Conservation assessments and Red Listing of the endemic Moroccan flora (monocotyledons)

Setting conservation priorities for the Moroccan flora (endemic monocotyledons) using the IUCN Red Listing and Species Distribution Modelling.

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Abstract

IUCN Red Listing assessment and species distribution modelling or ecological niche modelling have much potential for selecting conservation action priorities and designing new conservation priority areas. In this study, we assessed the conservation status of the Moroccan endemic monocotyledons flora by applying the IUCN red list criteria and we modelled the distribution of this flora for the present day by using bioclimatic niche modelling based on presence locality data only in combination with climate variables. We then considered the utility of both analyses as a planning tool to establish conservation priority measures in specific areas.

Our results showed that the IUCN red listing revealed high extinction risk to the Moroccan flora in specific floristic regions and the species distribution model provides informative biogeographical data, offers innovative potential for the discovery of new distribution areas and highlighted priority areas for conservation.

We concluded that urgent actions are needed to preserve the future of the Moroccan flora from many threats mainly habitat loss and degradation, direct and indirect human disturbance, changes in vegetation dynamics, climate change and species intrinsic factors. This will require sustainable management, legal protection of species and their habitats, education and research. We also established priority areas for conservation primarily the Atlas (High Atlas, Anti Atlas and Middle Atlas), Rif Mountains and coastal areas (North Atlantic and Middle Atlantic of Morocco). Despite the importance of Moroccan biodiversity hotspots, little is being done in terms of habitat protection, conservation assessment and rising public awareness. This study is an important contribution that uses new tools to highlight the extinction risk of a Mediterranean hotspot.

Keywords: Moroccan flora, monocotyledons, biodiversity conservation, hotspot, threatened flora, IUCN red listing, species distribution modelling, ecological niche modelling.

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Introduction

Since the global and regional biodiversity is experiencing the sixth great extinction event (Canadell and Noble 2001), in this context floras and biodiversity hotspots are exposed to extinction and many habitats are threatened, especially in the mountains which are very sensitive to climate change (Barry 1992, Hodar & Zamora, 2004). Therefore, we used two main tools; the IUCN Red list assessment and species distribution modelling, to prevent the deterioration of the Moroccan biodiversity hotspots, to identify conservation action priorities, and protected areas and to facilitate appropriate decision making.

The IUCN Red List has become an essential tool for setting priorities for biodiversity conservation. It is widely recognized as the most comprehensive way to evaluate conservation status (Rodrigues et al., 2006; Miller et al., 2007). It is used as indicator for assessing ecosystem status (Butchart et al., 2006) and even as an indicator for allocating funds and conservation efforts (Trousdale & Gregory, 2004). However, Species Distribution Models (SDM) that predict distributions of species by combining known species occurrences with environmental data have also much potential for application in conservation planning, reserve selection, design of protected areas, ecology, invasive species management and discovery of new populations (Araújo et al. 2011a, Araújo and Williams 2000, Corsi et al., 1999, Scott et al., 2002, Williams et al. 2005, Wilson et al. 2005a).

In this study, we assessed the conservation status of the Moroccan endemic monocotyledon flora by applying the IUCN red list criteria and categories. Then, we modelled the distribution of this flora for the present day by using bioclimatic niche modelling based on locality data in combination with climate variables, in order to generate an actual map and estimate the potential geographic distribution of this threatened flora.

The purpose of this study is to provide some management recommendations in specific geographic areas through analyzing the data associated with the conservation assessments and the species distribution modelling of this flora. The main aim is to answer the following questions; (i) What is the situation of the threatened endemic monocots flora? (ii) What are the main threats to the Moroccan flora and habitats? (iii) What are the priority zones for protection and conservation? (iv) What conservation measures will protect the threatened flora?

The outcomes of this study and the complementary analyses of the data will support conservation planning, provide information for policy and decision makers in Morocco, and will aid enforcement of conservation policies and creation of new networks of protected areas. But, most importantly this study will help Moroccan government to achieve their obligations, commitments and targets under international agreements, especially the Convention on Biological Diversity (CBD 2002) and the Global Strategy for Plant Conservation (GSPC 2020).

Materials and Methods

Overview of the endemic Monocotyledons flora

Morocco is a major contributor to the Mediterranean Basin hotspots as it contains two of the eleven regional biodiversity hotspots: the Moroccan Atlas and the Betico-Rifan complex (Medail and Quezel 1997 & 1999, Médail and Myers 2004, Quézel and Médail 1995, Mittermeier et al. 2004, Myers et al., 2000). Morocco is known for its floristic richness and taxonomic diversity, contains 3913 taxa including 1298 subspecies in 981 genera and 155 families (Fennane and Ibn Tattou 1998 and 2012). Morocco is characterized by a high level of specific and sub-specific endemic species, 22%, which contains 879 endemic taxa with 600 taxa at the species level containing 540 dicotyledon and 60 monocotyledon species (Fennane & Ibn Tattou 2012, Valdés *et al.* 2002).

The endemic monocotyledons flora makes an important contribution to the entire endemic flora (Rankou et al., 2013). It contains 10 % (60 species) of the total flora which belongs to 8 families and 36 genera as follow; Poaceae (21 genera, 29 species, 48%), Amaryllidaceae (5 genera, 12 species, 20%), Asparagaceae (4 genera, 7 species, 12%), Iridaceae (2 genera, 6 species, 10%), Cyperaceae and Orchidaceae (one genus, two species, 3%), Juncaceae and Xanthorrhoeaceae (one genus, one species, 2%). This endemic monocotyledons flora is well distributed and occurs in all the major floristic divisions with different proportions as follow: High Atlas (HA, 45%), Middle Atlas (MA, 24%), Anti Atlas (AA, 26 %), Rif (R, 25%), Middle Atlantic of Morocco (Mam, 30 %), North Atlantic of Morocco (Man, 28 %), Moroccan Sahara (Ms, 11.6 %), Mediterranean Cost (LM, 13.3 %) and Eastern-lands (Op, 1.6 %).

