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Use of Indices of Ecosystem Function to Identify Levels of Degradation in a Semiarid Mediterranean Landscape

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Abstract
We evaluated the landscape structure and function of a semiarid catchment by means of indices of landscape function. The indices obtained showed differences in the vegetation spatial structure and the soil surface quality between the landscape units identified in the catchment. Structural attributes of the source-sink system pointed to a reforested area as the most functional unit and to the upper part of the catchment as the least functional area. However, taking into account both structural pattern and functional soil quality, the scrubland was the most functional unit. The potential of these indices as surrogates of the runoff and sediment production is of great interest as they are inexpensive, rapid and easy to obtain compared to measured values.

Résumé
La structure et la fonction du paysage d´une zone semi-aride sont évaluées grâce à des indices de fonctionnement. Les indices obtenus ont permis de détecter des différences dans la structure de la végétation et dans la qualité de la surface du sol des unités du paysage identifiées. La structure spatiale des zones d'importation/exportation des ressources dans les plantations forestières a été la plus fonctionnelle, pendant que la structure spatiale dans la partie supérieure du bassin versant a été la moins fonctionnelle. Par contre, si on considère la structure spatiale en conjonction avec l'évaluation de l'état de la surface du sol, l'unité du paysage dominé par des arbrisseaux est la plus fonctionnelle. Les différents niveaux de fonctionnalité trouvés peuvent être indicateurs des différentes réponses hydrologiques et érosives.

Introduction

In semiarid ecosystems, a source-sink dynamic is commonly generated where vegetated zones act as sinks, retaining water, sediments and nutrients, while unvegetated areas act as source zones (Puigdefábregas, 2005). These resources are excessively lost in degraded or dysfunctional ecosystems, while the loss of resources is very limited in functional ecosystems (Tongway & Ludwig, 1997). In this way, for a given range of environmental conditions, the functional variability of the ecosystems should be inversely related to their runoff and sediment production. Several indicators of ecosystem function have been proposed in the related literature (Herrick et al, 2005; Imeson & Prinsen, 2004; Tongway & Hindley, 2004; Basin et al, 2002). In this study, we applied the "Landscape Functional Analysis" (LFA) methodology, developed by Tongway & Hindley (2004), to characterise the functional status of several landscape units in a semiarid Mediterranean catchment. The LFA methodology assesses the functional status of a landscape by means of easily observed indicators, relative to the soil surface state, from which indices of infiltration, stability and nutrient cycling are derived. These indices are rapid and easy to obtain, sensible to temporal changes and have a predictive capacity of the ecosystem behaviour, properties recommended for ecological indicators (Dale & Beyeler, 2001). We studied the potential of the LFA methodology to distinguish areas, at different spatial scales, with different degradation levels that might be related to a different runoff and sediment response.

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Methods

The study catchment (22.7 ha) was located in El Ventós mountain range (38° 28' N, 0° 37'W), Alicante province, E Spain. The area is characterised by very steep slopes, shallow soils and a discontinuous vegetation cover. The climate is semiarid with an average annual precipitation of 273 mm (1976-2004 period). We distinguished 4 landscape units within the catchment according to the vegetation type and to physiographic or topographic properties, which might have a different hydrological response: (I) The upper part of the catchment (*Upper*), where a tussock grass, *Stipa tenacissima*, and a resprouting shrubby oak, *Quercus coccifera*, were the dominant species; limestone outcrops and very shallow soils (120 mm on average) were also characteristic of this area. (II) *Stipa tenacissima* steppes (*Steppe*), covering the lower and East-facing slopes of the catchment, where *S. tenacissima* was clearly dominant and soils were slightly deeper than in the upper areas. (III) Dwarf scrubland (*Scrubland*), covering the West-facing slopes of the catchment, and (IV) a small area recently reforested with *Pinus halepensis* (*Reforestation*). In the reforested area, the pine trees were planted along subsoiling lines, creating a bank and trough system that clearly modified the slope microtopography. Inside each landscape unit the vegetation was sparsely distributed in patches made of one or several plants surrounded by inter-patches of unvegetated soil or limestone outcrops. Patches of vegetation act as barriers to the flow of resources as water, sediments or nutrients, functioning as sinks, while "smooth" areas or inter-patches function relatively as sources. Following this approach, we identified two types of inter-patches: unvegetated soil and rock outcrops; and six patch types: (1) the perennial grass *Brachypodium retusum* (Pers.) P. Beauv. mixed with chamaephytes, hereafter mix (MI); (2) *Stipa tenacissima* tussocks (ST); (3) tall shrubs (TS), (4) small shrubs (< 50 cm) (SS), (5) subsoiling segments in the reforested area including a planted pine sapling (VT) and (6) unvegetated subsoiling segments (UT).

Within each landscape unit, we established four, 50 m-long, transects following the maximum slope, along which we measured the length intercepted by patches and inter-patches and the width of patches perpendicularly to the transect. From this data we obtained, mean patch and inter-patch length, mean patch width, patch density (m/10 m), and total patch and inter-patch length, which were used to estimate the cover of each zone in the area of study. We used 50 x 50 cm quadrats to characterize the soil surface state of the patch and interpatch types. We measured 6 quadrats per landscape unit of the dominant inter-patch type, the unvegetated soil areas, and 3 quadrats per patch type and per landscape unit, with the exception of the specific zones created by the subsoiling lines that were only present and sampled in the reforested area. In each quadrat, 11 indicators of the soil surface condition were sampled (see details in Tongway & Hindley, 2004). These indicators were summed to obtain three indices, which represented different ecosystem functions as water infiltration capacity, resistance to erosive processes and nutrient cycling. The three indices vary between 0 and 100 %, with low values equivalent to dysfunctional or degraded landscapes and high values to functional landscapes. To obtain the global indices for each landscape unit (including patch and inter-patch areas), the indices obtained for each patch and inter-patch type were weighted by the proportion of each type in each landscape unit.

