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Effects of climate change and grazing pressure on shrub communities of West Asian rangelands

Mounir Louhaichi
International Center for Agricultural Research in the Dry Areas, Beirut, Lebanon and Oregon State University, Corvallis, Oregon, USA

Azaiez Ouled Belgacem
International Center for Agricultural Research in the Dry Areas, Beirut, Lebanon

Steven L. Petersen
Brigham Young University, Provo, Utah, USA, and

Sawsan Hassan
International Center for Agricultural Research in the Dry Areas Jordan, Amman, Jordan

Abstract

Purpose – The purpose of this study is to evaluate the vulnerability of the important rangeland shrub, *Atriplex leucoclada* (Boiss) to both climate change and livestock grazing, within the Syrian rangelands as a representative landscape type of West Asia.

Design/methodology/approach – Ecologically based quantitative niche models were developed for both shrub species using maximum entropy and 13 spatially explicit GIS-based layers to predict current and future species distribution scenarios. Climatic variables varied over time in line with the predictions created from the HADCM3 global circulation model.

Findings – Results indicate that with grazing and climate change, the distribution of *A. leucoclada* will be reduced by 54 per cent in 2050, with the mean annual and minimum temperatures of the coldest month having the highest contribution in the model (28.7 and 21.2 per cent, respectively). The contribution of the grazing pressure, expressed by the overgrazing index, was estimated at 8.2 per cent.

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Originality/value – These results suggest that the interaction of climate and increased grazing has the potential to favor the establishment of unpalatable species, while reducing the distribution of preferred plant species on western Asia rangelands.

Keywords Ecological niche modeling, Geographical distribution, Rangeland shrub species, Species occurrence, Species vulnerability

Paper type Research paper

1. Introduction

Climate change has been considered a primary global environmental threat that will limit the distribution and abundance of plant populations worldwide (Pearson and Dawson, 2003). Research suggests that by 2100, impacts related to climate change may be the primary causal factor of the decline in global biodiversity and ecosystem services (Metzger *et al.*, 2006; Phillips *et al.*, 2006). This loss in biodiversity may be attributed to the inability of native plants to survive changes in climate patterns, such as poor adaptability of some species to seasonal fluctuations in temperature and precipitation (Ouled Belgacem and Louhaichi, 2013).

Climate change scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) identify a steady increase in global mean surface temperature of 2°C-6°C above pre-industrial levels by 2100 (IPCC, 2007). In response to this increase, climate change scenarios predict greater fluctuations in global mean soil surface temperatures and temporal precipitation patterns that may induce more severe flooding and prolonged drought patterns, impacting ecosystem services at global scales (IPCC, 2007). In recent years, the ecological consequences of ongoing climate change patterns have been debated (Ouled Belgacem and Louhaichi, 2013). However, a body of recently published literature warn of the potentially negative effects of climate change on plant community dynamics and ecosystem sustainability, particularly when coupled with impacts resulting from human-related activities (i.e. grazing) (Freier *et al.*, 2011; Ouled Belgacem and Louhaichi, 2013).

Rangelands are highly susceptible to the impacts of climate change in response to limited water availability and higher air and soil temperatures (Ouled Belgacem and Louhaichi, 2013). Impacts on rangeland vegetation include reduced growth rates, lower photosynthetic rates, impaired mineral absorption, low tissue regeneration and increased concentrations of secondary metabolites such as ginsenosides and polyphenols (Jochum *et al.*, 2007). The reduced vegetation cover and lower plant biodiversity increase the susceptibility of rangelands to projected fluctuations in climate change (Ouled Belgacem and Louhaichi, 2013; Hudson *et al.*, 2014). This is often accentuated by shallow soils with low nutrient content that limits plant growth and cover and increases erosion potential (Hudson *et al.*, 2014).

