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TITLE

Dynamics and biophysical characteristics of forest and pre-forest formations in Hodna

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Dedication

This one goes to you Mom,

To all my family and friends,

To all the future generations…

Abstract

This study aims to investigate the dynamics and biophysical characteristics of forest and preforest formations in Hodna Mountains, specifically Boutaleb and Djebel Messaad forests. The methodology involves measuring the biophysical variables (height and diameters) of trees during the years 2022 and 2023, as well as evaluating the photosynthetic activity using remote sensing techniques of this vegetation formation. The Normalized Difference Vegetation Index (NDVI), the Normalized Difference Moisture Index (NDMI) and Evapotranspiration between the period 2014 and 2024 were calculated. The results of the structure is therefore regressive for Boutaleb forest, characteristic of natural stands with high regeneration potential, small diameter and high heights individuals. The structure in Djebel Messaad forest stands is characterized with a predominance of older and high heights individuals. The results of Vegetation Indices, over the years, shows that the diachronic study of vegetation productivity (NDVI), vegetation humidity (NDMI) and Evapotranspiration varies from one site to another, with maximum values in Boutaleb forest formations. This is due to changes in the physiological processes of plants over time.

Keywords

Dynamics, Hodna, remote sensing, NDVI, NDMI

Résumé

Cette étude vise à étudier la dynamique et les caractéristiques biophysiques des formations forestières et préforestières dans les montagnes du Hodna, en particulier les forêts de Boutaleb et de Djebel Messaad. La méthodologie consiste à mesurer les variables biophysiques (hauteur et diamètre) des arbres au cours des années 2022 et 2023, ainsi qu'à évaluer l'activité photosynthétique de cette formation végétale à l'aide de techniques de télédétection. L'indice de végétation par différence normalisée (NDVI), l'indice d'humidité par différence normalisée (NDMI) et l'évapotranspiration entre la période 2014 et 2024 ont été calculés. Les résultats de la structure sont donc régressifs pour la forêt de Boutaleb, caractéristique des peuplements naturels à fort potentiel de régénération, de petits diamètres et de grandes hauteurs d'individus. La structure des peuplements de la forêt de Djebel Messaad est caractérisée par une prédominance d'individus âgés et de grande taille. Les résultats des indices de végétation, au fil des années, montrent que l'étude diachronique de la productivité de la végétation (NDVI), de l'humidité de la végétation (NDMI) et de l'évapotranspiration varie d'un site à l'autre, avec des valeurs maximales dans les formations forestières de Boutaleb. Ceci est dû à l'évolution des processus physiologiques des plantes au cours du temps.

Mots clés

Dynamique, Hodna, Télédétection, NDVI, NDMI

الملخص

تهدف هذه الدراسة إلى دراسة الديناميكيات والخصائص البيوفيزيائية للتشكيلات الحرجية وما قبل الحرجية في جبال الحضنة، وتحديداً غابات بوطالب وجبل مسعد. وتتضمن المنهجية قياس المتغيرات البيوفيزيائية الحيوية (الارتفاع والأقطار) للأشجار خلال عامي 2022 و2023، بالإضافة إلى تقييم النشاط الضوئي باستخدام تقنيات الاستشعار عن بعد لهذا التكوين النباتي. تم حساب مؤشر الاختلاف المعياري للغطاء النباتي (NDVI)، ومؤشر الاختلاف المعياري للرطوبة (NDMI) ومؤشر التبخر والنتح خلال الفترة من 2014 إلى 2024. وبالتالي فإن نتائج البنية انحدارية بالنسبة لغابة بوطالب، وهي سمة من سمات المدرجات الطبيعية ذات إمكانية التجدد العالية والقطر الصغير والارتفاعات العالية للأفراد. تتميز البنية في مدرجات غابة جبل مسعد بغلبة الأفراد الأقدم والأكثر ارتفاعاً. تُظهر نتائج مؤشرات الغطاء النباتي، على مر السنين، أن دراسة مؤشرات الغطاء النباتي (NDVI) ورطوبة الغطاء النباتي (NDMI) والتبخر النتحي تختلف من موقع إلى آخر، مع وجود قيم قصوى في تشكيلات غابة بوطالب. ويرجع ذلك إلى التغيرات في العمليات الفسيولوجية للنباتات بمرور الوقت.