The endemic monocotyledon flora consists of geophytes (50%), perennials (30%) and annuals (20%) and is found in a range of ecoregions with different climates from humid to arid and mostly narrower elevation band which give some indication of vulnerability to habitat loss and resistance to climate change. The main habitats where these species occur and which they depend are wet meadows, woodlands, scrub, limestone mountain, coastal areas, Mediterranean and temperate mixed forest.

Mapping and inventory

The distribution data mapping had not been established or properly recorded but we launched an inventory involving many collaborators who assisted with field work, checking the existing scientific literature and visiting major herbaria to record the labels data. As a result, we created a distribution record database for each species and a total record of 2100 occurrences for the entire endemic monocotyledons flora.

Locality data were derived from three sources: (1) field survey data of most of the Moroccan floristic regions; (2) records of wild populations from the existing literature and the major taxonomic databases; and (3) herbarium specimens surveyed at the major herbaria (Reading University Herbarium RNG, Institut Scientifique Rabat Maroc RAB, Caddi Ayad University Marrakech MARK, Montpellier Herbarium MPU, Paris Herbarium P, Conservatoire et Jardin botaniques Genève G, Kew Herbarium K and Natural History Museum BM). The occurrences and localities of species were recorded with their geographical coordinates and verified using Google Earth (Version 5; _2010 Google). The survey of species distribution was quantified by calculating two main metrics; the extent of occurrence (EOO) and area of occupancy (AOO) using Geocat software (Bachman et al., 2011) and following the IUCN recommendations (IUCN 2001). The EOO was calculated by constructing the minimum convex polygon around known occurrences and the AOO was calculated by overlaying a grid of 2 by 2 km and counting the occupied grid cells. Both metrics were used to estimate the geographic range, population trend and population fragmentation inference. The occurrence data was used to apply the IUCN criteria, to evaluate the extinction risks and in conjunction with climate variables was used to produce potential species distribution in the climatic niche model.

IUCN Red Listing and Conservation Assessments

By Red Listing the endemic Moroccan monocotyledons we established a baseline from which to monitor the changes in status of species and habitats, and to provide data and analyses regarding trends and threats to species and populations in order to prioritize alternative actions regarding conservation.

We completed the Red listing and the conservation assessment status of all 60 endemic Moroccan monocotyledon species using IUCN Red List categories and criteria, version 3.1 (IUCN 2001) with reference to the latest guidelines (IUCN 2011). All the assessments were reviewed and verified by the IUCN Red List Unit.

We used the calculated AOO, EOO, population size, population trends, and threats to species in order to apply the quantitative Red List criteria (B, geographic range size and fragmentation, decline, or fluctuations; C, small population size and fragmentation, decline or fluctuations and D, very small population) and eventually classify a species in one of the IUCN Red List categories: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC). In some species we used more than one criterion to fulfil the IUCN rules request and to respect the IUCN guidelines for publication of a national Red List (IUCN 2011; Vie et al. 2009).

Species distribution modelling/Ecological niche modelling

Species distribution models, Bioclimatic envelope models or niche based modelling are the most common strategies for estimating and predicting the actual or potential species geographic range on species distributions (Araújo and Peterson 2012, Guisan and Zimmermann 2000, Hampe 2004). Species distribution modelling uses a combination of climate variables and occurrence data to identify a set of conditions where the species can survive. However, there are a number of reasons why the species may not actually occupy all suitable sites such as dispersal barriers and species competition.

The environmental conditions suitability for a species is categorized by two type of modelling approaches either a mechanistic or a correlative model; Mechanistic models aim to incorporate the species physiologic mechanisms with tolerance to environmental conditions such as dispersal, colonization, and complex interactions with other organisms. Mechanistic models are difficult to develop as they require detailed understanding of the physiological response of the species to environmental variables but they are often the preferred approach (Ellis 2011). Correlative modelling is the most frequently used approach. It aims to estimate the environmental conditions that are suitable for a species by associating known occurrence records with environmental variables that can affect the species physiology and probability of persistence thought this approach does have several limitations (Bourg et al., 2005; Raxworthy et al., 2003).

Producing species distribution models from presence only data is a challenging task (Graham et al. 2004) and several approaches and models have been used but MaxEnt modelling has been demonstrated to give the best result of all the modelling algorithms available using presence only data (Elith and Leathwick 2009).

In this study we modelled the species distribution of all the 60 endemic Moroccan monocotyledons species using MaxEnt software (version 3.3.3a) to produce actual and predictive maps on the basis of our occurrence data and environmental layers (Phillips et al., 2004, 2006 & 2008). MaxEnt software uses a correlative approach of the environmental conditions (environmental grids or bioclimatic variables) that meet a species ecological requirement and predicts suitability areas and habitat where the species can occur.

The current bioclimatic variables were downloaded from the WorldClim website (http://www.worldclim.org/bioclim), using as grid data 30 arc seconds resolution (approximately 1 km) and then clipped to Morocco only. We used the VIF function (variance inflation factor) to test the collinearity of the 19 climates variables in order to exclude the highly correlated variables, to reduce the processing time and data (Naimi et al. 2014). We kept the default settings in MaxEnt to achieve reliable results (Phillips et al., 2008) and we tested the initial model for each species by omitting 20% of the occurrence data for each species (20% sample points for testing and the rest to produce the model), to measure the robustness of the model.

For each species we produced a predictive potential map. We then combined all the 60 maps for the endemic Moroccan monocotyledons species together in order to highlight floristic regions with conservation concerns and predict potential areas. Prediction maps are not about where the species occur but where the species could occur in order to help identifying suitable sites for reintroduction programmes and favouring success in regional conservation planning.

