Landscape Ecol
DOI 10.1007/s10980-007-9189-0

RESEARCH ARTICLE

Quantifying the effect of grazing and shrub-clearing on small scale spatial pattern of vegetation

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Received: 29 August 2007 / Accepted: 14 December 2007

Abstract Disturbances such as grazing, invading species, and clear-cutting, often act at small spatial scales, and means for quantifying their impact on fine scale vegetation patterns are generally lacking. Here we adopt a set of landscape metrics, commonly used for quantifying coarse scale fragmentation, to quantify fine scale fragmentation, namely the fine scale vegetation structure. At this scale, patches often consist of individual plants smaller than 1 m^2, requiring the grain of the analysis to be much smaller. We used balloon aerial photographs to map fine details of Mediterranean vegetation (pixel size <0.04 m) in experimental plots subjected to grazing and clear-cutting and in undisturbed plots. Landscape metrics are sensitive to scale. Therefore, we aggregated the vegetation map into four coarser scales, up to a resolution of 1 m, and analyzed the effect of scale on the metrics and their ability to distinguish between different disturbances. At the finest scale, six of the seven landscape metrics we evaluated revealed significant differences between treated and undisturbed plots. Four metrics revealed differences between grazed and control plots, and six metrics revealed differences between cleared and control plots. The majority of metrics exhibited scaling relations. Aggregation had mixed effects on the differences between metric values for different disturbances. The control plots were the most sensitive to scale, followed by grazing and clearing. We conclude that landscape metrics are useful for quantifying the very fine scale impact of disturbance on woody vegetation, assuming that the analysis is based on sufficiently high spatial resolution data.

Keywords Disturbance · Fragmentation · Grazing · Spatial-pattern · Landscape-metrics

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Introduction

The concept of habitat fragmentation has been central to conservation research and practice in recent decades (Haila 2002). Fragmentation is typically viewed as a spatial phenomenon that takes place at the landscape scale or at larger spatial scales (Lindenmayer and Fischer 2006). Fragmentation is a result of various disturbances, such as wildfire, windstorms, forest-clearing, urban sprawl, etc., that are relatively homogeneous at large scales. Some types of disturbance, such as grazing, tree-clearing, low-intensity fires and invading species, affect the ecosystem at a variety of scales, including spatial scales smaller than the landscape scale (Adler et al. 2001; Henkin et al. 2007; Naveh and Kutiel 1986). However, these small scale effects are traditionally conceived as 'modifying' the land, rather than fragmenting it.

Lord and Norton (1990) noted that these fine-scale processes can also be considered as fragmentation, and termed it 'structural fragmentation', as oppose to 'geographical fragmentation', which they assigned to fragmentation at landscape scale or larger scales. Here, we refer to these two types as fine-scale fragmentation vs. geographical fragmentation. In geographical fragmentation, the scale of the process is much larger than the scale of the individual plants, while in fine scale fragmentation, the scale of the process is close to the scale of the individual plants. Invasion of exotic plants, and heavy grazing, were both described as inflicting fine scale fragmentation on ecosystems.

Lord and Norton (1990) highlighted the potential differences between geographical and fine scale fragments. These include lack of intact core area in the fine scale fragments, resulting from their overall small area. This essentially leads to lack of difference between the edge and the core, making the entire patch an "edge" patch, and thus increasing its susceptibility to disturbances (in contrast to geographical fragments where the edge can absorb external disturbance, leaving the core area undisturbed). Additionally, functional interactions between organisms are more likely to be disrupted in fine scale fragments since only a fraction of the original species assemblage is retained.

The changes in spatial heterogeneity of landscape are important because they may imply on changes in habitat diversity and influence the diversity of organisms ranging from insects to birds and mammals (Bock and Bock 1984; Dennis et al. 1998) and interactions among them. Activities of many organisms depend on the structure of their immediate environment, and thus are expected to be affected by changes in spatial heterogeneity of landscape caused by fine scale fragmentation. For example, the shape of a shrub can affect movement and browsing patterns of large herbivores (Etzenhouser et al. 1998), beetle movements (Crist et al. 1992), and foraging behavior of seed harvesting ants (Crist and Wiens 1994). It was found that habitat alteration affects individual movements and patch selection of insect species, and thus change species richness, guild structure and species distributions (Golden and Crist 1999).

Fine scale fragmentation may affect processes that occur at small spatial scale but have also considerable impact on the ecosystem, through their effect on interactions such as pollination (Ghazoul 2005) or seed consumption (Crist and Wiens 1994). In a meta-analysis of independent fragmentation studies, it was found that fragmentation has an overall large and negative effect on pollination and on plant reproduction (Aguilar et al. 2006; Goverde et al. 2002).

Typifying small scale impacts of disturbance as 'fragmentation' has important implications, since there exist a whole set of well studied tools for evaluating, quantifying, and analyzing fragmentation, namely landscape metrics (Li and Wu 2004; McGarigal and Cushman 2002; Neel et al. 2004). In contrast, the quantification of the current concept of 'land modification' as a result of local disturbance is not straightforward, and tools equivalent to landscape metrics are not available to assess the degree of modification that results from such disturbances.