الكلمات المفتاحية

ديناميكيات, الحضنة, الاستشعار عن بعد, NDVI, NDMI

Lists of abbreviations

NDVI: Normalized Difference Vegetation Index

NDMI: Normalized Difference Moisture Index

GIS: Geographic Information System

RS: Remote sensing

LAI: Leaf Area Index

FCC: False Color Composite

VI: Vegetation Indices

PVI: Perpendicular Vegetation Index

ET: Evapotranspiration

3D: Three-Dimensional

MODIS: Moderate Resolution Imaging Spectroradiometer

NASA: National Aeronautics and Space Administration

OLI: Operational Land Imager

TIRS: Thermal Infrared Sensor

DBH: Diameter at Breast Height

TH: Tree Height

FAO: Food and Agriculture Organization

°C: Degree Celsius

IUCN: International Union for Conservation of Nature

ETM: Enhanced Thematic Mapper

List of tables

Lists of figures

Table of contents

Introduction

Over the past millions of years, the Earth's climate has experienced numerous changes as evidenced by researches using various proxies like ice cores, pollen, and tree rings (La Marche 1974; Dansgaard *et al*., 1993; Lara & Villalba, 1993; Briffa *et al*., 1995; Petit *et al*., 1999; Fowell *et al*., 2003). Natural factors such as solar cycles and biotic influences are mainly responsible for these fluctuations.

Climate change is seen as the foremost health threat of the 21st century on a worldwide scale (Costello *et al*., 2009). Mediterranean ecosystems, known by their dry and hot summer are considered exceptional models for studying the effects of climate change (Doblas-Miranda *et al*., 2015) which increase the vulnerability of many species.

The forest or reforestation is a diverse and intricate ecosystem that provides habitats for a wide variety of animal, plant, fungal, and microbial species. These species often rely on each other to survive and thrive (Boumendjel and Dorbani, 2010). Mediterranean forests, covering around 8 million hectares, make up 94% of the globe's forest area and compose of a combination of different forest species (Mugnossa *et al*., 2000). They are considered a valuable global natural heritage due to their rich biological diversity (Palahí *et al*., 2022) and occupy a crucial role in reducing poverty and supporting local economies.

Recently, numerous natural Mediterranean forests and afforestation projects are experiencing a lack of balance. It is widely accepted that climate change, manifested through repeated droughts, has significantly affected the health of forest communities (Sarris *et al*., 2011; Girard *et al*., 2012; Sanchez-Salguero *et al*., 2012).

The conservation and regeneration of the Mediterranean forest currently poses very concerning issues due to the various aggressions it faces, and it is evident that reforestation operations, whether voluntary or natural reseeding, are one of the main factors in its preservation and even survival in certain regions (Quezel *et al*., 1990).

A key question in ecology is determining how climate change will affect ecosystem structure and function. There is an increasing focus on researching to find early indicators of these effects and pinpoint areas that at risk. The way vegetation reacts to climate change is influenced by the extent of change, the connections between factors such as rainfall, temperature and CO_2 levels, as well as past environmental conditions such as changes in land-use (Davis-Reddy, 2018).

At present, it is not possible to manage a forest in a rational and sustainable manner without fully understanding its growth conditions. In a strict sense, phenology is the study of the climatic relationships and external morphological characteristics of plant development (Differt, 2001). Han et al. (2018) stated that it serves as an effective measure of how ecosystems react to climate change.

On a larger scale, disturbances are one of the primary causes of spatial heterogeneity. Indeed, the spatial distribution of biodiversity is controlled by environmental factors (e.g. climate, physico-chemical characteristics of soils...), by intra- and inter-specific relationships (e.g. reproduction/mortality, predation, competition, mutualism...) but also by disturbances (Ettema & Wardle, 2002).

Algerian forests particularly pine and cedar forests are subject to strong anthropogenic pressure (overgrazing, logging, and sometimes fires) and harsh climatic conditions with prolonged drought periods negatively impacting tree growth and natural regeneration.

