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Grazing intensity effects on soil quality: A spatial analysis of a Mediterranean grassland

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ABSTRACT

Intensive grazing, such as that occurring in the vicinity of animals' shaded concentration points (CPs), causes the degradation of many soil properties, creating patterns as a function of distance from the CPs. The aim of this research is to characterize the spatial patterns of land degradation as a function of grazing intensity, in terms of soil quality, with respect to (1) the distance from CPs; (2) grazing density; and (3) additional environmental variables, in typical Mediterranean grassland, in the eastern Galilee region of Israel. To fulfill this aim, a soil quality index (SQI) was developed based on the integration of 12 physical, biological, and chemical soil properties. Soil properties and quality surface maps were developed by using the spline interpolation technique as a geostatistical analysis on a small spatial scale. In addition, a spatial statistics technique, namely the geographically weighted regression (GWR), was used to measure the effect of different explanatory variables (grazing density, distance from CPs, vegetation cover, aspect, slope, and landscape cover classification) on the SQI. The results show that near the CPs, there is a clear effect of grazing activity on all soil properties and nutrients that can be attributed to a low SQI. Significantly lower soil quality was found around the CPs with moderate and high stocking rates than in the pasture and the control area, where grazing was excluded. Applying the GWR model, using the landscape-cover classification as the explanatory variable for the SQI, provided the best results in the spatial analysis with $R^2_{adjusted} = 0.97$. The second and third most influential explanatory variables for the SQI were the distance from the CPs and grazing density, with $R^2_{adjusted} = 0.94$ and $R^2_{adjusted} = 0.93$, respectively. This outcome demonstrates grazing intensity effects on SQ and its complexity, mainly due to the impact of landscape cover and grazing density. In conclusion, the presented framework was found adequate and could potentially be made operational for assessing SQ under different grazing intensities and degradation stages in a spatial scale.

1. Introduction

Grazing management is a major land-use requirement and is critical in preserving environmental quality and ecological sustainability, as well as providing ecosystem services, mainly after long-term grazing (Lin et al., 2010). Many of the rangelands across the Mediterranean basin are commonly viewed as degraded landscapes, the end result of high grazing intensity (Perevolotsky and Seligman, 1998). Gradients in soil and vegetation composition that were generated by grazing have been widely reported (e.g., Smet and Ward, 2006). Grazing impact tends to be most intensive around watering points and in the vicinity of shaded locations or resting places, namely concentration points (CPs). High grazing density (e.g., by sheep, goats, cattle, and horses) can be found near CPs, and the density decreases gradually with increasing distance from the CPs (e.g,. Butt et al., 2009; Karnieli et al., 2008). Studies showed that grazing intensity is characterized by concentric circles around the CPs, but also that the measured biotic, abiotic, and environmental variables are distributed in a radial pattern (Harris and Asner, 2003). Each variable has a low (or high) value near the CPs and changes exponentially as the distance increases (Chillo et al., 2015).

Scientific knowledge about the effect of grazing intensity on ecosystem structure and function is extensive (Lin et al., 2010). Among the biotic, abiotic, and environmental effects as a function of distance from the CP are vegetation cover, species richness and diversity, and the distribution of biological soil crusts (Chillo et al., 2015). Other studies have addressed soil chemistry and physical properties, as well as erosion impacts and trampling gradients. Many soil properties have shown a rate of improvement (or decline) due to grazing intensity, such as soil pH, organic matter content, nitrate concentration (Stott and Turner, 1998), soil nutrient concentrations (West et al., 1989), track density (Pringle and Landsberg, 2004), and potassium and phosphorus (Stumpp et al., 2005). Most of these studies show that the rate of improvement/decline

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of each variable does not change beyond several kilometers from the CP (Perkins and Thomas, 1993).

Two concurrent research gaps were identified from the above literature review. First, there is a complex gradient and interaction of grazing intensity affecting different soil properties, and there is a need for an integrated approach to estimate soil function or quality. Most studies focused on several soil properties and not on integrative approaches of monitoring soil quality on spatial scales. Second, although the distance from CPs is the cause of major grazing effects, additional factors need to be considered in relation to the spatial distribution, the habitat selection, and the site preference of the grazing livestock in rangelands that may affect soil quality (SQ). In addition, environmental aspects, such as slope, aspect, landscape cover, and vegetation cover, may affect the foraging pattern of grazing and thus have an impact on soil and vegetation properties on spatial scales. There is a lack of studies that monitor the spatial effect and patterns of grazing intensity on SQ in relation to distance from CPs. Filling these two knowledge gaps may improve grazing management and facilitate the understanding of the effect of grazing density on SQ.

To fill the first research gap in the current study, the soil quality index (SQI) was developed with respect to distance from CPs. Since overall SQ cannot be measured directly, its assessment relies on selected soil properties (indicators) to quantify the management-induced changes in a soil system (Karlen et al., 2001). The SQI that integrates soil physical, biological, and chemical attributes has attracted attention due to an increased awareness of the impact of soil management on agricultural production and environmental quality (Doran and Parkin, 1994). Several studies have proposed various conceptual frameworks for monitoring SQ (e.g., Andrews et al., 2002). These frameworks usually share common steps, including selecting soil properties that are essential in terms of soil functioning (Herrick, 2000; Rezaei et al., 2006). The group of soil properties that best describes changes in response to management practices constitutes the minimum dataset for a particular management goal (Rezaei et al., 2006). The selected soil properties are normalized to a unitless scoring scale and are eventually integrated into a SQI value (Idowu et al., 2008). However, because many soil analyses are involved, monitoring the SQI at large spatial scales remains expensive, as well as time and labor consuming, when using standard procedures (Cécillon et al., 2009).