Threats and extinction risk factors

We managed to identify the major threats by floristic region and categorize them from 1 to 5 with 1 as the most severe threat in the floristic region and five the least severe (Table 1). We based our inventory on expert knowledge, field surveys of species populations, knowledge on species ecology, habitat ecology and local expertise to identify the most probable threats. We followed the IUCN guidelines and we used IUCN Species Information Service (SIS) software to compile and record them.

The threats to this flora comprise both natural and anthropogenic actions. The main direct threats on the Moroccan flora are: (i) habitat loss and degradation, (ii) human disturbance,

(iii) Changes in vegetation dynamics and invasive species, (iv) climate change and intrinsic factors.

Habitat loss and degradation

The main threat for 90 % of the endemic Moroccan monocots species is habitat loss, fragmentation and degradation, widely recognised as the main threat to biodiversity (Baillie et al., 2004, Blondel and Médail. 2009). This issue is relentless in countries such as Morocco with high diversity and low priority for conservation biodiversity.

The increased pressure in natural habitats due to overgrazing and intense trampling is driven by nomadic grazing or by local people's livestock (cattle, sheep and goats). Goats have a particularly damaging effect on trees and plant species. Not only do they browse the foliage but they also dig the species roots and climb through trees. This increased livestock pressure has become particularly damaging due to excessive animal density in some areas with high plant diversity, lack of land rotation and grazing at inappropriate times relative to the flora productivity cycle (Johnson 1996, Sharma et al., 1997). As a result the negative effects on natural resources are rigorous; from selective browsing, soil erosion, depletion of nutrients, compaction of the topsoil, increase desertification and fire risks from the build up of combustible materials in the forests (Benabid 2002, Ouassou et al., 2006., Dahan et al., 2012)

The changes in land-use patterns, abandonment of local agricultural practices and agriculture intensification played a major role in diversity loss, extensive land clearing, soil erosion, increases of water extraction for irrigation and pollution by herbicides and fertilisers. Agriculture intensification in Morocco took both scales; large-scale farming in low lands and small-scale farming by local people to secure essential resources for their livelihood.

Deforestation, logging and wood harvesting are very serious problems driven by land clearing to prepare for livestock grazing or expansion of crop planting, illegal commercial logging and fires (Aafi et al., 2005, Benabid 2002, Barbero et al., 2009; Boukil 1998). This destruction increases soil erosion, habitat fragmentation, erosion of biological community structure, the disappearance of species and has adverse climate impacts.

Human disturbance

More generally the Moroccan endemic monocot flora is threatened by the direct and indirect impact of human activities (Blondel and Aronson 1995 and 2009). The main forms of human disturbance are tourism, leisure activities especially in the floristic hotspots (Atlas and Rif mountains) as they receives large numbers of national and international visitors, management activities (direct effect by destruction of plants and indirect effect via alteration of habitat), unsuitable plant exploitation and ruthless collection for domestic uses or for trade.

Urban expansion is a major threat to the Moroccan flora caused by population growth and expansion of cities, villages, coastal areas and areas with low control of human settlements. Urbanization and infrastructure development (building of paths, tracks, service lines and new roads) are affecting most of the habitats especially the fragile ones. They have an adverse effect on the Moroccan flora not only because of direct habitat destruction resulting from the construction, but also open the way to more traffic, trampling and high accessibility.

Wetland in Morocco is also in a continuous regression due to drainage, drought, climate change and pollution by domestic and industrial waste (Alaoui Haroni et al., 2009, Hammada et al., 2002 and 2004, Ramdani et al., 2001, Nilson et al., 2005, MADRPM 2008, Plan bleu 2009). The extent of deterioration varies from one floristic region to another but pollution problems are increasing and becoming more complex particularly because of tourism and by the construction of leisure centres especially in the Atlas Mountains (e.g. Oukaimeden ski resort).

Changes in vegetation dynamics and Invasive species

Changes in vegetation dynamics include changes through time in the occurrence, abundance and productivity of all species, and reflect the effects of many factors, including climate, abiotic environment, biotic interactions, and disturbance history (Mueller-Dombois and Ellenberg 2003, Van Der Maarel 2004). These changes in plant community composition gave invasive species and newly introduced species favourable ecological conditions to spread and become more competitive. The Moroccan endemic flora is affected by newly introduced species recognized worldwide as invasive plants for their colonizing influence and their ability to spread wider (Taleb and Bouhach 2006, Gurevitch and Padilla 2004, Didham et., 2005). The risks from these invasive species to the endemic flora are apparent and vary from competition for natural recourses to the disappearance of the species. They cause a significant biodiversity loss, due to underestimation of the issue and a lack of information, awareness, adequate prevention and mitigation measures.

Climate change and intrinsic factors

Prediction of climatic change and global warming studies demonstrated that Morocco is threatened by climatic change due to the change in the precipitation patterns (a decrease in rainfall by 10 and 20%) and an increase in desertification (temperatures are likely to rise between 2 and 3 ºC by 2050). In fact, the most important impacts of climate change are now clearly tangible in Morocco. Droughts occur more frequently and with greater intensity, while flooding also affects the country more often than before (Mooney 1990, Newman et al., 2011, Schilling *et al.*, 2012).
The combination of decreasing water supplies, densely populated regions, pastoral productivity and intrinsic factors (restricted distribution range, small population size, low dispersal rate and low recruitment rate) aggravated the risks of climate change and decreases the resilience of most of the threatened plants and their habitat.

