XII INTERNATIONAL RANGELAND CONGRESS AUSTRALIA 2025

Modeling the distribution of *Vachellia tortilis* (forssk.) in Tunisian drylands under climate change scenarios

Msadek, J[1]; Tarhouni, M[1]

[1] Laboratory of Pastoral Ecosystems, Spontaneous Plants and Associated Microorganisms. Arid Regions Institute - Medenine 4100. University of Gabes, Tunisia.

Key words: Climate change; habitat; modeling; drylands.

Abstract
Biodiversity conservation, through the creation of national parks, is generally helping to maintain a greater level of resilience within ecosystems and to protect the natural plant cover and threatened plant species. This research was conducted in Bou Hedma national park, a UNESCO-MAB biosphere reserve containing the unique *Vachellia tortilis* (Forssk.) Gallaso & Banfi steppe with trees in Tunisia. The focus is to explore how the distribution of suitable habitat for *V. tortilis*, might shift under climate change scenarios using Maxent modeling algorithm. The Canadian Earth System Model version 5 (CanESM5) was used for projecting the future distribution. The model was run under two Shared Socioeconomic Pathways (SSP245, SSP585) during four time periods (2021-2040, 2041-2060, 2061-2080 and 2081-2100). The tested climate change scenarios seem affecting the specie's suitable habitat in the park. Three soil variables (Clay, Coarse, WRB Classes) are significant factors in determining *V. tortilis*'s suitable habitat. Distribution modeling provides valuable information for managers to implement suitable strategies to conserve this endemic, rare and threatened plant tree and the overall ecosystem.

Introduction
Dryland ecosystems are threatened both by climate variations and human disturbance (Millennium Ecosystem Assessment (MEA) 2005). Increased temperature, variability in rainfall and severe droughts are the main climatic conditions threatening the ability of these ecosystems to produce (Yao et al. 2020) and represent significant problems to biodiversity conservation both by altering habitats and affecting species distributions (Hilbert et al. 2007). Active management is recently considered as the major challenge for maintaining biodiversity and reducing natural resource degradation and combat desertification (Gamoun and Louhaichi 2021). The establishment of national parks is one of the main strategies to achieve biodiversity conservation (Ouled Belgacem et al. 2019) and to preserve the natural plant cover as well as the threatened plant species in arid and desert area of Tunisia and all around the world (Ouled Belgacem et al. 2008).

Vachellia tortilis (Forssk.) Gallaso & Banfi (Fabaceae) is a "Keystone species", widely distributed in arid and semi-arid ecosystems of North, East and Southern Africa, the Middle East and the Arabian Peninsula

(Taha et al. 2022). It is well adapted to disturbances (drought, fire and browsing) (Noumi and Chaieb 2012). It is also known by the ability to improve the soil fertility and to increase biodiversity (Abdallah et al. 2008). This study focuses on modeling the distribution of *V. tortilis* in Bou Hedma national park under both optimistic and pessimistic climate change scenarios. By examining the shifts in suitable and unsuitable habitats, we aim to understand the potential impact of climate change on this vital species and inform conservation strategies to optimize its future safeguarding.

Methods

Study area

Bou Hedma national park (34.476102 N, 9.649239 E; Figure 1), created in 1980, plays a key role in the conservation of flora and fauna biodiversity and contains the unique *V. tortilis* steppe with trees in Tunisia (Tarhouni 2003). It is characterized by an arid Mediterranean bioclimate (Le Houérou 1969). The average annual rainfall varies between 100 and 200 mm. The average annual temperature is about 17.2°C.

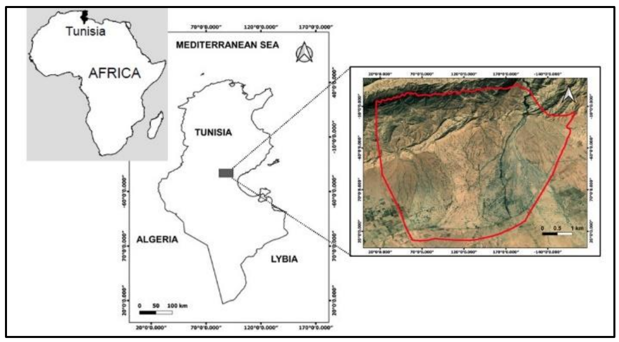

Fig. 1 Geographical location of Bou Hedma national park

Environmental variables & species distribution modeling

The undertaken environmental data is downloaded from the "WorldClim" database (www.worldclim.org) (19 bio-climatic variables from each time-period (2021-2040, 2041-2060, 2061-2080 and 2081-2100) in addition to three topographical ones) and from the soil grids database (www.soilgrids.org) (12 soil variables). All these variables are used to model the current and future distribution of *V. tortilis* according to the Canadian Earth System Model version 5 (CanESM5) predictions under two Shared Socioeconomic Pathways (SSP245, SSP585).

