland, from 2013 to 2015. In addition, we accessed the existence and changing patterns of ecosystem service trade-offs using Spearman coefficients and a trade-off index. The results revealed the existence of trade-offs among provisioning and regulating services. Plowing and sowing could convert the trade-off relationships into synergies immediately. Grazing exclusion reduced the level of trade-offs gradually over time. Thus, the combined plowing and sowing treatment promoted the total supply of multiple ecosystem services when compared with natural grassland. We argue that the variations in dry matter allocation to above- and belowground serve as one cause of the variation in trade-off relationships. Another cause for variation in trade-offs is the varied species competition between selection effects and niche complementarity. Our study provides empirical evidence that the effects of trade-offs among ecosystem services could be reduced and even converted into synergies by optimizing management techniques.

1. Introduction

Ecosystem services have been defined as the benefits that people obtain from ecosystems. Four major types of ecosystem services have been identified: provisioning, regulating, supporting and cultural services (Millennium Ecosystem Assessment, 2005). Provisioning services include the provisioning of resources such as food or fiber while regulating services included services such as soil retention, provisioning of carbon stocks, and water regulation; these all affect people directly (Millennium Ecosystem Assessment, 2005). Enhancing some ecosystem services, especially provisioning services, may cause a reduction in desirable regulating services provided by ecosystems, a situation that has been recognized as a trade-off (Bennett et al., 2009).

Conservation and sustainable use of grassland is a common issue worldwide (Bond and Parr, 2010; Fynn et al., 2016; Kamp et al., 2015). In China, the Tibetan Plateau provides many crucial ecosystem services to Asia and the world, such as the provisioning of forage and meat, water conservation and regulation, and the sequestration and stockpiling carbon (Pan et al., 2014; Piao et al., 2012; Wang et al., 2002). Under the combined effects of climate change and anthropogenic activities, many areas of alpine grassland in the Tibetan Plateau have been degraded and even become desertified (Chen et al., 2014; Harris, 2010). In about 2003, China began to enforce a policy that provides payments to herders in support of its Grazing Withdrawal Program for the grasslands across Tibet with the goal of conserving grassland habitat (Chen

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et al., 2014). This policy has led to the establishment of grazing exclusion in many grasslands and a reduction in stocking rates for livestock and has thus reduced the supply of provisioning services. However, with the ever increasing demands for regional development and increased personal consumption, scientific support for the sustainable use of these grasslands is urgently needed. The key to the sustainable use of grassland is to balance the trade-offs between the provisioning and regulating services and to promote the supplies of multiple ecosystem services.

Two types of mechanisms related to the trade-offs among ecosystem services were proposed to improve our understanding of how trade-offs occurred and to propose potential solutions designed to reduce the negative effects of trade-offs (Bennett et al., 2009). One proposed mechanism is that trade-offs are caused by common drivers, such as land use change (Bennett et al., 2009). For example, a conversion of grassland to farmland might trigger trade-offs between grain supply and soil retention (Pan et al., 2013). The other proposed mechanism is caused by interactions between different ecosystem services (Bennett et al., 2009). The interacting services commonly shared the same ecosystem functions and processes. For example, the water cycle is related to both the formation of dry matter and to water conservation. High net primary productively is usually connected to high levels of evapotranspiration. However, this may lead to a reduction in water availability in an ecosystem, and in areas receiving relatively low amounts of precipitation. At a regional level, this will lead to trade-offs between carbon sequestration and water conservation (Wang et al., 2011; Feng et al., 2016). Many studies have mapped and modeled how ecosystem services and trade-offs affect various types of land use change (Barnett et al., 2016; Nelson et al., 2009; Schneibel et al., 2016). Various types of grassland management may cause variations in ecosystem functions and processes. Few studies have focused on measuring and analyzing changes in ecosystem services and on how the related trade-offs are affected by different types of grassland management. Studies with type of focus could further contribute to the mapping and modeling of how grassland management affects ecosystem services and the related trade-offs.

