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Floristic and vegetation successional processes within landslides in a Mediterranean environment

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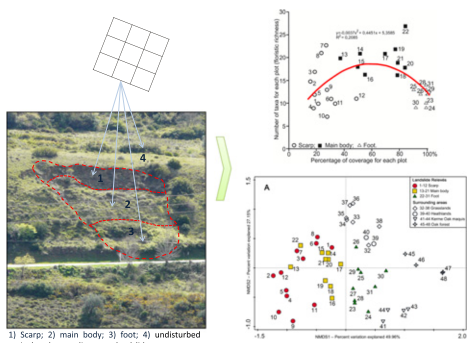
HIGHLIGHTS

- A method to understand successional processes in disturbed landslide areas is presented.
- A floristic and vegetation analysis is performed considering different landslide sectors.
- A gradient in the seral vegetation stage is observed from landslide scarp to foot.
- Landslide disturbed areas can be biodiversity reservoirs.

GRAPHICAL ABSTRACT



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ABSTRACT

Floristic and vegetation analysis in seven Mediterranean landslides led to the understanding of the successional processes occurring in different landslide disturbed sectors. Our study showed that in landslides that occurred between 1996 and 2010 there is a clear differentiation between the three main landslide sectors (scarp, main body and foot) concerning floristic composition, vegetation structure, floristic richness, successional processes and plant functional type. Additional differences were found between landslide areas and undisturbed agricultural areas adjacent to landslides. In this study 48 floristic relevés were made using a stratified random sampling design. The main landslide body exhibits the highest floristic richness whereas the landslide scarp has the lowest coverage rate and the highest presence of characteristic species from ruderal and strongly perturbed habitats. Finally, the landslide foot shows a late stage in the succession (maquis or pre-forest stage) with a high dominance of vines. We further discuss the importance of landslides as reservoirs of biodiversity especially for Mediterranean orchids.

1. Introduction

Disturbances caused by natural disasters such as earthquakes, typhoons, landslides, floods and forest fires, among others, change the biological organization of ecosystems (del Moral and Walker, 2007). These events often lead to primary or secondary succession, depending on whether the disturbance involves species changes on substrates with little or no biological legacy (primary succession) or the succession begins with some biological legacy (secondary succession) (Franklin et al., 1985; Walker and del Moral, 2003; Geertsema and Pojar, 2007; Walker and Shiels, 2013). The study of environmental disturbances has a long research tradition focusing on different impacts, restoration and succession process (White and Jentsch, 2001; Restrepo et al., 2009). Landslides

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are major phenomena responsible for natural disturbance on ecosystems removing organic matter and topsoil, exposing bare rock and shallow subsoil and generating extreme environmental gradients (Myster and Femández, 1995; Myster, 1997; Pearson et al., 2013). These natural disturbances provide new substrates for plants and community development and alter the landscape (Elias and Dias, 2004, 2009). The mobilization of soil mass (engineering perspective) takes place when a landslide occurs allowing the study of the successional processes, as well as the analysis of the competition processes among colonizing plants.

The principle of ecological succession on landslides is well established with the nature and rate of succession being determined by changes in soil type, available nutrients, light, wind and hydrology (Walker et al., 1996; Myster and Walker, 1997; Stokes et al., 2007; Shiels and Walker, 2013). However, the ecological characteristics of habitats created by the landslide are not homogeneous and a longitudinal gradient (from upper to lower landslide zone) of the chemical and physical properties may exert a big influence on the spatial distribution of flora and vegetation and on the successional process (Lundgren, 1978; Adams and Sidle, 1987; Guariguata, 1990; Reddy and Singh, 1993; Francescato et al., 2001; Shiels et al., 2008). According to Guariguata (1990) the lower zone of the landslide (the landslide foot) has higher concentration of carbon and total organic nitrogen exchangeable cations than the upper landslide rupture zone. On the other hand, the changes in soil structure and texture induced by the soil mass mobilization leads to a spatial differentiation of water-holding capacity and root penetrability among the different landslide zones. The spatial mosaic of habitats provided by the soil mass mobilization leads to different plant strategies and functional types of colonization of the main landslide sectors.

Worldwide studies on how landslides alter the structure of populations, communities and ecosystems relate to the soil characteristics and floristic and structural comparison between the landslide and the undisturbed adjacent area (Lundgren, 1978; Zarin and Johnson, 1995a; Restrepo and Alvarez, 2006; Elias and Dias, 2009). Some studies, however, explore plant succession on landslides (Flaccus, 1959; Mark et al., 1989; Dalling, 1994; Zarin and Johnson, 1995b; Francescato and Scotton, 1999; Gers et al., 2001; Elias and Dias, 2009; Walker et al., 2009; Walker and del Moral, 2009; Walker et al., 2010a, 2010b; Walker et al., 2013). However, only a few studies focus on the differentiation of flora and vegetation within different landslide sectors, especially the scarp, the main body and the foot (Sakai and Ohsawa, 1993; Velázquez and Gómez-Sal, 2008, 2009; Velázquez et al., 2014).