Results

Model validation and influencing variables

It is clear from table 1 that the Maxent model showed good predictive ability with an Area Under Curve (AUC) ranging from 0.854 to 0.894.

Table 1 Area Under Curve (AUC) of the distribution of Vachellia tortilis under current (2018) and future climate scenarios (SSP245, SSP585) according to the Canadian Earth System Model version 5 (CanESM5) in Bou Hedma national park.

	Current	**SSP245**				**SSP585**			
	2018	**2021-2040**	**2041-2060**	**2061-2080**	**2081-2100**	**2021-2040**	**2041-2060**	**2061-2080**	**2081-2100**
AUC	0.855	0.866	0.871	0.888	0.862	0.854	0.877	0.894	0.855

Under both scenarios, it seems that coarse and soil classes-WRB are the strongest predictors of *V. tortilis* distribution with respectively 42.15% and 14.87%, under SSP245, and 31.92% and 27.6% under SSP585 (Figure 2). Bio17 and clay are also important but with lesser contributions (respectively 6.47% and 7.92% under SSP245; 5.9% and 6.05% under SSP585).

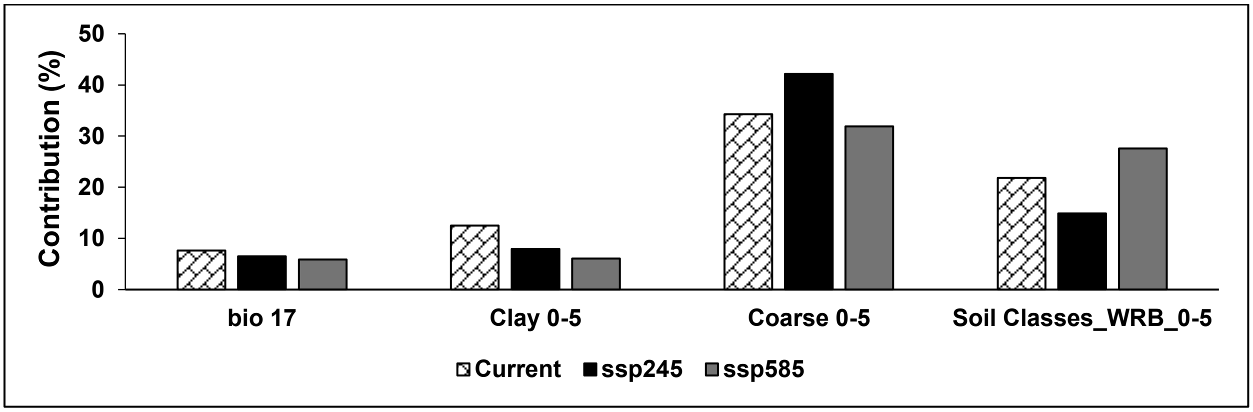

Fig. 2 Contribution (%) of bio-climatic and soil variables when predicting the distribution of Vachellia tortilis in Bou hedma national park using MaxEnt model.

Habitat suitability for Vachellia tortilis

The results of Maxent are represented in table 2 and figure 3. Under current climate condition, Maxent indicated that 214.30ha are suitable (very high potential, VHP) for *V. tortilis* to grow (table 2). The species is covering some hectares in the south-western and the south east parts of the park (figure 3). In the center, it occurs over a large area of Moderate (MP) to high (HP) potential (911.24ha and 650.41ha respectively) (table 2). In the North parts, the habitat of the species seems to be completely unsuitable (low potential, LP) (1386.23ha).

Table 2 Changes in suitability of Vachellia tortilis habitat (ha, %) from the current situation to 2100 according to SSP245 and SSP585 scenarios from the Canadian Earth System Model version 5 (CanESM5).

		Area (ha)				Changes (%)			
		LP	**MP**	**HP**	**VHP**	**LP**	**MP**	**HP**	**VHP**
2018	**Current**	1386.23	911.24	650.41	214.30	-	-	-	-
2021-2040	**SSP245**	1438.74	877.33	604.44	241.66	3.79	-3.72	-7.07	12.77
	SSP585	1483.95	776.50	620.90	280.82	7.05	-14.79	-4.54	31.04
2041-2060	**SSP245**	1563.42	968.24	400.14	230.38	12.78	6.25	-38.48	7.50
	SSP585	1532.24	836.02	529.69	264.23	10.53	-8.25	-18.56	23.30
2061-2080	**SSP245**	1770.51	765.44	385.30	240.92	27.72	-15.10	-40.76	12.42
	SSP585	1579.14	890.07	470.93	222.04	13.92	-2.32	-27.60	3.61
2080-2100	**SSP245**	1350.39	986.24	620.32	205.23	-2.58	8.23	-4.63	-4.23
	SSP585	1579.47	967.20	386.48	229.04	13.94	6.14	-40.58	6.88

Under SSP245, climate change could increase the most suitable habitat (very high potential) with 12.77%, 7.50% and 12.42% in 2040, 2060 and 2080 respectively, and a decrease of 4.23% in 2100. SSP585 showed also a great increase of very high potential that reached 31.04% by 2040 (table 2). Using the future MaxEnt layers, the predicted distribution map (figure 3) indicates a decrease in areas of moderate and high potentials in the center of the park, where the unsuitable areas (low potential) will dominate.

