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Stand transpiration of *Stipa tenacissima* grassland by sequential scaling and multi-source evapotranspiration modelling

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Summary We have calculated stand-scale transpiration (E_p) by sequential scaling up and down in a *Stipa tenacissima* grassland in the SE of Spain. To this end, we differentiated three tussock size groups obtained from the extrapolation of transpiration measured from leaves, applying corrective functions for overestimation of individual transpiration. The transpiration found that way was compared with the transpiration of the *S. tenacissima* grasslands (E_p) estimated by a multi-source evapotranspiration model that divides the surface into vegetated and non-vegetated evaporative components (Clumped Model). We conducted the research in two seasons with high and low water availability in the study area. The daily E_p estimated by the Clumped Model was positively correlated to the daily stand transpiration scaled down from individual transpiration (average difference – 6.5%). The strong coherence between E_p found using a stand-scale model and the stand transpiration calculated by sequential scaling (leaf-individual-population or stand), represents a breakthrough for future population or stand-scale study of these semiarid *S. tenacissima* grasslands. The difficulty and complexity involved in some cases in implementing and setting up evapotranspiration models in the field could be partly overcome by means of sequential scaling.
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Introduction

Many ecological studies have focused on small spatio-temporal scales because of their easy accessibility and exploration (Jarvis, 1995). Considering this bias, scaling could

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constitute a useful tool for exploring higher scales from other lower ones and vice versa. This procedure involves a gradual process in which knowledge of how information is transferred from one scale to another is crucial to understanding the mechanisms responsible for natural phenomenon pattern generation, which are in turn important for resource management (Levin, 1995). On the other hand, scaling is done, as for other ecological problems, from a reductionist perspective (Loehle, 1988). This perspective is based on detecting the mechanisms accounting for the main processes operating at a particular level or scale, and scaling them up or down from the scale studied. This reductionist approach has been proposed for the study of complex hierarchical systems such those in biology (Wimsatt, 1976 cited by Inchausti, 1994). This strategy was also proposed by Baldocchi et al. (1991) in the context of scaling stomatal conductance from the leaf to the canopy. These authors proposed this physiological variable be studied from a hierarchical approach, by scaling up and down to explore different scales. This scaling must be done sequentially in three adjacent scales: sub-, operational and macro-scale (Baldocchi et al., 1991). In this sense, exploration and understanding of the individual scale might very well be the key to reaching stand scale as part of a sequential scaling from leaf-individual-population or stand.

The perspective of Baldocchi et al. (1991) mentioned above could be useful in calculating evapotranspiration (ET), the main part of the water balance in arid and semi-arid climates. This variable, difficult to estimate and model in these areas, is characterised by clumped and sparse vegetation, where the bare soil often make up the largest part of the area (e.g. Wallace et al., 1993; Dugas et al., 1996; Yunusa et al., 2004), making for high spatial heterogeneity. It is therefore important to differentiate soil evaporation (E) and vegetation transpiration (T) to understand the processes involved. Despite this, ET calculation models are being developed and improved, and experimentally validated, in the above conditions, by E and T measured by lysimeters and/or sap flow gauges, respectively (e.g. Lascano et al., 1987; Massman, 1992; Massman and Ham, 1994; Qui et al., 1999). This includes the work of Shuttleworth and Wallace (1985) in sparse crops. These authors extended the Penman–Monteith model to two evaporation sources, bare soil and vegetation, using coefficients to modify the aerodynamic, vegetation and soil surface resistances, which are components of the Penman–Monteith equation. Brenner and Incoll (1997) varied the Shuttleworth and Wallace model to incorporate a third source of evaporation, soil under vegetation. In turn, the three evaporation sources are weighted according to the fraction of plant cover (f):

$$\lambda E_t = f(\lambda E_p + \lambda E_s) + (1 - f)\lambda E_{bs} \quad (1)$$

where λE_t is total evapotranspiration, and λE_p , λE_s , λE_{bs} are evaporation from vegetation, soil under vegetation and bare soil, respectively. This Clumped Model (Brenner and Incoll, 1997) has been improved, and the modified calculation of soil resistance in stands of *Retama sphaerocarpa*, *Anthyllis cytisoides* and *Stipa tenacissima* in SE Spain, have provided quite satisfactory results for finding total evapotranspiration and transpiration in vegetation (Domingo et al., 1999; Villagarcía, 2000; Ramírez et al., 2007). Experience in a semiarid territory in Almería, Spain showed the usefulness

of the Clumped Model for studying ET in vegetation, and it has proved to be a useful tool for identifying water source sink areas and managing water resources (Domingo et al., 2001).

In the context of this background, the main purpose of this paper is to compare stand-scale transpiration from sequential scaling (leaf-individual-population) with the stand-scale transpiration estimated by the Clumped Model. Our main working hypothesis is that the result of sequential scaling of transpiration from adjacent scales according to the above-mentioned recommendations of Baldocchi et al. (1991), will be the best way to estimate transpiration at population or stand scale in a *S. tenacissima* grassland. The ability to estimate transpiration at population or stand scale, based on leaf-individual information, constitutes an important breakthrough due to the fact that it is often difficult to implement a system for modelling transpiration at stand scale (costly, model requirements, etc).

The present study was conducted in *S. tenacissima* L., the most representative vegetation type in the semiarid Mediterranean region (Le Houérou, 2001). *S. tenacissima* is a perennial and rhizomatous tussock grass with a shallow root system reaching a maximum rooting depth of 0.5 m (Sánchez, 1995). It is dominant on the Iberian Peninsula, particularly between the 200 and 400-mm isohyets (Barber, 1997). Historically, the economic importance of *S. tenacissima* for agriculture, the manufacture of paper, jute and thread, among others, promoted the growth of this species, which as a result became widespread (Servicio del Esparto, 1951). The role played by *S. tenacissima* tussocks in the dynamics and distribution of water and nutrients (Puigdefábregas and Sánchez, 1996; Puigdefábregas et al., 1999), along with its potential for promoting the restoration of autochthonous shrub species (Maestre et al., 2001, 2003), make *S. tenacissima* grasslands priority areas for studies dealing with water use.

Materials and methods

Study area

Our study area is located in a south-facing micro-basin in the Sierra del "Ventós" mountains in the recharge area of the Ventós-Castelar aquifer (38° 28'N, 0° 37'W), in the municipality of Agost in Alicante province, Spain. This micro-basin occupies an area of approximately 19 ha, with altitudes ranging from 470 to 800 m, 37% to 73% slopes and SE and SW orientations. The soil, developed over marls and calcareous bedrock, is a calcareous Regosol (FAO-UNESCO) with a silt loam texture (17.7% clay, 50.9% silt, 8.4% fine sand and 23.0% coarse sand; Chirino, 2003), having an average bulk density of 1,276 kg m⁻³, 58.2% porosity and an average depth of 0.15 m (Chirino, 2003; Ramírez, 2006).

The climate is characterised by highly variable rainfall pulses, with an annual average of 291.7 mm. The average annual temperature is 17.4 °C, rising to 26.3 °C in the month of August and going down to 11.7 °C in January. This study was conducted in two periods with different water availability, one in spring comprising three sub-periods, April 19–27, May 7–18 and May 25–28, 2004, and another in summer

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