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A Conceptual Framework for Conservation and Management of Moroccan Forest Genetic Resources Using Biogeography-Based Approach

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ABSTRACT

The introduction of mal-adapted genotype is a major concern in conservation and management of forest genetic resources. This is risky because it potentially threatens the integrity of the natural genetic structure of populations. Therefore, it is necessary to provide guidance on the choice of appropriate germplasm and determine how far it can be moved from its native environment. The most basic guidelines for germplasm movement involve the use of Regions of Provenance (RoP). The RoP for a forest species or sub-species is the area or group of areas subject to sufficiently uniform ecological conditions in which stands or seed sources showing similar phenotypic or genetic characters are found, taking into account altitudinal boundaries where appropriate. However, there is little information concerning Regions of Provenance and limited knowledge about safe limits to the movement of seed, cuttings and planting stock in Morocco. This paper establishes a conceptual framework based on Regions of Provenance that is designed to better understand, protect and use forest genetic resources in Morocco, especially the species for which no specific knowledge on local adaptation or no data about population differentiation are currently available. This is the first study that represents a precise map of Regions of Provenance for Moroccan forest reproductive material and that provides detailed description on topographical, environmental and forest characteristics that characterize each Region of Provenance, by using geographical information system (GIS) techniques. A biogeography-based approach was applied and revealed that the territory was hierarchically organized into 2 Biogeographic Divisions, 9 Biogeographic Units and 19 Regions of Provenance. The RoP proposed are intended as a practical provenance decision-making tool to guide the movement of forest reproductive material in Morocco. This ensures the traceability of planting stock throughout the harvesting-seedling production-plantation process to a specified Forest Basic Material.

Keywords: region of provenance; local provenancing; germplasm movement; forest reproductive materials; seed transfer guideline; provenancing strategy

INTRODUCTION

Forests are the most important reservoirs of biodiversity in terrestrial ecosystems. They offer a wide variety of products and services. Maintaining genetic variation of this unique and irreplaceable repository is vital, not only now, but also for the future generations.

Forest genetic resources (FGR), which represent the heritable materials contained within and between forest plant species (FAO 2002), are at the root of sustainable forest management, providing the basis to safeguard their health (EUFORGEN 2021). Moreover, they are essential for the adaptive capacity and the evolutionary processes of forests (FAO 2014b). Their genetic diversity, both inter and intraspecific, promotes survival and good growth while at the same time enhances resilience and resistance to biotic and abiotic stresses, such as environmental variations, including those caused by climate change (Dawson et al. 2009, Pautasso 2009, Schueler et al. 2012) or pests and diseases (Schweitzer et al. 2005, Cardinale et al. 2012).

Due to its privileged position between oceanic, continental and Saharan influences, Morocco is of the

largest biodiversity hotspot in the Mediterranean Basin after Turkey (Medail and Quezel 1997, MEMEE 2009). It has a very rich natural heritage, 39 terrestrial ecosystems, including 30 forest ecosystems covering an area of approximately 9 million hectares, among which 5.8 million hectares corresponds to wooded forests (HCEFLCD 2016). The identified terrestrial ecosystems are home to more than 4,200 vascular plant species and subspecies, including more than 800 endemic ones (Fennane et al. 1999, Fennane et al. 2007, Fennane et al. 2014). The climate is Mediterranean across the greater part of the territory, but it is strongly influenced by the ocean (Sauvage 1963, Achaal et al. 1980).

The Moroccan forests provide environmental, economic and social functions valued at 17 billion dirhams per year. In addition to its role in protecting the environment and combating desertification, the forestry sector also participates in the socio-economic development of rural populations. It generates an annual value of about 5 billion dirhams to users, who represent nearly half of the rural population. The activities undertaken annually in the sector create eight to ten million working days (the equivalent of 50,000 permanent jobs). Moreover, the forestry sector contributes to 30% of the country's needs in lumber and industrial wood (600,000 $m^3 \cdot year^{-1}$), 18% of the national energy balance (4 million tons of oil equivalent), 4% of the world supply of cork (150,000 quintals·$year^{-1}$) and 17% of the needs of livestock for forage (equivalent to 15 million quintals of barley) (DEF 2020).

However, in view of the alarming levels of degradation of natural ecosystems, it is particularly urgent to conserve forest genetic resources in Morocco (Cauvin et al. 1997).

The conservation of these resources aims to preserve groups of genotypes or populations and their various combinations of genes (Gregorius 1991) by maintaining conditions where the genetic composition of a species can continue to evolve in response to changes in its environment (Eriksson 2001). It was also the reason why FAO has launched a global plan of action for the conservation, sustainable use and development of forest genetic resources in 2014 (FAO 2014a).

The introduction of nonlocal and potentially maladapted genotype is a major concern in conservation of forest genetic resources. A number of studies have shown that in most cases, using locally adapted populations not only preserves alleles that are adapted to local conditions but also prevents numerous dangers regarding the introduction of non-local material (Kawecki and Ebert 2004, Bischoff et al. 2006, Urban et al. 2008, Bischoff et al. 2010). These include the disruption of genotype frequencies across geographic areas, the introduction of genes poorly adapted to local conditions, the fixation of maladapted genotypes due to genetic drift, impaired ability to adapt to future environmental change and potential threats to the integrity of the natural genetic structure of populations (Jones 2013). The transfer of germplasm has also raised concerns, such as the potential for spreading pests and diseases (Koskela et al. 2014). Several authors argued that the use of local materials reduce outbreeding depression and genetic swamping in natural populations (Hufford et al. 2003, Crémieux et al. 2010, Vander Mijnsbrugge et al. 2010).

In addition, it has been shown that local plants performed significantly better than foreign plants at their site of origin (Leimu and Fischer 2008, Hereford 2009), because they have higher fitness, higher levels of survival, reproduction, productivity, disease resistance and abiotic resilience than non-local materials.