West Asia rangelands represent a large and ecologically important land-use type that are characterized by arid or semi-arid climates with low and unpredictable precipitation, as well as variable air and soil temperature patterns (Louhaichi *et al.*, 2016a). These lands provide a diversity of ecological services (i.e. nutrient cycling, pollution filtering, soil stabilization, the preservation of unique plants and animals) that are socially and economically important, providing an important forage resource for livestock production and sustaining local pastoral communities and culture (Louhaichi *et al.*, 2016b). Complex political, socio-economical and environmental interactions have led to the progressive degradation of West Asia rangelands over the past century (Hudson *et al.*, 2014). This degradation has been exacerbated by poor rangeland planning, insufficient implementation of appropriate land management practices and the unsustainable use of limited resources (i.e. water, forage and soil; Hudson *et al.*, 2014). Additionally, these impacts have been amplified by harsh environmental conditions such as frequent and prolonged drought (Louhaichi and Tastad, 2010).

For evaluating and predicting rangeland plant establishment and distribution patterns related to climate change related variables, ecological niche models (ENMs) are a valuable tool (Guisan and Zimmermann, 2000). ENMs examine the association between species occurrence and any number of associated biotic and abiotic environmental variables within a specified area and are then applied broadly to yield estimates for comparison with suitable environmental conditions (Peterson *et al.*, 2007, 2011; Shcheglovitova and Anderson, 2013). ENMs help land managers identify environmental conditions that facilitate the establishment and survival of rangeland plant species in response to climate change (Guisan and Zimmermann, 2000). Such changes include fluctuations in temperature, limitations in water availability and changes in climate-soil microsites that all lead to greater susceptibility, lower establishment and decreased plant survival rates (Schneider *et al.*, 2007).

A suite of tools has been developed to evaluate and prioritize management actions in response to different climate change scenarios, such as current and historic distribution patterns (Millar *et al.*, 2007). These output data are then used to guide the development of new policy that would help mitigate the actual or anticipated impacts on biodiversity for a particular area (Fitzpatrick *et al.*, 2008). For example, climate envelope modeling rapidly assesses the potential impact of climate change on species spatial distribution (Hijmans and Graham, 2006). Climate envelope models use the geographic distribution of a represented species for predicting the probable occurrence of a particular climatic niche (Pearson and Dawson, 2003). These tools can help managers assess risk and identify land management practices or technologies that improve plant establishment potential (Hijmans and Graham, 2006; Pearson and Dawson, 2003).

The Syrian rangelands play an important role for sustaining the local human populations and maintaining ecological sustainability (Bryceson, 2003). The shift in plant community composition in such rangelands may have a negative impact on livestock grazing, and, as such, the purpose of this study is to assess the effect of climate change and grazing pressure on the geographical distribution of *Atriplex leucoclada* in the Syrian rangelands. This study also seeks to characterize the potential effect this distribution may have on current and future rangeland structure and therefore associated livestock grazing.

2. Materials and methods

2.1 Study area

The Syrian rangelands, considered as a representative landscape type of western Asia, cover over 10 million ha, or 55 per cent of the country's land area, including large regions of central and eastern Syria (Louhaichi and Tastad, 2010). Soils are classified as Aridisols with distinct calcic or gypsic horizons near the soil surface (Louhaichi and Tastad, 2010). These soils have weak structure and a relatively light texture, which predisposes them to potentially higher rates of erosion (ACSAD, 2004). The Syrian rangelands are characterized by low rainfall (less than 200 mm per year), which decreases from west to east (Al-Bakri *et al.*, 2001). The local communities that use rangelands for raising livestock herd approximately 12 million animals (ACSAD, 2004). Livestock raised in these lands are predominantly sheep (10 million), followed by goats (about 1.6 million) and camels (about 27,000; ACSAD, 2004). Stocking rates have typically exceeded carrying capacity which has led to drastic deterioration of native plant communities and the inability to sustain successful animal production systems (Louhaichi *et al.*, 2012). For this study, we focused on the central region of Syrian rangelands (2.8 million ha or approximately 30 per cent of the total area).

2.2 Target range species

A. leucoclada is an important native rangeland plant species that range from West Asia to Egypt (Le Houérou, 1996). *A. leucoclada* grows in dry and desert areas of West Asia rangelands

(Post and Dinsmore, 1933). It is drought-resistant and halophytic, tolerating soil salinity levels as high as 30 dS/m (Al-Oudat and Qadir, 2011). The plant exhibits high forage value and is grazed by all livestock classes (Murad, 1996). *A. leucoclada* has been shown to readily establish from seed (Le Houérou, 1996), thus enhancing restoration efforts (Murad, 1996).