Results

In the whole study catchment, the proportion of inter-patch area (61.2 % ± 1.8) was higher than the proportion of patch areas. At the landscape unit level, this difference was significant for *Upper* and *Scrubland* and marginally significant for *Steppe*. The proportion of unvegetated soil was similar between landscape units. However, the average length of this type of inter-patch was higher in *Upper* and lower in *Reforestation* than in other units. The

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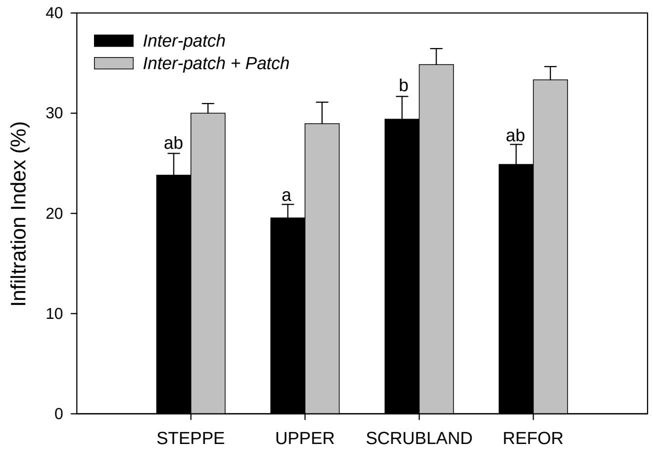
proportion of rock outcrops was slightly higher in *Upper* than in other units, and was nil in *Reforestation*. Patch structure varied between vegetation types. Patches of TS were the largest, showing the highest width, and together with ST the highest length. Patches of MI and SS were the smallest and the most dense. *Reforestation* showed the highest patch width, patch density and patch area and the lower distance between patches, although differences were only significant for patch width. *Upper* showed the opposite trend.

The LFA indices showed higher values for patches than for inter-patches. Vegetated patches showed more ground cover, canopy cover and litter, less erosion features, eroded materials and soil compaction than inter-patches. LFA indices varied also between patch types: TS showed the highest values for the three indices and MI the lowest. There were no functional differences between ST and SS patches. Although the global values of the indices (including patch and inter-patch zones) did not vary significantly between landscape units (e.g. see Infiltration index, Fig. 1), *Upper* showed the lowest values for the Infiltration and Nutrient cycling indices, while *Scrubland* showed the highest values for the three indices. *Reforestation* showed the lowest Stability index. The Infiltration index for the unvegetated soil varied significantly between landscape units (Fig. 1), with *Scrubland* showing the highest value and *Upper* the lowest value. However, the LFA indices for each patch type were similar between units.

Fig. 1. Infiltration index (%) for the unvegetated soil (inter-patch) areas in the various



landscapes units (black bars), and global infiltration index (patch + inter-patch) at the landscape level for each landscape unit (grey bars). Different letters indicate significant differences between the infiltration index for the unvegetated soil. REFOR: Reforestation.

Discussion

The structural differences of the source-sink system between the landscape units lied on the width of the sink zones, which was particularly high in the reforested area due to the subsoiling lines that were perpendicular to the maximum slope. The reforested area would potentially be the less resource-leaky unit due to the high roughness that the subsoiling lines provide to the hillslope and that would limit the run off of resources. In spite that patch width was the only property that varied significantly between units, other structural attributes of the source-sink system, such as patch density or the distance between consecutive patches, pointed to the reforested area as the most functional unit and to the upper part of the catchment as the least functional area.

Vegetated patches showed higher potential than inter-patches to remain stable, have higher infiltration rates and behave as fertility islands. Surface properties differed also

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between patch types. Thus, patch zones formed by tall shrubs showed the best soil surface status. Patch zones formed by planted pines in the reforested area showed also high stability and nutrient cycling potential. According to the LFA methodology, the infiltration capacity of the unvegetated soil was higher in the scrubland than in the upper part of the catchment, probably due to the higher compaction of the soil surface found in the upper part of the catchment. On the contrary, the various patch types did not showed different soil surface conditions depending on their location within the landscape. This result implies that the sink role of a vegetation patch is maintained independently of the overall condition of the landscape, while the unvegetated soil would better reflect the spatial variation of soil conditions and landscape functioning.

The scrubland was the most functional unit analysed, mainly due to the relatively good soil conditions of the unvegetated soil in this unit. The variability in landscape function found in the study area might be translated into variability in the hydrologic and erosive response. Ongoing runoff and soil loss monitoring in the study catchment will help to analyse the relationship between LFA indices and the quantitative hydrologic and erosive response of the catchment. The validation of the LFA indices as surrogates of the functions that they represent would be of great interest as this methodology is an inexpensive, rapid and easy to use-monitoring procedure compared to measured values.

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