However, the use of "local" germplasm is hampered by the lack of knowledge concerning the question "how local is local?" (McKay et al. 2005). Thus, there is a need for guidance on the choice of appropriate germplasm for forest restoration in Morocco, and also for determining how far it can be moved from its native environment.

The most basic guidelines for germplasm-movement involve the use of Regions of Provenance (RoP). This is an essential tool currently used in forestry practice to manage forest genetic resources (Carolina 1998). An additional benefit of RoP is that they contribute to maintaining genetic diversity and structure of forest trees at landscape scales that are likely most important for adaptation (St Clair 2014). The use of well-adapted provenances can give many advantages, from survival rate to growth rate (O'Neill and Aitken 2004).

"Local-is-best" is the pivotal assumption that has given rise to the delineation of Regions of Provenance (De Kort et al. 2014). This means that, even with limited or no knowledge of genetic structure of a species, a reasonable assumption is that native populations are at least relatively adapted to their local environments (Savolainen et al. 2007).

The definition of Regions of Provenance has been discussed by several authors (e.g. Burley et al. 1976, Zobel and Talbert 1984). According to the definition published by the Organization for Economic Cooperation and Development (OECD 1974, OECD 2019), the RoP for a forest species or sub-species can be defined as following: "the area or group of areas subject to sufficiently uniform ecological conditions in which stands or seed sources showing similar phenotypic or genetic characters are found, taking into account altitudinal boundaries where appropriate".

The definition of Regions of Provenance is not only scientific, it is, first of all, a legal instrument (Camerano et al. 2012). Following several countries' regulations, the Regions of Provenance are a compulsory tool for the management of forest genetic resources; thus, the country must create its own map of RoP, according to the ecological variability of its environment, its administrative structure and its most valuable forest species (Marchi et al. 2016).

Establishing Regions of Provenance is an important tool in the implementation of the scheme for the certification of forest reproductive material moving through international trade (OECD 2019). All the activities connected to the nursery process and reforestation (e.g. forest reproductive material, forest basic materials), must be linked to the RoP (Marchi et al. 2016).

However, there is little information concerning Regions of Provenance and limited knowledge about safe limits to the movement of forest reproductive material in Morocco. No previous study has mapped and described RoP in detail. Currently, no precise tools are available to restoration actors to minimize maladaptation in forest plantations. Therefore, given the huge environmental variability of Morocco

(Benabid 1982b), there is a demand for guidelines on the movement of forest reproductive material that (1) regulate the movement between donor origin and restoration site, and (2) are practical and operationally manageable.

The objectives of this paper were: (i) to present a conceptual framework that is designed to help researchers, practitioners and administrators to better conserve and manage Forest Genetic Resources in Morocco and (ii) to show the delineation, mapping and description of the Regions of Provenance through a biogeography-based approach that can be used as a guide for specifying sources and control movement of forest reproductive material (FRM).

This study presents the first delineation that shows precise mapping of Regions of Provenance for forest reproductive material and provides detailed key information about topographical, environmental and forest characteristics that characterize each Region of Provenance, by using geographical information system (GIS) techniques, with accurate geospatial data and long time-series climate dataset.

MATERIALS AND METHODS

Study Area

The study area corresponds to the kingdom of Morocco. Located in the extreme north-western part of the African continent between 21° and 36° north latitude and between the 1° and 17° west longitude (Figure 1), Morocco covers a surface area of 710 850 km^2 (HCP 2018).

Conceptual Basis

To establish the Regions of Provenance, two main approaches are generally used: associative and partitive (CTGRF 1976). The associative method mainly takes into account the genetic parameters of populations; it groups the stands of a species with similar genetic structure to form a region of provenance (Kleinschmit et al. 2004). This method can be used when a large amount of information on genetic variation is available on a considerable number of populations, in order to ensure sufficient representativeness. Due to this difficulty, most of the national systems use the partitive method.

The partitive method divides the country into disjoint ecologically homogeneous regions for all species. Therefore, each portion of the territory is necessarily included in a region of provenance**.** The major advantage of this method is that it defines the same regions for all the species under consideration (García del Barrio et al. 2001)**.** Usually a divisive method has been applied to the delineation of regions of provenance, using geographical and ecological information (Auñón et al. 2011). In this study the second approach was applied due to the scarcity of genetic information on Moroccan forest species and their populations.

Delineation and Mapping Procedure

We used the partitive method to establish the regions of provenance, as adopted in similar studies (CEMAGREF 2003, BFW 2017, UKFC 2017).

Firstly, the division was carried out from the forest regions of Morocco, which are described as relatively large units of land sharing large similarities in physical, topographical and

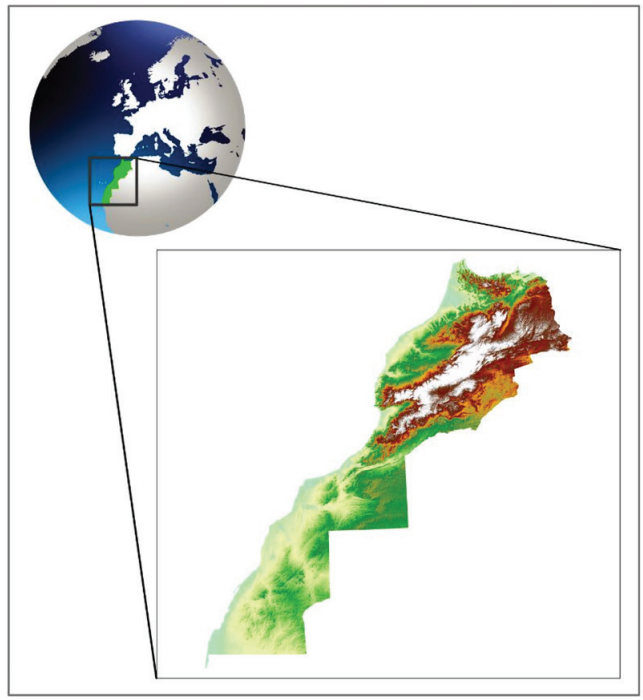

Figure 1. Map of the study area, showing the location of Morocco in the world map.

forest characteristics. This major homogeneous regions were used as fundamental biogeographic units (BgU) serving as a basis for the establishment of the regions of provenance.