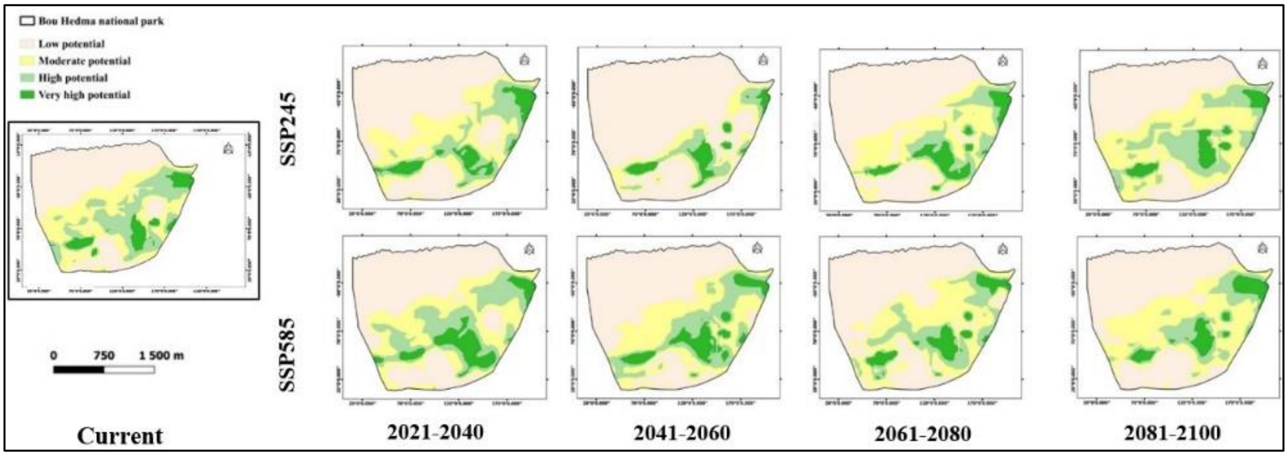

Fig. 3 Changes in suitability of Vachellia tortilis habitat under SSP245 and SSP585 climate change scenarios of the CanESM5 model.

Discussion

To guide conservation priorities and management planning, predictive vegetation models could help to identify hotspots of environmental change or plant habitat suitability (Bedair et al. 2023). Species distribution and predictive vegetation models represent excellent tools to mitigate the impact of climate change (Capera et al. 2023), especially the MaxEnt model, which requires datasets of actual presence called "Occurrences", and will be helpful in identifying suitable area for future habitats. *Vachellia tortilis*, in Bou Hedma national park, seems to follow a kind of regressive dynamic proved by the replacement of suitable area by the unsuitable ones. Similar results are showed by Anthelme and Michalet (2009) who demonstrated the absence of regeneration of *V. tortilis* in the Air-Tenere Nature Reserve (Sahara, Niger) under climate change. The low regeneration of *V. tortilis* in Bou Hedma could be explained by the dominance of large and aged individuals in one hand (Noumi and Chaieb 2012) and by the negative interaction between *V. tortilis* and other plant species in the other hand (Noumi et al. 2023).

The obtained results indicate that the distribution of *V. tortilis* is significally influenced by soil texture, especially the presence of clay and coarse particles. Several studies emphasized the crucial role of edaphic factors in enhancing the accuracy of projection (Buri et al. 2017). Clay soils, known for their water retention capabilities (Romero et al. 2011), may provide necessary moisture during dry periods, while Coarse particles enhance soil aeration and drainage (Bigelow et al. 2001). This combination of soil properties creates an optimal environment for the establishment of *V. tortilis* in arid and semi-arid ecosystems (Ludwing et al. 2003; Yadeta et al. 2018).

Conclusion

Distribution of *Vachellia tortilis* is modeled under optimistic and pessimistic climate change scenarios. In the future of Bou Hedma national park, unsuitable habitats of *V. tortilis* will increase and take place of suitable area. This regressive dynamic indicates that the species is situated under greater danger and highly sensitive to climate change. Such results can be very useful to conserve habitats of this threatened species. Recommendations are given to protect and to enhance the current *Vachellia* suitable area.

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