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UTILIZATION AND TRANSFER GUIDELINES OF FOREST GENETIC RESOURCES IN MOROCCO: BIOGEOGRAPHIC SYSTEM AS A STRATEGIC PROVENANCE DECISION-MAKING TOOL

SUMMARY

The assessment of Regions of Provenance (RoP) to preserve local gene pools and prevent mal-adapted genotype introduction is a relevant tool for the correct management of Forest Genetic Resources (FGR). However, there is limited knowledge of RoP in Morocco and no previous study has focused on theirs bioclimatic and physical characterization in detail. A study was carried out with the aim of characterizing RoP and analysing their bioclimatic and physical characteristics. Characterization of these areas is performed by biogeographic-based approach, where the elevation and area has been chosen as physical variables and six environmental variables was considered as bioclimatic variables (primarily related to temperature and precipitation). High-resolution gridded geospatial data and long-time-series climate dataset of a reference normal period 1960-1990 was used to analyse the homogeneity within and between RoP, through Geographic Information System (GIS). The results reveal that despite the intra-region ecological similarity of the 19 obtained RoP, some regions are relatively heterogeneous in terms of physical (elevation) and bioclimatic variable (temperature and precipitation). This finding has been particularly observed for RoP at a high altitude. Thus, in order to improve the intra-region environmental homogeneity, the interest of inclusion of elevation bands to the established RoP. The proposed biogeographic scheme can be considered a starting point for germplasm movement, and should be utilized in in combination with appropriate information on climatic suitability between donor origin and restoration site.

Keywords: Region of Provenance, Bioclimatic Indices, Seed Transfer Guideline, Local Provenance, Germplasm Movement, Seed Zones

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INTRODUCTION

Biogeography as a discipline is closely linked and often collaborates and intersects with the disciplines of the broader realm of physical geography, such as Soil Geography - Pedology, Biogeochemistry, Ecology, Climatology, Geomorphology, but also Conservation Biology, Ecology, Climatology and researchers in these fields often work together to gain a comprehensive understanding of the complex interactions between organisms and their surroundings.

Biogeography, by studying the distribution of living organisms across the Earth's surface, is closely linked with forest conservation and plays a crucial role in informing and guiding forest conservation efforts in several ways, by assessing the diversity of plant and animal species within a forest or a particular region.

Biogeographic studies provide insights into the specific habitats and ecological niches that exist within a forest, as well as helps identify endemic species, which are unique to specific regions. Biogeography research also informs forest conservation by identifying invasive species and understanding their distribution; and can help predict how climate change may affect the distribution of species within forests. It is a fundamental tool in forest conservation providing the knowledge and data needed to make informed decisions about where and how to protect and manage forests to preserve their ecological integrity and the diverse life forms they support. By understanding the distribution of species and ecosystems, conservationists can develop effective strategies to safeguard forests for current and future generations.

The forests are among the most important natural ecosystems (Bozovic *et al*., 2022) and human dependence upon forests is a multifaceted phenomenon due to the fact that forests provide a diverse stream of benefits to humans (Adam & El Tayeb, 2014; Beckley, 1998). Forest conservation, sustainable use of forest genetics resources (FGR), and sustainable management of the numerous forest functions are the main goals of monitoring programs in forest ecosystems at the national and international levels (Schwartz *et al*., 2007). The Food and Agriculture Organization (FAO) of the United Nations appealed strongly for the establishment of monitoring systems in order to improve the information on forest genetic resources (FAO, 2014). Conserving and managing genetic diversity contribute to increasing overall resilience of forest ecosystems, by fostering tree adaptive responses to environmental changes and in mitigating the effects of pests and diseases (Alfaro *et al*., 2014, Fady *et al*., 2016).

Due to its geographical position, Morocco is characterized by a wide range of bioclimate and a great floristic richness (Medail and Quezel, 1997, MEMEE, 2009). However, the natural ecosystems in Morocco and especially forests are continuously affected by degradation (Cauvin *et al*., 1997). So there is an urgent need to protect Morocco's forest genetic resources.

Restoration guidelines widely advocate using local genetic material to maximize local adaptation (Ozbey and Bilir, 2022), enhancing resistance to high temperatures and drought (Kolupaev *et al*., 2023), limiting ‘pollution’ of local gene pools and preventing outbreeding depression (Callaham, 1964, Keller *et al*., 2000, Mortlock, 2000). Recommendations to use Regions of Provenance (RoP) as a practical provenance decision-making tool to guide the movement of germplasm-movement are rooted in scientific literature (Brown and Marshall, 1995, McKay *et al*., 2005). Several authors indicate that Regions of Provenance is a legal instrument and a compulsory tool for the management of forest genetic resources (Camerano *et al*., 2012, Marchi *et al*., 2016). However, there is limited knowledge of Regions of Provenance in Morocco and no previous study has focused on their bioclimatic and physical characterization in detail.

Several studies have highlighted the important role of bioclimatic and physical variables, in the geographic distribution and adaptation of forest plant species (Emberger, 1955, Benabid, 2000, Horning *et al*., 2010, Bradley *et al*., 2013). Thus, the main aims of this study were to establish accurate map and to perform detailed bioclimatic and physical characterization of the Region of Provenance, by using geographical information system techniques applied to long time-series climate dataset and high-resolution gridded geospatial data. In addition, by analyzing the environmental characteristics, the purpose is to enhance the understanding of physical and bioclimatic homogeneity within and between RoP, to provide a basis for monitoring and managing Moroccan forest genetic resources properly.

MATERIAL AND METHODS

Study Area. The study area of the research consists of the kingdom of Morocco which covers 710 850 km^2 (HCP, 2018), and located between 21° and 36° North latitude and between the 1st and the 17th degree of West longitude. It is limited from the West and East by the Atlantic Ocean and Algerian borders respectively and from the North by the Mediterranean Sea and from the South by the Mauritania's borders (Figure 1).

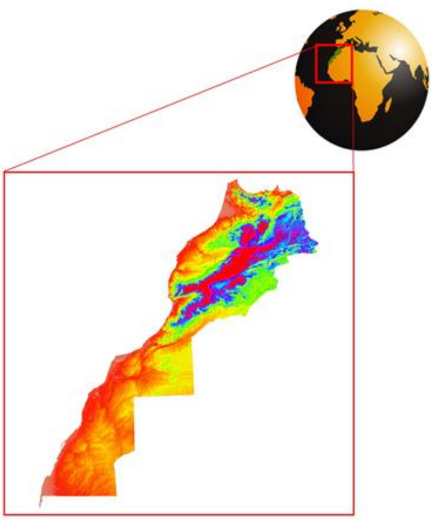


Figure 1: Map of the study area, showing the location of Morocco in the world map

Morocco is one of the most original countries in the North African region from a geographical, climatic and ecological point of view and, consequently, among the most interesting from a biological and biogeographical aspect (FAO, 2013). It contains 30 forest ecosystems covering an area of about 9 million hectares, of which 5.8 million hectares correspond to wooded forests (HCEFLCD, 2016). Its ecosystem is rich in flora, including more than 4,200 species and subspecies of vascular plants, among which, over 800 are endemic (Fennane *et al*., 1999, Fennane *et al*., 2007, Fennane *et al*., 2014).