However, to this date, we are unaware of any attempt to analyze and quantify fine scale fragmentation in a manner similar to the ubiquitous analyses of geographical fragmentation, where the grain size is much larger. This is unfortunate, since rapid fine scale fragmentation is taking place in vast parts of the world, where grazing, wood cutting and invading species have strong impact on local ecosystems, and precise measurements and analyses of these phenomena are of utmost importance. Moreover, active management based on landscape manipulation is suggested for various ecosystems in order to maintain biodiversity (Perevolotsky 2006). If this practice becomes widespread, a quantitative tool to assess the intervention (or management) impact would be required. Landscape metrics may serve as such quantitative tools.

Over the past 20 years, much research was directed to landscape metrics, highlighting their potential applications but also their limitations (Li and Wu 2004). Landscape metrics react in complex manners to changes in landscape patterns (Neel et al.

2004) and analysis scale (Saura 2004; Wu 2004; Wu et al. 2002). Different metrics respond differently to changes in class aggregation and abundance, ranging from simple linear responses to complex, non-linear responses (Neel et al. 2004). Therefore, vegetation patterns cannot be described adequately by a single landscape metric, and it is recommended to use an entire set of metrics from different classes instead (Li and Wu 2004). Additionally, scale and extent of the analysis are well known to affect the behavior of landscape metrics (Garci'a-Gigorro and Saura 2005; Saura 2004; Turner et al. 1989; Wu 2004; Wu et al. 2002). It is important to define and account for three different scales in studies that use landscape metrics: (1) the scale of observation, in which the landscape pattern is captured by the remote sensing platform or the field data gathered; (2) the scale of analysis, in which the landscape metrics analysis is actually performed, usually following some sort of filtering, aggregation, or resampling of the original data (Li and Wu 2004); (3) the actual scale (or scales) of the ecological patterns and processes of interest (Levin 1992). In order to better tackle the problem of scale, multiple-scale analysis is often performed, either by directly comparing data from different sensors (Benson and MacKenzie 1995; Saura 2004), or by synthetically rescaling the data by means of aggregation techniques (Saura 2004; Wu 2004; Wu et al. 2002). A comparison that would include different sensors for each scale would be a better representative of reality than aggregation, due to the different physical properties of different sensors (Saura 2004). However, the majority of multi-scale studies used aggregation due to limitations on image availability.

The lack of studies quantifying fine scale fragmentation may be attributed, at least partly, to technical challenges. In order to analyze spatial phenomena, the resolution of the data needs to be finer than the scale of the phenomenon of interest (Campbell 1996). Thus, for example, forest fragmentation in the continental United States (Riitters et al. 2002), where the units of interest were forest stands, was studied using Landsat TM images, at a spatial resolution of 30 m. Global forest fragmentation was assessed using land cover maps derived from AVHRR imagery at a spatial resolution of 1 km (Riitters et al. 2000). In fine scale fragmentation, the units of interest are single plants—trees, shrubs, and dwarf shrubs, sometimes smaller than 1 m^2. The spatial resolution required to study fine scale fragmentation should therefore be much higher, at the order of centimeters.

Currently, most vegetation maps derived from satellite images and air photos have coarser spatial resolutions. The highest spatial resolutions used for mapping spatial pattern were 0.125 m, where aerial photographs were used to map shrubby patches within an agricultural matrix in the Negev desert, Israel (Svoray et al. 2007); 0.13 m, where a color infrared aerial photo was used to map serpentine grassland in California (Lobo et al. 1998); and 0.15 m, where wetland vegetation was mapped from an aerial photo acquired from a low-altitude balloon platform, in Japan (Miyamoto et al. 2004). In this study, we employ a very low altitude balloon platform, combined with meticulous mapping techniques, in order to achieve an extremely high resolution vegetation map, with a pixel size of 0.04 m. This technique enables quantitative analysis of fine scale fragmentation of woody vegetation composed of small patches, among other structures.

The major goal of this study is to describe local effects of grazing and tree clearing in terms of fine scale fragmentation (structural fragmentation, sensu Lord and Norton 1990). Quantifying various landscape metrics for areas that are subject to different disturbance regimes will enable us to quantify the magnitude of their impact on the landscape, and to determine whether such impacts are significantly different for different types of disturbance. A secondary objective of this study is to assess the effect of analysis scale (in the range between high and very high spatial resolutions) on the behavior of the metrics and their ability to differentiate between the effects of different disturbances. The study combines high-resolution mapping of the natural woody vegetation in experimental plots, followed by a multi-scale analysis of the fine scale structure of the vegetation using a set of landscape metrics.

Methods

Study site and experimental design

The study was conducted at Ramat Hanadiv Nature Park, located at the Southern tip of Mt. Carmel, Northern Israel (32°30′ N, 34°57′ E, Fig. 1). The area is a plateau with a mean elevation of 120 m a.s.l., descending steeply towards the coastal plain in the west via a series of rock cliffs, and descending gently towards the Nadiv Valley in the east. The parent rock formations consist of limestone and dolomite, with a volcanic marly tuff layer below the upper limestone layer. The soil in the area is mainly Xerochreps, developed on hard limestone or dolomite (Kaplan 1989). The climate is eastern Mediterranean, with an average annual rainfall of 600 mm, mostly between November–March. The vegetation is mostly Eastern Mediterranean Batha and Garigue, dominated by dwarf shrubs (*Sarcopoterium spinosum*), low summer deciduous shrubs (*Calycotome villosa*), evergreen medium shrubs (*Pistacia lentiscus*), and evergreen tall shrubs (*Phillyrea media*). The area has a very rich flora of annuals and geophytes in open patches (Hadar et al. 2000; Hadar et al. 1999). Landscape structure is a fine-grained mosaic of woody patches at different heights and sizes, herbaceous clearings, exposed rocks, and bare ground (Perevolotsky et al. 2003).

