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Multi-indicator sensitivity analysis of climate change effects on landscapes in the Kiskunság National Park, Hungary

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ABSTRACT

A multi-indicator approach assessing sensitivity to drought within different landscape types was explored within the Kiskunság National Park (Hungary) and its surrounding landscapes. The National Park preserves alkaline lakes, sand dunes, wetlands, dry steppes and forests, surrounded by a matrix of intensively used agricultural land and forests. The investigated indicators rely to soil moisture regime, changes in groundwater resources, biomass production of vegetation and wind erosion hazard. The study also estimated future drought hazard as an indicator of climate change (CC) by REMO and ALADIN regional climate model simulations applying two future time periods (2021–2050 and 2071–2100). Overlaying analysis of future CC scenarios and the multi-indicator assessment indicates increasing drought hazards over the whole area investigated, with landscapes in the northern part of the territory relatively more exposed. On the basis of the calculated indicators, the most sensitive areas were identified as being located in the areas of highest altitude and within the sandy area/alluvial plain transitional zone, which are mostly wetland and sand-dune regions. Results indicate that conservation management should especially focus on the northern part of the Kiskunság as an area most at risk of increasing drought. The outcomes of this research demonstrate the utility of a dynamic, multi-indicator landscape sensitivity approach to developing strategies to adapt on the multilayered and complex effects of CC on nature conservation practice.

1. Introduction

Due to climate changes, alteration in physiology, phenology, species distribution and ecological stability have been reported in several ecosystems (Menzel and Fabian, 1999; Hughes, 2000; Menzel, 2000; Parmesan and Yohe, 2003; Kovács-Láng et al., 2008). In the long run decreasing ecological stability results in decreased biodiversity, species loss or declining ecosystem services (Hughes, 2000; Kovács-Láng et al., 2008). In particular, climate changes (CC) such as increasing temperature and changing precipitation characteristics highly influence natural areas that are near to the critical thresholds and limits of hydrological conditions. Vulnerable areas include, for example, wetlands where water quantity is an important limiting factor. As such ecosystems fall out of equilibrium they start to degrade due to decreasing precipitation (Poiani et al., 1995; Winter, 2000; Normand et al., 2007; Pitchford et al., 2012). In addition, increasing abiotic (e.g. fires, floods, storms, heat-waves, droughts, etc.) and biotic (e.g. pest outbreaks) disturbances associated with a rapidly changing climate can further accelerate ecosystem disruptions (Hobbs et al., 2009).

Several indicators and methods are available to assess the sustainability of natural areas under future climate change, e.g. changes in water supply, vegetation greenness, soil moisture. According to Cherwin and Knapp (2012), semi-arid grasslands are predicted to be among the most sensitive ecosystems to changes in precipitation based on the relationship between precipitation amount and aboveground annual net primary production. Based on an investigation of the implications of CC for nature conservation on Austrian rain-fed mire ecosystems (Essl et al., 2012), mires (i.e. bogs, transition bogs and fens) are identified as being especially vulnerable to climate change because they depend on the occurrence of cool, humid climatic conditions. Holsten et al. (2009) reported changing soil moisture dynamics and large decreases in annual soil water availability in nature conservation areas in Brandenburg (Germany), by simulating past trends and future effects of CC on soil moisture. Lorz et al. (2010) identified regions with high

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probabilities of natural hazards (drought, forest fire, windthrow) occurring in forested landscapes of Central and South-Eastern Europe using GIS based assessments.

Within Europe, a considerable extent of natural areas is protected under the Convention on Wetlands (1994) and the European Union Habitats Directive (1992) and their sustainable management and restoration is hence an important task. With CC effects increasingly reported throughout Europe (IPCC, 2007, 2012, 2014) the robust projection and scaling-down of future CC effects is a growing issue within the scientific community. Planning appropriate adaptation measures to underpin sustainable management plans requires better information at the regional and local planning and management levels (Rannow et al., 2010; Lorz et al., 2010). According to Hickler et al. (2012) considerable successional shifts in vegetation types have been reported throughout most areas of Europe, with 31–42% of the total area identified as hosting a different 'shifted' vegetation type. Furthermore, in southern Europe, the same study predicts widespread shifts in vegetation cover, from forest to shrubland, for 2085 as a result of droughts.