Biogeographic system identification. As a tool commonly used in monitoring of forest genetic resources (Carolina, 1998), the Organization for Economic Cooperation and Development defined the Regions of Provenance (RoP) as a forest species or sub-species as: “the area or group of areas subject to sufficiently uniform ecological conditions in which stands or seed sources showing similar phenotypic or genetic characters Following this definition, the territory was firstly divided into relatively large Biogeographic Units (BgU) sharing great similarities in physical, topographical and forest characteristics. The resulting map was, secondly, used to delineate area subject to sufficiently uniform ecological conditions, designated as Regions of Provenance.

Lastly, the obtained RoP were classified using a coding system with two digits number. The first digit indicates the Biogeographic Units, and the second indicates the RoP within the biogeographic unit. They are written in Roman numerals system and Arabic numerals system respectively.

Characterization methodology. Taking into consideration these inferences to characterize BgU and RoP, an ensemble of eight environmental variables was used, as shown in Table 1. The Elevation and Area had been chosen as a physical variable, and six environmental variables were considered as bioclimatic variables (primarily related to temperature and precipitation).

Table 1. List of the bioclimatic and physical variables, at a spatial resolution of 1 km^2, used to characterize RoP.

Category of variables	**Acronym**	**Unit**	**Spatial variable**
Bioclimatic variables	AMT	°C	Annual Mean temperature
	MTWM	°C	Maximum temperature of warmest month
	MTCM	°C	Minimum temperature of coldest month
	AP	mm	Annual precipitation
	PWM	mm	Precipitation of wettest month
	PDM	mm	Precipitation of driest month
Physical variables	Elev	m	Elevation
	Ar	Km^2	Area

In addition, inter and intra-regional variations were examined based on statistical analysis of parameters related to the involved variables (mean, standard deviation, maximum and minimum values). To calculate values for the various parameters for each region, the zonal GIS techniques were performed by incorporating polygons of the RoP's vector maps and raster maps of the involved parameters.

Spatial data sourcing and analysis. As a period prior to the recent climatic disturbances, an average of 30 years of climate data from 1960-1990 with reference to normal periods was used.

The spatial climatic data were downloaded as grids at a 30 arc-seconds for about 1 km of resolution, from WorldClim dataset (Hijmans *et al*., 2005). The WorldClim codes of the six bioclimatic variables under investigation are as follows: Annual mean temperature (BIO1), Maximum temperature of warmest month (BIO5), Minimum temperature of coldest month (BIO6), Annual precipitation (BIO12), Precipitation of wettest month (BIO13) and Precipitation of driest month (BIO14).

As physical source data, the ASTER digital elevation model (DEM) with a spatial resolution of 30 m was used, which was freely available in Land Processes Distributed Active Archive Center (LPDAAC, 2022).

Furthermore, several detailed contributions for the whole country (Boudy and Guinier, 1958, Nanson, 1995, AEFCS, 1997), served as a basis database to collect biogeographical data.

The geospatial data were implemented, processed, analyzed and mapped using the open source Geographic Information System Quantum-GIS software (QGIS version 3.22). The statistical data analysis and graphing were performed using the open source Orange Software (ORANGE version 3.33.0).

RESULTS AND DISCUSSION

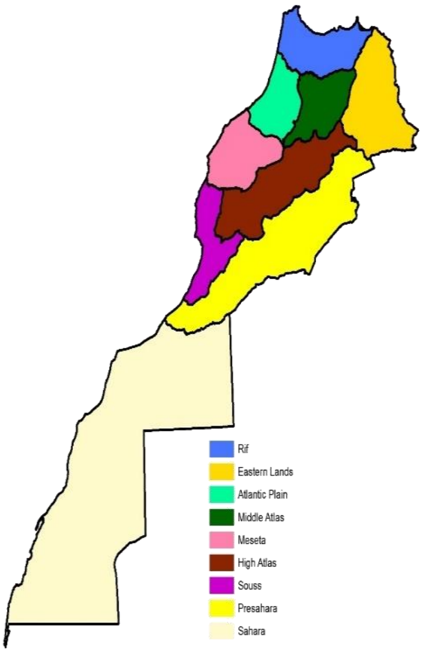
Regionalization scheme for FGR

The hierarchical organization of the Moroccan territory proposed as a biogeographic scheme for the management and conservation of forest genetic resources is presented in the Table 2.

The proposed regionalization scheme consists of the division of the country into 19 ecologically homogeneous disjointed regions for all species (Figure 2.a and 2.b). Thus, each portion of the territory is necessarily included in a RoP. This partitive method provides the advantage of defining the same Region of Provenance for all species under consideration, especially for the case of Morocco where information on population genetics and adaptation of forest species provenances are scarce.

Table 2. Regionalization scheme for FGR management and conservation in Morocco.

Biogeographic unit		**Region of provenance**	
Name	Acronym [Code]	Name	Acronym [Code]
Rif	RBgU [I]	Atlantic Rif	ARRoP [I.1]
		Western Rif	WRRoP [I.2]
		Eastern Rif	ERRoP [I.3]
Eastern Lands	ELBgU [II]	Moulouya Plain	MPRoP [II.1]
		High Plateaus	HPRoP [II.2]
Atlantic Plain	APBgU [III]	Maamora	MARoP [III.1]
		Central Plateau	CPRoP [III.2]
Middle Atlas	MABgU [IV]	Western Middle Atlas	WMARoP [IV.1]
		Eastern Middle Atlas	EMARoP [IV.2]
		Steppic Middle Atlas	SMARoP [IV.3]
Meseta	MBgU [V]	Atlantic Meseta	AMRoP [V.1]
		Continental Meseta	CMRoP [V.2]
High Atlas	HABgU [VI]	Western High Atlas	WHARoP [VI.1]
		Central High Atlas	CHARoP [VI.2]
		Eastern High Atlas	EHARoP [VI.3]
Souss	SBgU [VII]	North Souss	NSRoP [VII.1]
		South Souss	SSRoP [VII.2]
Presahara	PSBgU [VIII]	Presahara	PSRoP [VIII.1]
Sahara	MSBgU [IX]	Sahara	MSRoP [IX.1]



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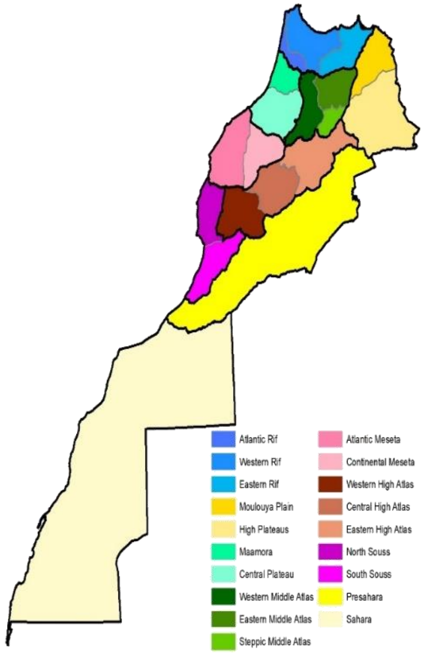