However, the BgU are largely to be considered as areas with identical or similar ecological conditions. Therefore, the resulting map of fundamental biogeographic units were, secondly, used to establish Regions of Provenance, subject to sufficiently uniform ecological conditions. In other terms, the polygons of the biogeographic units were split into ecological homogeneous sub-polygons. Then, in order to establish a practical and easily usable tool, the boundaries of RoP have been chosen to follow natural or physical features.

Lastly, we classified RoP using a coding system that includes a two-digit number, with ascending order number from Northwest to Southeast. The first digit written in Roman numerals system designates the biogeographic units within the country, when the second written in Arabic numerals system identifies the RoP within the biogeographic unit.

Features Description

Following the OECD guidelines (OECD 2019), we have delimited the Regions of Provenance by means of geographical boundaries and established maps showing the boundaries of this RoP with their biogeographic units. We have also characterized each RoP by means of most important topographical, environmental and forest characteristics.

Climate is generally considered a useful indirect indicator of genetic variability (De Dato et al. 2018). It represents the most important driving force behind the spatial distribution of forest species, and reliable time series are one of the more valuable dataset for forest monitoring (Ferrara et al. 2017). For this reason, based on the RoP's maps created, the polygons obtained were employed with a long-term (30-year) averages of climate data (temperature and precipitation), to characterize the environmental variability within the RoP, by using a GIS software.

Spatial and Climatic Datasets

To map and characterize the environmental variability of Regions of Provenance, we used and processed the data listed below.

Elevation data: the ASTER digital elevation model (DEM) was used to retrieve the altitude. The data (spatial resolution of 30 m) are publicly available at https://lpdaac.usgs.gov.

Bioclimatic data: to perform the description of climate variability, we considered climate data of a reference period that precedes the climatic disturbances currently observed, using averages from 30 years (1960-1990 climate normal). The data was downloaded from Worldclim dataset (Hijmans et al. 2005), available at http://www.worldclim.org. This dataset provides interpolated current climate layers (for the climate period 1960-1990), for each bioclimatic variable based on historical data with a resolution of 30 arcsec (cell of ≈ 1 km^2). The following six bioclimatic variables were considered to characterize climate in each RoP (Table 1).

Topographic data: in addition to the open access online topographic map collections (https://www.lib.utexas.edu), the maps used were acquired from other official databases of the administrative units.

Physical features: general morphological settings such as prevalently mountainous chains, plains, plateaus and valleys were obtained from the Scientific Institute of Rabat database. Additional information from other sources covering the whole national territory (Michard 1976, El Gharbaoui 1987, Michard et al. 2008, MATUHE 2009) were also compiled.

Administrative data: were acquired from the Moroccan High Commission for Planning. The data are available at https://www.hcp.ma.

Biogeographical features: the forest descriptions for the whole country (Boudy and Guinier 1958, Nanson 1995, AEFCS, 1997) represent the basic information for the geographical and ecological characterization of BgU and RoP. The national forest inventory produced for the country (NFI 2005) served as a basic database to collect information on major forest plant species, and was supplemented with more detailed contributions (DEFCS 1978, Benabid 2000).

Data Processing and Analysis

To achieve the objectives of this study, the open source Geographic Information System Quantum-GIS software (QGIS ver. 3.22) was used for the implementation, visualization, processing and analysis of geospatial data and the long time-series climate dataset.

Table 1. Complete list of bioclimatic variables used to describe climate in RoP.

Raster layer	Unit	Acronym
Mean annual temperature	°C	MAT
Mean maximum temperature of the warmest month	°C	MMTWM
Mean minimum temperature of the coldest month	°C	MMTCM
Mean annual precipitation	mm	MAP
Mean precipitation of wettest month	mm	MPWM
Mean precipitation of driest month	mm	MPDM

RESULTS

Conceptual Framework

The basis for the delineation of the biogeographic units were the Moroccan forest regions, which have been identified based on their homogeneous characteristics (physical, topographical and forest). The delimitation of this regions depended largely on the natural distribution of the major species, especially with regard to forest climatological differences. These forest regions were then adjusted and disaggregated into Regions of Provenance with similar ecological conditions, based on expert judgment and knowledge of the local prevailing characters that can protect natural patterns of intraspecific biodiversity. Subsequently, in order to simplify practical implementation, the exact borders of the resulting regions of provenance have been chosen to follow natural features, such as great rivers (Moulouya, Souss, Drâa) and valleys, or physical features, such as roads, highways and railroads.

This procedure resulted in a final number of 19 Regions of Provenance concentrated in 9 biogeographic units as shown in Table 2.

Regions of Provenance Delineation

Using Geographical Information System techniques, the Regions of Provenance recognized in the present study have been mapped, as well as the biogeographic regions in which they are located. The maps of the resulting BgU and RoP are shown, respectively, in Figure 2 and Figure 3.

Regions of Provenance Description

The geographic location, administrative distribution and concise description of geography, landforms and climate of

Table 2. Hierarchical arrangement of Biogeographic Units and Regions of Provenance in Morocco.

Biogeographic unit	Region of provenance	Acronym		Code	
		BgU	RoP	BgU	RoP
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

Abbreviations: BgU – biogeographic unit, RoP - region of provenance.