In 2004, twenty rectangular plots of ca. 1,200 m^2 each were set up in a small watershed at the northern part of the park (Fig. 2). The plots were divided into four groups of five plots, each group subjected to a different treatment, applied annually since the beginning of the experiment. The treatments were (1) goat grazing (approximately 400 goat days/1,000 m^2/year), (2) shrub clearing (shrubs were cut mechanically every fall to ground level; rapid spontaneous regeneration was uninhibited), (3) shrub clearing combined with goat grazing (goats enter the plots 6 months after the clearing treatment and consume the regenerating shrubs), and (4) control (no disturbance). Thus, the experiment consisted of four treatments with five repetitions.

Several isolated trees of species that are rare in the park were left in three clearing + grazing plots

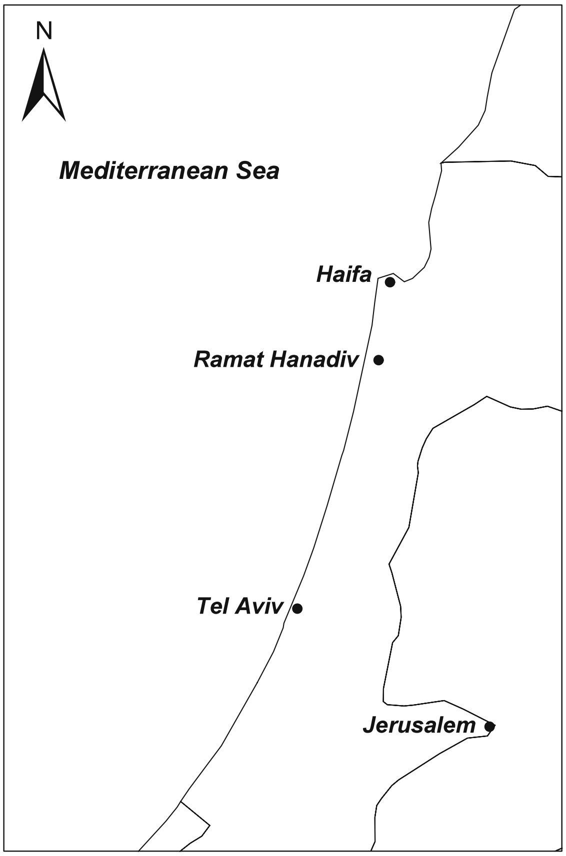


Fig. 1 The location of Ramat Hanadiv Nature Park in Israel

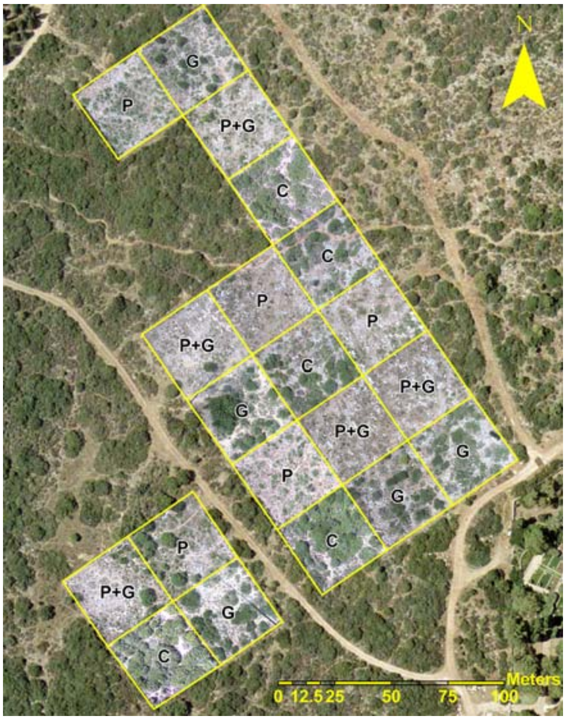


Fig. 2 Aerial photo of the experimental setup, comprised of 9 geo-corrected balloon images (spatial resolutions ranging between 2 and 4 cm) overlaid on an orthophoto of the study area (spatial resolution of 25 cm). The study plots are marked by rectangles, with the corresponding treatment type written inside. C—Control, G—Goat grazing, P—Shrub clearing, P+G—Clearing with Grazing

(with percent cover of 15.7%, 3.68%, and 1.69%) and one clearing plot (with percentage cover of 33.27%). These trees were digitized and omitted from all further analyses.

Vegetation photography and mapping

An aerial survey of the 20 study plots was performed in July 2006 by Sky Balloons™, using a digital camera (Minolta dimage™) mounted on a helium balloon. The camera was operated manually from the ground with a remote control. The operator controlled all camera functions, and its tilt relative to the balloon platform. The altitude of the survey was 110 m above ground surface. More than 100 images of the study plots were acquired from varying angles and locations. A subset of 9 images was selected for geo-correction, based on a visual appreciation of image quality, contrast, and proximity to nadir angle.

