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Effects of land use and climate change on ecosystem services in Central Asia's arid regions: A case study in Altay Prefecture, China

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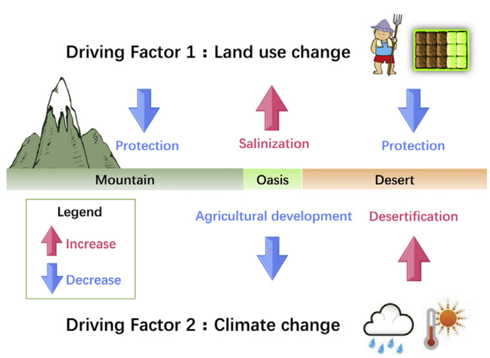
HIGHLIGHTS

- The study area is representative of the mountain-oasis-desert system.
- Four ecosystem services are assessed based on biophysical models.
- Different land use and climate change conditions are established.
- The influences of land use and climate change are demonstrated.
- Some targeted ecosystem management strategies are proposed.

GRAPHICAL ABSTRACT



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ABSTRACT

The sustainable use of ecosystem services (ES) can contribute to enhancing human well-being. Understanding the effects of land use and climate change on ES can provide scientific and targeted guidance for the sustainable use of ES. The objective of this study was to reveal the way in which land use and climate change influence the spatial and temporal variations of ES in the mountain-oasis-desert system (MODS). In this study, we assessed water yield, soil conservation, crop production, and sand fixation in 1990, 2000, and 2010 in Altay Prefecture, which is representative of the MODS, based on widely used biophysical models. Moreover, we analyzed the effects of different land use and climate change conditions on ES. The results show that the area of forest and bare land decreased in Altay Prefecture. In contrast, the area of grassland with low coverage and cropland increased. The climate of this area presented an overall warming-wetting trend, with warming-drying and cooling-wetting phenomena in some areas. Soil conservation in the mountain zone, water yield in the oasis zone, and sand fixation in the desert zone all decreased under the influence of land use change alone. The warming-drying trend led to decreased water yield in the oasis zone and increased wind erosion in the desert zone. Based on the results, we recommend that local governments achieve sustainable use of ES by planting grasslands with high coverage in the oasis zone, increasing investment in agricultural science and technology, and establishing protected areas in the mountain and desert zones. The methodology in our study can also be applied to other regions with a MODS structure.

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1. Introduction

Ecosystem services (ES) refer to the direct and indirect benefits that people obtain from ecosystems, including products and services (Costanza et al., 1997). The scientific issues related to ES have received attention from many scholars in the fields of geography, ecology, and economics over the past 20 years (Bennett et al., 2005; Burkhard et al., 2014; Daily, 1997; Kremen, 2005; Perrings et al., 2010). With global population growth, social development, and technological progress, humans are constantly changing the natural world. This simultaneously changes the material cycling and energy flow of ecosystems, thus affecting ES and human well-being (Vitousek et al., 1997). The Millennium Ecosystem Assessment (MEA) evaluated the changes in 24 ES worldwide under the influence of multiple driving forces and the results showed that 15 ES are currently declining (over 60% of the total ES). This trend will be aggravated by future global warming (MEA, 2005). In the arid regions of Xinjiang, China, human living conditions and social development are highly dependent on natural resources. However, in recent years, people have overexploited the productivity of the grasslands while neglecting their ecological function. Overgrazing and land reclamation have led to the decline and degradation of ES in many areas (Wu et al., 2007). Therefore, it is urgent that the mechanisms driving changes in ES be studied.

Land use/land cover and climate change are considered the two main driving factors of ES change (Bateman et al., 2013; Schröter et al., 2005). Land use/land cover change alters the supply of ES by influencing ecosystem patterns and processes (Fu and Zhang, 2014). Climate change affects ES directly or indirectly by changing hydrological processes, CO_2 concentration, etc. (Nelson et al., 2013). Recent research has shown that an increase in agricultural areas, urbanization, grazing, and other factors have led to the reduction in carbon storage, water quality, and biodiversity, resulting in a significant decline in ES (Le Maitre et al., 2007; Li et al., 2013; Polasky et al., 2011). In the context of climate change, many regions are experiencing warming and drying trends, which has increased the possibility of water shortages, natural disasters, and desertification and has placed considerable pressure on the sustainable use of ES (Schröter et al., 2005). To mitigate these negative impacts, it is essential to develop effective ecosystem management and land use strategies.