To fill the second research gap, geostatistical analyses were performed and implemented on soil properties and quality at a small spatial scale. Many studies based on ground measurements and/or interpretations by geostatistical methods and remotely sensed data have been carried out to monitor the spatial variability of grazing impacts on rangelands (Karnieli et al., 2008; Pickup et al., 1994). Various remote sensing models, incorporating geographic information systems (GIS) techniques, were developed to estimate the spatial distribution of different variables around CPs (e.g. Harris and Asner, 2003; Karnieli et al., 2008). Many techniques have been used as prediction methods for interpolating point data to a continuous surface at unknown locations (Svoray et al., 2015). However, very few studies have dealt with grazing effect on SQ on a spatial scale by integrating soil science with geostatistical models.

The objectives of this study were: (1) to study the effect of grazing intensity in relation to distance from CPs on soil properties and quality at a small spatial scale; (2) to apply a geostatistical model in order to develop SQI surface maps; and (3) to relate these changes in SQI to the distribution of grazing density and additional environmental aspects by applying geo-information and spatial statistics techniques on a small scale. In the current study, we tested the comprehensive hypothesis that distance from CPs would improve SQ as a function of the grazing intensity. In addition, we tested the hypothesis that the distribution of grazing density and additional environmental variables, such as slope, aspect, landscape cover, and vegetation cover, as explanatory variables, will improve the SQ pattern prediction in addition to the effect of distance from CPs.

2. Methods

2.1. Study site and experimental design

The study was conducted at the Karei-Deshe experimental farm, located in the eastern Galilee area of Israel (long. 35°35′E; lat. 32°55′N; altitude 60–250 m a.m.s.l) (Golodets et al., 2010). The topography is hilly, with slopes up to 20°. Basaltic rocks cover about 30% of the area (Gutman and Seligman, 1979; Henkin et al., 2015). The soil is a fertile brown basaltic protogromosol of variable depths, but mostly no deeper than 60 cm (Henkin et al., 2011). The area has a Mediterranean climate, characterized by wet, mild winters with mean minimum and maximum temperatures of 7 and 14 °C, respectively, and hot, dry summers with mean minimum and maximum temperatures of 19 and 32 °C, respectively (Gutman and Seligman, 1979). The mean annual rainfall is 558 mm with very high variability between years and months (Henkin et al., 2011), beginning in October and ending in April. As a result, the vegetation is green between December and April, but during May, most plants dry out and remain so until the next rainy season. The vegetation is composed of rich hemicryptophytic grasslands (Zohary, 1973) dominated by *Hordeum bulbosum* L., *Echinops* spp., *Bituminaria bituminosa* L., as well as many annual species (Sternberg et al., 2000).

The total area of the Karei-Deshe experimental farm is about 1450 ha divided into paddocks. The current study was based on two different stocking densities, and two paddocks were selected. The two paddocks included moderate (0.55 cows ha^{-1}) and high stocking densities (1.1 cows ha^{-1}). The area of each of the paddocks was about 27 ha. In these paddocks, a sampling area of about 6.75 ha was determined, with 3.94 ha representing moderate grazing intensity, 2.5 ha representing high intensity and 0.3 ha as a control sampling site with no grazing. In the sampling area, five different habitat types were defined: (a) not stony and flat land; (b) stony cover of about 25–35% and gentle slopes; (c) stony cover of about 35–34% and steep slopes; (d) rocky cover of about 45–55 % and steep slopes; and (e) boulder cover above 55%. The selected sampling area included two habitat types, (a) and (b), as they represent a more homogenous coverage (Fig. 1a). The selected sampling area was determined with respect to elevation contour lines in order to follow a certain topographic pattern. In addition, the sampling area was selected to have a representative and dense soil sampling size in which to apply the geostatistical model and develop the SQI surface maps. Each of the grazing intensity treatments was tested with respect to the distance from the CPs. In the moderate and high stocking density paddocks, 8 and 16 cows were introduced, respectively. The cattle were introduced to the range in mid-winter (January), when the standing biomass exceeded 700 kg dry mass ha^{-1}. In the summer, the herds remained in moderately grazed paddocks until October-November, depending on the occurrence of the first rainfall event, but in the heavily grazed paddocks, they were removed toward the end of August (Henkin et al., 2015). From early June until the end of September, the cows were offered supplementary feed. The sampling design was based on the different grazing densities and included 10 replicates, with a distance from the CPs in each paddock. In total, five sampling sites were examined: (1) control, in which grazing was excluded over the past 40 years; (2) CPs with a moderate stocking density; (3) CPs with a high stocking density; (4) moderate stocking density; and (5) high stocking density (Fig. 1b).

2.2. Soil sampling and laboratory analysis

Soil samples were collected in September 2015, at the end of the dry season, at a depth of 0–0.15 m. In this study site, the soil is shallow and characterized by patchiness of soil and rocks with a maximum stony cover of 35% (Fig. 1a). The sampling design included 10 soil samples of the different grazing densities; thus in total, 50 soil samples were collected. The soil sampling was accomplished using an accurate global positioning system (GPS). All soil samples were transferred to the