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Plant Area Index and microclimate underneath shrub species from a Chilean semiarid community

Y. Tracol[a,d,*], J.R. Gutiérrez[a,b,c], F.A. Squeo[a,b,c]

[a] Center for Advanced Studies in Arid Zones (CEAZA), Terrestrial biology, Casilla 599, La Serena, Chile
[b] Departamento de Biología, Facultad de Ciencias, Universidad de La Serena, Casilla 599, La Serena, Chile
[c] Institute of Ecology and Biodiversity (IEB), Santiago, Chile
[d] Centre de Recherches sur les Ecosystèmes d'Altitude, Chamonix Mont-Blanc, France

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ABSTRACT

In drylands, environmental conditions under shrub canopy differ from those found in open sites. We should expect that microclimate conditions under shrubs with distinct canopy architecture should also be different. Plant Area Index (PAI) of the three most abundant shrubs species (*Porlieria chilensis*, *Adesmia bedwellii* and *Proustia cuneifolia*) in Bosque Fray Jorge National Park, north-central Chile was measured using a Plant Canopy Analyzer. During two years (2004–2005), we recorded the Relative Humidity and Air Temperature underneath and away from the canopy of the shrubs.

The three shrub species showed significant differences in PAI. Microclimate at 30 cm and 2 m above the soil in the open conditions were drier and warmer than underneath shrub canopies. Vegetation patches generate moderate microclimate conditions.

Canopy structure can buffer climatic variability, contributing to high herbaceous productivity as well as shrub recruitment. Reflecting shrub architecture and observed PAI values, the lowest microclimate variations were observed under the canopies of *P. chilensis*, followed by *P. cuneifolia* and finally *A. bedwellii*. We bring a novel approach quantifying the Plant Area Index instead of the Plant cover and using a low cost method that integrates the distribution of leaves and may be derived from remote sensing products.

1. Introduction

Shrubs in arid and semiarid lands have been considered as “fertile islands” or “nurse plants” because they improve the herbaceous development and seedling emergence under their canopies (Gutiérrez et al., 1993a). Soil under shrub canopies has a crucial role concerning microorganism functioning and nutrient turnover depending on the shade effect resulting of the light canopy interception (Tiedemann and Klemmendson, 1973; Del Pozo et al., 1989). Particularly in dry areas, processes structuring diversity and interactions shift from competition to facilitation depending on water and nutrient availability (Holmgren et al., 1997). According to Holmgren et al. (1997), facilitation occurs when benefits of available water exceeds the costs of light limitation.

Numerous studies have highlighted the role of positive plant interactions in all biomes (Garcia-Moya and McKell, 1970; Bertness and Callaway, 1994; Callaway, 1995; Brooker and Callaghan, 1998; Callaway et al., 2002). These authors hypothesized that availability of soil resources, protection against grazing, and microclimate may explain this pattern and facilitate the growth of understory plants. Nevertheless, shading from shrub canopy in arid systems may limit the physiological response of associated annuals and cacti below (Franco and Nobel, 1989; Holmgren et al., 1997; Forseth et al., 2001).

In North American (Chihuahuan, Mojave and Sonoran), Australian, and Chilean deserts the absence of some annual plant species or decrease of physiological processes under shrubs can be explained by their intolerance to shade (Jaksic and Montenegro, 1979; Franco and Nobel, 1989; Gutiérrez et al., 1993a; Forseth et al., 2001). According to Polis (1993), the spatial heterogeneity of landscape is due in part to different shrub composition in vegetation patches. Our aim is to analyze the relationships between canopy characteristics and microclimate under shrubs in semiarid northern Chile to clarify conditions associated with patterns of plant species richness and biomass distribution.

Abbreviations: PAI, Plant Area Index; RH, Relative air Humidity; T, air Temperature.

