Balancing challenges and benefits: climate change impacts and microclimatic regulation by *Macrochloa tenacissima* in north African arid steppe

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Abstract

Macrochloa tenacissima steppes in Tunisia are facing significant challenges due to the effects of climate change, which exacerbate the problem of desertification. *Macrochloa tenacissima* L. play a critical role in regulating microclimatic conditions and it is considered as a nurse species. An urgent need for sustainable land management and conservation strategies of *M. tenacissima* to mitigate the adverse effects of climate change and desertification on arid steppes. This study examines both the impacts of climate change on these steppes and the beneficial effects of *M. tenacissima* tussocks on microclimate regulation. Historical trends and future climate projections in Tunisia were studied in relation with the distribution of *M. tenacissima* steppes. Furthermore, microclimatic stations with temperature and moisture sensors were used to explore microclimate conditions under tussocks and in bare soil. Our findings reveal that rising temperatures and altered precipitation patterns are reducing the extent of *M. tenacissima* habitats, affecting biodiversity and ecosystem services. Concurrently, *M. tenacissima* tussocks create microhabitats with lower soil temperatures and higher moisture levels, enhancing water infiltration and reducing evaporation rates. These microclimatic modifications are essential for maintaining soil health and supporting biodiversity. This dual role underscores the importance of *M. tenacissima* in both mitigating adverse climate impacts and promoting ecosystem resilience. Effective conservation and sustainable management practices are essential to leverage these benefits, ensuring the stability and productivity of Tunisia's arid landscapes in the face of ongoing climate change.

Introduction

Climate change is a major issue impacting species distribution across ecosystems, community dynamics, and ecosystem functioning (Weiskopf et al. 2020). Endemic species are the most susceptible to climate change, which are plants that only exist in restricted distribution regions with distinct ecological characteristics (Refaat et al. 2024). Variations in temperature and precipitation patterns cause spatial and temporal species distribution change, often leading to biodiversity loss and alteration of ecological interactions. Changes are most evident in arid and semi-arid areas, such the steppes of *Macrochloa tenacissima*. In these ecosystems, microclimatic conditions, temperature and humidity variations, play a crucial role in species' responses to climatic changes (Tan et al. 2023). Macro- and micro-climate heterogeneity exposes populations to mosaics of resource availability, varying abiotic conditions, and influencing biotic interactions (Denney et al. 2020). Tussocks *M. tenacissima*, a dominant perennial grass in Mediterranean steppes, exemplify such microhabitats. Acting as nurse plants, these tussocks modify the surrounding microenvironment by reducing soil erosion, enhancing soil fertility, and regulating temperature and humidity (Navarro et al. 2008). These facilitative interactions are essential for seedling establishment, community stability, and ecosystem resilience. Understanding the interplay between climate change, and microclimatic conditions is crucial for predicting species distribution patterns and managing fragile ecosystems like *M. tenacissima* steppes. This study explores the critical role of microclimatic conditions and the current and future species distribution patterns in responses to climate change in arid and semi-arid ecosystems in order to establish a rescue program for *Macrochloa tenacissima* to ensure its survival and to maintain the health of arid ecosystems.

Methods

Study Area and Microclimatic Data Collection

The study was conducted in Tunisia, covering its diverse climatic and ecological zones. Microclimatic conditions were monitored over one year using sensors installed at a height of 2 m above ground to measure air temperature (°C) and humidity (%), and at soil level to record soil temperature (°C) and soil moisture (%) in bare soil and under tussocks in Kasserine region. Measurements were recorded at hourly intervals. Occurrence data for the target species (*Macrochloa tenacissima*) were obtained from field surveys. These data were used to model habitat suitability under current and future climatic conditions.

Environmental Variables

Climatic variables for the current period were sourced from WorldClim at a spatial resolution of 30 arc-seconds (~1 km^2) representing the historical climate data (1970-2000). Future projections were based on the HadGEM3 climate model for the SSP5-8.5 scenario, representing the years 2081-2100. Five bioclimatic variables (e.g., maximum, mean, and minimum annual temperature and mean annual precipitation) were selected based on ecological relevance. Elevation data were included to test topographic influences.

Habitat Suitability Modeling

MaxEnt (Maximum Entropy Modeling) was used to predict habitat suitability under both current and future conditions. The model was trained using occurrence data and current environmental layers. Predicted suitability maps were generated for both scenarios and classified into binary maps using a threshold value of 0.5, representing areas of suitable habitat. The total area of suitable habitat was calculated by summing the pixels with values exceeding the threshold and converting this to square kilometers.