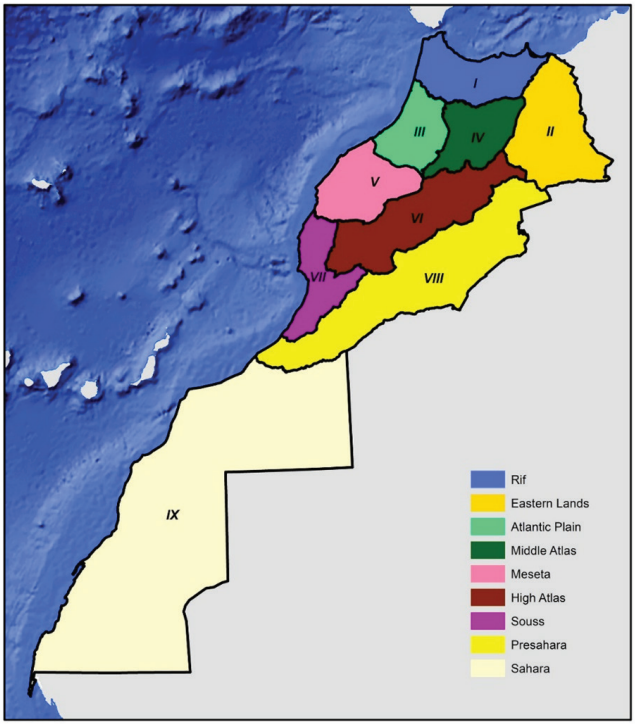

Figure 2. Map of Biogeographic Units of Morocco produced in this study.

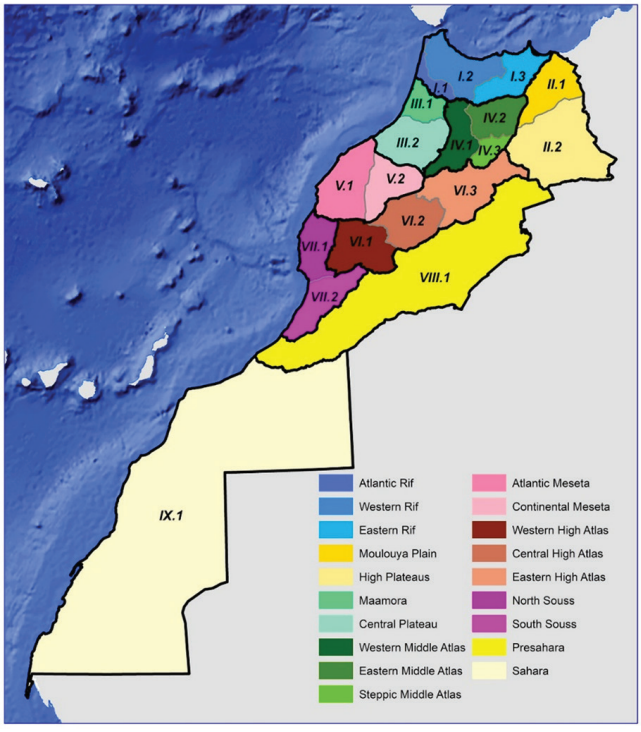

Figure 3. Map of the Regions of Provenance of Morocco produced in this study.

the 9 Moroccan biogeographic units, are presented below. The Regions of Provenance within each biogeographic unit are described by means of a synthetic table with the most important topographical, environmental and forest characteristics.

The Rif biogeographic unit occupies the northernmost part of Morocco and extends east to the Moulouya River. The unit forms a coastal mountainous area. It covers an area of 41 250 km^2 (i.e. 5.8% of the national territory) and straddling several administrative regions: Tanger-Tétouan-Al Hoceima (43%), Oriental (25%), Fès-Meknès (24%) and Rabat-Salé-Kénitra (8%).

It is the most watered biogeographical unit in Morocco and benefits from two oceanic facades, one on the Mediterranean Sea and the other on the Atlantic Ocean. There is a marked contrast in climate according to Emberger's quotient (Emberger 1930). While the west belongs to the humid (typically found in the Rif chain) and sub-humid bioclimatic stages, the east falls within the semi-arid and arid bioclimatic stages.

The privileged geographical situation gives the Rif a climatic originality which, combined with the regional orographic and geological diversity, favoring great ecological wealth (Benabid 1982a).

The Rif biogeographic unit contains the three Regions of Provenance described in the Table 3 below.

The Eastern Lands biogeographic unit starts from the Moulouya River and extend to the easternmost part of Morocco, over an area of 58 700 km^2, representing 8.26% of the national territory. Two administrative regions are concerned: Oriental (91%) and Fès-Meknès (9%).

The two regions of this unit (see Table 4) are distinguishable from each other based on their biophysical attributes: the generally sparsely forested plains in the north and the High Plateaus Steppic landscapes in the south. From an orographic perspective, except for the northern part with a wrinkled topography, particularly in the Beni Snassen Mountain and Horst Chain, most of the land is generally tabular.

The whole of the Eastern Lands unit belongs to the arid bioclimatic stage of Morocco according to Emberger's quotient (Emberger 1930). The presence of a few isolated semi-arid patches is mainly limited to the mountain ranges of Beni Snassen, Gadat Debdou and Zekkara.

The Atlantic Plain biogeographic unit is bordered by the Rif chain to the north, the Atlas chain to the east, the Atlantic Ocean to the west, the meridional Meseta to the south-east and the phosphate plateaus to the south-west. The area covered is 29 800 km^2 (i.e. 4.19% of the national territory), including several administrative regions: Rabat-Salé-Kénitra (56%), Béni Mellal-Khénifra (20%), Casablanca-Settat (17%), Fès-Meknès (8%).

The northern and southern parts of this unit have distinct form of land topography. To the north, the Rharb-Mamora plain represents a vast enclosed depression without pronounced topographic features, with a lower altitude. In the south, with the exception of the low coastal fringe, the central plateau forms tabular mountains (Beaudet 1969), which progressively gain altitude towards the western edges of the Atlas Mountains.

