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Model-based analysis of the environmental impacts of grazing management on Eastern Mediterranean ecosystems in Jordan

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ABSTRACT

Eastern Mediterranean ecosystems are prone to desertification when under grazing pressure. Therefore, management of grazing intensity plays a crucial role to avoid or to diminish land degradation and to sustain both livelihoods and ecosystem functioning. The dynamic land-use model LandSHIFT was applied to a case study on the country level for Jordan. The impacts of different stocking densities on the environment were assessed through a set of simulation experiments for various combinations of climate input and assumptions about the development of livestock numbers. Indicators used for the analysis include a set of landscape metrics to account for habitat fragmentation and the "Human Appropriation of Net Primary Production" (*HANPP*), i.e., the difference between the amount of net primary production (NPP) that would be available in a natural ecosystem and the amount of NPP that remains under human management. Additionally, the potential of the economic valuation of ecosystem services, including landscape and grazing services, as an analysis concept was explored. We found that lower management intensities had a positive effect on *HANPP* but at the same time resulted in a strong increase of grazing area. This effect was even more pronounced under climate change due to a predominantly negative effect on the biomass productivity of grazing land. Also Landscape metrics tend to indicate decreasing habitat fragmentation as a consequence of lower grazing pressure. The valuation of ecosystem services revealed that low grazing intensity can lead to a comparatively higher economic value on the country level average. The results from our study underline the importance of considering grazing management as an important factor to manage dry-land ecosystems in a sustainable manner.

1. Introduction

The Eastern Mediterranean ecosystems in Jordan are classified as dry-land systems which are potentially prone to desertification. The UN Convention to Combat Desertification defines the term "desertification" as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNEP, 1994). Potential proximate causes are identified by Geist and Lambin (2004) and include land-use change processes such as cropland expansion, overgrazing, and the expansion of road infrastructure and urban area. In Jordan, the main reasons for land-use change are the growing demands for settlement area and food by an increasing human population, aiming at a higher standard of living. Traditionally livestock grazing plays an important role in the agricultural sector. Here, the overarching problem is the overuse of the dry-land ecosystems caused by inadequately high stocking densities of grazing animals (overgrazing). Potential environmental impacts are changes in the vegetation cover/composition and soil degradation (Gillson and Hoffman, 2007; Ibanez et al., 2007) which reduce the productivity of forage grasses (van de Koppel and Rietkerk, 2000). In consequence, these processes can threaten the livelihoods of farmers and regional food security as well as biodiversity (Alados et al., 2004; Alhamad, 2006). An additional pressure on both ecosystems and livestock grazing will be climate change. The 4th IPCC Assessment Report points out that the Mediterranean region will face increasing mean annual temperatures and decreasing precipitation accompanied by a likely increase in length and frequency of dry spells in the coming decades (Christensen et al., 2007).

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In order to meet these challenges, there is a need for a more sustainable management of grazing land in Jordan (Millennium Ecosystem Assessment, 2005). According to World Bank (2006), the objective of sustainable land management is to fulfill the growing food and fiber demands (provisioning services) while sustaining other ecosystem services such as soil fertility, erosion control, or landscape esthetics. de Groot et al. (2010) illustrate that intensive management favors the provisioning services on cost of the portfolio of other ecosystem services. Regarding the management of grazing land this implies an adjustment of stocking densities at a level where environmental impacts are considerably reduced (Köchy et al., 2008) and in consequence a balance between provisioning services and other services is achieved.