Forests and preforest formations are essential for maintaining the ecological equilibrium of our planet. Hodna region, located in Algeria, between the Tellian region in the north and the Sahara in the south, thus favoring a diversity of bioclimatic environments. The climate is Mediterranean type with the presence of four major bioclimatic zones ranging from sub-humid, semiarid, arid, and Saharan (Khoudour, 2021). It is known for its diverse and unique forest ecosystems. This climatic diversity leads to the confrontation of two main types of plant communities; those with a steppe character and others with a forest and pre-forest character. Understanding the dynamics and biophysical characteristics of these formations is necessary for effective preservation and management plans. In this research, we will focus on studying the structure and health state of trees in the Hodna region, with a particular emphasis using remote sensing methods.

To conduct this work, two sites were selected from different regions in Algeria: Boutaleb and Djebel Messaad forests. Boutaleb forest, located in the wilaya of Sétif in northeastern Algeria, is known for its diverse plant life including Aleppo pine, evergreen Oak, and Atlas cedar (Merikhi, 1994; Madoui, 1995; Sedjar, 2012). On the other hand, Djebel Messaad natural pine forest is situated in the Algerian Saharan Atlas mountain range within the wilaya of M'sila, serving as a protective barrier against the encroaching southern desert (Kadik, 1987).

During this study, two approaches were used: field measurements approach and remote sensing approach. Field measurements consist of determining biophysical parameters (diameter, height and tree importance value index) with the aim of comprehending the ongoing real state of the forest vegetation. To clarify the dynamics of this vegetation cover, the spatio-temporal distribution and inter-annual changes have been evaluated using remote sensing techniques based on satellite data over a period of ten last years. Remote sensing data were utilized to analyze various indices such as NDVI (Normalized Difference Vegetation Index), NDMI (Normalized Difference Moisture Index), and Evapotranspiration to evaluate the health and vitality of forest and preforest formations in Hodna

Compared to terrain surveys of ecosystems, determining vegetation index is relatively simple and there are multiple options available for their use. The values of these indicators are relative and correspond to specific aspects of plant development, such as biomass, chlorophyll levels, and leaf cover. They can be utilized to identify issues within a specific ecosystem (Shevyrnogov *et al*., 2019).

Other factors such as climate, anthropogenic activities, topography, etc. will also be studied and subject to further analysis. From a cartographic perspective, GIS (Geographic Information System) and satellite imagery can be used to establish soil occupation maps and other parameters of specific situations.

By combining field observations with remote sensing data, we aim to supply a comprehensive understanding of the dynamics and biophysical characteristics of the forests in Hodna region. This research will not only contribute to the scientific knowledge of forest ecosystems but also provide valuable insights for sustainable forest management practices.

To better address the various aspects of the issue at hand, our study is structured around four chapters:

- First chapter, with a literature review, is dedicated to the investigation of dendrological measurements carried out in the Hodna mountains region, as well as various methods of monitoring the health of forest ecosystems, ranging from field measurements to remote sensing, including the effect of climate change on soil ecosystems.

- Second chapter deals with the territorial context of the study area.

- Third chapter include the methodology and tools used in data processing.

- Fourth chapter primarily examines the results obtained and their discussions with the incorporation of satellite images and dendrological measurements for the enhancement of the forest and pre-forest vegetation of Hodna.

Chapter 1: Bibliographical overview

1. Investigation of dendrological measurements carried out in Hodna Mountains area

Hodna is a massive depression located in central Algeria at an altitude of 400 meters. Isolated from the sea by a succession of mountain ranges, this depression covers a closed basin of some 24,500 km^2. The depressed central basin has an area of 8,500 km^2. It is fed by wadis, including from the north: oued Barika, oued el Ksob, oued el Lehan. These rivers flow down from the mountains, which form a continuous arc linking the Tellian Atlas to the Saharan Atlas. From west to east, these include Ouennougha Mountains, Maâdid mountains, Boutaleb and other secondary ranges (Camps, 2000).

The mountains of Hodna have been the subject of many works. According to Boudy (1955), they once knew a very large area of cedar, of which only isolated cantons remain, without regeneration.

Phytosociological studies were carried out by Merikhi (1994) on Boutaleb forest massif. This study reported that the Atlas cedar forest is not as well developed as in the Aurès and Babors. The presence of therophytic groups dependent on anthropozoological actions, thus indicators of environmental disturbances.