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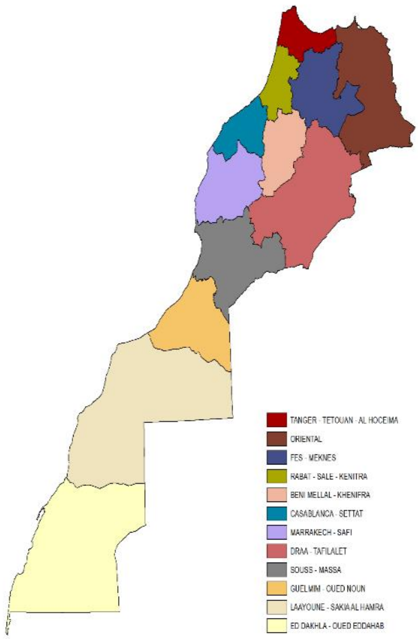


(c)

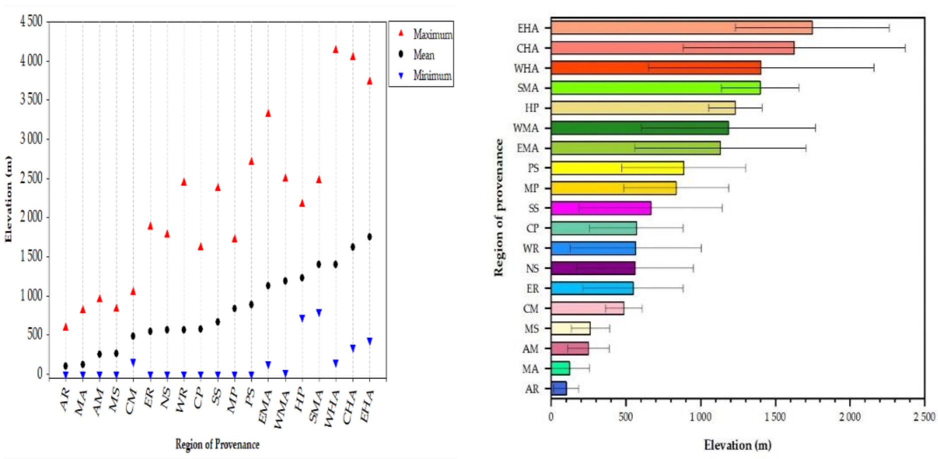
Figure 2:
a) Biogeographic Units,
b) Regions of Provenance and
c) Administrative regions maps of Morocco.

The delineated Regions of Provenance were significantly different from the Administrative Regions (AdR) shown in Figure 2.c, which had been published by the Higher Planning Commission in Morocco (HCP, 2018). Several cases were obtained according to the intersection RoP-AdR: Various Administrative Regions are fully included in a common Region of Provenance, the same RoP straddling several AdR and a single AdR covering many RoP.

Environmental characterization

Physical characteristics

The comparative analysis performed between Regions of Provenance (Figure 3), shows that the mean elevation varies from 100 m at the Atlantic Rif to 1 747 m at the Eastern High Atlas. Furthermore, the exam of altitudinal variations within RoP reveals that the minimum value 0 m has been obtained especially in the coastal regions (Atlantic Rif, Western Rif, Eastern Rif, Moulouya Plain, Maamora, Central Plateau, Atlantic Meseta, North Souss, South Souss, Presahara and Sahara RoP). The maximum value of 4 141 m was attained in Western High Atlas RoP.



(a) **(b)**

Figure 3: Fluctuation of elevation in m.
a) Within Regions of Provenance and b) Between Regions of Provenance.

The intra-region investigation (Table 3) shows relatively little variation within Region of Provenance at a low altitude. This is especially evident in the coastal regions. On the other hand, the elevation in interior regions varies widely (Western Middle Atlas, Eastern Middle Atlas, Western High Atlas, Continental Meseta, Central High Atlas, Eastern High Atlas, High Plateaus and Steppic Middle Atlas RoP).

Table 3. Physical characteristics, including area and elevation, of each Region of Provenance.

Bio-geographic unit	Region of provenance	Area		Elevation (m)		
		Surface (km²)	Part of Morocco (%)	Lower	Upper	Mean
Rif	Atlantic Rif	6 150	0.9	0	598	100
	Western Rif	19 700	2.8	0	2 450	564
	Eastern Rif	15 400	2.2	0	1 878	547
Eastern Lands	Moulouya Plain	17 400	2.4	0	1 719	835
	High Plateaus	41 300	5.8	728	2 174	1 231
Atlantic Plain	Maamora	9 400	1.3	0	813	122
	Central Plateau	20 400	2.9	0	1 624	570
Middle Atlas	Western Middle Atlas	14 800	2.1	21	2 494	1 186
	Eastern Middle Atlas	13 700	1.9	130	3 326	1 132
	Steppic Middle Atlas	6 100	0.9	792	2 480	1 399
Meseta	Atlantic Meseta	22 900	3.2	0	952	248
	Continental Meseta	16 300	2.3	164	1 049	486
High Atlas	Western High Atlas	20 300	2.9	154	4 141	1 403
	Central High Atlas	19 100	2.7	343	4 043	1 624
	Eastern High Atlas	26 700	3.8	434	3 735	1 747
Souss	North Souss	14 400	2.0	0	1 779	560
	South Souss	17 100	2.4	0	2 378	666
Presahara	Presahara	108 000	15.2	0	2 705	886
Sahara	Sahara	301 700	42.4	0	840	261

In terms of surface area (Figure 4), it appears that Sahara and Presahara RoP are significantly the greatest (with values of 301 700 and 108 000 km^2 respectively), while Steppic Middle Atlas and Atlantic Rif RoP are noticeably smaller (with values of 6 100 and 6 150 km^2 respectively).

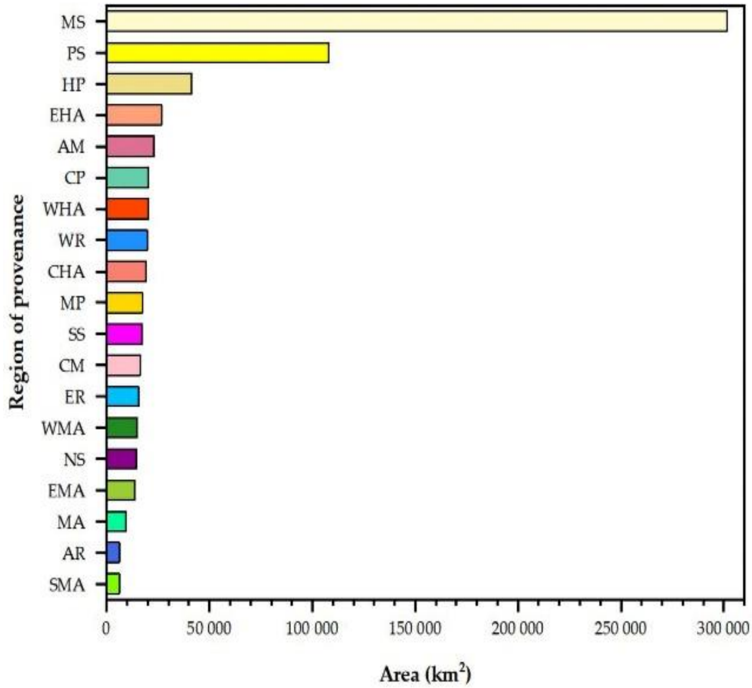


Figure 4: Area of various Regions of Provenance.

Bioclimatic characteristics

Temperature-related variables. The analyses of the temperature fluctuation within RoP (Table 4, Figure 5), indicate that:

-The annual mean temperature ranges from 0.8 to 27 °C in Morocco. The minimum of the annual mean temperature is recorded in the Western High Atlas. This region comprises the highest and the coldest segment of the entire Atlas range, including Mount Toubkal (ranging to over 4 167 m). The maximum of the annual mean temperature occurred in the Saharan Region of Provenance.

