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Mediterranean drylands: The effect of grain size and domain of scale on landscape metrics

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ABSTRACT

This study first sought to isolate a select group of landscape metrics particularly well-suited for describing dryland Mediterranean landscapes in Jordan. We examined the response of 50 landscape metrics to a large range of imagery grain sizes. Most of the metrics exhibited an expected behavior, similar to what has been previously reported in literature such as (a) a predictable (linear or power law) response to changing grain size, and (b) an unpredictable (staircase-like or erratic) response to changing grain size. Some metrics, however, exhibited a domain of scale effect, in particular the core area metrics. Using correlation analysis, the original 50 metrics were placed into 19 groups such that all metrics within a group were strongly correlated with each other, and were represented by a single representative metric. Using these representative metrics in the context of principal components analysis, we then found that six factors explained 95.35% of the total variation found in the landscape pattern. The highest loadings for these six factors, in order, were the number of patches (NP), mean proximity index (PROX_MN), largest patch index (LPI), patch cohesion index (COHESION), total core area (TCA), and the proximity index coefficient of variation (PROX_CV). It was concluded that east Mediterranean landscapes with a long history of anthropogenic-driven change showed a domain of scale for core area metrics. We also recommend that the majority of the pattern in dry Mediterranean landscapes, particularly those in Jordan, can be described with six metrics. We suggest that our procedure for landscape metric selection can be utilized in other regions of study as well.

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1. Introduction

Quantifying landscape pattern is fundamental to understanding the relationship between landscape structure and ecological process (Turner, 1989; Wu and Hobbs, 2002). Many landscape metrics and indicators have been developed to describe landscape pattern and quantify spatial heterogeneity (O'Neill et al., 1988; Turner et al., 2001), as based on remote sensing-derived thematic maps (McGarigal and Marks, 1995; McGarigal et al., 2002; Shao and Wu, 2008). Landscape metrics have been employed to measure the impact of humans on landscapes (Luck and Wu, 2002; McGarigal et al., 2001; Saura and Carballal, 2004; Antwi et al., 2008; Uuemaaa et al., 2008), to aid in landscape design (Gustafson and Parker, 1994; Brooker, 2002; Cook, 2002; Corry, 2004), to measure ecological sustainability (Renetzedera et al., 2010), and to contribute to conservation planning (Lombard et al., 2003; Sundell-Turnera and Rodewald, 2008). Landscape metrics have also been used to develop guidelines for forest management and to evaluate forest management from the perspective of landscape structure (Sanoa et al., 2009), in addition to comparing spatial heterogeneity among different landscapes (O'Neill et al., 1988; Hulshoff, 1995; Garrabou et al., 1998; Trani and Giles, 1999; Corry and Lafortezza, 2007).

Landscape patterns and ecological processes are well-known to be scale-dependent (Krummel et al., 1987; Turner et al., 1989a,b; Costanza and Maxwell, 1994; Wickham and Riitters, 1995; Cain et al., 1997; Lausch and Herzog, 2002; Suárez-Seoane and Baudry, 2002; Wu, 2004). Yet, landscape metrics also have been found to be sensitive in their response to the resolution of remotely sensed data (Li and Reynolds, 1993; Baldwin et al., 2004; Bailey et al., 2007; Buyantuyev and Wu, 2007; Castilla et al., 2009), in terms of altering the grain and/or extent of the data source (Turner et al., 1989a,b; Wickham and Riitters, 1995; Saura, 2004; Wu et al., 2002; Wu, 2004). The ability to quantify landscape pattern in response to a changing scale has gained increasing attention from landscape ecologists (Yoshida and Tanaka, 2005), particularly for the interpretation of biodiversity patterns (He et al., 2002; Kallimanis et al., 2008; Rossi and van Halder, 2010). Moreover, knowledge about the scale-dependency has become useful for applications related to sustainable landscape planning and management (Corry, 2004).

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Grain and extent are the two primary components of spatial scale. Extent is the size of a study area, whereas grain is the finest spatial resolution of a data set (pixel size in raster data) (Turner et al., 1989a,b; Wiens, 1989). In particular, the effect of altering the grain has been investigated in a wide spectrum of applications, including monitoring biotic diversity and landscape stability (O'Neill et al., 1997), quantifying landscape change over time (O'Neill et al., 1997; Lausch and Herzog, 2002), and assessing habitat fragmentation (Hargis et al., 1998; Riitters et al., 2000). Also, grain size has been related to ecological processes at the landscape level (Tischendorf, 2001; Fahrig, 2002; Bender et al., 2003).