Prior to the aerial survey, 36 ground control points were marked in the field using calibration marks. The images were geo-corrected using the linear rubber sheeting method (Saalfeld 1985; White and Griffin 1985), based on the locations of the control points visible in each image. A set of 4–9 control points was used per image. The spatial resolutions of the geo-corrected images ranged between 0.0209 and 0.038 m, depending on the exact altitude of the balloon at the time of photo acquisition.

Vegetation classification

The images were classified into three thematic classes, (1) woody vegetation, (2) bare ground + herbaceous vegetation, and (3) rocks, using a maximum likelihood supervised classification in ERDAS IMAGINE 8.6 (ERDAS 1999). Bare ground and herbaceous vegetation were assigned into the same class since the photos were taken in the dry season, when dry herbaceous vegetation is inseparable from bare ground. Spectral signatures of the three classes were acquired separately for each image since there was a large variation in the overall brightness of different images.

Classification accuracy was assessed with 100 reference points (interpreted manually) selected in a stratified random scheme. To reduce edge effects, only pixels that were located in homogeneous regions of the classified image (defined by a neighborhood of seven by seven pixels of the same class) were used as reference points (Verbyla and Hammond 1995). A subset of 30 reference points was selected and validated in the field, in order to evaluate the quality of the manual interpretation.

Landscape metrics analysis

In order to standardize the spatial resolution of the classified images, all images were resampled to the largest pixel size, 0.038 m, and merged into a single mosaic. A clumping algorithm (ERDAS 1999) was then applied to the image using a 8-pixels neighborhood rule, and a map of individual patches was constructed. Patches <10 pixels (corresponding to an area of ca. 0.014 m^2) were typically artifacts of the classification process, and were therefore eliminated using a focal majority filter (ERDAS 1999). The resulting image was divided into 20 images, one per study plot, and imported into Fragstats 3.3 software (McGarigal et al. 2002).

Only a few basic metrics of more than a hundred that appear in the literature were used in this study. Landscape metrics are frequently strongly correlated, and can be confounded (Gustafson 1998; Hargis et al. 1998; McGarigal and McComb 1995; Riitters et al. 1995; Tinker et al. 1998). Analysis of these authors' recommendations revealed reasonable agreement on a core set of metrics (Botequilha Leitão and Ahern 2002). Therefore, we have selected seven basic metrics for the spatial analysis of the woody patches in each of the 20 study plots (Table 1): proportion of landscape, mean patch area, edge density, mean proximity index, patch density, mean radius of gyration, and mean shape index. These metrics capture the basic spatial processes studied here (decrease in woody cover and patch size, increase of edge and spacing between patches, and change in patch shape).

The seven landscape metrics derived from the four treatments in the 20 study plots were analyzed in the following manner. First, one way analysis of variance (ANOVA) was performed separately for each metric to find whether at least one of the treatments had a significantly different mean metric value than the

Table 1 A list of landscape metrics used in this work

Metric name	Description	Range
Proportion of landscape (PLAND)	A measure of landscape composition: the proportional abundance of each patch type in the landscape	PLAND $\geq$ 0
Patch density (PD)	Number of patches per unit area	PD $\geq$ 0
Edge density (ED)	Total patch edge lengths per unit area	ED $\geq$ 0
Mean patch area (AREA)	Mean area of patches in the landscape in m^2	AREA $\geq$ 0
Mean radius of gyration (GYRATE)	Radius of gyration is a measure of patch extent: the mean distance between each cell (pixel) in the patch and the patch centroid in meters	GYRATE $\geq$ 0, Equals 0 when the patch consists of a single cell; increases with patch growth.
Mean shape index (SHAPE)	Shape index is a measure of patch shape complexity: how close the patch shape to a square	SHAPE $\geq$ 1, Approaches 1 when the shape is close to a square; grows as the shape is more irregular
Mean proximity index (PROXIM)	Proximity index is a measure of landscape fragmentation, based on the distribution of distances between patches and patch sizes in a defined neighborhood size with N' patches.	PROXIM $\geq$ 0, Approaches 0 when the landscape consists of small, isolated patches; increases as the landscape consists of large, continuous patches

Description follows McGarigal et al. (2002)

others. Some replicate plots had common boundaries, and the assumption of spatial independence may have been very slightly violated, yet we considered this to be a minor effect, still allowing us to conduct ANOVA. For cases where the one way ANOVA revealed significant differences, multiple comparisons were performed to detect pairs of treatments that resulted in different metric values, using Tukey's HSD. As an additional indication of small scale effects of fine scale fragmentation on vegetation structure, a principal component analysis was performed using the entire set of landscape metrics combined.