Statistical Analysis

Different statistical analyses, models and Maps of current and future suitability were analysed and fitted using R software. A post hoc Tukey test at $p < 0.05$ determined differences among microclimatic conditions.

Results

Microclimatic conditions

The soil temperature and humidity under *M. tenacissima* tussocks were lower than bare soil (Fig. 1). Air and bare soil temperature almost displayed the same value. The temperature under tussocks is 1.61°C lower compared to bare soil. The mean air temperature was 25.4°C. The soil moisture showed a better response under tussocks, with a mean humidity difference of 2.26%. The mean air humidity was 52.7°C. The mean soil humidity is 10% lower than air humidity.

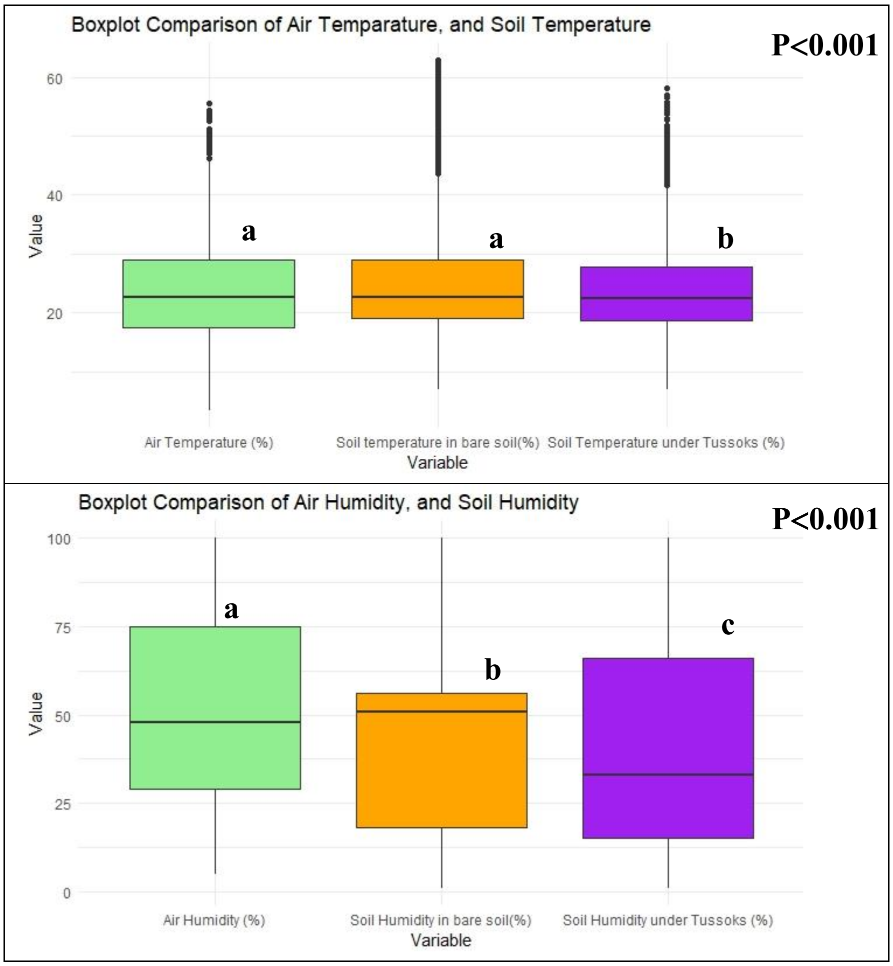

Fig.1. Boxplot comparison of air and soil temperatures and humidity under tussocks and bare soil.

Species distribution model

The binary maps indicate a clear reduction in suitable areas under future climate conditions of *Macrochloa tenacissima*, particularly in Kasserine region (Fig. 2.). The total suitable area decreases from 6735 km² to 4290 km², resulting in a net loss of -2445 km². Some areas, like Matmata mountain (Gabes) show new suitability under future conditions, but these gains do not offset the losses.