The same remark is made by Madoui and Gehu (1999) who argue that the vegetation of the forest massif of Boutaleb reflects a destructive action manifested for a long time and accelerated occasionally by man and his daily and seasonal activities. The regression of some precious species such as Atlas cedar and the rise of xerophyl species such as Retama (or even Aleppo pine) is a bad sign for the future of this forest.

The research work of Sedjar (2012) on the floristic diversity and the vegetation dynamics of this massif, allowed to shift the predominance of certain families namely the Asteraceae, the Fabaceae, the Poaceae, the Brassicaceae and the Apiaceae. The families surveyed include 43% of all Algerian flora.

Missaoui's work in 2020 on the dynamics of ecosystems in Setif facing global changes showed that there is a decline in vegetation cover and that the phenology of cedar forests is highly influenced by snow cover.

The study of Zerroug (2020), on the forest vegetation of the Righa Dahra massif of the Hodna Mountains, determined the distribution of forest species, the Holm Oak dominates the northern part, while the Juniper of Phoenicia, Aleppo Pine and Cedar share the lands of the southern part. It also revealed a regressive trend in the forest, progressions are exclusively related to the pine forest and stable areas are rare and fragmented.

Guechi (2022) proposed a first catalogue of the regional flora of the Maadid Massif comprising more than 392 taxa spread across 59 botanical families and 223 genera, with a predominance of the family *Asteraceae*, *Lamiaceae*, *Poaceae* and *Fabaceae*, with a remarkable presence of the *Orchidaceae* family. This work confirmed that the Maadid massif has a typical biogeographic character thanks to its isolation and the presence of heritage species that require in situ conservation.

The research work of Ouadeh *et al* (2022) on the state forest of Dreat, showed a regressive dynamic as a result of many factors including the presence of anthropozoic activities and illegal cuts that lead to a very rapid change in the physiognomy of this territory.

The results of the work of Louail (2023) on the Ouled Hannèche forest, situated in the Hodna mountains, confirm the increased capacity of the forest, compared to the non-timber sector, to provide more water vapor flows and thus regulate the climate more effectively, especially during the summer period.

2. Distribution and floristic characteristics of plant formations in the Mediterranean region and Algeria

The Mediterranean floristic region is one of the richest hotspots of the world, with over 24,000 species distributed in the large territory (2,300,000 km^2) of the Mediterranean Basin. A large number of genera (appoximately 2000) and families (about 200) have been recorded, making this region the most diverse of the five Mediterranean floristic zones in the world (Vargas, 2019). It is rich in terms of floristic diversity (Mittermeier et *al*., 2004). The Mediterranean Basin is still home to a large number of trees, with around 290 native taxa (species and subspecies) including 201 endemics (Quézel and Médail, 2003).

Mediterranean climate characterized by mild and humid winters, hot and dry summers and a relative long period of aridity each imposing an effective and severe drought on the plants. Rainfall patterns and the oceanity are extremely varied, and this explain why the Mediterranean Basin has the lowest rainfall reliability (quantified as interannual variations in monthly and seasonal rainfalls, and as the frequency of individual rainfalls) of the five Mediterranean-climate ecosystems of the world (Cowling *et al.*, 2005).

Mediterranean vegetation types vary widely with environmental constraints (climate, geology, geomorphology, soil type), dominant plant species, and disturbances induced by man. The woody vegetation is constituted by diverse types of matorrals or shrublands (maquis, garrigue, phrygana) and forests. In relation to the bioclimate type and the altitude, several major types of this vegetation can be recognized in the Mediterranean-European region (Quézel and Médail 2003; Médail 2008):

(i) a thermo-Mediterranean belt, dominated by sclerophyllous communities most often as a narrow strip along the coast (with *Olea europaea*, *Ceratonia siliqua*, *Chamaerops humilis*, *Pistacia lentiscus*, *Pinus halepensis*, *Pinus brutia*, etc.);

(ii) a meso-Mediterranean belt, mainly with sclerophyllous forests (*Quercus ilex*, *Quercus suber* and *Q. coccifera*) or *Pinus halepensis*/*P. brutia* forests in areas with low rainfall or formerly disturbed by man;

(iii) A supra-Mediterranean belt, with diverse deciduous oaks forests (including Acer, Carpinus, Ostrya, Quercus and Sorbus) in the more humid ombrotypes;

(iv) A mountain-Mediterranean level, including Fagus and deciduous and semi-deciduous Quercus forests and notably coniferous forests with *Pinus nigra*, *Pinus sylvestris* and firs (*Abies alba* and most of the Mediterranean *Abies spp*.) and even cedar (*Cedrus libani s.l.*) on Cyprus.

