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Above-ground biomass and productivity in the Montado: From herbaceous to shrub dominated communities

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ABSTRACT

Our study was focused on the effect of abandonment on above-ground biomass and net primary productivity (ANPP) in a Montado in Southern Portugal. The Montado has a long history of human management and control of invasion by shrubs is achieved by clearing, ploughing and grazing. When these cease, it is invaded by Mediterranean matorral species. We hypothesized that the change in life form dominance would affect both biomass and productivity, but while the total biomass was expected to increase, the effects on ANPP were less clear. We tested our hypothesis by determining above-ground biomass and ANPP along a gradient of decreasing land use intensity, ranging from extensive grazing to 20 years of abandonment.

Above-ground biomass increased with abandonment, which was related with the increase in shrub cover. In addition, we found a decrease in herbaceous ANPP that was more than compensated by an increase in shrub ANPP in plots abandoned for longer time, resulting in a significant increase in total ANPP. This increase was strongly related with the increase in the cover of *Cistus ladanifer*, a pioneer species that colonises degraded areas and forms one of the first stages of succession of woody communities.

1. Introduction

The agro-pastoral systems of South Portugal, as most Mediterranean rangelands, have originated from natural forests following the removal of trees by human activities such as clearing, burning and grazing (Pulido et al., 2001). When agricultural practices decrease or stop, succession generally leads to the invasion by woody plants. In the studied system abandonment lead to a change in vegetation structure and composition that resulted in the replacement of herbaceous dominated communities with shrub-dominated communities, often with one or few dominant species. Shrub encroachment has been reported in many grassland and savanna ecosystems in North and South America, in Africa and Australia (e.g. Van Auken, 2000; Bowman, 2002; Hughes et al., 2006), often as a result of overgrazing of herbaceous species or changes in fire regime (Van Auken, 2000; Asner et al., 2004). It has also been reported in Greek rangelands as a consequence of decreasing land use intensity (Karakosta and Papanastasis, 2007; Zarovalli et al., 2007). Woody encroachment is likely to cause substantial alterations in the sequestration and cycling of carbon and nitrogen (Briggs et al., 2005; Hughes et al., 2006) because grasslands are generally expected to have high biomass turnover, productivity and nutrient cycle, and only moderate capacity for carbon sequestration in biomass when compared to woody communities (Díaz and Cabido, 1997; Gill and Burke, 1999). Increases in above-ground carbon storage with shifts to woody vegetation have been reported by some authors (e.g. Jackson et al., 2002; Asner et al., 2003; Hughes et al., 2006). Several specific aspects of ecosystem function, among which above-ground net primary productivity (ANPP) was directly affected by the relative abundance of the grass and shrub functional types in a study in the Patagonian steppe (Aguiar et al., 1996). Above-ground primary productivity decreased as shrubs increased because shrubs did not fully compensate for the decrease in grass production (Aguiar et al., 1996). Zarovalli et al. (2007), and Karakosta and Papanastasis (2007) noted a decrease in herbaceous biomass and production as woody species cover increased. Considering the productivity of herbaceous and woody components together, Huenneke et al. (2002) reported a small but significant decrease in overall productivity of desertified shrub systems of New Mexico in comparison to grasslands. However, there is still a degree of uncertainty regarding how biomass and productivity of herbaceous and woody components interact in response to shifts in plant life form composition (Hughes et al., 2006), particularly in

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Mediterranean, where such studies are scarce. Studies in Mediterranean areas (Karakosta and Papanastasis, 2007; Zarovalli et al., 2007) suggest a possible decrease in herbaceous ANPP but this may be compensated by shrub productivity, resulting in no change in ANPP, or more than compensated, resulting in an increase in ANPP (Reich et al., 2001; Huenneke et al., 2002; House et al., 2003).

Our question is focused on the effect of abandonment and, more specifically, the shift from herbaceous to shrub dominated communities, on the community above-ground biomass and ANPP. We hypothesized that the change in life form dominance would affect both biomass and productivity but while the total biomass was expected to increase, because shrubs have larger biomass than herbaceous species, the effects on ANPP were less clear.