Floristic Divisions & Threats		Agriculture intensification	Overgrazing	Deforestration	climate change	Drought	Habitat fragmentation	Unsuitable plant exploitation	Urbanisation	Tourism & Reacreational	Fires (Burning of Vegetation)	Flooded wetlands	water pollution	Drainage	infrastructure (roads..)
HA	HA-1: Ida-ou-Tanane	4	2	3	2	1	3	3	3	2	4	5	5	5	4
	HA-2: Seksaoua	4	2	3	3	2	4	3	5	3	5	5	5	5	4
	HA-3: Middle HA	4	2	2	3	2	3	3	5	1	5	5	4	5	4
	HA-4: Mgoun	4	1	2	3	3	3	2	5	1	5	5	4	5	5
	HA-5: Ayachi	3	1	2	2	2	3	1	5	2	4	5	5	5	5
	HA-6: Eastern HA	3	1	1	3	2	3	1	3	5	5	5	5	5	5
MA	MA-1: Tazekka	3	3	3	2	3	4	2	4	3	3	5	4	5	3
	MA-2: Nort-Eastern	5	2	2	2	2	3	1	5	2	5	5	5	5	4
	MA-3: Middle MA	4	1	2	2	3	3	2	4	3	5	4	4	5	3
	MA-4: South-West	4	2	3	2	3	4	2	4	4	4	5	4	5	3
AA	AA-1: Western AA	3	2	2	2	2	3	2	3	2	4	5	5	5	4
	AA-2: Kest	4	2	3	2	2	3	2	3	3	4	5	5	5	5
	AA-3: Middle AA	4	1	3	2	2	3	2	4	3	4	5	5	5	5
	AA-4: Siroua	4	1	2	2	2	2	2	4	3	5	5	5	5	5
	AA-5: Eastern AA	4	2	3	2	2	3	2	5	4	5	5	5	5	5
Rif	R-1: Tangier	3	3	2	4	4	1	1	1	1	1	4	2	4	1
	R-2: Middle-West Rif	3	2	2	4	4	2	1	2	1	1	5	3	5	2
	R-3: Eastern Rif	3	1	1	3	3	2	1	2	3	2	5	3	5	3
MAM	Mam-1: Doukkala	1	3	4	3	2	2	2	1	1	5	2	1	3	1
	Mam-2: Abda	1	3	3	3	2	2	2	1	1	5	4	2	4	2
	Mam-3: Souss	1	2	2	2	1	1	1	1	1	4	4	2	4	1
	Mam-4: Haouz	1	3	3	2	1	2	2	1	3	4	5	2	3	2
	Mam-5: Oum-Rabiâ	2	2	3	2	2	2	2	3	4	4	5	3	4	3
MAN	Man-1: Middle Sebou	1	3	3	3	2	3	3	2	3	4	4	3	5	3
	Man-2: Rharb	1	2	3	3	2	2	1	1	1	4	1	2	2	1
	Man-3: Maâmora	3	1	2	2	2	1	1	1	1	4	2	2	2	3
	Man-4: Zaïare	3	2	2	2	2	2	2	3	3	4	5	3	5	3
MS	Ms-1: East desert	5	3	4	2	1	3	3	4	3	5	5	5	5	4
	Ms-2: West desert	5	3	4	2	1	3	3	4	3	5	5	5	5	4
	Ms-3: Sahara	4	2	3	2	1	3	2	3	2	5	5	4	5	3
LM	LM-1: Nekkor	3	2	2	2	1	2	2	3	3	4	5	3	5	3
	LM-2: Moulouya	2	3	3	3	2	2	1	2	2	4	4	2	3	1
OP	Op-1: Low Moulouya	4	1	3	2	1	2	2	4	3	4	4	4	5	3
	Op-2: High Moulouya	3	1	3	2	1	2	2	5	4	4	4	4	5	4
	Op-3: Highlands	3	1	3	2	1	2	2	5	3	5	5	5	5	4
OM	Om-1: Bni Snassén	3	2	2	2	1	3	2	3	3	2	5	3	5	3
	Om-2: Jerada	3	2	1	2	1	2	2	3	4	3	5	3	5	4
	Om-3: Debdou	4	2	1	2	1	2	2	3	4	4	5	3	5	4
AS	As: Atlas Sahara	5	1	2	2	1	2	2	5	5	4	5	5	5	5

Table 1: Main threats by floristic region (1 is the most severe threat in the region and 5 is the less concerned threat).

Results:

A threatened endemic Monocotyledons flora

The results of our complete assessment of the conservation status of the endemic Moroccan monocotyledons are summarised in Annexe 1. This red list revealed a very high extinction risk and some shocking results; with regards to the 60 species assessed, we found that 56 species 94% are threatened [20% Critically Endangered (CR), 49% Endangered (EN), 25% Vulnerable (VU)] and only four species 6% are not threatened [3% Near threatened (NT) and 3% Least concern (LC)]. (Table 2).

	IUCN Red List Category	Number of Species	(%)
Threatened	Critically Endangered (CR)	12	20%
	Endangered (EN)	29	49%
	Vulnerable (VU)	15	25%
Near Threatened	Near Threatened (NT)	2	3%
Non Threatened	Least Concern (LC)	2	3%
	Total number of taxa assessed	60	100%

Table 2: Number of endemic monocots species in each Red List Category

The families that were most threatened (CR, EN and VU) are: Poaceae (27 species, 93%), Amaryllidaceae (12 species, 100%), Asparagaceae (7 species, 100%), Iridaceae (6 species, 66.6%), Cyperaceae and Orchidaceae (two species, 100%), Juncaceae and Xanthorrhoeaceae (one species, 100%). (Fig. 1)