An essential prerequisite for the development of regional strategies for a sustainable land management is to improve the scientific understanding of the functioning of the land-use system under consideration. Therefore, the aim of our study is to explore the effects of different driving factors on the future development of grazing land and provisioning of ecosystem services in Jordan as well as to quantify potential environmental impacts. The considered drivers include changing livestock numbers, climate change, and different options of grazing management, expressed as allowable maximum stocking densities. We applied the land-use model LandSHIFT (Koch et al., 2008, 2012; Schaldach et al., 2011) in combination with the vegetation model WADISCAPE (Köchy et al., 2008) to simulate the spatial distribution of grazing land and stocking densities of grazing animals under different scenarios, which are defined as combinations of these drivers. Based on the model output, which comprises information on the change in land-cover and land-use intensity, we assessed the resulting environmental impacts as well as the consequences for the provisioning of ecosystem services. Indicators for the environmental impacts were the Human Appropriation of Net Primary Productivity (*HANPP*) (Haberl et al., 2007) and a set of landscape metrics, including "Number of Patches", "Largest Patch Index", "Proximity Index", and "Total Core Area" (Alhamad et al., 2011). In our case, the *HANPP* indicator defined the impact of grazing on the available biomass of ecosystems and served as a local metric for the human influence on ecosystem structure. In contrast, the landscape metrics were used to quantify ecosystem fragmentation as an important factor for the loss of biodiversity (e.g. Gustafson and Parker, 1994; Fahrig, 2003). Additionally, beneficial and adverse effects of the applied management schemes were evaluated by estimating the economic ecosystem service value, which integrates services from intact landscapes and savings in feed costs due to livestock grazing (Fleischer and Sternberg, 2006).

2. Material and methods

2.1. Study region

Study region is the Hashemite Kingdom of Jordan which is bordered by Syria in the north, by Iraq and Saudi Arabia in the east, and by Israel as well as the West Bank in the west (Fig. 1). The country has a land area of about 90 000 km^2. The climate is characterized by hot, dry summers and cool, wet winters. Mean annual precipitation ranges from less than 50 mm in the southeast to 660 mm in the northwest. In 2000, the population of Jordan was approximately 5 million people; about one fifth of which lived in Amman, the administrative capital and largest city in the country (United Nations, 2009). With about 2.2 million goats and sheep (FAO, 2011), the production of small ruminants is an important factor of Jordan's agricultural sector. The landscape can be classified as an eastern-Mediterranean ecosystem, which has been modified by human activity for several thousand years. Besides limited natural freshwater resources, current environmental problems include overgrazing and a high risk of desertification (Abahussain et al., 2002).

2.2. Modeling framework

The modeling framework (Fig. 2) that we have applied for our study includes a regional version of the land-use model LandSHIFT (Koch et al., 2008, 2012; Schaldach et al., 2011) and the WADISCAPE model to determine biomass productivity of semi-natural vegetation under grazing pressure (Köchy, 2007; Köchy et al., 2008). The models were used to calculate a series of grid maps showing the spatial distribution of grazing land and the respective stocking density of sheep and goats on each cell between 2005 and 2050. Based on these maps the environmental impacts of different types of grazing management were analyzed with a local level indicator

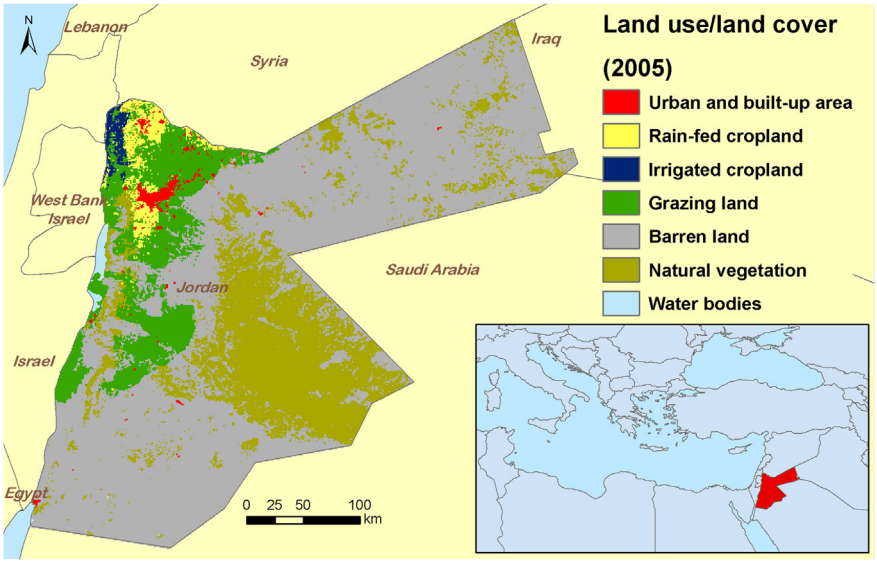

Fig. 1. Map of Jordan, the study area of this analysis, showing the land-use/land-cover distribution for the year 2005 as simulated with LandSHIFT.