Data rescaling

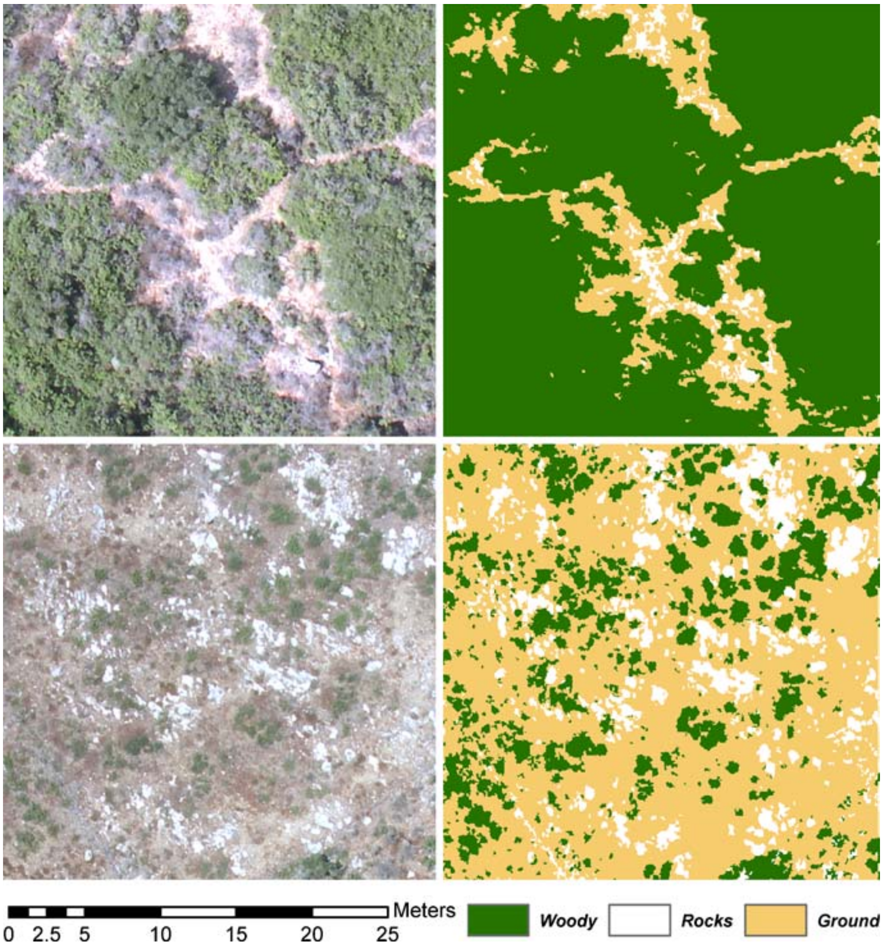
The original vegetation maps (~4 cm pixel size) were rescaled to four coarser scales, with pixel sizes of 25 cm, 50 cm, 75 cm, and 100 cm. Each new map was derived directly from the original vegetation map using a majority rule, where the new pixel value is set to the value of the most abundant class in the corresponding area in the original map. Maps with pixel sizes larger than 100 cm were not evaluated since the small number of pixels in each study plot, makes the landscape metric analysis inappropriate. Following the rescaling, the statistical analyses described above were applied to each rescaled data set. In addition, a scaling function was fitted to each metric in each treatment, from one of the following possibilities: logarithmic, power, exponential, linear, or none. One scaling function per metric was selected based on its coefficient of determination (R^2). The function was fitted to the raw data that included 25 points per treatment (5 scales $\times$ 5 repetitions) for each metric.

Results

Classification results and accuracy

The classified vegetation maps followed closely the fine spatial patterns of woody vegetation and of rocks (Fig. 3). Classification accuracy was 90%, and the overall kappa statistic was 0.82. User accuracy for the woody class was 90.2% and producer accuracy was 93.88%. The conditional kappa statistics were 0.81, 0.87, and 0.73, for woody vegetation, bare ground, and rocks, respectively. There was a complete agreement between the 30 field measured reference points and their manually interpreted counterparts.

Fig. 3 Aerial images (left) and their corresponding classifications (right), of a control area (top) and a grazed + cleared area (bottom)



Landscape metrics

Generally speaking, disturbance increased fine scale fragmentation at all spatial scales (Fig. 4). Analysis of variance revealed that for six of the seven landscape metrics, at least one of the treatments had a significantly different mean metric value than the others ($P < 0.05$). These results were consistent at all spatial scales (Fig. 5). The impact of clearing was consistently stronger than the impact of grazing, and clearing followed by grazing had yet a stronger impact (Figs. 4 and 5). The effect of disturbance was expressed in several ways: the proportion cover of woody vegetation decreased with increased disturbance, (Fig. 4a) while patch density increased (Fig. 4b), in agreement with a major reduction in mean patch area (Fig. 4c). Edge density also increased, providing additional indication that disturbance results in fine scale fragmentation (Fig. 4d). Mean proximity index decreased following disturbance (Fig. 4f), corresponding to an increased spacing between patches. Mean shape index was the only metric for which differences between treatments were not significant at the four finer scales, although differences were significant at the coarsest scale (Figs. 4g and 5).

The various metrics exhibited five types of scaling relations (Fig. 5). Edge density exhibited a logarithmic scaling relation ($y = a\ln x + b$, where a and b are parameters) in the majority of treatments, with an average R^2 of 0.87. Mean patch area and mean proximity index exhibited a power law scaling relation ($y = ax^b$) in the majority of the treatments, with an average R^2 of 0.85 and 0.82, respectively. Patch density and mean radius of gyration exhibited an exponential scaling relation ($y = ae^{bx}$) in all treatments, with an average R^2 of 0.88 and 0.91, respectively. Proportion of landscape was relatively