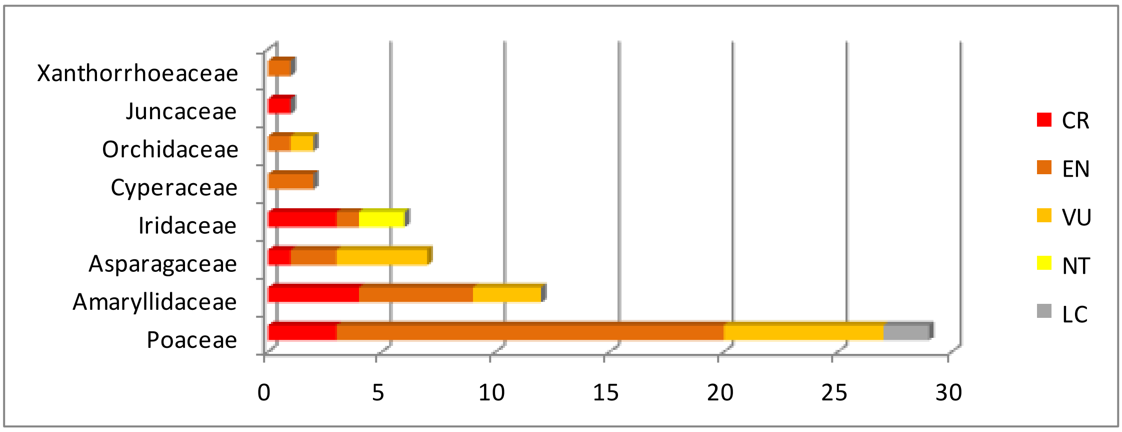


Figure 1: Proportion of endemic monocots species in each Red List Category by family in Morocco.

The number of threatened endemic monocot species (CR, EN and VU) by floristic region is shown in Fig. 2: High Atlas (15 % CR, 55.5 % EN and 22.2 % VU), Anti Atlas (6.25 % CR, 43.75 % EN and 37.5 % VU), Rif (13.3 % CR, 40 % EN and 20 % VU), Middle Atlas (7.2 % CR, 28.6 % EN and 50 % VU), Mediterranean Cost (37.5 % CR and 50 % EN), North Atlantic of Morocco (53 % EN and 29.4 % VU), Middle Atlantic of Morocco (27.8 % EN and 61.1 % VU) and Moroccan Sahara (42.9 % EN and 57.2 % VU).