Climatically, the Atlantic Plain is relatively homogeneous due to its geographical location between two natural barriers, the Rif and Atlas mountain ranges. Aside from the mountainous part of the central plateau and the northern coastline fringe, which belong to the sub-humid bioclimatic stage, the large portion of lands belongs to the semi-arid stage, with a small arid patch at Maaziz.

This biogeographic unit is subdivided into two Regions of Provenance (Table 5).

The Middle Atlas biogeographic unit separates Atlantic Morocco from arid Eastern Morocco. It is bordered north by the South-Rifan corridor, south by the High Atlas, east by the Moulouya river valley and west by the Atlantic Plain. This unit is completely continental and has an area of 34 600 km^2, representing 4.87% of the country's surface area. Several administrative regions are included: Fès-Meknès (70%), Béni Mellal-Khénifra (13%), Oriental (10%), Draa-Tafilalet (7%).

Table 3. Topographical, environmental and forest characteristics of the Rif Regions of Provenance.

	Atlantic Rif	Western Rif	Eastern Rif
Area (km^2)	6 150	19 700	15 400
Part of Morocco (%)	0.86	2.77	2.17
Average elevation (m)	100	564	547
Climate			
MAT (°C)	18.5	16.5	16.8
MMTWM (°C)	33.3	31.9	32.0
MMTCM (°C)	6.2	4.2	4.4
MAP (mm)	672	737	392
MPWM (mm)	125	125	62
MPDM (mm)	0	1	2
Major forest plant species	*Quercus suber* L., *Quercus coccifera* L., *Ceratonia siliqua* L., *Pinus pinaster var. atlantica* H. del Villar, *Pinus pinea* L.	*Abies maroccana* Trab., *Cedrus atlantica* Manetti, *Tetraclinis articulata* (Vahl) Mast., *Pinus nigra var. mauritanica* Maire & Peyerinhoff, *Pinus pinaster var. maghrebiana* H. del Villar, *Pinus pinaster var. Iberica* H. del Villar, *Pinus halepensis* Mill., *Quercus suber, Quercus pyrenaica* Willd., *Quercus rotundifolia* Lam., *Quercus faginea* Lam.	*T. articulata, P. halepensis, Pistacia atlantica* Desf., *Juniperus phoenicea* L., *Q. rotundifolia*

Table 4. Topographical, environmental and forest characteristics of the Eastern Lands Regions of Provenance.

	Moulouya Plain	High Plateaus
Area (km²)	17 400	41 300
Part of Morocco (%)	2.45	5.81
Average elevation (m)	835	1 231
Climate		
MAT (°C)	15.4	15.8
MMTWM (°C)	31.2	34.7
MMTCM (°C)	2.6	0.6
MAP (mm)	303	257
MPWM (mm)	42	34
MPDM (mm)	3	4
Major forest plant species	*T. articulata, Acacia gummifera* Willd., *J. phoenicea, P. atlantica, Q. rotundifolia, Q. coccifera, P. halepensis, Stipa tenacissima* L., *Artemisia herba-alba* Asso.	*S. tenacissima, Artemisia inculta* Delile., *Atriplex halimus* L., *Chamaecytisus albidus* (DC.) Rothm., *Rosmarinus officinalis* L.

Table 5. Topographical, environmental and forest characteristics of the Atlantic Plain Regions of Provenance.

	Maamora	Central Plateau
Area (km²)	17 400	41 300
Part of Morocco (%)	1.32	2.87
Average elevation (m)	122	570
Climate		
MAT (°C)	18.8	16.9
MMTWM (°C)	33.7	33.6
MMTCM (°C)	6.8	3.7
MAP (mm)	546	521
MPWM (mm)	102	86
MPDM (mm)	0	1
Major forest plant species	*Q. suber, J. phoenicea, T. articulata*	*Q. suber, Q. rotundifolia, T. articulata, C. siliqua, P. atlantica*

The western and eastern part of the Middle Atlas, which respectively corresponds to the pleated and tabular Middle Atlas called Middle Atlas Causse by Henri (1937), are separated by the major tectonic accident known as the "North-Middle Atlas" (Colo 1961).

There is a marked contrast in climate between sides of the mountain range. The northern and western sides, which are open to the Atlantic, are more watered, while the southern and eastern sides receive much less water and are subject to intense insolation and evaporation. The mountain stops the clouds rising from the ocean on its Atlantic side and places the eastern side in the "rain shadow", which increases the continental character of the Moulouya plain and reduces the rainfall significantly.

In climate terms, the sub-humid and humid bioclimatic stages are the most predominant. The arid bioclimatic stage is located in the steppe portion.

The Middle Atlas biogeographic unit is composed of three Regions of Provenance. Their topographical, environmental and forest characteristics are shown in Table 6.

The Meseta biogeographic unit covers an area of 39 200 km² (i.e. 5.51% of the national territory), including the plains, plateaus and massifs that are located between the Atlantic plain, the Atlas and the Souss biogeographic units. It extends over the administrative regions of Marrakech-Safi (44%), Casablanca-Settat (43%) and Béni Mellal-Khénifra (13%).

In general, the Meseta plains have a subdued topography, a level surface and a fertile soil with high agricultural potential. These plains can be distinguished into two categories: the sub-Atlantic plains (Chaouia, Abda, Doukkala, Bahira) and the continental plains (Tadla and Haouz).

The plateaus are regularly inclined from north to south, between the altitudes of 1 000 and 600 m, and include those of the Phosphates and the Ganntour. The massifs have a generally moderate altitude with an East-West direction, and concern the Rehamna (less than 700 metres altitude) and the Jbilete (culminating around 1 000 m altitude).

Table 7 shows the Meseta Regions of Provenance and its corresponding description.

The High Atlas biogeographic unit occupies 9.30% of the landmass of Morocco (i.e. 66 100 km²). Several administrative regions are covered: Draa-Tafilalet (43%), Béni Mellal-Khénifra (22%), Marrakech-Safi (21%), Souss-Massa (9%), Oriental (2%) and Fès-Meknès (2%).