Our study aims: (i) to identify the flora and vegetation differences between the three main sectors of a landslide (scarp, main body, foot) as a consequence of the different habitat characteristics created by the moving soil mass (longitudinal gradients); and (ii) to find out whether the differences in floristic composition and vegetation structure are reflected in the succession process; (iii) to find out if the three landslide sectors of landslides of similar ages are now in the same seral stage or if the succession process has produced different seral stages along the longitudinal gradients and compare these seral stages with those of the undisturbed areas adjacent to the landslides but submitted to agricultural processes that have not taken place in the landslide area; and concerning the floristic composition (iv) to find out the contribution of landslides towards the formation of nodes or hotspots of non-forested or non-shrubby habitat and biota (Geertsema and Pojar, 2007) that in the Mediterranean region are fundamental to the preservation of many protected plants, mainly of the *Orchidaceae* family, some of which are rare.

2. Study area

As test site we selected a set of seven landslides (Fig.1; Table 1) that occurred within a 4.5 km^2 study area north of Lisbon, specifically, along the small catchment of the Pequeno River. The study area is characterized by the existence of a monocline structure with lithological layers dipping south from 5° to 25°. The dominant lithological outcrops are: carbonated rocks of Jurassic age, volcanic dykes and alluvial deposits filling the valley bottom. The carbonated rocks are essentially associated to a lithological complex of limestones and marls. The northern section of the study area comprises two minor outcrops of pelites, sandstones, marls and limestones. The elevation ranges from 120 m in the southern central part of the study area along the channel of the Pequeno River to 310 m in the Alrota hill. The major slopes are part of the Pequeno River valley that flows from the north to the south following the dip of the geological layers.

The differential erosion during the Quaternary generated a hilly landscape that includes structural landforms (cuestas) and large erosional depressions such as the Arruda dos Vinhos basin located 10 km northwards of the study area. Additional elements on the geomorphology of the area north of Lisbon can be found, for example, in Ferreira and Zêzere (1997), Zêzere et al. (1999) or Zêzere et al. (2008).

The natural vegetation in the studied territory is dominated by Portuguese oak forests and the respective substitution communities as presented in Table A1. According to the national cartography of land use cover (COS-Soil Occupation Map form 1990 and 2007) the majority of the studied landslide test sites underwent substantial changes between the early 1990's and 2007, in particular reverting from agricultural to shrub areas (Table 1) due mainly to the progressive abandonment of agricultural activities.

The climatic characteristics of the study area are defined based on the climate profile obtained from the São Julião do Tojal meteorological station, located 10 km south of the study area and with a Mean Annual Precipitation – MAP of 730 mm (Zêzere and Trigo, 2011). The contrast between the wet period (October to May) and the drier period (June to September) is clear. Shallow landslides are typically triggered by intense rainfall accumulating within a 1 to 15-day period (Zêzere et al., 2005; Zêzere et al., 2015).

2.1. Landslide data

Data on landslides in the study area (Fig. 1) was acquired through detailed field geomorphological mapping. All the landslides occurred within the lithological unit composed by limestones and marls dated from the lower Tithonian. Table 1 summarizes the main characteristics and morphometric properties of the seven landslides that make up the test site. With the exception of landslide #5, all studied landslides occurred within a similar time span (1996–2010), 6 to 20 years ago. Their position on the slopes is mainly associated with elevations ranging from 158 to 253 m and on moderate to steep slopes (22° to 36°). This slope variation is related to the lithological variations along the lower Tithonian lithological formation (Fig. 1) where steeper slopes are typically associated to limestones layers or interbedded limestones and marls, which originate rock halls on the slope top or along the middle slope. The landslide areas are mainly oriented to the E, NW and W. With respect to the landslide magnitude, defined by landslide area, length and width, landslides are essentially small (maximum landslide area $\pm$ 3300 m^2).

3. Methods

In order to answer the initial question about the floristic and physiognomic-structural differentiation between the vegetation on the different landslide sectors (landslide scarp, main body, foot and undisturbed area adjacent to landslide) seven landslides and seven landslides strata were selected. Thus we ensure that the results are not influenced by a substantial age difference between landslides or by a considerable human influence (agricultural activities or fire impact).

In order to understand the floristic differentiation between the different landslide sectors seven landslide strata were defined (Fig. 2):