Algerian forest covers about 4 million ha or less than 2% of the land area. The real forest represents only 1.3 million hectares, the rest (2.8 million hectares) consisting of scrub. Since independence, the Algerian institutions responsible for the preservation and extension of forest formations have been committed to reforestation. In half a century, all actions have been unsuccessful except for some sporadic and localized successes. A simple comparison between 1960 and 2010 of the areas of major forest and steppe formations reveals a quantitative average regression of more than 20% and disturbing qualitative. Forests in the strict sense represent only 1 million hectares of the 4,300,000 ha where successful reforestation is only 750,000 ha on the 3 million hectares reforested (Tab. 1).

Table 1. Main species of Algerian forests (D.G.F, 2007)

Species	Surface area (ha)	Percentage (%)
Pinus halepensis	881 000	21,5 %
Quercus suber	230 000	5,6 %
Quercus ilex	108 000	2,6 %
Quercus canariensis and *Quercus afares*	48 000	1,2 %
Eucalyptus	43 000	1 %
Pinus pinaster	31 000	0,8 %
Cedrus atlantica	16000	0,4%
Other (*Thuja*+ *Juniperus* + *Fraxinus*)	124000	3 %
Reforestation and protection	717000	17,5%
Maquis and scrub +voides	1902000	46,4%
Total	4100000	100%

The main characteristics defining the Algerian forest can be outlined as follows:

- A primarily light forest, unevenly, with coniferous stands or resinous trees of varying dimensions and ages, often creating a messy combination;
- Presence of an abundant undergrowth made up of numerous secondary species limiting visibility and accessibility promoting the spread of fire;
- Low average yield of wood content;
- Existence of notable feeding (particularly in *Quercus suber*) and expansion onto forest zones by nearby communities (Meddour-Sahar and Deridji, 2012).

The resinous formations (*Pinus halepensis, Juniperus oxycedrus, Juniperus phoenicea*) constitute almost the majority of forest and preforest ecosystems, they are also associated with *Quercus ilex* and *Olea europea*. These species are extremely important both economically and ecologically, particularly in terms of protecting against desertification and erosion. In addition, these forest formations are subject to overgrazing related to the surplus of the sheep, cattle and goatherd, as well as the fires posted in recent decades (Benabadji *et al.*, 2007). Recent taxonomic revisions suggest that northern Algeria (excluding the Sahara) has more than 300 national endemic species (Yahi *et al.*, 2012).

3. Methods for monitoring the health status of forest ecosystems

Monitoring the health of trees is essential for environmental stability. Tracking and detecting a system that identifies changes in the health, damage and malformations of trees will help identify signs of decline in forest species.

3.1 Dendrological and dendrometric approaches

Dendrology actually means "the study of trees." In common usage it has come to mean the taxonomy of woody plants, which is the systematic classification, naming, and identification of trees based on natural characteristics and relationships. The study of dendrology also includes knowledge about the features of trees and their geographical range (Harlow *et al*., 1979).

The expression dendrology (dendrología in Spanish) is both a scientific and artificial word. It is aquired from two Greek words that signify “trees” and “discourse” or “study”, or the study of trees. The limits of the science of dendrology are controversial. Basically, dendrology covered all aspects of trees, and in that time there was no science of forestry. (Little, 1955)

Dendrometry is a sub-discipline of dendrology that focuses on measuring the trees (size, height, shape, age, bark thickness, etc.) and their stand (slender, density of trees, covered area, distribution, standing volume, etc.). It can correspond to two needs that although close to each other and can be differentiated:

- It can be used to measure timber volumes as accurately as possible for commercial transactions (purchase or sale of cuttings). This is the broad field of forestry.

