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Original article

Severe dry winter affects plant phenology and carbon balance of a cork oak woodland understorey

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ABSTRACT

Mediterranean climates are prone to a great variation in yearly precipitation. The effects on ecosystem will depend on the severity and timing of droughts. In this study we questioned how an extreme dry winter affects the carbon flux in the understorey of a cork oak woodland? What is the seasonal contribution of understorey vegetation to ecosystem productivity?

We used closed-system portable chambers to measure CO_2 exchange of the dominant shrub species (*Cistus salviifolius*, *Cistus crispus* and *Ulex airensis*), of the herbaceous layer and on bare soil in a cork oak woodland in central Portugal during the dry winter year of 2012. Shoot growth, leaf shedding, flower and fruit setting, above and belowground plant biomass were measured as well as seasonal leaf water potential. Eddy-covariance and micrometeorological data together with CO_2 exchange measurements were used to access the understorey species contribution to ecosystem gross primary productivity (GPP).

The herbaceous layer productivity was severely affected by the dry winter, with half of the yearly maximum aboveground biomass in comparison with the 6 years site average. The semi-deciduous and evergreen shrubs showed desynchronized phenophases and lagged carbon uptake maxima. Whereas shallow-root shrubs exhibited opportunistic characteristics in exploiting the understorey light and water resources, deep rooted shrubs showed better water status but considerably lower assimilation rates. The contribution of understorey vegetation to ecosystem GPP was lower during summer with 14% and maximum during late spring, concomitantly with the lowest tree productivity due to tree canopy renewal. The herbaceous vegetation contribution to ecosystem GPP never exceeded 6% during this dry year stressing its sensitivity to winter and spring precipitation.

Although shrubs are more resilient to precipitation variability when compared with the herbaceous vegetation, the contribution of the understorey vegetation to ecosystem GPP can be quite variable and will ultimately depend of tree density and canopy cover.

1. Introduction

Shaped by a complex historical interplay of harsh environmental conditions and anthropogenic influences, the Portuguese cork oak woodlands (*montados*) are examples of man-made ecosystems requiring human intervention to maintain high biodiversity, as well as socio-economical and ecological services (Bugalho et al., 2011). Cork production is by far the most important economic product but there is a variety of other goods and services provided, namely cattle and pork and agricultural crops (Aronson et al., 2009; Grove and Rackham, 2003). Climate change, land abandonment, desertification, pests, diseases and shrub encroachment are serious threats to tree vitality, therefore putting at risk the sustainability of the ecosystem. In the Mediterranean basin countries (including Portugal), the long term sustainability of almost 2.2 million ha of cork oak woodlands is at stake with an unknown and unpredictable cascade of negative impacts on the cork oak economic sector.

Highly competitive and opportunistic shrubs are becoming dominant in many decaying *montados* in encroachment stages, demanding measures to prevent severe and recurrent wildfires

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(Acacio et al.,2009; Caldeira et al., 2015). However, shrub recruitment is not necessarily detrimental, and can enhance ecosystem productivity in some Mediterranean regions and help to prevent desertification processes (Torras et al., 2009). An ideal condition would be a mosaic of land uses dominated by species with complementary environment resources exploitation, maintaining ecosystem services, providing goods but with low fire risk. The montado ecosystem is such an example. The relatively low tree density allows the establishment of understorey plant communities whose resilience and sustainability depends on a complex interplay of physiological tolerances, phenological patterns, biotic relations, changing in time and space according with ecological regions and interannual climatic conditions (Blank and Carmel, 2012; Holzapfel et al., 2006). Climate change is likely to alter plant–plant interactions because climatic stresses will be intensified, which are the first drivers of plant responses (Noumi et al., 2015). Specifically in the case of the *montado*, it is important to identify the processes involved in the maximization of ecosystem net primary productivity and how it is altered by human interference and climate. This can help improving management and optimize ecosystem services like soil nutrition (Maestre et al., 2009), biodiversity (Medail and Quezel, 1999), tree recruitment (Rivest et al., 2011) and carbon sequestration (Pereira et al., 2007).

Only a few studies quantified the understorey forest contribution to carbon sequestration in Mediterranean or semi-arid sites (Misson et al., 2007; Unger et al., 2009; Dubbert et al., 2014b) with studies on shrublands being particularly scarce. A recent study conducted by Petrie et al. (2015) investigated ecosystem carbon exchange dynamics for 5 years in the Mexican desert and concluded that overall carbon sink was lower in shrublands but persisted during dry years contrasting with grassland dominated sites. Shrubs had a longer growing season and assimilated most of the annual carbon during spring and autumn. Grasslands were more sensitive to drought as the plants are drought avoiders that have their life cycle tuned to the duration of soil water abundance.