While the effect of spatial resolution on landscape quantification has been empirically analyzed in numerous locations around the world (Saura, 2004; Wu, 2004; Frohn and Hao, 2006; Kojima et al., 2006; Saura and Castro, 2007), it has not been quantified for a highly fragmented Mediterranean landscape with a relatively long time frame of anthropogenic modification, such as the case found in Jordan. The concept of a 'domain of scale' is among the most important aspects of landscape ecological studies (Levin, 1992; Marceau, 1999). Peng et al. (2010) highlighted that there is a lack of understanding about the effectiveness of landscape metrics to quantify this concept, despite the numerous works. In addition, some landscape metrics show unstable and unpredictable behavior when there are aggregated spatial pattern at multiple levels of domains of scale (Wu et al., 2002; Wu, 2004; Frohn and Hao, 2006). Furthermore, metrics based on real landscape data, generally have low predictive power when applied to other landscapes (Baldwin et al., 2004), and there has been little study in fragmented Mediterranean landscapes.

Wheatley (2010) states that the literature lacks a good understanding of the 'domain of scale', a concept first discussed by Wiens (1989). Wheatley (2010) argues that although many landscape ecological studies have been conducted and that many landscape ecologists believe that there is well-established knowledge on this topic (Hay et al., 2001, 2002), actual examples are rarely reported either due to the fact that most study areas do not contain clear domains of scale, or due to the difficulty in identifying domain of scale (Wheatley, 2010). The majority of landscape studies have recognized three types of landscape metrics as responding to grain size, such as the predictable response, the erratic response and the staircase-like response (Wu, 2004; Baldwin et al., 2004; Saura, 2004; Frohn and Hao, 2006). We argue that dryland East Mediterranean landscapes have a good potential to explore the domain of scale as this area is shaped by anthropogenic and natural factors that have been intermixing with each other for thousands of years (Naveh, 1998). In this context, the objectives of the present study were:

1. To investigate the behavior of landscape level metrics in response to changing grain size across heterogeneous landscapes, especially the domain of scale pattern.
2. To identify redundancy among landscape level metrics, and to find metrics that best quantify the pattern in dry Mediterranean landscapes.
3. To develop a procedure for landscape indicator selection, that can be extrapolated to other regions of study.

Using theoretical landscapes, Hay et al. (2001) has demonstrated the importance of identifying domain of scale in differentiating the various agents that shape the landscape at different spatial scales. The present study will attempt to distinguish the relevant domain of scale for both anthropogenic factors and natural factors, and then distinguish their respective influence in shaping dryland Mediterranean landscapes. Such an analysis could demonstrate clear needs for management and conservation actions. Identifying the domain of scale is very important in explaining factors behind landscape change (Millington et al., 2003) and formulating a spatially explicit landscape evaluation (Blaschke and Petch, 1999; Backhaus et al., 2002).

2. Materials and methods

2.1. Study area

Our study was conducted on the three governorates in the north-western corner of Jordan (Fig. 1), covering a total area of about 250,000 ha, representing approximately 2.8% of the total area of Jordan. This area is inhabited by approximately 1,370,000 peo-

Table 1
List of landscape metrics used in the study (see McGarigal et al., 2002 for a detailed description of the metrics).

Landscape metrics	Abbreviation
Grain and edge metrics	
No. of patches	NP
Patch density	PD
Largest patch index	LPI
Landscape shape index	LSI
Patch area distribution	AREA_MN
	AREA_AM
	AREA_CV
Radius of gyration coefficient of variation	GYRATE_CV
Total edge	TE
Edge density	ED
Square root patch area	SQRPATCH
Shape metrics	
Perimeter–area ratio distribution	PARA_MN
	PARA_CV
Mean shape index distribution	SHAPE_MN
	SHAPE_CV
Patch fractal dimension distribution	FRAC_MN
	FRAC_CV
Perimeter–area fractal dimension index	PAFRAC
Contiguity index distribution	CONTIG_MN
	CONTIG_CV
Core area metrics	
Mean core area distribution	CORE_MN
	CORE_AM
	CORE_CV
Total core area	TCA
Core area index distribution	CAI_MN
	CAI_AM
	CAI_CV
Number of disjunct core areas	NDCA
Disjunct core area density	DCAD
Disjunct core area distribution	DCORE_MN
	DCORE_AM
	DCORE_CV
Isolation/proximity metrics	
Proximity index distribution	PROX_MN
	PROX_AM
	PROX_CV
Euclidean nearest neighbor distance distribution	ENN_MN
	ENN_AM
	ENN_CV
Patch cohesion index	COHESION
Contagion/interspersion metrics	
Percentage of like adjacencies	PLADJ
Contagion index	CONTAG
Aggregation index	AI
Interspersion and juxtaposition index	IJI
Landscape division index	DIVISION
Splitting index	SPLIT
Effective mesh size	MESH
Diversity	
Shannon's diversity index	SHDI
Simpson's diversity index	SIDI
Shannon's evenness index	SHEI
Simpson's evenness index	SIEI

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