- It can also be used to establish and calculate various dendrometric parameters for describings stands and tracking their development. This field corresponds to silviculture and management (Gaudin, 1996).

3.2 Remote sensing approach

3.2.1 Definitions

Remote sensing (RS) is the process of extracting data about the earth’s land and water surfaces by taking images from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth’s surface (Campbell, 1966).

3.2.2 The importance of remote sensing in vegetation monitoring

Remote sensing is a valuable tool that offers significant insights into the structure and functioning of forest ecosystems because of its distinctive abilities in spatial and temporal resolutions. This tool was primarily tested to monitor changes in forest canopy structure over time, especialy when these changes reflect varying levels of green leaf biomass or chlorophyll amount (Soudani *et al,* 2014).

Several methods have been applied in the literature to evaluate change in vegetation. Chen (2002) and Ouyang *et al.*, (2010) have noted that the rapidly advancing remote sensing technology offers quick and effective method for mapping vegetation types change across large regions.

Remote sensing indicators of vegetation conditions are commonly utilized for monitoring ecological and biodiversity. Using various remote sensing technologies to evaluate and survey forest ecosystems, including products like biomass, LAI, etc., combined with high resolution long term monthly-data, represents the future of detecting forest dynamics. (David *et al.*, 2022). Vegetation status has been monitored using remote sensing informations in various regions around the globe. Zhao analyzed vegetation changes in Guanzhong Basin in northwestern China from 2000 to 2020 using NDVI, land cover, and climate data, and examined their response to climate change and human activities through trend and regression analyses (Zhao *et al.*, 2021). Kayet used airborne hyperspectral data to evaluate the conditions of health of plants near a mining site, while also measuring the effects of mining on plant health (Kayet *et al.*, 2022).

Remote sensing methods have progressed from early evaluation of vegetation classification and composition signs to the current precise monitoring of various indicators including coverage, LAI (structural indicators), primary productivity, vegetation health and phenology (functional indicators) (Li *et al.*, 2023).

3.2.3 Color composites

In Remote Sensing, change detection is the act of identifying differences in the state of objects by observing them at various moments. This task can be completed manually or using Remote Sensing software (Seikh *et al.*, 2017). The color composite method, which involves combining different bands, is commonly used for extracting vegetation from satellite images. Trial band combinations have been tested to detect vegetation and identify the optimal view of landscape patches. The correct interpretation of the image was ensured by comparing different vegetated and non-vegetated areas using corresponding colors in various band combinations. For instance, a standard ‘false color’ composite (FCC) 4-3-2 shows vegetation in different shades of reds, with coniferous plants appearing darker red than broadleaf varieties such as birch and rowan, which appears crimson.

3.2.4 Vegetation indices (VI)

An index is a number qualifying the intensity of a phenomenon, which is too complicated to be decomposed into known parameters. Although it is possible to identify the portion of impact of many factors when in a well-documented and controlled environment, it is often difficult to make this decomposition for signals observed on remote sensing images. The notion of vegetation index is well adapted for qualifying vegetation over large areas, for example over areas covering many pixels of an image (Bannari *et al.*, 1996).

Vegetation indices are quantitative measurements indicating the vigor of vegetation (Campbell, 1987). They are more sensitive than specific spectral bands for detecting biomass (Asrar *et al*., 1984).

The Ratio Vegetation Index (RATIO) was first reported by Birth and McVey (1968). It is calculated by simply dividing the reflectance values of the near infrared band by those of the red band. The result clearly show the contrast among the red and infrared bands for vegetated pixels, with high index values created by combinations of low red (because of absorption by chlorophyll) and high infrared (as a result of leaf structure) reflectance. Furthermore, because the index is constructed as a ratio, issues with fluctuating illumination caused by topography are minimized. However, the index is susceptible to division by zero errors and the resulting measurement scale is not linear. A study regarding its efficiency has been published by Vaiopoulos *et al*. (2004).