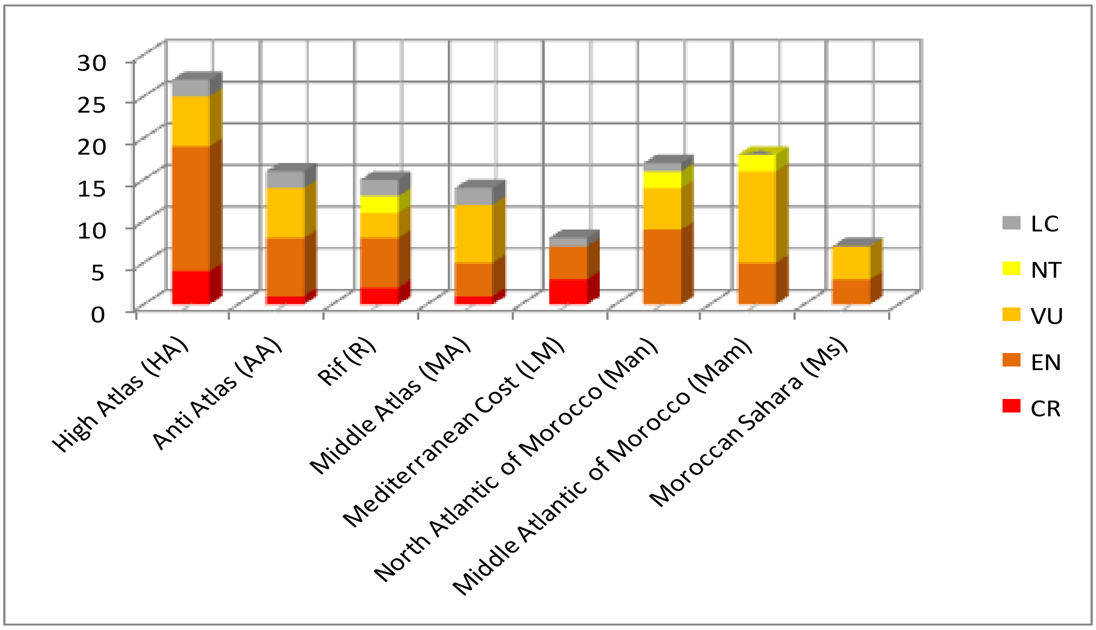


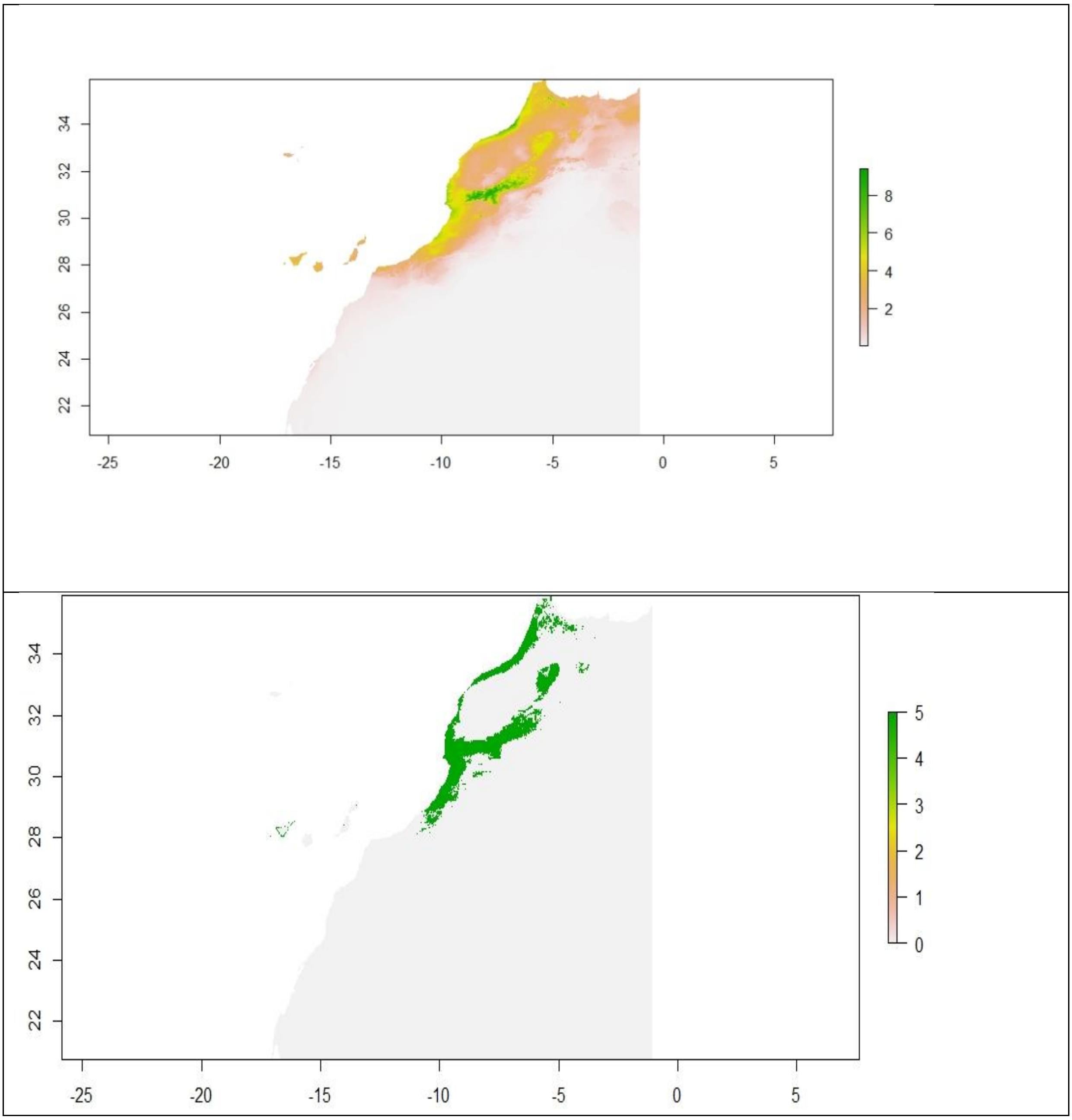
Figure 2: Proportion of endemic monocots species in each Red List Category by floristic region

Model of present-day distribution

The present-day distribution model of the endemic Moroccan monocotyledons as derived from MaxEnt is shown in Figure 3. The predicted distribution includes three fundamental centres and biodiversity hotspots in Morocco the Atlas (High Atlas, Anti Atlas and Middle Atlas), Rif Mountains and coastal areas (North Atlantic and Middle Atlantic of Morocco).

Variance inflation factor (VIF) of the 19 climates predictors showed that the following BIOCLIM layers give the highest contributions to the model of predicted distribution: bio 1 (annual mean tempretaure); bio 7 (Temperature annual Range); bio 8 (Mean Temperature of Wettest Quarter); bio 10 (Mean Temperature of Warmest Quarter); bio 11 (men temperature of coldest quarter) bio 14 (Precipitation of Driest Month); and Therefore, the main drivers for the model are temperature, precipitation, and their relationship with seasonality. These are manifest as a decrease in rainfall and an increase desertification.

Our study shows that modelling driven by locality data of sufficient quantity and quality (i.e. 60 species, 2100 unique localities, each accurate to 30 arc seconds resolution (c. 1 km diameter) or less), and conducted on a regional scale, drives robust models for Moroccan endemic monocotyledons (Fig. 3).



Figures 3: Predicted distribution of the endemic Moroccan monocotyledons species. Coloured areas (red to green) show predicted distribution based on MaxEnt modelling.

Assessment of threats

With respect to threat status, the situation of many species is worrying, given that most species are classified as threatened because of population decline or because they occur over a small geographic range with a low number of mature individuals. Threats can be identified at any scale by the interaction between the biological mechanisms promoting species diversity and mechanisms intimidating this diversity (Orme et al., 2005). The major threats to the Moroccan flora are habitat loss and degradation. These have also been identified as the most pervasive threats to the important plant areas of Morocco (Taleb and Fennane 2011).

However, the decline of these species is related to different sources of threat as recorded in this study. These were classified on the following order (Figure 4): habitat loss, overgrazing, climate change and drought, agriculture intensification, deforestation, tourism and recreational activities, unsuitable plant exploitation, urbanisation, infrastructure development, fires and pollution.