* Corresponding author. Center for Advanced Studies in Arid Zones (CEAZA), Terrestrial biology, Casilla 599, La Serena, Chile. Tel.: +56 51 334856/33 (0)4 50 53 45 16; fax: +56 51 334741.
E-mail address: yann.tracol@ceaza.cl (Y. Tracol).

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Tools used in this study mixed simultaneously two approaches to quantify the microclimate conditions under and outside the shrub with HOBO data logger and the shade amount derived from Plant Area Index (and Sky visible fraction) measured by a Plant Canopy Analyzer. The Plant Area Index (PAI, $m^2\ m^{-2}$) corresponds to the one-sided plant area per ground area or the sum of Stem and Leaf Area Indices (SAI and LAI, respectively) as a function of total ground area. Due to the strong influence of the vegetation on climate (Bonan, 1993; Chase et al., 1996), ecosystem functioning (Tracol et al., 2006), radiative transfer balance (Bégué, 1993), and hydrological models, the PAI and more specifically the LAI represents an accurate parameter to approximate vegetative productivity, the gas surface exchange (transpiration), the solar radiation absorption surface, and interception surface of precipitations. The PAI has two additional important advantages: it is a non-destructive method (tested in arid ecosystem: White et al., 2000) and it is a large-scale index readily monitored by remote sensing (Baret and Guyot, 1991; Bégué, 1993; White et al., 2000; Huete et al., 2002). Due to the high proportion of bare soil and the scale of study of the Chilean semiarid zones, the field measurements of shrubs are necessary to complement (and ground truth) results from remote sensing (White et al., 2000).

2. Materials and methods

2.1. Study sites

Bosque Fray Jorge National Park (9959 ha), a World Biosphere Reserve, is located right on the coast in the north-central Chilean semiarid zone (30°38′ S, 71°40′W, 85 km south of La Serena and 385 km north of Santiago). It is a transitional zone between the central Mediterranean region and the hyperarid Atacama Desert to the north. Our field study was carried out in an interior valley, "Quebrada Las Vacas" (230 m elevation). Mean annual rainfall is 145.4 ± 31.3 mm (1 SE) (1989–2002, Fray Jorge weather station) with 90% falling during the cold months (May–September). However, periodic El Niño Southern Oscillation (ENSO) events cause strong inter-annual variation (e.g., rainy El Niño years, 1991, 229 mm; 1992, 233 mm; 1997, 434 mm; 2000, 244 mm and 2002, 337 mm, vs. dry La Niña year, 1998, 2.2 mm). The maximum daily temperature is 24 °C in summer and the minimum daily temperature is 4 °C in winter. Fog and coastal breezes strongly influence plants by contributing water, particularly during the dry season.

Conditioned by climate, the plant community is characterized by spiny drought-deciduous (sclerophyllous) and evergreen shrubs 2–3 m in height, with an herbaceous understory and low vegetated sandy areas. Major species of shrub layer include *Porlieria chilensis* (Zygophyllaceae), *Proustia cuneifolia* (Asteraceae) and *Adesmia bedwellii* (Papilionaceae) which form the characteristic vegetation pattern of the "matorral." The shrub species richness and cover has remained relatively constant for the last 50 years, about 60% (Gutiérrez et al., 1993b, 1997). The herbaceous layer corresponds mainly to an ephemeral community, with annuals (e.g. *Plantago hispidula*, *Camissonia dentata*, *Viola pusilla*, *Eryngium coquimbanum*, *Lastarriaea chilensis*, *Calandrinia* sp.), geophytes (*Alstroemeria sierrae*, *Leucocoryne purpurea*, *Rhodophiala phycelloides*), and a suffruticose perennial species, *Chenopodium petiolare*. Herbaceous cover has changed dramatically according the climate variability (Gutiérrez et al., 1997, 2004). A complete account of plant species composition and abundance at the site is supplied in Gutiérrez et al. (1993b, 2004).