It mainly extends over the High Atlas mountain chain, which forms a 800 km long and 40 to 80 km wide barrier. This unit is bordered northwest by the Continental and Atlantic

Table 6. Topographical, environmental and forest characteristics of the Middle Atlas Regions of Provenance.

	Western Middle Atlas	Eastern Middle Atlas	Steppic Middle Atlas
Area (km²)	14 800	13 700	6 100
Part of Morocco (%)	2.08	1.93	0.86
Average elevation (m)	1 186	1 132	1 399
Climate			
MAT (°C)	14.4	14.4	14.0
MMTWM (°C)	33.5	32.8	33.0
MMTCM (°C)	-0.1	0.2	-0.5
MAP (mm)	641	397	293
MPWM (mm)	93	55	40
MPDM (mm)	6	6	7
Major forest plant species	*C. atlantica, Q. rotundifolia, Q. faginea, T. articulata, P. pinaster var. maghrebiana, P. halepensis, Juniperus thurifera* L.	*C. atlantica, P. pinaster var. maghrebiana, P. halepensis*	*Q. rotundifolia, J. phoenicea, S. tenacissima*

Messeta, northeast by the Western and Steppe Middle Atlas, east by the High Plateaux, south and southwest by the Pre-Sahara, and west by the South Souss RoP.

From west to east, there are increases in drought. The Western High Atlas is the highest and wettest segment of the entire range, including Mount Toubkal (ranging to over 4 167 m). However, generally lower altitudes and a drier climate, particularly in its eastern limit at the contact with the high plateaus of Eastern Morocco, characterize the Eastern High Atlas.

The characteristics of the High Atlas Regions of Provenance are shown in Table 8.

Table 7. Topographical, environmental and forest characteristics of the Meseta Regions of Provenance.

	Atlantic Meseta	**Continental Meseta**
Area (km²)	22 900	16 300
Part of Morocco (%)	3.22	2.29
Average elevation (m)	248	486
Climate		
MAT (°C)	18.1	18.4
MMTWM (°C)	31.5	36.4
MMTCM (°C)	6.3	4.3
MAP (mm)	331	372
MPWM (mm)	57	62
MPDM (mm)	0	1
Major forest plant species	*P. atlantica, J. phoenicea, A. gummifera, C. siliqua*	*A. gummifera*

Table 8. Topographical, environmental and forest characteristics of the High Atlas Regions of Provenance.

	Western High Atlas	**Central High Atlas**	**Eastern High Atlas**
Area (km²)	20 300	19 100	26 700
Part of Morocco (%)	2.85	2.69	3.76
Average elevation (m)	1 403	1 624	1 747
Climate			
MAT (°C)	14.2	14.0	13.4
MMTWM (°C)	31.9	34.6	34.2
MMTCM (°C)	-1.0	-2.2	-2.4
MAP (mm)	439	432	369
MPWM (mm)	62	62	51
MPDM (mm)	3	4	7
Major forest plant species	*Argania spinosa* (L.) Skeels, *Q. rotundifolia, T. articulata, Cupressus atlantica* Gaussen, *J. phoenicea, P. halepensis, J. thurifera, C. siliqua, Juniperus oxycedrus* L.	*Q. rotundifolia, T. articulata, P. halepensis, P. pinaster var. maghrebiana, J. oxycedrus, J.phoenicea, J. thurifera, C. siliqua*	*Cedrus atlantica, Q. rotundifolia, Q. faginia, J. thurifera, J. phoenicea, T. articulata, P. halepensis, P. pinaster var. maghrebiana, C. siliqua, S. tenacissima*

The Souss biogeographic unit is the most original unit of all North Africa in terms of ecology and forestry (Boudy and Guinier 1958). It is bordered to the north by the Jbilete massif and the Mouissate plateau, to the east by the High Atlas and the Anti-Atlas chains, to the south by the Oued Noun Valley and to the west by the Atlantic Ocean.

With an area of 31 500 km^2, which represents 4.43% of the country's surface area, this unit falls within the semi-arid and arid bioclimatic stages and extends across three administrative regions: Sous-Massa (55%), Marrakech-Safi (33%), and Guelmim-Oued Noun (11%).

The terrain is characterized by step-like topography. The Haha and Ida-Outanane high plateaus dominate the septentrional part. They gradually descend from the Assif Aït Moussa-Tizi-Machou break in the east, towards the Atlantic Ocean in the west. Further north, the plateaus cedes place to the Chiadma plain. In the south, the Siroua massif connect the High Atlas and the Anti-Atlas chains, to border the Souss plain and protect it from the desert influences of eastern and southern Morocco. The most southerly portion of the unit is occupied by the Chtouka and Tiznit plains. The dunes of marine origin are characteristic of most of the coastal fringe.

The characteristics of each of the two Souss Regions of Provenance are given in Table 9.

The Presahara biogeographic unit occur as band in a Southwest-Northeast direction, from the southern limits of the High Atlas to the northwestern limit of the Moroccan desert. Extending over 15.19% of the country, this unit forms a broad transition between the lands of Mediterranean and Saharan Morocco. The area covered falls within the territory of four administrative regions: Draa-Tafilalet (55%), Sous-Massa (29%), Guelmim-Oued Noun (13%), and Oriental (2%).

The unit falls within the arid and Saharan bioclimatic stages, with a significant difference between the western and eastern parts, which includes, respectively, the Draa and Ziz Rivers watersheds. The eastern one is considerably more desertic.

There are four major landforms. The mountains located in the Anti-Atlasic area, Mount Sagho and Mount Bani. A continuum of Hamada, raised rocky plateaus typical of desert areas, including from North to South: the Guir, Kem-Kem, Daoura, Draa and Touassine Hamadas. Numerous steppic valleys are located at the foot of the mountains, consisting of: the Dadès, Draa, Todgha, Ziz and Guir valleys. One of the most specific landscape feature is the occurrence of an isolated oasis in southeastern portion of this unit, lying in the hollow of the Ghéris and Ziz valleys.