2.3 Environmental and socioeconomic data

Environmental and grazing variables were used to develop niche models which were the same as those used by Ouled Belgacem and Louhaichi (2013) in a previous study. They included eight climatic layers, three soil property layers, one altitude layer and one grazing pressure layer. The eight climate variables included mean annual temperature, minimum temperature of the coldest month, maximum temperature of the warmest month, seasonal temperature variation, mean annual precipitation, precipitation of the wettest month, precipitation of the driest month and seasonal precipitation variation. These variables were developed as GIS-based data layers provided by the world climate database (www.worldclim.org; Hijmans *et al.*, 2005), with a 2.5 arcmin pixel size. Climatic variables also included altitude and the distribution area for each shrub species.

In addition to current climate estimates, the change in climate patterns over time for each variable was modeled for the year 2050. These were based on predictions created from the global circulation model HADCM3 that uses the frame of an A2 CO_2 emissions scenario (IPCC, 2000). A2 "storyline" scenarios describe heterogeneous environments with an underlying theme of self-reliance and preservation of local human identities. Human fertility patterns across these regions slowly converge, resulting in continuously increasing populations that contribute to increased CO_2 emissions. Economic development is regionally oriented, and per capita economic growth and technological change are more fragmented and slower than other storylines. The A2 emissions scenario was chosen as it was one of the "marker" scenarios developed through the IPCC. The A2 scenario is at the higher end of the Special Report on Emissions Scenarios preferred because, from an impact and adaptation point of view, if one can adapt to a larger climate change, then adaptation to smaller climate changes of the lower end scenarios are expected. These data (grid format) were downloaded from the gisweb database (www.gisweb.ciat.cgiar.org), also with 2.5 arcmin resolution.

The three soil variables included soil texture (percentage of sand, silt and clay), soil depth and soil salinity. These variables are considered critical for accurately mapping the spatial distribution of individual plant species within arid areas (Florêt and Pontanier, 1982). These layers were extracted from the Badia Development Project (ACSAD, 2004). A socioeconomic parameter was used to assess the influence of anthropogenic pressures that contribute to plant cover and species composition changes in addition to environmentally associated climatic factors.

Livestock grazing is the primary anthropogenic factor that influences species vulnerability, ecological degradation, extirpation of species, and low productivity (O'Brien *et al.*, 2004). The socioeconomic layer developed for this study is represented by a synthetic variable, the coefficient of overgrazing (CO), which reflects the current condition of the species in relation to grazing intensity (Ouled Belgacem and Louhaichi, 2013). To distinguish the influence of climate change from grazing, grazing pressure remained constant over time. Grazing intensity data sets were generated from both current grazing capacity (GC) and stocking density (SD) (expressed as the spatial distribution of herds managed within the study area) (ACSAD, 2004). It was determined based on the following formula (Le Houérou, 1980):

$$\mathrm{CO}:\ 100 * (1 - \mathrm{GC}/\mathrm{SD})$$

2.4 Climate envelope and species spatial distribution modeling

Climate envelope models are used to predict future shifts in a climatic niche which, in turn, estimate climate projections provided by global circulation models (Hijmans and Graham, 2006). To meet our objective, we applied the ecological niche concept (Elith *et al.*, 2006, 2011; Phillips *et al.*, 2006) to establish a relationship between species occurrence and environmental factors. We used maximum entropy (MaxEnt) to model species distribution, as it can accurately model species spatial distribution for both present (Elith *et al.*, 2006, 2011; Ouled Belgacem and Louhaichi, 2013) and future environmental conditions (Hijmans and Graham, 2006). MaxEnt allows for multiple iterations of model development that are then averaged (Phillips *et al.*, 2006). Contrary to other modeling techniques, which focus on model development using presence/absence or abundance data, MaxEnt uses presence-only occurrence data (Phillips *et al.*, 2006), with a strong focus on the role of regularization in parameter estimation. Regularization has the most impact when sample sizes are small, subsequently MaxEnt regularizes in relation to sample size (Phillips *et al.*, 2006). In this case, only presence maps of both target species were produced using 2004 ACSAD (Figure 1).