The Normalized Difference Vegetation Index (NDVI) was introduced by Rouse *et al*. (1974) in order to produce a spectral VI that separates green vegetation from its background soil brightness using Landsat MSS digital data. It is calculated as the difference between the near infrared and red bands normalized by the sum of those bands. It is the most widely used VI as it retains the ability to minimize topographic effects while producing a linear measurement scale. In addition, errors resulting from division by zero are considerably reduced. Furthermore, the measurement scale has the desirable property of ranging from -1 to 1, with 0 reflecting the approximate value of no vegetation and negative values for non-vegetated surfaces.

The Perpendicular Vegetation Index (PVI) suggested by Richardson and Wiegand (1977) is the parent index from which this entire group is derived. The PVI employs the perpendicular distance between each pixel coordinate and the soil line.

3.2.5 Evapotranspiration and reflected irradiation from satellite images

EvapoTranspiration (ET) is the total amount of evaporation and transpiration from the surface of the earth to the atmosphere. The flux of water to the air from sources such as the soil, canopy interception, and water bodies is accounted for by evaporation. On the other hand, transpiration is the loss of water as vapor through stomata in the leaves. Evapotranspiration is an important phenomenon within the land–atmosphere interface that regulates the earth's energy and water cycles. Both evaporation and transpiration take place at the same time and are influenced by solar radiation, air temperature, relative humidity, vapor pressure deficit, and wind speed. Crop characteristics, environmental factors, and cultivation practices influence the rate of transpiration. Transpiration rates also vary depending on the type of plant (Saha *et al*., 2022).

Evapotranspiration is an essential nexus between terrestrial water, carbon, and surface energy exchanges and is a basic element of the global water cycle (Zhang *et al*., 2016). Precise estimation of ET is necessary for undertaking research on climate change, and for controlling agricultural water demands, drought forecasting and monitoring, and optimal water resource development and exploitation, among other applications. Climate change is predicted to cause a reduction in soil moisture, an extension in daily ET, and these will raise the irrigation demand and cause further depletion of groundwater level (Shahid, 2011).

ET can be measured using empirical equation or remote sensing algorithm or can be estimated by traditional methods (Liou and Kar, 2014). A complementary relationship-based model established by Anayah and Kaluarachchi (2014) has been used to compute real evapotranspiration in a recent study in the Ganges Delta (Murshed and Kaluarachchi, 2018;Murshed, Rahman, and Kaluarachchi, 2019) where meteorological data have been used. The Penman–Monteith formula is employed frequently to overcome this issue, but it requires several climate data and surface factors that are not easily available (Stannard, 1993).

4. Relationship between remote sensing techniques and field measurements

Remote sensing has the ability to provide consistent, reproducible and up-to-date information on various forest parameters in order to make inventories more effective (Waster *et al*., 2017). The most used forms of remote sensing in the environmental sciences are images of the Earth's surface acquired from sensors mounted on airborne and spaceborne platforms.

Remote sensing has been used for mapping the distribution of forest ecosystems, global fluctuations in seasonal plant productivity, and the three-dimensional (3D) structure of forests (Lechner *et al.*, 2020). RS data with high spatial and temporal resolution are essential for detecting the rapid change of the earth's surface. Besides, spatial-temporal analysis using RS satellite images plays an important role to understand the impact of extreme events on a global scale (Ferchichi *et al.*, 2022). The ability to recognize, locate, and characterize features on the Earth's surface is made possible by remotely sensed imaging. Moreover, although each image provides a snapshot of the environment, it is typically possible to obtain imagery repeatedly in time. As a result, remote sensing has been used in a wide range of forest ecology and management applications including mapping invasive species, monitoring land-cover changes, such as habitat fragmentation and estimating biophysical and biochemical properties of forests (Lechner *et al.*, 2020). MODIS is one of the main tools designed as part of NASA earth observing system to enable long-term global monitoring of Earth's land, ocean, and atmospheric properties. Actually, MODIS is a sensor located on both Terra and Aqua satellites. Terra MODIS and Aqua MODIS are capable of collecting data in 36 spectral bands with wavelength ranging from 0.4 μm to 14.385 μm and at different low spatial resolutions (2 bands at 250 m, 5 bands at 500 m, and 29 bands at 1 km). Both instruments capture the entire Earth with high temporal resolution every 1–2 days (Kahn *et al*., 2009; Zheng, 2020). Moreover, LANDSAT system is a series of optical and infrared RS satellites for land monitoring. For Example, Landsat 7 data contains 8 spectral bands with high spatial resolution varying from 15 to 60 m but lower temporal resolution (e.g., more than 10 days) (Zhu *et al*., 2018). Landsat 8 carried onboard two sensors; Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) as opposed from prior Landsat where the thermal and reflective band images were acquired with the same sensor.