Different grassland management methods may result in variations in the supplies of ecosystem services. In alpine grassland, grazing exclusion could result in increased aboveground carbon and nitrogen stocks, and changes in the belowground carbon and phosphorous pools (Lu et al., 2015), resulting in a variation in carbon stock and soil nitrogen supply services. Grazing at moderate levels often leads to additional carbon being translocated to belowground in alpine grasslands (Hafner et al., 2012), causing variations in the carbon stock and sequestration services. In tallgrass prairie and temperate steppes, nitrogen addition enhanced gross primary production and net ecosystem C exchange (Niu et al., 2010, 2013). However, it is still unclear whether changes in grassland management will result in trade-offs among ecosystem services, or if the trade-offs could be reduced by optimizing land management methods.

The relationships among ecosystem services that cause trade-offs may vary. A regional study in southern Quebec in Canada demonstrated that the use of appropriate land management resulted in a shifting of the relationship between various ecosystem services, from causing trade-off relationships to creating synergistic relationships over a 35-year period (Renard et al., 2015). In this paper, we aim to measure the variations of ecosystem services and the related trade-offs while using five different grassland management techniques in an alpine grassland ecosystem. We aim to answer the following questions. Could a change in management result in various trade-offs among ecosystem services in a short period of years, and if so, how would this occur? Would the variation in trade-offs promote the level of multiple supplies of ecosystem services?

2. Materials and methods

2.1. Study region and experimental sites

The Tibetan Plateau (or the Qinghai-Tibetan Plateau) reaches elevations (mean 4000 m) higher than any other plateau worldwide and extends over 2.4 million km^2. The research area of Bailang Village is located in the southern part of the Tibetan Plateau in Linzhou County, Lhasa City, Tibet Autonomous Region, China (Fig. 1). The annual average precipitation and temperature are 500 mm and 2 °C, respectively, in the study area. Natural grassland forms the major ecosystem type in Bailang Village. The study area receives relatively high amounts of precipitation and experiences relatively high temperatures when compared with the northern part of the Tibetan Plateau, where the annual temperature and precipitation ranged from −9 to 0 °C and 50–400 mm, respectively. Therefore, the southern part of the entire Tibetan Plateau is the most suitable area for growing forage grass. In addition, the climate, geography and land use of Bailang Village is highly representative of the Lhasa River region, the largest population center of Tibet.

The growing season of the original natural grassland extends from approximately late May to mid-September, and produces about 30 g dry forage/m^2. Farmers traditionally grazed sheep for more than 10 h each day, which created a large amount of grazing pressure on natural grasslands. Starting in 2011, a project was established to support the cultivation of sown grassland by local residents with the goal of increasing forage production and to allow for the fencing and restoration of degraded natural grassland. After 2011, sheep were only grazed for 4 h daily during the growing season on natural grassland. Then, about 400 g/d of harvested forage were supplied as supplementary feed to each sheep.

Four different types of experimental plots with varying grassland management were established on natural grassland in Bailang Village: 1) grazing excluded grassland (no plowing or sowing, no grazing after fencing in 2011), 2) plowed and grazing excluded grassland (plowed, no sowing, no grazing after fencing in 2011), 3) sown grassland (no plowing, mixed sowing of perennial forage plants in 2013, grazing), and 4) plowed and sown grassland (plowed, mixed sowing of annual forage plants every year, grazing; Table S1). In addition, natural grassland plots (no plowing or sowing, with grazing) were used as controls. We collected samples from all five grassland types (four experimental and one control) in mid-August 2013, 2014 and 2015. Four ecosystem services were considered in this paper: forage supply, biodiversity conservation, soil nitrogen supply and ecosystem carbon stocks. Forage supply was classified as a provisioning service, while the other three were classified as regulating services.

2.2. Soil and plant sampling

Three replicated treatments were setup for grazing excluded grassland, sown grassland, plowed and grazing excluded grassland and plowed and sown grassland. Three random sampling points (5 × 5 m) were selected in each of the four types of grassland. Three small vegetation plots (50 × 50 cm) were randomly established in each of the 5 × 5 m sampling points. No replicated treatment was used for natural grassland, although, at least nine sampling points were selected randomly each year to sample in natural grassland. Some samples, especially for sown grassland in 2014, were compromised by unexpected grazing and those samples were excluded from this study (Table S2). Plants in each small sampling plot were identified to the species level, and the number, heights and percent vegetation cover of each species were recorded for