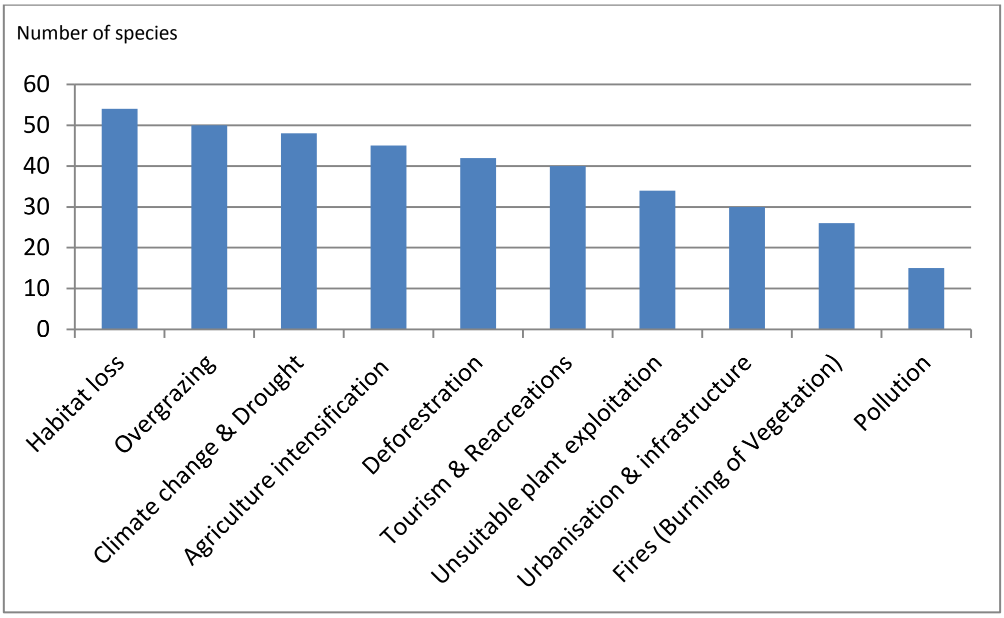


Figure 4: The main threats to the endemic monocots species

Priority conservation areas

The priority conservation areas and biodiversity hotspots in Morocco were selected on the basis of the outcomes from IUCN red listing and species distribution modelling maps following the steps in Figure 5.

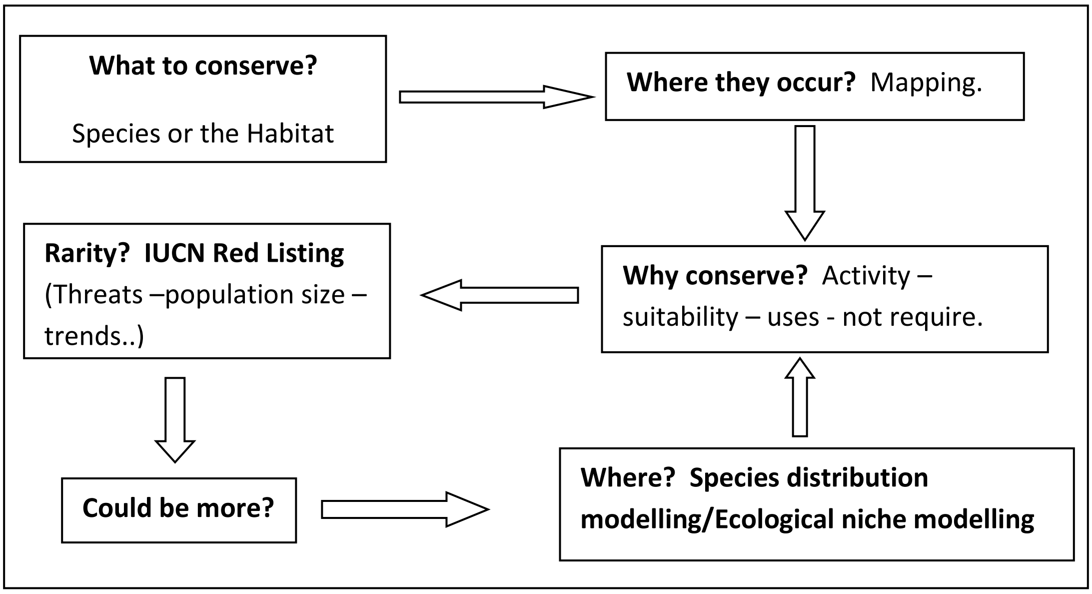


Figure 5: Steps followed to highlight priority conservation areas and floristic regions.

The IUCN Red list of the endemic Moroccan monocotyledons (Figure 3) and species distribution modelling according to MaxEnt software for actual and predictive maps (Figure 4) showed that there are two fundamental centres and biodiversity hotspots in Morocco that should be prioritised in terms of optimising biodiversity conservation efforts. These main conservation centres and floristic regions are the Atlas Mountains (including High Atlas, Anti Atlas and Middle Atlas), Rif Mountains and coastal areas (North Atlantic and Middle Atlantic of Morocco).

These hotspots correspond to floristic regions with high number of species, endemism rate and threatened species. They also correspond to all the established and identified Mediterranean biodiversity hotspots for the whole vegetation, i.e. the Atlas Mountains and the Betico-Rifan arc, stretching across northern Morocco and western Algeria which comprises the southern part of the Rif and the mountains of the Oriental region of Morocco.

The Atlantic plain of Morocco is not represented as a Mediterranean biodiversity hotspot but it is an important area of endemic threatened species richness due to the abundance and diversity of habitats in this region, a pathway for species spreading from the two neighbouring hotspots (Atlas and the Rif) and from the Macaronesian Islands especially the Canary Islands.

Conservation actions and recommendations

Assessment of extinction risk and setting conservation priorities are two related but different processes. The purpose of the Red List categorization and species distribution models is to produce a relative estimate of the likelihood of extinction of the species and find suitable areas and habitat where the species could occur, respectively. However, setting conservation priorities takes into account other factors such as ecological preferences, phylogenetic, historical, cultural preferences for some taxa over others, as well as the probability of success of conservation actions, availability of funds or personnel to carry out such actions, and legal frameworks for conservation of threatened taxa (Milner et al. 2006, Miller et al. 2007).

The shocking results that we have described show that the conservation of the Moroccan flora is becoming crucial. Therefore conservation efforts must address sustainable development and coherent management of habitats and natural resources in the highlighted priority conservation areas. The main urgent actions are: (i) Species management and protection, (ii) Site and habitat protection, (iii) Communication and Education, (iv) Monitoring and research.

Species management and protection

In situ conservation and protecting the threatened Moroccan monocots endemic species in their natural habitats is considered to be the most efficient way to conserve rare species in long term (Cheldeman and van Zonneveld 2010). It can take various forms including legal protection of the habitat, designation of different categories of protected area, zoning and land use restrictions, habitat restoration and development of recovery species plan.