When decision-makers and scientists manage ecosystems, they must understand the spatial features, change dynamics, and influencing factors of ES. To date, researchers have conducted multiple studies related to ES, some of which have investigated changes in the values of ES and the relationships with influencing factors (Chuai et al., 2016; Estoque and Murayama, 2012; Mendoza-González et al., 2012; Wang et al., 2014). Others have used biophysical models to simulate changes in the physical quantity of the ES and their relationship with influencing factors (Jiang et al., 2016; Lorencová et al., 2013; Nelson et al., 2010; Su and Fu, 2013). However, in earlier research, correlation analysis was typically used to analyze the effects of land use/land cover and climate change on ES. This can only qualitatively determine the changes in factors that are most influential. Only a few studies have explored in depth the related ecological processes and ecological significance of these effects and proposed targeted countermeasures. Moreover, researchers have generally focused on urban ecosystems and have paid less attention to ES in arid regions.

An alternating distribution of mountains and basins is the basic feature of the natural geography of the arid regions of Central Asia. This combination of terrestrial ecosystems has been termed a mountain-oasis-desert system (MODS) by Zhang (2001). It is a composite system consisting of a vertical mountain vegetation belt and a concentric annular (geologic landform) vegetation belt in a desert basin (Fig. 1). The three subsystems, mountain, oasis, and desert, are not isolated from each other but are linked through the flow of energy, material, life, values, and culture. This classic model has been widely applied to studies of the arid regions of northwest China (Dong et al., 2006; Wu and Zhang, 2000; Zhang, 2011), but there have been few comprehensive studies linking the MODS and ES.

To narrow the research gaps, we assessed ES in Altay Prefecture, which is representative of the MODS, and we investigated the effects of land use and climate change on ES during 1990–2010. The objective of this study was to reveal the way in which land use and climate change influence spatial and temporal variations of ES in Altay Prefecture. Given this challenge, three questions were addressed: (1) What characterizes the process of change in ES over the past 20 years in the Altay Prefecture? (2) How do land use and climate change influence ES and where do the influences occur in the Altay Prefecture? (3) How can ecosystems with a MODS structure be managed to promote the sustainable use of ES? We provide a methodology to quantify the influences of land use and climate change on ES and to identify the location of the influences. This study has the potential to provide scientific support for the sustainable use of ES in Altay Prefecture, and the methodology can be applied to other regions with a MODS structure.

2. Materials and methods

2.1. Study area

Altay Prefecture (44°59′35″ ~ 49°10′45″N, 85°31′57″ ~ 91°01′15″E) is located in the northernmost part of the Xinjiang Uygur Autonomous Region, China, which borders Kazakhstan, Russia, and Mongolia (Fig. 2). The total area is approximately 118,000 km^2, and the total population is approximately 675,900 (2015). The altitude in Altay Prefecture gradually declines from the Altai Mountains in the north to the Junggar Desert in the south and the terrain is characterized by a steppe-like topography. The region has a typical temperate continental climate with a mean annual precipitation ranging from 139.3 mm to 268.4 mm and a mean annual temperature ranging from 0.7 °C to 4.9 °C (Gulzat and Zhao, 2011). The water resources in this region are unevenly distributed both spatially and temporally, and there exists considerable interannual variability in the amount of runoff. Spatially,

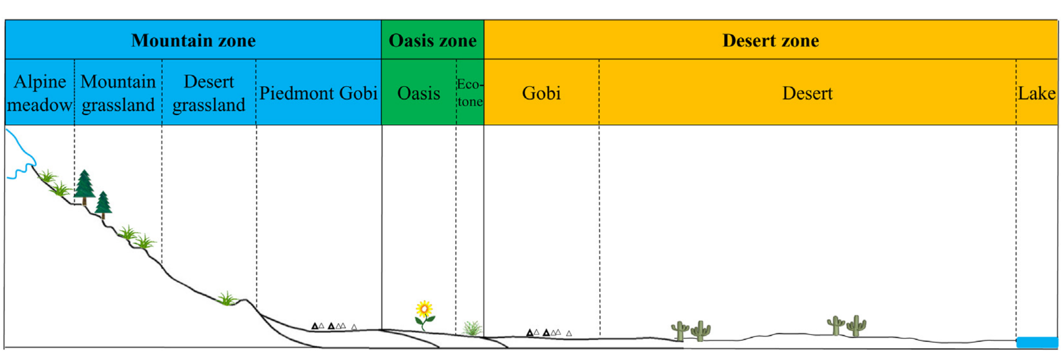

Fig. 1. Sectional diagram of the MODS landscape.