The one Region of Provenance that constitute this unit is described in Table 10.

Table 9. Topographical, environmental and forest characteristics of the Souss Regions of Provenance.

	North Souss	South Souss
Area (km^2)	14 400	17 100
Part of Morocco (%)	2.03	2.40
Average elevation (m)	560	666
Climate		
MAT (°C)	16.2	17.4
MMTWM (°C)	26.8	29.8
MMTCM (°C)	5.1	4.8
MAP (mm)	322	230
MPWM (mm)	53	40
MPDM (mm)	1	1
Major forest plant species	*J. phoenicea, A. spinosa, T. articulata, A. gummifera, C. siliqua, J. oxycedrus, Q. rotundifolia*	*A. spinosa, T. articulata*

Table 10. Topographical, environmental and forest characteristics of the Presahara Region of Provenance.

	Presahara
Area (km^2)	108 000
Part of Morocco (%)	15.20
Average elevation (m)	886
Climate	
MAT (°C)	19.6
MMTWM (°C)	38.9
MMTCM (°C)	2.7
MAP (mm)	129
MPWM (mm)	23
MPDM (mm)	1
Major forest plant species	*A. spinosa, Dracaena draco subsp. ajgal* Benabid & Cuzin*, A. gummifera, Acacia raddiana* Savi*, Acacia ehrenbergiana* Hayne*., Balanites aegyptiaca* (L.) Delile*, Tamarix articulata* Vahl*, Capparis decidua* (Forssk.) Edgew.*, Faidherbia albida* (Delile) A.Chev

The Sahara biogeographic unit covers an area of 301 700 km^2 and represents consequently the largest biogeographical unit in Morocco. It includes several administrative regions: Laayoune-Boujdour-Sakia Al Hamra (48%), Ed Dakhla-Oued Eddahab (43%) and Guelmim-Oued Noun (9%).

It is characterized by a Saharan climate, which is arid only on some portions of the littoral band where the oceanic influences attenuate it. The aridity become more pronounced further east and south. The rainfall is very little, with less than 42 mm of precipitation a year.

The territory is marked by a notable physical homogeneity. Excluding some major massifs in the northeast (Mount Ouarkziz, Mount Zini and Mount Janfra) and the littoral dune ridge, most of the rest of the territory is principally dominated by the large areas of the Hamadas, with the presence of several depressions (Graara-Maader and Sebkhas).

Table 11 shows the Sahara Region of Provenance and its corresponding characteristics.

DISCUSSION

The delineation of Regions of Provenance is a starting point for the implementation of a national forest resource conservation and management program. It also provides a unified global framework for coordinating the actions of the various forestry actors in the planting process: seed collection, nursery management and plantation operations.

The Regions of Provenance which have been proposed here are delineate areas with sufficiently uniform ecological conditions within which forest germplasm can be moved with limited risk of maladaptation and loss of productivity. The use of the homogeneous forest regions as biogeographic units, which are then partitioned into regions with uniform ecological conditions, has allowed obtaining of the areas subject to sufficiently uniform ecological conditions, taking into consideration the altitudinal gradient, which can be used within Regions of Provenance. It is generally assumed that ecological distance between source and introduction sites is often a better indicator of local adaptation of forest germplasm than geographic distance (McKay et al. 2005, Noël et al. 2011).

The application of a biogeography-based approach in this study revealed that the territory was hierarchically organized into 19 Regions of Provenance concentrated in 9 biogeographic units. The resulting biogeographical units can be aggregated into two biogeographical divisions: Mediterranean and Saharan (Figure 4). A similar division was also proposed by Benabid (2000).

It has also been shown that the Biogeographical Divisions are unequal in terms of the number of BgU and RoP. The Mediterranean Division is represented by 7 BgU, compared to only 2 BgU for the Saharan Division. The highest number of Regions of Provenance was found in the Mediterranean division (18 RoP), when there are only two RoP in the Saharan Division. It is interesting to note that in terms of area, 57% of the national territory (409 700 km^2) is contained in just 2 RoP (Presahara and Sahara).

Another important finding was that three categories of biogeographical units can be recognized depending on the number of RoP: (i) those extending over the Rifan and Atlas Mountains included three RoP, (ii) those with two RoP located on the northwest and northeast sides and (iii) those covering the pre-Saharan and Saharan part of Morocco constituted by a single RoP.

Climatically, the present study shows that the Mean Annual Temperatures ranged from 13.5°C in the Eastern High Atlas RoP to 22°C in the Sahara RoP. In addition, Mean Maximum Temperatures of the Warmest Month reached 39°C within the continental part of Presahara RoP, whereas the Mean Minimum Temperatures of the Coldest Month decreased until the negative value of -2.4°C in the Eastern High Atlas RoP. Thus, Eastern High Atlas was the coldest RoP, while Presahara and Sahara were the warmest. This can be explained by the effect of the high altitude on the Eastern High Atlas RoP and the influence of the Saharan climate on the Presahara and Sahara RoP.

For precipitations, the Mean Annual Precipitations varied between 737 mm and 42 mm, in high mountains of the Western Rif RoP and the Sahara RoP respectively. With a decreasing gradient from north to south, Mean Precipitations of wettest month exceed 125 mm at the Western and Atlantic Rif RoPs, while the mean precipitations of the driest month was less than 1 mm at Sahara, Atlantic Rif, Atlantic Meseta and Maâmora RoPs.

The obtained RoP are intended as a practical provenancing decision-making tool to guide the movement of seed, cuttings and planting stock used for forestry

Table 11. Topographical, environmental and forest characteristics of the Sahara Region of Provenance.