In cork oak woodlands, the understorey has a strong impact on ecosystem carbon balance. For example, in savannah-type ecosystems with low tree density growing in marginal climatic regions, the herbaceous contribution to gross primary productivity reached 50% in spring due to the slow tree growth (Unger et al., 2009). Similar values were found by Dubbert et al. (2014b) for a pasture understorey in a mesic site during a favorable hydrological year. In Pereira et al. (2007), herbaceous understorey governed the response of the oak savannah and the net ecosystem exchange dropped by 80% from a normal to a severe dry year. This illustrates that ecosystem sink strength in grassland-dominated understories is mainly driven by inter-annual climatic variability.

Long term climatic records for the Iberian Peninsula report a significant increase in average temperatures and a decreasing trend in spring precipitation (de Lima et al., 2013). This trend overlaps with the peak of the growing season of the majority of Mediterranean plant species and thus, provides high risk to potential ecosystems. If the autumn-winter rains failed to occur, drought can have a negative impact on plants' post-summer recovery and the formation of the herbaceous layer. Climate change scenarios for the Mediterranean region will likely exacerbate these trends, with projections indicating an increase of annual mean temperatures accompanied by changes in precipitation seasonality (Giorgi and Lionello, 2008). The Mediterranean region is therefore especially vulnerable to climate change.

In this study, we focused on disentangling the effect of a dry winter season with only 6% (10 mm in total) of rain from January to March, on the understorey species of a cork oak woodland in Portugal. Specifically, we: 1) compared the shrubs and herbaceous vegetation response in terms of phenology and biomass productivity; 2) related the particular meteorological conditions recorded during the growing period with plant net carbon uptake and respiration fluxes from plants and soil; 3) compared the impact of winter water shortage in shrub species water status; 4) conducted a partitioning experiment quantifying the contribution of the different understorey vegetation layers to ecosystem gross primary productivity.

2. Materials and methods

2.1. Site description

The experimental site is located in central Portugal (39°08′20.9″N and 9°19′57.7″W, 165 m a.s.l.) in an open, cork oak woodland (*Quercus suber*) with approximately 50 years old trees (Table 1). The understorey vegetation consists of patches of shrubs dominated by three Mediterranean species *Ulex airensis*, *Cistus salviifolius* L. and *Cistus crispus* L. with herbaceous species from the native seed bank with representatives of legumes, forbs and grasses (Fig. 1). The soil is a Cambisol (FAO), with 81% sand, 5% clay and 14% silt (Correia et al., 2014). The site was plowed the last time in 2009 so the shrubs were 3 years old at the time of the experiment. The climate is Mediterranean with wet and mild winters and dry and hot summers. Average annual precipitation is 608 mm and mean annual temperature is 15.9 °C (period 1971–2000 from Évora meteorological station).

According with the World Meteorological Organization (www.wmo.int), 2012 was among the top 13 warmest years since records began in 1850 with 0.45 °C (±11 °C) above the 1961–1990 time series. In the experimental site, the year of 2012 was dryer than usual with an annual rainfall of 469 mm, 31% lower than the long term average. In winter only 10 mm of rain were recorded i. e. 6% of the precipitation of the long term average. Rain started in April and May 2012 (111 mm in total) attenuating the drought effect of the previous period.

Table 1
General soil, climate and vegetation characteristics in 2012. Values are means ± se.

	Characteristic		Units
Climate	Mean temperature	15.2	°C
	Total precipitation	469	mm
	Reference evapotranspiration	1469	mm
	Net radiation	3249	MJ m^{-2} $year^{-1}$
Soil	Organic matter	3.2 ± 0.2	%
	C/N	19.3 ± 1.4	
	Carbon stock (up to 60 cm)	62.2	tC ha^{-1}
Trees	Tree density	177	Trees ha^{-1}
	Height	7.9	m
	DBH	24.7	cm
	LAI	1.6	m^2 m^{-2}
	Total C stock	33.7	tC ha^{-1}
	Maximum height	1.00	cm
Shrubs	Total C stocks:	0.78	tC ha^{-1}
	Ulex airensis	0.156	tC ha^{-1}
	Cistus crispus	0.093	tC ha^{-1}
	Cistus salviifolius	0.548	tC ha^{-1}
	LAI (in Spring 2012):		
	Ulex airensis	0.055	m^2 m^{-2}
	Cistus crispus	0.032	m^2 m^{-2}
	Cistus salviifolius	0.231	m^2 m^{-2}
Grasses	Aboveground C stocks:	0.15	tC ha^{-1}
	Forbs	37	%
	Grasses	48	%
	Legumes	15	%
	LAI (in Spring 2012):	0.12	m^2 m^{-2}

Leaf area index (LAI), Diameter at breast height (DBH).