Protected areas usually have broad term management plans and maintenance requirements of the sites. However management of the plant communities in conservation centres and floristic regions will frequently be required especially in the Atlas (High Atlas, Anti Atlas and Middle Atlas) and Rif Mountains. In addition, specific management plans and particular instructions are necessary for most of the Moroccan monocots species to preserve viable populations in their original native range. This will involve effective monitoring and active manipulations and protection from unwanted human disturbance from grazing, tourism, trampling, collection and local practices of cutting some species and the time of collecting them. However, the most urgent conservation action required is legal protection of threatened species and strengthening the protection measures by enforcement of the existing legislation and by producing new ones which ban the threatened species from being picked or dug up. Since only little information is available about the biology and ecology of most of the Moroccan monocots endemic species, quick and decisive action is necessary to maintain a rapidly declining flora. Research from *ex situ* conservation may also be helpful. As seen in the results most of the Moroccan monocots endemic flora is seriously threatened and in risk of extinction unless immediate conservation actions are undertaken with intensive management such as cultivation of threatened species in botanic gardens and nurseries to ensure the survival of the species, seed collection for the long term conservation of genetic resources and reestablishment of wild population via reintroduction of the species to their natural habitats or to new suitable areas according to the distribution model of each species.

Conservation of the Moroccan monocots endemic flora in the long term will be efficient and successful via a combined approach of both *in situ* and *ex situ* conservation measures.

Site and habitat protection

Areas or floristic regions in Morocco specifically protected for threatened species are inexistence as most plant conservation legislation is concerned with protecting species from various plant collection or human disturbance. In order to effectively safeguard the threatened Moroccan monocots endemic species, protected areas need to be designed as representative networks to ensure complete regeneration of the species ecosystems and to restore the quality of wild environments. Specific site protection in the main floristic regions (Atlas and Rif Mountains) through the designation of protected areas will be one of the most effective means of preserving the threatened flora.

Site protection can take many forms from zoning restrictions of grazing, establishment of a rotation system for pasture to reduce overgrazing, pastoral and silvo-pastoral improvement by creating collective sites, restricting the grazing time by exclusions and development of water points for livestock to reduce the impact of trampling. However, the most urgent action will be the delimitation of the forest estate based on negotiation between the forest administration (Haut Commissariat aux Eaux et Forêts) and local people, and finally the establishment of natural sanctuaries were a traditional pastoral system has been installed with the number of livestock managed ("Agdel"). Protection of habitats through land use restrictions will involve similar approach, i.e. delimitation of agriculture extension close to the sites, promoting agro-ecological practices within communities, saving and improving local agriculture practices, and development of biological quality products to support the livelihood of local people.

Although protected areas are a key tool for protecting species, many species has a wide coverage and occur outside these areas with other important species. They could also occur in other new areas according to the species distribution model. Therefore it is essential that biodiversity conservation is incorporated into a broader ecosystem management plan and integrated into public policy in other sectors that impact on species and their habitats, notably agriculture, forestry, urban planning and transport.

Communication and Education

Achieving successful conservation results depend on the participation of local people and the impact of natural resources on their livelihoods. Rising public awareness and identifying priorities is not enough. Conservation actions are required to support socio-economic development with a participative approach, improve the livelihoods of rural populations and establish an environmental educational program. This will require staff training, institutional strengthening and the development of local human resources.

Monitoring and research

Monitoring of the species, habitat status and constant evaluation of management practices are necessary to evaluate the success of management plans and conservation actions.

The Moroccan endemic monocot red list and the ecological niche models provide a baseline against which future progress can be assessed. They also provide the necessary data on species status, population size and trends, actual and predictive distribution, habitat requirements, threats, conservation actions and other information that will be of use to policymakers and conservation practitioner. However, more scientific research is needed mainly in floristic, biogeographical studies and inventories of threatened species to further develop appropriate conservation actions and policies.

Discussion

Analyzing the associated data with the conservation assessments of the Moroccan endemic monocot flora, considering the maps from the species distribution model and the threats evaluation we conclude that most of this endemic flora is threatened mostly by habitat loss and degradation, direct and indirect human disturbance, changes in vegetation dynamics, climate change and species intrinsic factors.

We concluded that urgent actions are needed to preserve the future of the Moroccan flora by sustainable management, legal protection of species and their habitats, education and research. In term of establishing conservation actions priorities, we took in consideration an appropriate approach with a combination of many threat factors from natural to human causes that act synergistically. Although limited action can be taken against natural causes, measures could be taken against other factors such as:

(i) Create and complete the regional network of protected areas with the proposed sites and floristic regions;
(ii) Complete the red listing of the flora and include the threatened vascular flora in the protected list;
(iii) Undertake an intensive monitoring programme for species population trends, habitat trends and conservation action
(iv) Control of human pressure, particularly the overgrazing of mountain areas and urbanisation development of coastal areas
(v) Perform research studies related to the conservation biology of the threatened flora.

As priority areas for conservation we highlighted primarily the Atlas (High Atlas, Anti Atlas and Middle Atlas), Rif Mountains and coastal areas (North Atlantic and Middle Atlantic of Morocco). Not only do they contain a considerable amount of this threatened flora, but these sites make up the centre of endemism, the Mediterranean biodiversity hotspot and are suitable sites for species reintroduction according to ecological niche models. However, other floristic regions are also of conservation concerns especially the Mediterranean Coast, North and Middle Atlantic of Morocco.

Our results also demonstrated that the current network of protected areas in Morocco and the conservation actions applied to date, do not appear to fulfil the conservation requirements of the country's threatened flora. However, in a country like Morocco where biodiversity is the main source of local people's livelihood, biodiversity loss will continue unless the conservation measures proposed are applied rapidly in a participative approach with local communities and the local people realize how important this biodiversity for their wellbeing and future .

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