2. Methods

2.1. Study site

The study site (Monte do Vento, Mértola), with an area of 198.44 ha, is located in the Southeast of Portugal, at about 37°48′21.72″N and 7°40′44.96″W. The study site used to be under a traditional scheme of rotation of crops/fallow/pasture. The rotation scheme generally consists of cereal fields, fallow land, pastures and ploughed fields, where the farm is divided into parcels and each parcel is under different phases of the rotation cycle, creating a mosaic of fallow, pasture and cultivated fields. For two years a parcel is under cereal cultivation (wheat, oat and barley), after which land is left fallow for a period of 2–3 years. Afterwards, the parcel is ploughed to re-initiate the rotation cycle (Marta et al., 2007). In the last decades large areas have been abandoned and at the present the study site is composed of different land uses that range from grazed areas to areas abandoned for more than 20 years. We selected three land use categories which represent a decrease in land use intensity. The first category, 'grazing', is used for extensive grazing by sheep (0.99 CU/ha). These are grasslands, composed mostly of annual herbaceous species (88% of plant cover) and of some disperse cork and holm trees (less than 2% cover). The two other categories, 'intermediate succession' and 'advanced succession', represent areas that were abandoned, 10–15 years, and 20 or more years ago, respectively. The first is composed of a mixture of herbaceous species, mostly annuals (28%), and small (41%) and tall shrub (24%) species, while the second is mostly composed of tall shrubs (78%) where *Cistus ladanifer* is the dominant species representing about 52% of plant cover. We selected a total of nine parcels, three parcels under each land use category and in each parcel a permanent plot was set. Plot size was adapted to the type of vegetation, resulting in plots with 900 m^2 in grazing and 2500 m^2 in intermediate and advanced succession. Distance between plots ranges from about 50 m to more than 500 m, and two of the parcels where advanced succession plot were set are separated by parcels of intermediate succession.

The area is hilly, with poor soils and steep slopes. The dominant soils are shallow schist soils with high stoniness. Soils of the three land uses were not significantly different in soil nitrogen ($F = 0.355$, $p = 0.715$) and carbon ($F = 2.006$, $p = 0.216$) content but phosphorous significantly decreased with time of abandonment ($F = 7.008$, $p < 0.05$).

2.2. Sampling

2.2.1. Herbaceous above-ground biomass and ANPP

The methods chosen to measure above-ground biomass and ANPP, in each land use category, were determined by the dominant life form in the site. Therefore, different estimation methods were used for shrub and herbaceous vegetation.

For herbaceous vegetation, the sampling of plant above-ground biomass and ANPP followed "Method 1" of Scurlock et al. (1999). This method estimates above-ground biomass and ANPP based on a single harvest at the peak of live biomass. It assumes that any standing dead matter or litter was carried over from previous years, and death in current year is negligible. This method was considered adequate for the studied communities, which are mostly composed of annual species.

One harvest of above-ground biomass was conducted in April–May 2004 to assess maximum standing biomass (Scurlock et al., 2002). Eight quadrates of 0.25×0.50 m were sampled in each of the three permanent plots in 'grazing' and 'intermediate succession' land use categories, resulting in an area of approx. 1 m^2 sampled per plot. Each plot was considered a replicate, resulting in three replicates per land use category (Garnier et al., 2007). For each quadrate, all above-ground material (live and dead) was collected by clipping at ground level. Live material was separated from the dead and the two fractions were oven-dried to constant mass at 60 °C and weighed (Garnier et al., 2007). Live material was used to determine above-ground live biomass and ANPP.

2.2.2. Shrubs above-ground biomass and ANPP

Shrub measurement techniques (e.g. Vora, 1988; Fernández et al., 1991; Armand et al., 1993; Jobbágy and Sala, 2000; Sternberg and Shoshany, 2001; Navarro and Oyonarte, 2006) used in other semi-arid areas of the world were examined with the objective of adapting a suitable, non-destructive, and relatively simple and accurate method to the shrub species in the study area. Although a large number of variables could be used to predict biomass and ANPP, variables that express the size of the crown appeared to be the most useful (Murray and Jacobson, 1982).

The collection of data for the estimation of shrub above-ground biomass and ANPP consisted of two steps.

First, in order to establish regression equations for the estimation of above-ground biomass and ANPP, we measured and harvested 6–12 individuals of the shrub species *C. ladanifer*, *Genista hirsuta*, *Helichrysum stoechas*, *Lavandula stoechas* and *Lavandula viridis*, which were the dominant shrub species in the studied plots (other shrub species present had negligible cover), at the end of the growing season. For each individual we measured: (1) Total height, defined as the maximum vertical distance from the ground level to the highest point of the plant; (2) Crown diameter, as the mean of two perpendicular diameters. From these measurements we determined crown area and volume. Crown volume was determined, for each species, using the formula of the solid that appeared to give the best fit of the natural shape of the crown. The geometric shape that best fitted the sampled species was the inverted cone. Assuming a cone shape, plant volume (V) was calculated as $V = \pi/3r^2h$, where r is the crown radius and h is total height.

In the laboratory, the harvested individuals were separated into green leaves and current year shoots, woody parts, and dead material. The different fractions were oven-dried to constant mass at 60 °C and weighed. Green leaves and current year shots were considered as current year production (Fernández et al., 1991; Alldredge et al., 2001) and used as an estimate of ANPP. Current year shoots are easily identifiable in all species and species sampled are either summer deciduous or semi-deciduous and therefore all (*G. hirsuta* and *H. stoechas*) or at least a large percentage of green leaves (*C. ladanifer*, *L. stoechas* and *L. viridis*) are current year production. The measured variables were regressed against dry weight (see description below).

Second, three quadrates of 6 m^2 per plot were sampled in 'intermediate' and 'advanced succession' land use categories. In each of these quadrates, we counted and measured (as above) all