Withholding a select portion of the data enables testing of model performance while taking advantage of all available data without requiring an independent data set. Executing multiple runs also provides a measure of the amount of variability in the model. In our study, we chose the auto features (linear, quadratic product, threshold and hinge features) function and selected the output format as Logistic and output file type as ".asc". Parameters used in selection setting included,

- a random test percentage of "null";
- no random seed; and
- a maximum number of iterations set at 500.

Model validation was conducted by comparing maps predicting current species vulnerability with actual distribution.

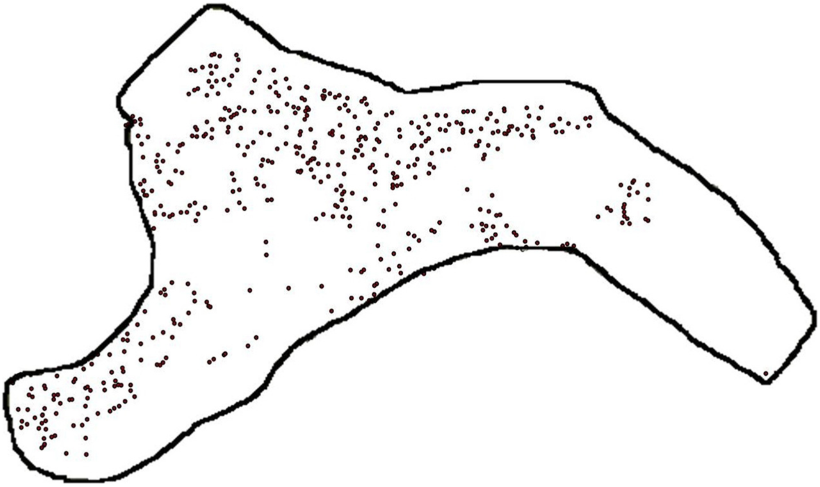

Figure 1.
Geographic distribution (presence only) of *Atriplex leucoclada* in the study area of the Syrian rangelands (ACSAD 2004)

3. Results

Under current favorable environmental conditions and when protected from heavy grazing, *A. leucoclada* establishes and occupies intact West Asia rangelands over time (Figure 2). However, when change in climate is coupled with heavy livestock grazing, the distribution of *A. leucoclada* is expected to be reduced to more than 54 per cent by 2050. Vulnerability was greatest in the 2050 model, which was characterized by a high number of small, restricted and scattered patches of *A. leucoclada* dominated sites. In this analysis, we used the per cent contribution, an estimate of the relative contribution of each variable to the MaxEnt model. Per cent contribution considers each environmental and socioeconomic variable for characterizing trends (Table I). Among the environmental variables, those that were found to most restrict the geographical distribution of *A. leucoclada* included:

- mean annual temperature (28.7 per cent contribution);
- minimum temperature of the coldest month (21.2 per cent);
- mean annual precipitation (14.1 per cent); and
- maximum temperature of the warmest month (11.7 per cent).

Grazing pressure contributed 8.2 per cent to the model, suggesting a negative effect of grazing and climate change on species and plant community resilience (recovery potential of a plant community; Briske *et al.*, 2005). The other variables associated with landform, i.e. geomorphology and soil conditions, present at the site contributed little in explaining species distribution trends and patterns.

4. Discussion

The impact of climate change on rangeland ecosystems has been predicted to impair vegetation composition, plant establishment and plant community resilience (McKeon *et al.*, 2009; Thornton *et al.*, 2009). Results of this study indicate that *A. leucoclada*, an ecologically