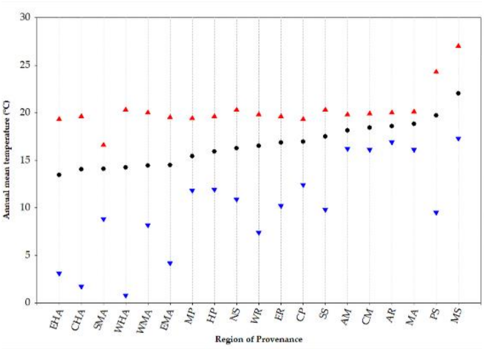
-The maximum temperature of the warmest month varies from 22 to 46.6 °C. The lowest maximum temperature of warmest month occurs in the mountain region of the Western High Atlas. The highest maximum temperature of warmest month occurs in the Presahara biogeographic unit.

-The minimum temperature of the coldest month is more than -15 °C and less than 13.6 °C. The smallest values have been found in the Central High Atlas, while the biggest values have been reached in the Sahara RoP.

As expected, the spatial pattern of temperature mean shows a large increase in the southern parts of Morocco over the Presaharan and Saharan RoP, and a significant decrease in temperature across the RoP belonging to the High and Middle Atlas, which extends over the Atlas chain.

Table 4. Characteristics of the bioclimatic variables related to temperature of RoP

Bio-geographic unit	RoP	Annual mean temperature (°C)			Max temperature of warmest month (°C)			Min temperature of coldest month (°C)		
		Lower	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**
Rif	Atlantic Rif	16.9	20.0	18.5	28.5	36.5	33.3	4.0	9.0	6.2
	Western Rif	7.4	19.8	16.5	26.3	36.9	31.9	-6.2	8.7	4.2
	Eastern Rif	10.2	19.6	16.9	28.1	37.0	32.1	-3.1	8.6	4.4
Eastern Lands	Moulouya Plain	11.8	19.4	15.4	28.0	34.3	31.3	-2.1	8.2	2.6
	High Plateaus	11.9	19.6	15.9	31.2	39.6	34.8	-3.8	3.2	0.6
Atlantic Plain	Maamora	16.1	20.1	18.8	28.2	36.6	33.7	2.8	8.2	6.8
	Central Plateau	12.4	19.3	17.0	27.7	39.6	33.7	-2.9	7.9	3.7
Middle Atlas	Western Middle Atlas	8.2	20.0	14.4	28.8	39.6	33.6	-7.2	7.3	-0.1
	Eastern Middle Atlas	4.2	19.5	14.5	25.7	37.0	32.8	-11.1	5.9	0.2
	Steppic Middle Atlas	8.8	16.6	14.1	29.1	35.3	33.1	-6.3	1.8	-0.5
Meseta	Atlantic Meseta	16.2	19.8	18.1	27.3	38.0	31.6	1.9	9.4	6.4
	Continental Meseta	16.1	19.9	18.4	31.1	39.6	36.4	1.2	6.1	4.3
High Atlas	Western High Atlas	0.8	20.3	14.2	22.0	38.2	31.9	-14.8	6.9	-1.0
	Central High Atlas	1.7	19.6	14.1	24.6	40.1	34.6	-15.0	4.8	-2.2
	Eastern High Atlas	3.1	19.3	13.5	25.8	40.6	34.3	-13.2	4.0	-2.4
Souss	North Souss	10.9	20.3	16.2	22.4	33.7	26.8	-2.0	10.4	5.1
	South Souss	9.8	20.3	17.5	24.5	35.4	29.9	-4.9	11.8	4.9
Presahara	Presahara	9.5	24.3	19.7	25.7	46.6	39.0	-7.5	11.5	2.7
Sahara	Sahara	17.3	27.0	22.0	24.1	44.6	34.5	4.2	13.6	10.4



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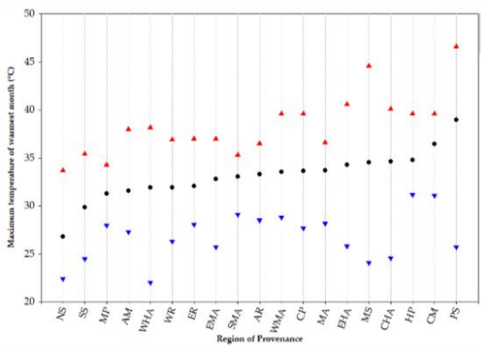

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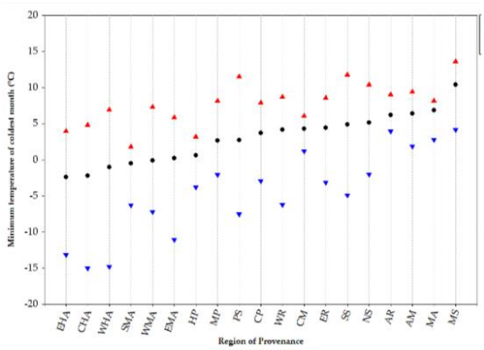

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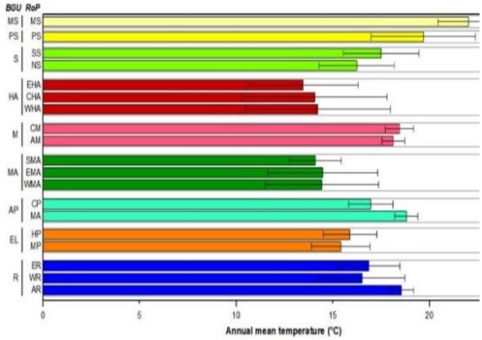
Figure 5. Temperature fluctuation within Regions of Provenance in degrees Celsius (°C). a) Annual mean temperature; b) Maximum temperature of warmest month; and c) Minimum temperature of coldest month.



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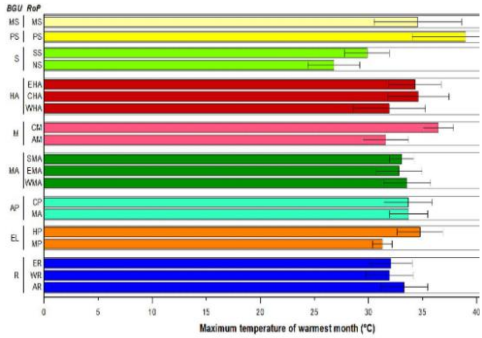

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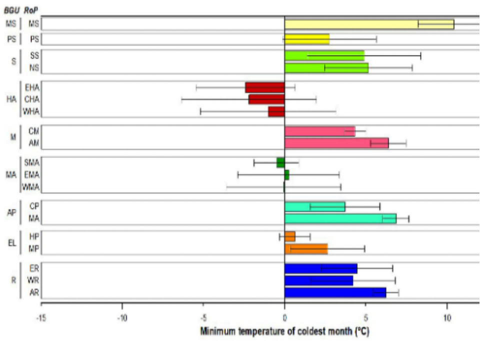

(c)

Figure 6. Temperature fluctuation between Regions of Provenance in degrees Celsius (°C). a) Annual mean temperature; b) Maximum temperature of warmest month; and c) Minimum temperature of coldest month.