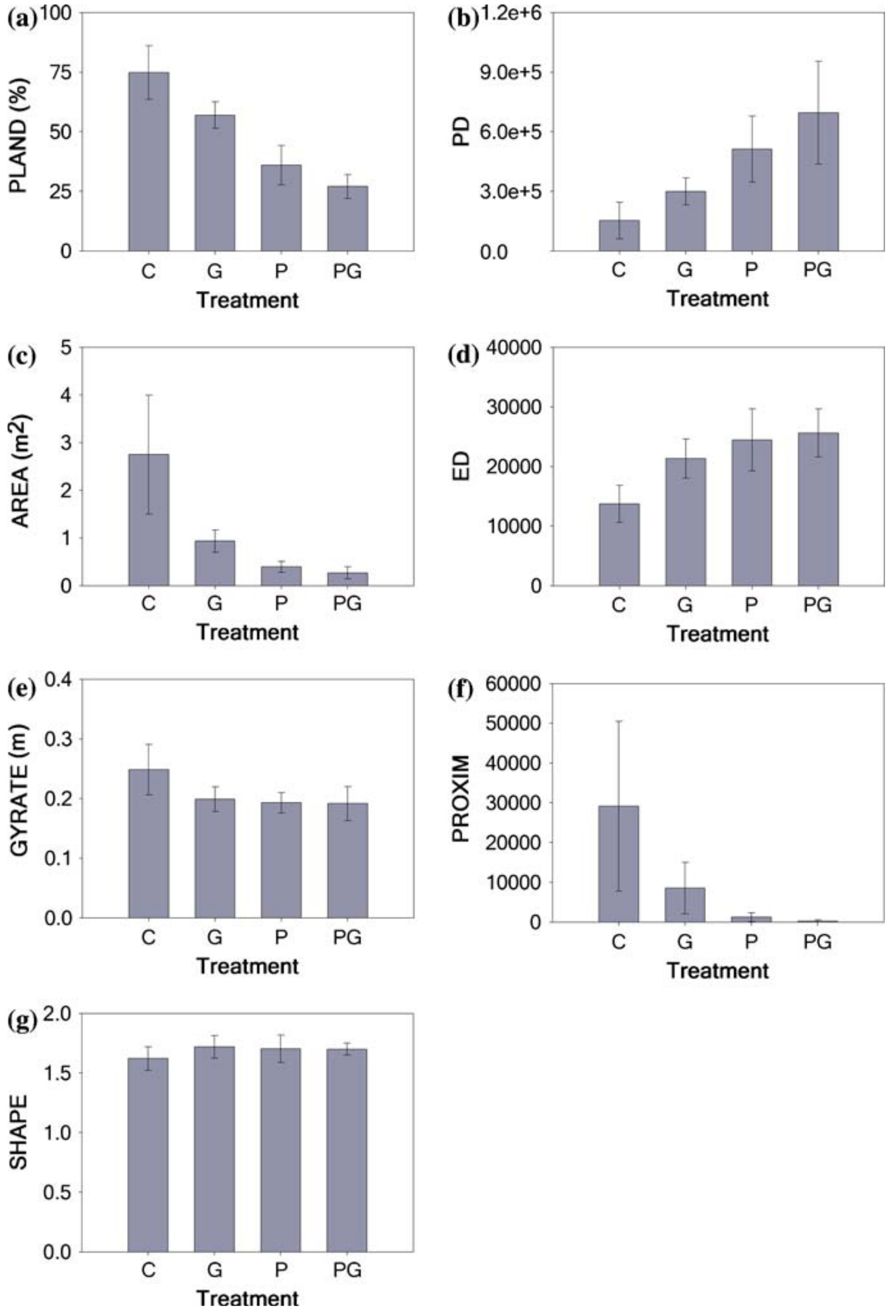


Fig. 4 Average values of landscape metrics for woody patches in the different treatments at the finest scale. PLAND is proportion of landscape, PD is patch density, AREA is mean patch area, ED is edge density, GYRATE is mean radius of gyration, PROXIM is mean proximity index, and SHAPE is mean shape index. The category axis lists the types of treatments: C—Control, G—Goat grazing, P—Shrub clearing, PG—Clearing with Grazing

constant at different scales, and mean shape index did not exhibit any consistent scaling relation. Accounting for the different disturbances, the control plots were the most sensitive to changing scales in all metrics except patch density and edge density (where the clearing with grazing treatment was the most sensitive), and proportion of landscape (where all treatments were insensitive to changing scales). Scale had mixed effects on the degree of difference between treatments. In patch density, edge density, and mean proximity index, the differences between treatments decreased with increasing scale, corresponding to a negative exponential coefficient. In proportion of landscape, the differences between