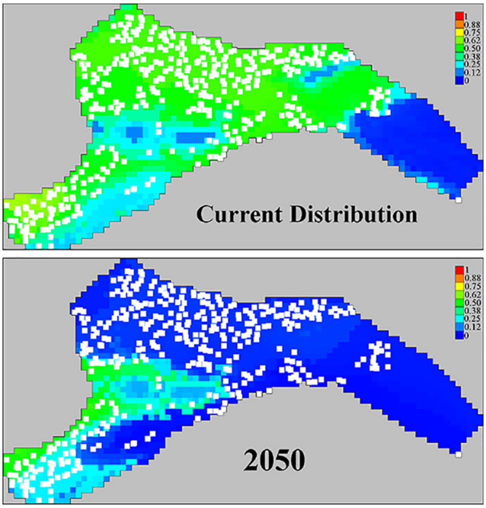

Figure 2. Potential geographic distribution of *Atriplex leucoclada* in Syrian rangelands under present climate and the HADCM3 global circulation models for 2050. MaxEnt produces a continuous prediction with values ranging from 0 (blue) to 1 (red). The higher the predicted value the more suitable the environmental conditions for the species. In the current situation map, white pixels represent random training sites generated by the model for calibration purposes

important rangeland species, exhibits sensitivity to increased temperature regimes and decreased precipitation levels. For example, plant emergence and establishment *of* *A. leucoclada* are limited by low soil moisture levels, a trait that is expected with current and future climate change scenarios. An increase in air temperature may limit plant emergence and survival by reducing available soil moisture and increasing plant evapotranspiration, particularly during the first and second year following seedling establishment. These results are supported by Assaeed *et al.* (2012), who reported a significant decrease in seedling survival during the summer months, when annual temperatures were highest.

Vulnerability of *A. leucoclada* to climate change is explained by not only its sensitivity to increased air and soil temperatures or by the reduction in total precipitation but also the influence of high grazing pressure and the subsequent reduction in the adaptive capacity of *A. leucoclada*. It has been shown that drought combined with high grazing pressure are convergent forces that are particularly detrimental to palatable perennial species, including *A. leucoclada* (Quiroga *et al.*, 2010). Overgrazing of desirable rangeland species impacts plant community composition and cover, potentially influencing ecological processes and their recovery following disturbance (i.e. reduced ecological resilience; Briske *et al.*, 2005, 2008). Furthermore, appropriate selection of grazing strategies is fundamental for predicting potential effects of grazing on plant communities, particularly with increasing temperature and decreasing precipitation trends (Fuhlendorf and Engle, 2001). Continuous grazing with no, or limited, management would likely have significant negative long-term effects on the occurrence and distribution of *A. leucoclada*. In contrast, carefully applied management that controls livestock stocking rates, grazing duration and the period (season) of grazing would be important considerations for reducing the impacts of climate change on grazing carrying capacity and species distribution (Holochek *et al.*, 2004).

In contrast, previous modeling of non-palatable Syrian rangeland species such as *Haloxylon salicornicum* (Moq.) Bunge, a xerophilous species that is known for its adaptation to drought and higher temperatures, suggested an increase of its geographic distribution with climate change (Ouled Belgacem and Louhaichi, 2013). This drought-tolerant species also maintains tolerance to a wide range of soil properties including soil salinity, low nutrient content and eolian movement (Salama *et al.*, 2005). Additionally, it has a low sensitivity to drought, salinity, poor nutrition, sand movement and high light intensity,

Table I. Per cent contribution of environmental and socioeconomic variables in explaining the current and predicted geographic distribution of *A. leucoclada* located in the Syrian rangelands

Variables	Values
Environmental variables	
Precipitation of wettest month	14.1
Minimum temperature of coldest month	21.2
Precipitation seasonality	0
Temperature seasonality	9.3
Annual precipitation	2.8
Annual mean temperature	28.7
Precipitation of driest month	0
Maximum temperature of warmest month	11.7
Altitude	1.4
Soil depth	0.5
Soil texture	0
Soil salinity	2.1
Socioeconomic variable	
Coefficient of overgrazing	8.2

because of the broad ecological niche expected for this species (Huang *et al.*, 2003). As a consequence, the increase in *H. salicornicum* distribution could result in a shift in plant composition and dominance, potentially resulting in impaired ecological processes and the potential transition across ecological thresholds (Stringham *et al.*, 2003; Petersen *et al.*, 2009). Such increases, which result from the interaction of livestock grazing and climate change, could alter the distribution and biodiversity of rangeland plant communities as evidenced in this study for the year 2050 (Guisan and Theurillat, 2000; Guma *et al.*, 2010). As such, the influence of increasing temperatures and lower precipitation could create conditions that favor invading species such as *H. salicornicum* at the expense of the high range value species such as *A. leucoclada*, particularly when considering rangelands with low ecological resilience (Briske *et al.*, 2008).