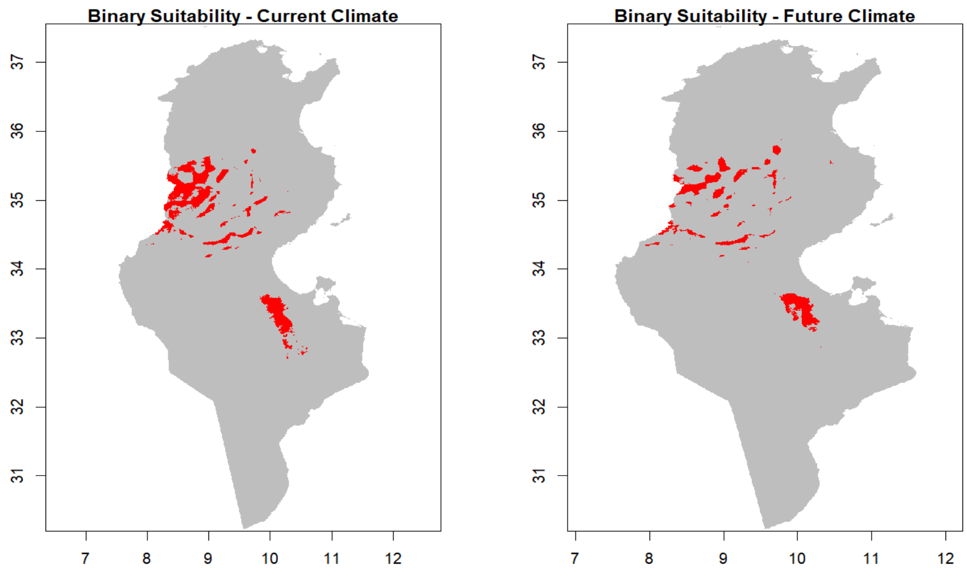

Fig. 2. Binary Suitability Maps for Current and Future Climate at 0.5 thresholds, with suitable region shown in red and non-suitable region in white.

Discussion [Conclusions/Implications]

The nurse and microclimate enhancer effects of *Macrochloa tenacissima* have been documented in several scientific studies (Navarro et al. 2008; Saiz and Alados 2011). Our study gives a precise projection by providing microclimatic conditions in each minute under the tussocks and in bare soil associated with atmospheric temperature and humidity. The presence of *M. tenacissima* moderates' temperatures and retains moisture, leading to better micro-environment conditions compared to bare soil. The Shade soil reduces direct solar radiation, preventing soil evaporation quickly which helps to retain moisture and regulate temperature fluctuations (Navarro et al. 2008). Under *M. tenacissima* tussock the temperature is decreased by about 2°C and the humidity is enhanced by 2%. The amelioration of arid microclimatic conditions facilitates co-occurring conditions for other species (Saiz and Alados 2011). The soil temperature under the tussocks is generally lower than that of bare soil, especially during the hottest parts of the day. Navarro et al. (2008) found higher K+, organic carbon, carbon:nitrogen ratio, and available water content inside and below the tussocks. In *M. tenacissima* steppe, under harsh climatic conditions, adaptation of co-occurring species results in facilitation by the amelioration of arid microclimatic conditions (Navarro et al. 2008; Saiz and Alados 2011).

The analysis of the species distribution model proved that *M. tenacissima* steppe occurred in Kasserine region and Matmata Gabes. It is generally related to the Tunisian Dorsal mountains chain, Matmata Mountains and steppes ecosystems characteristic of central Tunisia. The results showed that climate changes will significantly affect *M. tenacissima* suitability. According to the Maxent model maps, the suitable area will differ between current and future, the current distribution will decrease considerably. Ben Mariem and Chaieb (2017) found the same tendency of the decline of *M. tenacissima*. However, these authors found that *M. tenacissima* current cover (2000) was about *19304* Km^2 which could be very high in relation to the field observation. In this regards, Le Houérou (1995) estimates the *M. tenacissima* steppes cover to 32,000 km^2 in the western Mediterranean Basin. This finding confirms our estimation and reflects the significant habitat loss that *M. tenacissima* has experienced in Tunisia over recent decades due to climate change, land degradation, and changes in land use (e.g., overgrazing, agricultural expansion, and urbanization).

In conclusion, *Macrochloa tenacissima* is an important species to combat desertification, especially in arid areas. It plays a protective role by creating a microclimate that favors the growth of other plants and participates in the ecosystems' functioning. Since the species' suitable habitat is expected to decline in the future, there is a pressing need for a conservation program for *M. tenacissima*. Conservation in such areas is important to protect this species and the associated ecosystem services.

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