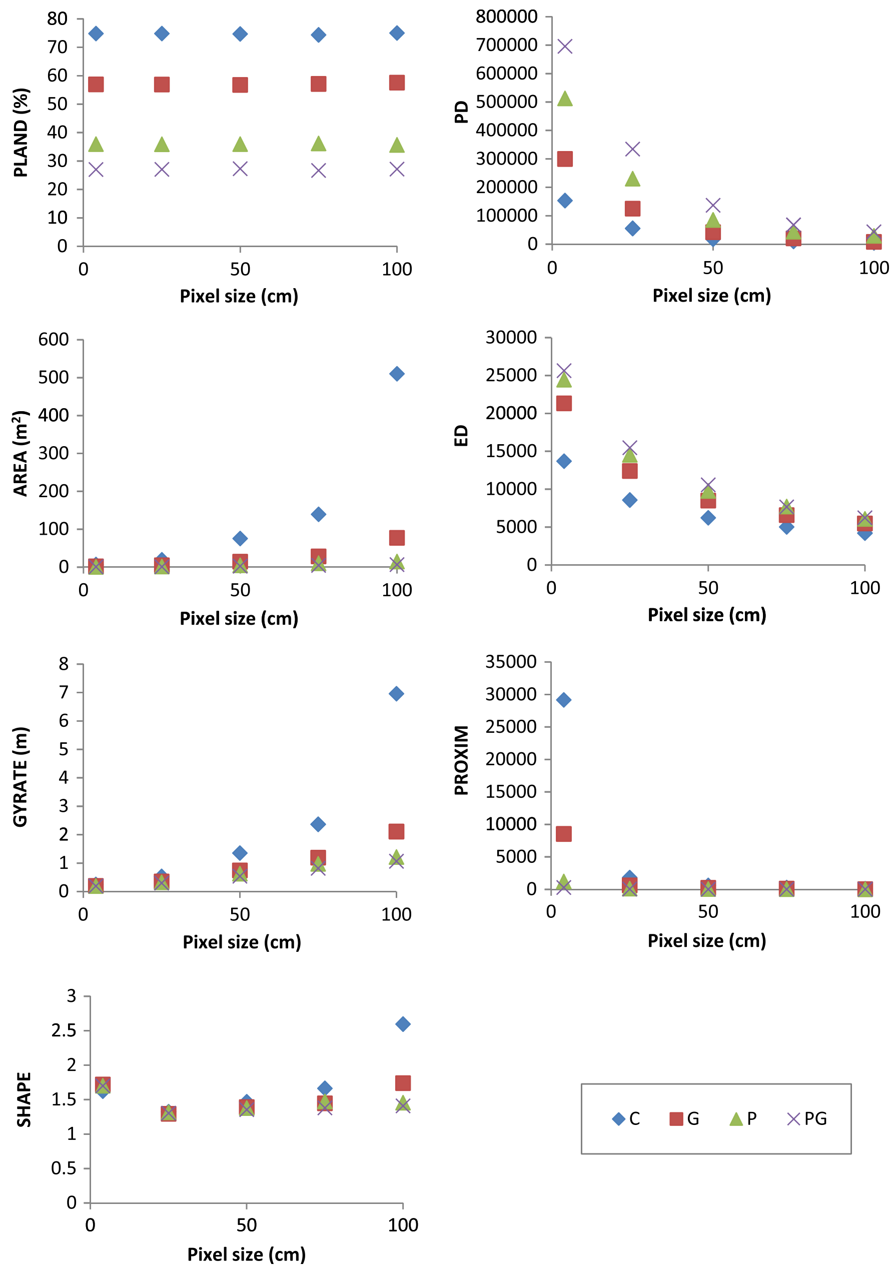


Fig. 5 The effect of changing scale on the average values of the landscape metrics of the four treatments: C—Control, G—Goat grazing, P—Shrub clearing, PG—Clearing with Grazing

treatments were consistent over the entire range of scales. In all other metrics, the differences between treatments increased with increasing scale.

The majority of landscape metrics captured significantly the effects of grazing and of clearing on vegetation structure when compared to the undisturbed control plots (Table 2). The multiple comparisons showed that in four landscape metrics—the grazing treatment differed significantly from the control at the basic scale. At the coarsest scale, only proportion of landscape differentiated between grazing and control plots. Edge density differentiated between them only at the finest scale, while patch density and mean shape index failed to do so at any scale. In six metrics, the clearing and the clearing + grazing treatments differed significantly from the control, and these differences were consistent over the entire range of scales except for mean

Table 2 Multiple comparisons of the effect of treatments on the value of the landscape metrics at various spatial scales

Treatment pair	Proportion of landscape	Patch density	Edge density	Mean patch area	Mean radius of gyration	Mean proximity index	Mean shape index
C–G	1 2 3 4 5		1	1 2 3 4	2 3	1 2 3 4	
C–P	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4	5
C–PG	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4	5
G–P	1 2 3 4 5	5				4	
G–PG	1 2 3 4 5	1 2 3 4 5				4	
P–PG		3					

Significant differences (at the 0.05 level) are marked by a number between 1 and 5, where 1 represents the smallest scale (pixel size of 4 cm), and 5 represents the largest spatial scale (pixel size of 100 cm). C is control, G is grazing, P is clearing, PG is clearing with grazing

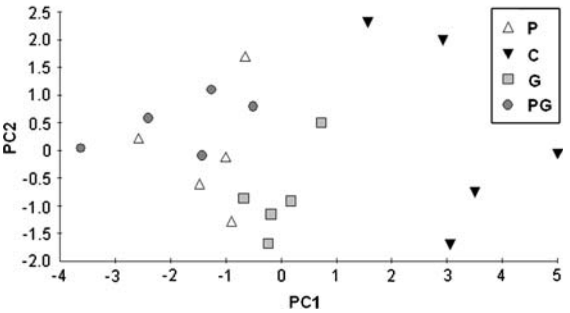


Fig. 6 The first two principal components of the multi-metric data in the four treatments at the finest scale

proximity index at the coarsest scale. In contrast, mean shape index differentiated between control and clearing plots only at the coarsest scale. The grazing and clearing plots differed only in the proportion of woody vegetation cover. The clearing + grazing plots differed from the grazing plots in the proportion of woody cover and in patch density. The clearing and the clearing + grazing plots differed only in the value of patch density at the pixel size of 50 cm.

A PCA on the original data set showed that the first three principal components of the multi-metric data contributed to 60.12%, 17.1%, and 12.3% of the variation in the data, respectively. The first component corresponds well to the different treatments (Fig. 6). The control treatment is clearly different than the other treatments, and the effects of clearing and clearing + grazing are hard to distinguish.