On the other hand, in the Figure 6, the length of the various bars displays the mean with standard deviation of the data obtained for each RoP in terms of temperature-related variables.

The comparison between RoP shows that the annual mean temperatures ranged from 13.5°C at the Eastern High Atlas to 22°C at the Sahara. Concerning the mean maximum temperatures of the Warmest Month, the continental part of Presahara RoP registered the greatest value (39°C), while the Eastern High Atlas showed the lowest value of mean minimum temperatures, -2.4 °C, of the Coldest Month. Thus, based on the mean value by RoP, Eastern High Atlas is the coldest, whereas Presahara and Sahara are the warmest RoP. This can be explained by the effect of the high altitude on the Eastern High Atlas and the influence of the Saharan climate on the Presahara and Sahara RoP.

The mean values of bioclimatic variables for RoP over biogeographic units are relatively homogeneous. However, based on the findings of the standard deviation values, two main categories of RoP can be distinguished regarding the homogeneity of the data within the same Region of Provenance. The first category consists of the regions with low to medium altitude located in northern coasts of Morocco (e.g., Maamora, Central Plateau, Atlantic Meseta, Continental Meseta, Atlantic Rif), where the standard deviation values show a little variability in temperature. The second category includes RoP with relatively large variability, which is generally located in high altitude and/or extends across large areas (e.g., Western High Atlas, Central High Atlas, Western Middle Atlas, Eastern Middle Atlas, Presahara, and Sahara).

Precipitations-related variables. The analyses of the precipitation fluctuation within RoP (Table 5 and Figure 7), indicate that:

-The annual precipitation is more than 16 mm and less than 1182 mm. The smallest value has been found in the Sahara, while the biggest value is reached in the Western Rif RoP.

-The precipitation of the wettest month ranges from 4 to 205 mm. The minimum of precipitation of the wettest month is recorded in the Sahara RoP. The maximum of the precipitation of the wettest month occurs in Western Rif Region of Provenance.

-The precipitation of the driest month varies from 0 to 29 mm in Morocco. The lowest precipitation of driest month occurs in Atlantic Rif, Western Rif, Eastern Rif, Maamora, Central Plateau, Western Middle Atlas, Atlantic Meseta, Continental Meseta, Western High Atlas, North Souss, South Souss, Presahara and Sahara Regions of Provenance. The highest precipitation of the driest month occurs in the Eastern Middle Atlas RoP.

The spatial pattern of temperature means during the normal period 1960-1990 reveal that the mountainous RoP of the Rif and Atlas chains have received the highest amounts of precipitation, followed by the Atlantic and Eastern regions and then by the Southern regions.

Table 5. Characteristics of bioclimatic variables related to precipitation of RoP.

Bio-geographic unit	RoP	Annual precipitation (mm)			Precipitation of wettest month (mm)			Precipitation of driest month (mm)		
		Lower	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**	**Lower**	**Upper**	**Mean**
Rif	Atlantic Rif	542	950	672	94	169	125	0	1	0
	Western Rif	266	1182	737	44	205	125	0	12	1
	Eastern Rif	215	747	392	35	104	62	0	9	2
Eastern Lands	Moulouya Plain	197	555	303	28	74	42	1	10	3
	High Plateaus	133	404	257	18	67	34	1	11	4
Atlantic Plain	Maamora	460	750	546	80	129	102	0	2	0
	Central Plateau	365	875	521	66	133	86	0	6	1
Middle Atlas	Western Middle Atlas	389	929	641	52	140	93	0	14	6
	Eastern Middle Atlas	165	851	397	23	102	55	1	29	6
	Steppic Middle Atlas	174	531	293	25	67	40	4	15	7
Meseta	Atlantic Meseta	236	417	331	33	81	57	0	3	0
	Continental Meseta	235	528	372	33	93	62	0	3	1
High Atlas	Western High Atlas	218	992	439	33	122	62	0	27	3
	Central High Atlas	147	890	432	25	108	62	1	27	4
	Eastern High Atlas	124	833	369	19	121	51	1	28	7
Souss	North Souss	218	518	322	36	73	53	0	4	1
	South Souss	118	463	230	27	68	40	0	4	1
Presahara	Presahara	32	502	129	9	72	23	0	9	1
Sahara	Sahara	16	128	42	4	34	10	0	1	0

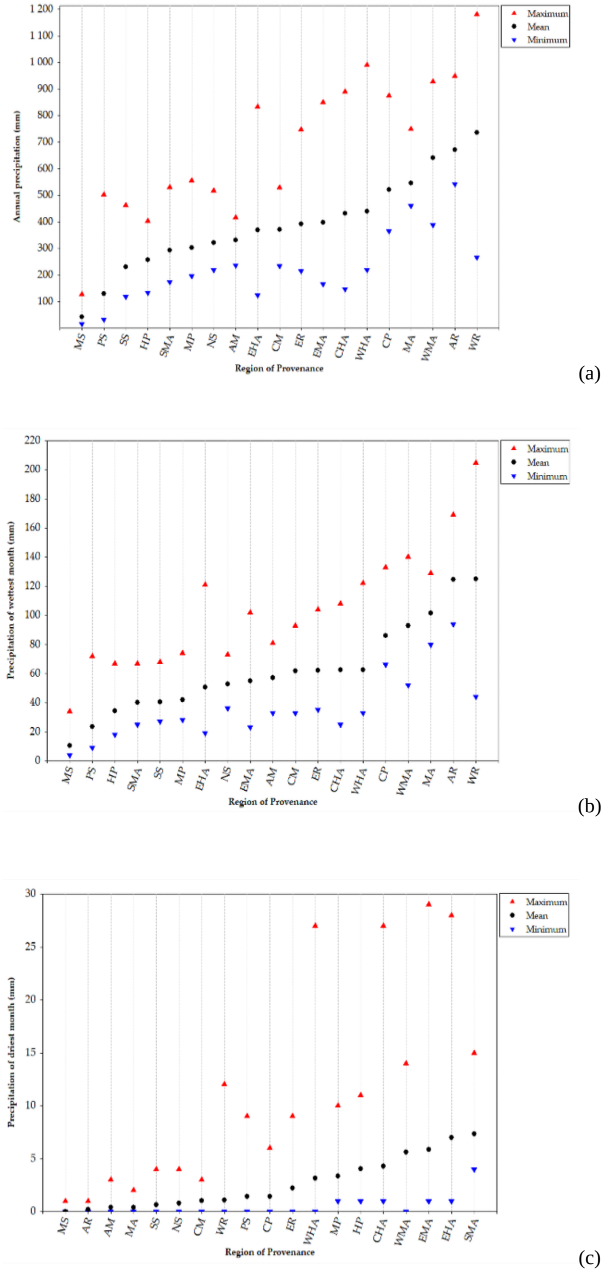

Figure 7. Precipitation fluctuation within Regions of Provenance in millimetres (mm). a) Annual precipitation; b) Precipitation of wettest month; and c) Precipitation of driest month.