In rangelands, there has been a shift from the nomadic or pastoral way of life to a more sedentary agro-pastoral production system, with extensive livestock production representing the main component of the agricultural economy of these agro-pastorals (FAO, 2010). This increase in livestock demand has intensified grazing pressure on natural resources, in particular natural vegetation cover and biomass (Lemaire *et al.*, 2014). This shift from nomadic to sedentary production systems has led to the expansion of cultivation into the best rangeland sites having deeper soil and higher organic matter (Nefzaoui *et al.*, 2014). Consequently, grazing lands cover only a small portion of the livestock feeding need (Nordblom, 1992). Thus, there is a negative impact on agriculture when rangelands are degraded. The more degraded the rangelands, the more the pressure will be on croplands (Reitsma *et al.*, 2015). As such, increased pressure on grazing land substantiates the model's findings that an increase in *H. salicornicum* is a more likely scenario, owing to the increased human population resulting in increased demand for livestock products and agricultural land (FAO, 2010).

Model validation was achieved using a specified number of iterations or training points. This, as is the case in other models, may give new predicted areas of occurrence for the studied species, and these are clearly among the most relevant outputs of ecological modeling (Hernandez *et al.*, 2006). However, new areas of predicted occurrence are rarely verified in the field (Rebelo and Jones, 2010) which is of concern, especially for areas outside the known geographical range of the species (Elith *et al.*, 2006). Such a lack of validation is highly relevant for rare or closely rare species like *A. leucoclada*, which are usually a conservation priority, but with a wider knowledge gap compared to more common and abundant species.

Considering these impacts and limitations, ecological niche modeling can be an excellent tool for obtaining approximate impacts of climate change and for assessing the potential for species impacts from plant invasions, as well as grazing intensities (Pearson and Dawson, 2003). These models can improve conservation and restoration efforts by aiding managers in locating sites with the highest potential for impacts (i.e. risk assessment) based on different climate change scenarios, interacting with utilization intensities of such important rangeland species. Consequently, a mitigation strategy to increase the resilience of the most vulnerable species, based on proper grazing, the selection of more drought tolerant taxa and the establishment of improved water harvesting techniques, needs to be developed and applied within West Asia rangelands.

5. Conclusion and management implications

The results of this study demonstrate that restoration and rehabilitation of degraded rangelands may be impaired by the combined effects of climate change and human-related activities (i.e. grazing pressure). These elements may result in altered ecosystem structure and function that can potentially impact the establishment of native desirable species, while facilitating invasive species. The risk from altered climate change scenarios on rangeland plant species depends on the sensitivity of the species to environmental change, change to host ecosystem structure and the vulnerability of already existing native species.

Research of arid land reclamation emphasizes poor establishment of native species and dominance of non-native/invasive species. This pattern continues to provide one of the greatest challenges to the management of arid rangeland landscapes, demonstrated by reduced ecological resilience and the potential transition of landscapes across ecological thresholds that are dominated by undesirable plant communities and slow ecological processes. This research uses geo-spatial technology and ecological modeling to assess site condition related to plant adaptability and then projects plant community dynamics in relation to global climate change scenarios. The unique contribution provided in this paper is the application of models for characterizing the suitability of two arid shrub species which are well adapted to the current and future climatic patterns. This information can be used by managers to determine the risk associated with change in current vegetation distribution of desired native plant species because of over utilization and to predict how these changes will impact rangeland ecosystem structure over time.

Although results from these models need to be cautiously interpreted, in particular because of the assumptions that underlie both model type and data used, the impacts described from these models warrant a clearer focus on how monitoring across a species' range can provide an early detection system for identifying potential climate change impacts. To validate and further refine these models, additional studies are needed that investigate the physiological thresholds, because of climate change scenarios, as well as disturbance intensities, for individual species of interest or value.

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Corresponding author
Mounir Louhaichi can be contacted at: M.Louhaichi@cgiar.org