CC and its effect on natural areas is an important issue in the Carpathian Basin, which covers a substantial part of the Pannonian Biogeographical Region and hosts a range of valuable ecosystem types (2013/735/EU; Bölöni et al., 2008; Molnár et al., 2008a). Kiskunság National Park preserves several protected areas (e.g. alkaline steppes, floodplains mosaics, alkaline lakes, sand dunes, fish ponds) contributing to a rich ecological diversity (Boros, 1952; Tölgyesi, 1979; Biró et al., 2007). The landscapes preserving unique flora, fauna and morphology are sensitive to natural and human-induced environmental and land use changes (e.g. CC, hydrological change or inadequately changed land use) (Biró et al., 2008b; Rakonczai, 2011; Szalai, 2012). The sensitivity of natural areas is further exacerbated, as the sporadically-occurring mosaics of protected alkaline lakes, sand dunes, dry steppes, forests and flood plain wetlands are surrounded by a matrix of intensively used agricultural areas and forests. One of the key environmental factors in this area is the climate with its impacts increasingly reported over the last decades (Bartholy et al., 2011; Rakonczai, 2011; Spinoni et al., 2013). This has led to research studies which have focused on rate and trend assessments of future climate change as a way to estimate the potential effects of CC on the environment in this area related to, e.g. drought hazard, landscape functions and land use changes (Mezősi et al., 2013; Malatinszky et al., 2013; Blanka et al., 2013).

The aim of this study was to analyze the sensitivity of different landscape types, and especially the protected areas in Kiskunság National Park and the surrounding landscapes, to drought using a novel indicator approach (Pitchford et al., 2000). Sensitivity to drought was assessed through an evaluation of changes in multiple indicators as the soil moisture regime, quantification of available groundwater resources, biomass production of vegetation and an analysis of wind erosion hazards. The individual results of these assessments were then integrated into a combined sensitivity map, which indicates the level of the affecting factors in relation to land cover classes. The study estimated future drought hazard as an indicator of CC using REMO and ALADIN simulation results. Overlaying analysis of two future CC periods (2021–2050 and 2071–2100) with the indicator assessments was carried out for to identify areas especially vulnerable to climate change and to develop a scientific basis for management applications.

2. Study area

The study area is the Hungarian Kiskunság National Park and its surrounding landscape, located between the lower Hungarian sections of the Danube and Tisza rivers. This area of 12,570 km^2 is an important region of the Pannonian Biogeographical Region (Carpathian Basin, Hungary) developed on fluvial sediments of the Danube (Borsy, 1989). The study area contains several protected habitats (see Table 1) and protected areas (e.g. alkaline lakes, sand dunes, fish ponds) contributing to the rich ecological diversity of the area. Protected areas cover approximately 10% of the study area (Fig. 1).

Table 1
Land cover types and Natura 2000 habitat types in the protected areas of the Kiskunság National Park.

Land cover types	Natura 2000 habitat types (code)	Size (ha)
Forests	Euro-Siberian steppic woods with *Quercus* spp. (91I0)	130
	Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Pandion*, *Alnion incanae*, *Salicion albae*) (91E0)	3500
	Riparian mixed forests of *Quercus robur*, *Ulmus laevis* and minor, *Fraxinus excelsior* or *angustifolia*, along the great rivers (91F0)	560
	Pannonic inland sand dune thicket (*Junipero-Populetum albae*) (91N0)	10,500
Wetlands	Pannonic salt steppes and salt marshes (1530)	77,000
	Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) (6410)	1500
	Alluvial meadows of river valleys of the *Cnidion dubii* (6440)	10,000
	Calcareous fens with Cladium mariscus and species of the *Caricion davallianae* (7210)	120
	Alkaline fens (7230)	95
Dry steppes	Pannonic loess steppic grasslands (6250)	160
	Pannonic sand steppes (6260)	40,000
Lakes	Natural eutrophic lakes with Magnopotamion or Hydrocharition-type vegetation (3150)	500

Source: www.knp.hu.

The study area consists of four large landscape units differentiated by physical geographical conditions in the Danube-Tisza Interfluve. The central landscape is located on the alluvial fan of the ancient Danube River (Kiskunság). It is covered by sand sheets and sand dunes forming a slightly wavy surface that is topographically different from the surrounding area: the northwest–southeast axis of the alluvial fan rises like an hour glass above the Danube and Tisza floodplain by 30–40 m. Some parts are covered by loess, but mostly blown sand forms are characteristic. The protected habitat types of the National Park are associated with blown sand: sand dunes and inter-dunal depressions with alkaline lakes. The vegetation of the sand and loess steppes is also protected. The landscape is categorized as sandy with partly fixed dunes, afforestation, and remnants of the original *Astragalo-Festucetum Rupicolae* vegetation (Pécsi et al., 1972; MNA, 1989; Lóki, 2000; Mezősi, 2011).

The Bácska plain is located south of the Kiskunság region (described above). The northern part of this area is also an alluvial fan with blown sand with medium or deep groundwater table (approx. 5–20 m). The typical land use is cultivated grassland and forests with mosaics of vineyards and orchards. Striking fixed dunes are the characteristic morphological forms. On the southern part of the landscape, some meters of loess cover the underlying sandy sediments. Chernozem soil with high levels of fertility occurs here, as evidenced by the widespread use of land for agriculture; natural vegetation is found only in small patches (Pécsi, 1996; Mezősi, 2011).

The remaining two landscape unit areas are the alluvial (flood) plains of the Danube and the Tisza Rivers. Swamps were prevalent in these areas before the river regulation works in the 19th century, and the typical morphological forms were cut-off river channels,