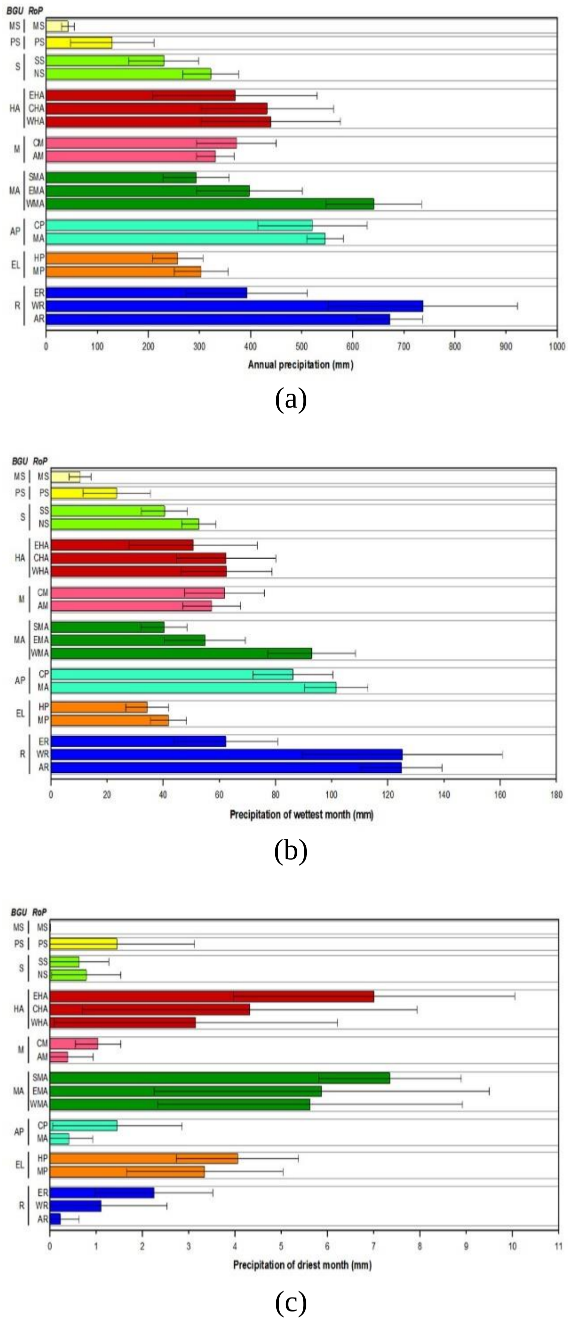

Figure 8. Precipitation fluctuation between Regions of Provenance in millimetres (mm). a) Annual precipitation; b) Precipitation of wettest month; and c) Precipitation of driest month.

At the same time, the length of the various bar in the Figure 8 displays the mean and standard deviation of the data obtained for each RoP in terms of precipitations-related variables.

Regarding the precipitations, the comparison between RoP shows that the mean annual precipitations vary between 42 mm and 737 mm in the Sahara and high mountains of the Western Rif respectively. With a notable decreasing gradient from north to south, mean precipitations of wettest month exceed 125 mm at the Western and Atlantic Rif, when the mean precipitations of driest month are less than 1 mm at Sahara, Atlantic Rif, Atlantic Meseta and Maamora RoP.

As seen in the case of temperature, two main groups of RoP can also be identified according to their intra-regional homogeneity and the precipitation means values. One group is formed by Regions of Provenance located in area without pronounced topographic features, which are characterized by little variability in precipitation (e.g. Maamora, Atlantic Meseta, and Sahara). The other group, for which the standard deviation analysis shows relatively large variability, contains the major Regions of Provenance situated in medium and high mountainous parts of the country (e.g. Western High Atlas, Central High Atlas, Eastern High Atlas, Western Middle Atlas, Eastern Middle Atlas, South Souss, Central Plateau, Continental Meseta, and Presahara).

In several countries, the RoP constitutes a valuable framework used in forestry to manage forest genetic resources (Carolina, 1998, O'Neill and Aitken, 2004, St Clair, 2014). The Regions of Provenance proposed in this study delineate areas with sufficiently uniform ecological conditions within which forest seed, cuttings and planting stock can be moved with loss of productivity and limited risk of maladaptation. It represents an essential tool to guide the choice of appropriate germplasm for forest restoration in Morocco.

On the whole, the obtained BgU presents great similarity with the structural domains of Morocco, which have been identified based on their geomorphological characteristics and geological features (Michard, 1976, Hoepffner, 1987, El Hassani, 1990, Piqué, 1994, Piqué *et al*., 2007). Furthermore, the comparison with the levels of vegetation for Moroccan flora proposed by Benabid (Benabid, 2000), shows relatively high correspondence to the Regions of Provenance presented in this study, which indicates that the method adopted to delimitate RoP allows to obtain areas that are ecologically homogeneous.

The RoP identified are significantly different from the administrative regions. Therefore, these administrative regions cannot be used as technical or regulatory instrument to invent, preserve or manage RGF. Similar results are founded by several countries adopting the partitive method to establish the regions of provenance (CEMAGREF, 2003, BFW, 2017, UKFC, 2017).

However, despite their intra-region ecological similarity, it has been shown that some RoP are relatively heterogeneous in terms of physical (elevation) and bioclimatic variables (temperature and precipitation). This finding has been particularly observed for RoP at medium and high altitude.

To improve the homogeneity of Regions of Provenances obtained in this study, the use of elevation bands within RoP would be of interest, as recommended by several authors in the case of authors' countries (Adams and Campbell, 1982, Conkle, 1997). This requires more information on the establishment of ecotypes from each RoP (survival, growth, productivity, etc.), based on reciprocal transplant studies evaluating intra-specific local adaptation.

Such information would certainly require substantial amounts of time. While waiting for this, the study proposes to adopt a provisional germplasm movement system using the proposed Regions of Provenance in conjunction with generalized elevation bands in 500-meter increments. The resulted Sub regions called "Seed Zones" are intended to be applied to all species.

To number the provisional system, this study recommends the adoption of the three-digit method of designation (XYZ), developed by the Western Forest Tree Seed Council in 1966 (Buck *et al*., 1970), as a coding system for seed zones. The first digit indicates the Biogeographic Units (X), the second designates the Region of Provenance (Y), and the third precise the Seed Zone (Z) within the RoP. The value of Z, written in Arabic numerals system, represents the top of the elevation range band where germplasm was collected, as follows: Z=5 for [0-500 m] range band, Z=10 for [501-1000 m] range band, Z=15 for [1001-1500 m] range band, Z=20 for [1501-2000 m] range band, Z=25 for [2001-2500 m] range band, Z=30 for [2501-3000 m] range band, Z=35 for [3001-3500 m] range band, Z=40 for [3501-4000 m] range band and Z=45 for [4001-4500 m] range band.

Within these Seed Zones, genetic material can be safely transferred from a source environment to a planting environment, with preservation of local gene pools and prevention of mal-adapted genotype introduction.

CONCLUSION

To preserve forest genetic resource in Morocco and avoid introducing nonlocal and potentially mal-adapted genotype, it is necessary to identify areas that ensured safe movement of forest germplasm and to express them spatially.

The current paper is a pioneer study that uses accurate geospatial data and long-time-series climate dataset, to provide a detailed bioclimatic and physical characterization of Regions of Provenance.

In this study, Moroccan territory was hierarchically structured into 19 Regions of Provenance concentrated in 9 Biogeographic Units. The environmental characteristics of each RoP were also described with an ensemble of eight environmental variables (6 bioclimatic and 2 physical variables), related to the local adaptation of forest species.