Discussion

In this study, landscape metrics that are commonly applied to describe large-scale vegetation structure were successfully employed for the analysis of fine scale fragmentation resulting from small scale disturbances.

At the finest scale of analysis, the first four parameters of the seven examined metrics revealed significantly the effect of grazing. This is not surprising, since goat grazing alters the shape of the woody patch mainly by browsing on its edges (leaves and twigs), which are accessible to the animal. Moreover, goats climb on the trees/shrubs with their front legs and break branches. As a result, woody patch area decreases while edge area increases. This tendency explains also the decrease in proportion of landscape. Patch density was higher in the grazing treatment, but not significantly. Increase in the number of patches following grazing is expected, since grazing can divide large woody patches into smaller sub-patches, but rarely eliminates entire patches. In our study, however, this trend is not significant. The decrease in patch area has lead to a decrease in the mean proximity index (corresponding to increased fragmentation between patches). The non-significant change in mean radius of gyration is probably a consequence of the grazer's inability to penetrate the patch core, thus the majority of feeding occurs at the edges—leading to an increased edge density while the changes in the mean radius of gyration are minor. In contrast to the expectations, mean shape index was not altered significantly by grazing, although patch perimeter increased and patch area decreased.

The scaling laws for five of the metrics in this study were compared to previously reported laws for the same metrics (Wu 2004; Wu et al. 2002). Three of the metrics (mean shape index, mean patch area, and proportion of landscape) were consistent between the studies, but two other (patch density and edge density) were inconsistent. Here, the scaling relations for edge density and patch density were logarithmic and exponential, respectively; while in Wu (2002) the relations were power law, although he reported that an exponential relation was almost as good as the power law. Differences in scaling relations between studies might be a result of the small number of scales used in this study (five), compared to the 24 scales used by Wu (2004). Here, relations were selected according to the coefficient of determination (R^2), which is dependant on the number of observations, and is possibly inflated by logarithmic transformations of the data used for fitting the linear regression line (Saura 2004). Consequently, differences between the coefficients of determination of different functions were rather small, with an average difference over all treatments of 0.037 for patch density and 0.083 for edge density. Another possibility is that scaling relations may vary over large range of scales (Garci'a-Gigorro and Saura 2005) and are consistent only for small ranges of scales (Saura and Castro 2007). This might explain the differences in scaling relations, since the finest scale studied by Wu (2004), is much coarser than the coarsest scale of the present study.

The sensitivity of the different metrics to changing scales was probably over estimated since re-scaling via aggregation yields different results than using datasets from different sensors (Benson and MacKenzie 1995; Saura 2004). This is important, since statistically there were not many differences in the ability of the landscape metrics to distinguish between different disturbances at the pixel size range of 4–75 cm (edge density was the sole metric where a 4 cm resolution was superior to all coarser resolutions for distinguishing between control and grazing plots). Therefore, using small pixel sizes for capturing subtle differences in vegetation structure through landscape metrics may be superior to using larger pixel sizes.

The performance of the landscape metrics was generally satisfactory. However, a major limitation of using conventional landscape metrics for quantification of fine scale fragmentation is the lack of a vertical dimension. Fine scale fragmentation often involves reduction of vegetation height (clear-cutting, grazing of medium-low woody species), which cannot be captured by the existing landscape metrics. Vegetation height has an important role, since it affects the light availability to the neighboring vegetation patches and the understorey vegetation, and contributes to the ability of the patch to withstand grazing by preventing access to its core. Mapping the vertical dimension of vegetation is harder than the horizontal dimension, due to technical limitations of automated height measurements, and the complicated crown structure (Ogunjemiyo et al. 2005).

Low altitude aerial photography may serve as an effective tool for the study of vegetation structure at small spatial scales. The high spatial resolution achieved by static low altitude platforms such as balloons enables the mapping of woody vegetation in precise details, which in the case of this study, reveals the fine scale fragmentation resulting from management. The method is especially appropriate for studies of fine scale fragmentation and small scale vegetation structure. A practical benefit of this approach is the low cost of a balloon-based survey, compared to an airplane-based survey. On the other hand, the method is impractical for coarse-scale studies, due to the large number of photos needed on order to cover larger areas.

Grazing and clear-cutting affect the spatial pattern of vegetation (Adler and Hall 2005; Henkin et al. 2007; Palmer et al. 2004; Sal et al. 1999). We are not aware of any attempts to analyze and quantify these impacts at small scales. Typifying small scale impact of disturbance as fine scale fragmentation enables us to apply metrics usually used for quantifying large-scale fragmentation. The results reported hereby suggest that common landscape metrics used for measuring large-scale landscape-heterogeneity can also capture small scale changes in landscape resulting from local disturbance or proactive management.

Grazing and clear-cutting may consist important tools in management for conservation because of their influence on habitat structure and biodiversity (Collins et al. 1998), changing physical and biological conditions (Dzwonko and Loster 1998; Woodcock et al. 2005) and increasing environmental heterogeneity at different spatial scales (Mcnaughton 1983; Sal et al. 1999). In order to use grazing and clear-cutting as management tools, we need to study the ways they affect landscape patterns. Using small scale landscape metrics to quantify the effects of such management on the landscape at fine scales offers a powerful means towards this end.

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