2.2. Field measurements

We monitored the shrub layer with PAI measurements from October 2004 to January 2006 with a Li-Cor LAI-2000 Plant Canopy Analyzer integrating radiation transmittance through the canopy from 0.32 to 0.49 μm at five different view zenith angles (0–7°, 16–28°, 32–43°, 47–58°, and 61–74°) (more details in Li-Cor, 1990; Welles and Norman, 1991). It is a hand-held instrument, whose optical sensor includes a fisheye lens (combined focal length: 8 mm) and five silicon detectors allowing simultaneous measurements of the radiation coming from the sky.

PAI was measured at two spatial scales every month along four 75 m line transects (15 m apart) in each of 8 study plots (75 m × 75 m). On each transect, we recorded at the beginning one reading at 2 m above ground (and above the plant canopy) and 8 readings at 30 cm above the ground and spaced 10 m along it. To minimize the influence of canopy gaps (and resulting PAI underestimation) we used a 45° view cap (Li-Cor, 1990). Thus, monthly PAI for each plot was based on 32 readings beneath and 4 readings above canopies. We also measured PAI seasonally (spring, summer, autumn and winter) under 8 focal individuals of each of the three dominant shrub species (e.g., one randomly selected individual of each species per plot). For each shrub, we recorded PAI by 4 readings beneath the canopy and oriented in the four cardinal directions with a 90° view cap. We designate the PAI values as PAI_{pc}, PAI_{pcu} and PAI_{ab} for *P. chilensis*, *P. cuneifolia*, and *A. bedwellii*, respectively. Following recommendations by Li-Cor (1990), measurements were performed before sunrise, when the proportion of diffuse radiation was high, and the canopy around the sensor was shaded from direct solar radiation by placing the operator between the sensor and the sun. A view cap was used for obscuring the operator.

The relative humidity and air temperature data at 30 cm above soil surface, under and away from canopies were recorded with HOBO H8 Pro Series data loggers (HOBO data loggers, ONSET Computer Corporation) beginning July 2003. Four HOBOs per plot were placed randomly, with three under the crown of the dominant shrubs at half radius from the trunk and one outside the canopy. Each sensor was calibrated and protected from solar radiation and rodents by a plastic cylinder and mesh. Net air temperature (T) and relative humidity (RH) differences were calculated under and outside the shrub's canopy respectively as $RH_{under} - RH_{outside}$ and $T_{under} - T_{outside}$

Environmental data (temperature and relative humidity) were analyzed with a triple within-subject repeated measure ANOVA (GLM procedure) with SPSS software. Between-subject factors were

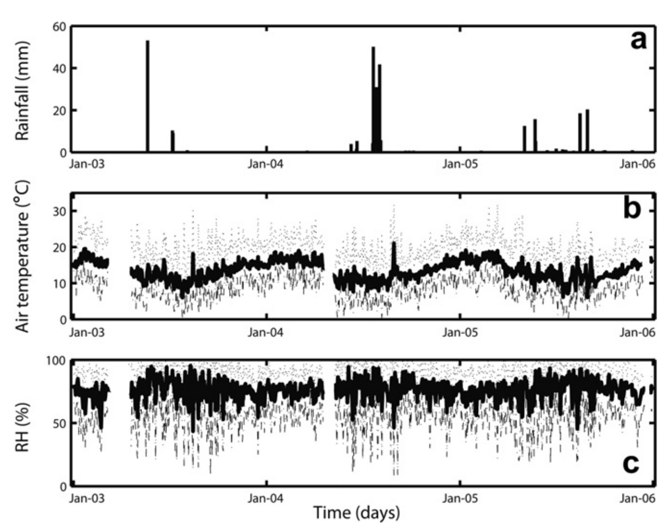

Fig. 1. Climatic data, a) rainfall, b) Air temperature and c) Relative Air Humidity (RH) in the "Bosque Fray Jorge National Park" for the 2003–2005 periods (maximum and minimum daily values are presented for b and c).