The calculation procedure of the statistical parameters related to various variables for each Region (mean, standard deviation, maximum and minimum values), was performed with zonal GIS techniques, by incorporating polygons of the RoP's vector maps and the raster maps of the involved parameters.

This study is an attempt to provide a precise regionalization scheme to manage forest genetic resources. It is significant that this study enhances the understanding of biogeographical arrangement of the Moroccan territory and investigates physical and bioclimatic homogeneity across each region.

In addition, it shows the interest of inclusion of elevation bands to the proposed Regions of Provenance, in order to improve the intra-region homogeneity.

Therefore, further studies on intra-specific local adaptation by species, should be conducted in order to refine the range of altitudinal bands, by studying other criteria that we have not considered, such as: microclimate (frost corridor, side effect), soil characteristics (acidity, salinity, compaction, mineral wealth, rooting depth, waterlogging), extreme weather events (drought episode, heatwave), biotic risks (fungal pathogen infection, insect pest attack), abiotic risks (forest fire, storms), and human impacts (land cover, silviculture).

REFERENCES

Adam, Y. O., El Tayeb, A.M. 2014. Forest dependency and its effect on conservation in Sudan: A case of Sarf-Saaid Reserved Forest in Gadarif State. Agriculture and Forestry, 60 (3): 107-121

Adams T., Campbell R. K. 1982. Genetic adaptation and seed source specificity, in Proceedings of a Workshop on Reforestation of Skeletal Soils, Oregon State University, Corvallis, Oregon, USA, SD H. and OT H., Eds., 17-19 November 1981 1982, Oregon, USA: Oregon State University. Forest Research Laboratory, Published, pp. 78–85. https://www.worldcat.org/fr/title/81890991

AEFCS. 1997. Les ressources génétiques forestières au Maroc, Administration des eaux, des forêts et de la conservation des sols ed. Rabat, Morocco: Ministère de l'agriculture et de la réforme agraire, 72 p.

Alfaro R. I., Fady B., Vendramin G. G., Dawson I. K., Fleming R. A., Sáenz-Romero C., Lindig-Cisneros R. A., Murdock T., Vinceti B., Navarro C. M. 2014. The role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change, Forest Ecology and Management, vol. 333, 76-87, doi: https://doi.org/10.1016/j.foreco.2014.04.006.

Beckley T.M. 1998. The nestedness of forest dependence: A conceptual framework and empirical exploration. Society and Natural resources, 11(2):101-121.

Benabid A. 2000. Flore et écosystèmes du Maroc: Evaluation et préservation de la biodiversité, Ibis Press ed. Rabat, Maroc: Kalila Wa Dimna, 359 p.

BFW. Austrian regions of provenance. https://bfw.ac.at/rz/bfwcms.web?dok=4930 (30 July 2023).

Boudy P. L. J., Guinier P. 1958. Description forestière du Maroc, in Économie forestière nord-africaine, vol. Tome III, PLJ B. and P G. Eds., no. Tome III). Paris, France: Larouse, ch. Description forestière du Maroc, 375.

Bozovic, D., Knezevic, M., Aleksic, M., Iker, O., Gostimirovic, L. 2022. Forest fire risk management information systems. Agriculture and Forestry, 68 (2): 65-81. doi:10.17707/AgricultForest.68.2.05

Bradley S. C. J., Kilkenny F. F., Johnson R. C., Shaw N. L., Weaver G. 2013. Genetic variation in adaptive traits and seed transfer zones for Pseudoroegneria spicata (bluebunch wheatgrass) in the northwestern United States, Evolutionary Applications, vol. 6, no. 6, 933-948, doi: https://doi.org/10.1111/eva.12077.

Brown A. H. D., Marshall D. R. 1995. A basic sampling strategy: theory and practice, in Collecting plant genetic diversity: technical guidelines, L G., RV R., and R R.

Eds. Wallingford, USA: CAB International, ch. A basic sampling strategy: theory and practice, 75-91.

Buck J. M., Adams R. S., Cone J., Conkle M. T., Libby W. J., Eden C. J., Knight M. 1970. California tree seed zones, Forest Service ed. San Francisco, California, USA: US Department of Agriculture, 7 p.

Callaham R. Z. 1964. Provenance research: investigation of genetic diversity associated with geography, FAO of the United Nations, Rome, Italy, https://www.fs.usda.gov/psw/publications/callaham/psw_1963_callaham001.pdf

Camerano P., Ferrazzini D., Ducci F., Belletti P. 2012. Regioni di Provenienza per l'abete bianco. Sherwood foreste ed alberi oggi. 35-40. Online available from www.rivistasherwood.it (30 July 2023).

Carolina V. M. 1998. Regions of Provenance for cork oak in Portugal, International Plant Genetic Ressources Institute, Sardinia, Italy & Almoraima, Spain, 9-12 June 1996 & 20-22 February 1997. Online available from https://www.euforgen.org/uploads/tx_news/130_Quercus_suber_network.Report_of_the_3rd_and_4th_meetings__9-12_June_1996__Sassari__Sardinia__Italy__20-22_February_1997__Almoraima__Spain.QS_0304.pdf (30 July 2023).

Cauvin B., Marien J. N., El Yousfi S. M. 1997. Protection, conservation et gestion des ressources génétiques forestiers au Maroc, in Annals of Forestry Research, SM E. Y. Ed. Rabat, Morocco: Forestry Research Center, ch. Protection, conservation et gestion des ressources génétiques forestiers au Maroc, 178-195.

CEMAGREF. 2003. Conseils d'utilisation des matériels forestiers de reproduction: régions de provenance, variétés améliorées, Direction générale de la forêt et des affaires rurales ed. Paris, France: Centre d'Étude du Machinisme Agricole et du Génie Rural des Eaux et Forêts, 20 p.

Conkle M. T. 1997. Zonificación de semillas en México, in Manejo de Recursos Genéticos Forestales, JJ V., B H., Y B., and T L. Eds. Montecillo, México: Colegio de Postgraduados, ch. Zonificación de semillas en México, 67-88.

El Hassani A. 1990. La bordure nord de la chaîne hercynienne du Maroc, Es-sciences Thesis, Institut de géologie, Louis pasteur University, Strasbourg, France, Online available from https://hal.archives-ouvertes.fr/tel-01256284/document

Emberger L. 1955. Une classification biogéographique des climats, in Recueil des Travaux des Laboratoires de Botanique, Géologie et Zoologie, vol. 7, Sci F. Ed. Montpellier, France: Faculté des Sciences de L'Université de Montpellier, ch. Une classification biogéographique des climats, 3-43.

Fady B., Cottrell J., Ackzell L., Alía R., Muys B., Prada A., González-Martínez S. C. 2016. Forests and global change: what can genetics contribute to the major forest management and policy challenges of the twenty-first century?, Regional Environmental Change, vol. 16, no. 4, 927-939, doi: https://doi.org/10.1007/s10113-015-0843-9.

FAO. 2013. Etat des ressources génétiques forestières mondiales - Le Royaume du Maroc, Food and Agriculture Organization of the United Nations. Rome, Rome, Italy. Online available from https://www.fao.org (30 July 2023).

FAO. 2014. The state of the World's Forest Genetic Resources, Commission on Genetic Resources for Food and Agriculture, Food and Agriculture Organization of the United Nations, Rome, Italy, 9251084025. Online available from http://www.fao.org/3/a-i3825e.pdf (30 July 2023).