	Sahara
Area (km^2)	301 700
Part of Morocco (%)	42.44
Average elevation (m)	261
Climate	
MAT (°C)	22.0
MMTWM (°C)	34.5
MMTCM (°C)	10.4
MAP (mm)	42
MPWM (mm)	10
MPDM (mm)	0
Major forest plant species	*A. raddiana, Rhus tripartita* (Ucria) Grande, *A. ehrenbergiana, F. albida, B. aegyptiaca, Tamarix articulata, C. decidua, Maerua crassifolia* Forssk

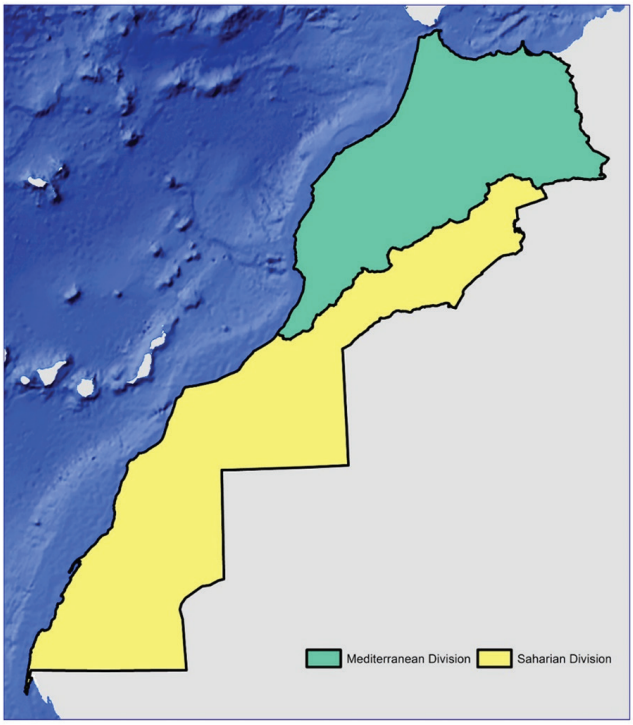

Figure 4. Map of the Biogeographic Divisions of Morocco produced in this study.

purposes in Morocco. They can serve as a unified national framework to better locate seed stands, select seed sources with low risk of maladaptation and plan seed procurement needs for national forestation programmes. This allows ensuring of the traceability of planting stock throughout the harvesting-seedling production-plantation process to a specified source of forest basic material. The RoP obtained from this study can be used also as a starting step for planning breeding or conservation programs.

Thus, the RoP represent a valuable tool for implementing a certification system that ensures the production and use of forest reproductive material in a manner that ensures their trueness to name, such as the scheme established by the Organisation for Economic Co-operation and Development (OECD 2019). Moreover, the adoption of this system will encourage and facilitate international exchange in forest seeds and plants for genetic evaluation and trade.

It is important to note that the RoP defined are not species-specific, but are equally applied to all species, in order to simplify practical implementation. They are destined to be used with species for which no specific knowledge on local adaptation or no data about population differentiation are currently available. The boundaries in these Regions of Provenance maps should not be perceived as lines but rather as large transition zones encompassing a certain degree of risk of maladaptation.

The strengths of our study include the use of expert-based approach mixed with accurate geospatial data and long time-series climate dataset. However, the findings of this study have to be seen in light of some limitations. The Regions of Provenance have been established on the basis of their ecological similarities. Certain criteria were not considered, such as: soil characteristics (compaction, mineral wealth, waterlogging, acidity, salinity, rooting depth, etc.), biotic risks (insect pest attack, fungal pathogen infection, etc.), abiotic risks (storms, forest fire, etc.), human impacts (silviculture, land cover, etc.), microclimate (side effect, frost corridor, etc.) and extreme weather events (heatwave, drought episode, etc.).

More information on intra-specific local adaptation would help to improve the Regions of Provenance established in this study. The use of elevation bands within RoP would also be of interest. We recommend, thus, the establishment of reciprocal transplant studies to better evaluate the establishment, survival, growth and reproduction of ecotypes from each of the RoP defined in a series of common garden test sites within this RoP (Kawecki and Ebert 2004).

CONCLUSION

In order to better understand, protect and use the genetic diversity in the Moroccan's forest trees, this study proposes a conceptual framework based on Regions of Provenance. This system aims to spatially contextualize the actions according to conservation and management of forest genetic resources.

The present study is the first to present a precise map of Regions of Provenance for Moroccan forest reproductive material and provide a detailed description on topographical, environmental and forest characteristics that characterize each Region of Provenance, by using geographical information system (GIS) techniques to manipulate and analyze accurate geospatial data and long time-series climate dataset.

Our suggested Regions of Provenance delineation are equally applied to all species and include 19 Regions of Provenance. Their limits should not be considered as fixed lines, but rather as large transition areas with a certain degree of risk of maladaptation.

The RoP results from this study represent a valuable tool that may help ensure that seeds, cuttings and planting stock used are well adapted to conditions at the restoration sites. However, to better evaluate the establishment, survival, growth and reproduction of ecotypes, we recommend the establishment of reciprocal transplant studies from each RoP at trial sites within each of these RoP. The reciprocal transplant would help to provide more information on intra-specific local adaptation and, thus, provide precise guidelines on transfers of genetic material between separated or adjacent Regions of Provenance.

Finally, we concur with the claim that the development of Regions of Provenance is more art than science, because practical knowledge and experience remains the significant component of the process (Ying and Yanchuk 2006). Using biogeography-based approach simply enables us to have a practical provenancing decision-making tool to guide the spatial movement of forest reproductive material, avoiding loss of productivity and forest health issues caused by maladaptation.

Author Contributions

KL, MF and LS study conception and design, KL and LS data collection, processing and analysis, MF supervised the research and helped to draft the manuscript, KL and LS writing of the manuscript draft, KL and MF checking the references and writing of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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