Fennane M., Ibn Tattou M., El Oualidi J. 1999. Volume 1 : Pteridophyta, Gymnospermae, Angiospermae (Lauraceae-Neuradadeae), in Flore Pratique du Maroc, Fennane M., Ibn Tattou M., Mathez J., Ouyahya A., and El Oualidi J. Eds., OKAD ed. Rabat, Morocco: Institut Scientifique, Université Mohammed V, ch. Volume 1 : Pteridophyta, Gymnospermae, Angiospermae (Lauraceae-Neuradadeae), 1-558.

Fennane M., Ibn Tattou M., El Oualidi J. 2007. Volume 2 : Angiospermae (Leguminosae-Lentibulariaceae), in Flore Pratique du Maroc, Fennane M., Ibn Tattou M., Mathez J., Ouyahya A., and El Oualidi J. Eds., OKAD ed. Rabat, Morocco: Institut Scientifique, Université Mohammed V, ch. Volume 2 : Angiospermae (Leguminosae-Lentibulariaceae), 1-635.

Fennane M., Ibn Tattou M., El Oualidi J. 2014. Volume 3 : Dicotylédones, Monocotylédones, in Flore Pratique du Maroc, Fennane M., Ibn Tattou M., Mathez J., Ouyahya A., and El Oualidi J. Eds., OKAD ed. Rabat, Morocco: Institut Scientifique, Université Mohammed V, ch. Volume 3 : Dicotylédones, Monocotylédones, 1-800.

HCEFLCD. 2016. Le Maroc Forestier: Stratégie du Secteur des Eaux et Forêts, Niras International Development Consulting ed. Rabat, Maroc: Haut Commissariat aux Eaux et Forêts et à la Lutte contre la Désertification, 76 p.

HCP. 2018. Le Maroc des Régions, Haut Commissariat au Plan ed. Rabat, Maroc: HCP, 186 p.

Hijmans R. J., Cameron S. E., Parra J. L., Jones P. G., Jarvis A. 2005. Very high resolution interpolated climate surfaces for global land areas, International Journal of Climatology, vol. 25, no. 15, 1965-1978, doi: https://doi.org/10.1002/joc.1276.

Hoepffner C. 1987. La tectonique hercynienne dans l'Est du Maroc, Es-sciences Thesis, Institut de géologie, Louis pasteur University, Strasbourg, France, Online available from https://theses.hal.science/tel-01340643/file/Hoepffner,%201987_A4.pdf

Horning M. E., McGovern T. R., Darris D. C., Mandel N. L., Johnson R. 2010. Genecology of holodiscus discolor (Rosaceae) in the Pacific Northwest, Restoration Ecology, vol. 18, no. 2, 235-243, doi: https://doi.org/10.1111/j.1526-100X.2008.00441.x.

Keller M., Kollmann J., Edwards P. 2000. Genetic introgression from distant provenances reduces fitness in local weed populations, Journal of Applied Ecology, vol. 37, no. 4, 647-659, doi: https://doi.org/10.1046/j.1365-2664.2000.00517.x.

Kolupaev, Y.E,. Yastreb, T.O., Ryabchun, N.I., Kuzmyshyna, N.V., Shkliarevskyi, M.A., Barabolia, O., Pysarenko, V.M. 2023. Response of Triticum aestivum seedlings of different ecological and geographical origin to heat and drought: relationship with resistance to oxidative stress and osmolyte accumulation. Agriculture and Forestry, 69 (2): 83-99. doi:10.17707/AgricultForest.69.2.07

LPDAAC. The NASA EOSDIS Land Processes Distributed Active Archive Center at the USGS Earth Resources Observation and Science Center, Sioux Falls, South Dakota, USA. Online available from https://lpdaac.usgs.gov (30 July 2023).

Marchi M., Chiavetta U., Castaldi C., Di Silvestro D., Contu F., Ducci F. 2016. Regions of provenance for reproductive materials of the three main forest species of Abruzzi, Journal of Maps, vol. 12, no. 1, 94-97, doi: https://doi.org/10.1080/17445647.2016.1159886.

McKay J. K., Christian C. E., Harrison S., Rice K. J. 2005. "How local is local?"a review of practical and conceptual issues in the genetics of restoration, Restoration

Ecology, vol. 13, no. 3, 432-440, doi: https://doi.org/10.1111/j.1526-100X.2005.00058.x.

Medail F., Quezel P. 1997. Hot-spots analysis for conservation of plant biodiversity in the Mediterranean Basin, Annals of the Missouri Botanical Garden, 112-127, doi: https://doi.org/10.2307/2399957

MEMEE. 2009. Quatrième Rapport National sur la Biodiversité, Département de l'Environnement ed. Rabat, Maroc: Ministère de l'Energie, des Mines, de l'Eau et de l'Environnement, 111 p.

Michard A. 1976. Eléments de Géologie marocaine, Service géologique du Maroc ed. Maroc: Ministère du Commerce, de l'Industrie, des Mines et de la Marine Marchande, 408 p.

Mortlock B. W. 2000. Local seed for revegetation: where will all that seed come from?, Ecological Management and Restoration, vol. 1, no. 2, 93-101, doi: https://doi.org/10.1046/j.1442-8903.2000.00029.x.

Nanson A. 1995. Consultation en amélioration des arbres forestiers au Maroc, Direction des eaux, des forêts et de la conservation des sols ed. Rabat, Maroc: Ministère de l'agriculture et de la réforme agraire, 115 p.

OECD. 1974. EOCD scheme for the control of forest reproductive material moving in international trade, The Organisation for Economic Co-operation and Development. Online available from https://www.oecd.org/agriculture/forest (30 July 2023).

OECD. 2019. OECD forest seed and plant scheme. Rules and regulations, The Organisation for Economic Co-operation and Development. Online available from https://www.oecd.org/agriculture/forest (30 July 2023).

O'Neill G. A., Aitken S. N. 2004. Area-based breeding zones to minimize maladaptation, Canadian Journal of Forest Research, vol. 34, no. 3, 695-704, doi: https://doi.org/10.1139/x03-227.

Ozbey, A.A., Bilir, N. 2022. Variation in growth among provenances of Pinus brutia in a 32-year-old experiment from southern Turkey. Agriculture and Forestry, 68 (2): 83-91. doi:10.17707/AgricultForest.68.2.06

Piqué A. 1994. Géologie du Maroc, les domaines structuraux et leur évolution structurale, Editions PUMAG ed. Marrakech, Maroc, 284 p.

Piqué A., Soulaimani A., Hoepffner C., Bouabdelli M., Laville E., Amrhar M., Chalouan A. 2007. Géologie du Maroc (nouvelle édition), Editions GEODE ed. Marrakech, Maroc, 287 p.

Schwartz M. K., Luikart G., Waples R. S. 2007. Genetic monitoring as a promising tool for conservation and management, Trends in Ecology and Evolution, 22(1): 25-33.

St Clair B. 2014. The development of forest tree seed zones in the Pacific Northwest of the United States, The Food and Agriculture Organization of the United Nations, Rome, Italy. http://ifgtbenvis.in/build/bibilography/b2.pdf#page=57

UKFC. Regions of provenance and native seed zones. Forestry Commission. Online available from https://www.data.gov.uk/dataset/754ca42f-f2e0-4eb3-a4d1-3bcbce33d3fc/gb-regions-of-provenance (30 July 2023).