Monitoring the measurements of trees enables us to grasp the characteristics of the forest ecosystem and implement appropriate management strategies that align with the unique environmental conditions. Forest resource knowledge follows a hierarchical structure (Luoma *et al*., 2017), where individual tree attributes are aggregated at the plot level, and subsequently, plot-level estimates are employed to derive comprehensive assessments of forest resources at the stand or large-area level. However, conducting surveys to gather dendrometric characteristics (biometric characteristics) is generally a resource-intensive and time-consuming effort due to the involvement of several specialized technicians (Holopainen and Talvitie, 2012).

Field measurement is categorized into two methods depending on the level of impacts on the tree:

Destructive methods that involve harvesting trees like tree trunk, leaves and branches. It comprises field (site preparation, measurement of felled trees, weighing of logs and take sampling for laboratory) and laboratory (measuring dry biomass, density and volume) operations (Ravindranath and Ostwald 2008; Picard *et al*. 2012) and non-destructive methods that do not require total cutting of the trees, only impacting small branches (Picard *et al.*, 2012). This applies to ecosystems with rare or protected tree species where it is not possible to harvest such species (Montes et al. 2000). Estimating the above-ground forest biomass through non-destructive method involves either climbing the tree to measure different parts measuring the tree's diameter at breast height, height of the tree, volume of the tree and wood density (Aboal et al., 2005; Liu and Westman, 2009; Ravindranath and Ostwald, 2007).

The main objective of any forest inventory is measuring and monitoring the wood volume, biomass or species diversity, and the monitoring. The majority of forest inventories use sampling plots for analyses, and the results are used to estimate the overall parameters of the forest cover being studied. The precision of the resulting worldwide parameters relies on the representativeness, spread and amount of the included samples (Barrett *et al.*, 2016).

Species, diameter at breast height (DBH) and total tree height (TH) are the most frequently recorded attributes, although numerous other parameters are also normally assessed in the field or calculated from such data (e.g. leaf area index, stem curve, crown diameter, or physiognomy of the lowest branches). Once all the trees of the plots have been described, the population values are estimated for the entire study area through interpolation or extrapolation (Liang *et al*., 2016). In most forest surveys, tree information is collected through meticulous tree-by-tree measurements utilizing mechanical or optical instruments like calipers, hypsometers, and measuring tapes. (Luoma *et al.*, 2017).

Conducting a traditional inventory of forest stand attributes through fieldwork can be challenging, expensive, and time-consuming when covering a large area. Remote sensing may be the only practical method to acquire forest stand parameter information at a suitable cost, with acceptable accuracy, and feasible effort because of its data advantages which include repeated data collection, multispectral and multitemporal images, synoptic view, fast digital processing of large amounts of data, and compatibility with geographic information systems (GIS) (Lu *et al*., 2004).

The correlation between remote sensing methods and biophysical parameters could be valuable to studies on diagnosis and monitoring, particularly in endangered habitats, such as the Atlantic Forest. Corlett (1995) proposed the use of remote sensing as a technique to fill the gap between local/intensive and global/wide studies, providing useful data for decision makers (Kangas *et al*., 2000). Remote sensing can provide vegetation indices that serve as biophysical indicator (Gamon *et al*., 1995).

5. Tree Distribution Pattern

The presence of trees in mixed forests results in varied horizontal and vertical distribution patterns, which are influenced by the ecological characteristics of trees (association degree, growth rate, shade tolerance, nutrient and water supply), environmental conditions at the site. (Getzin *et al*., 2006; Pretzsch *et al*., 2016) and applied silvicultural systems (Smith, 1986). It makes little sense to separate vertical and horizontal structural components, as they are functionally interconnected and influence each other (Fig.1). For example, introducing a new species can be lead to a new canopy layer due to differences in growth variations between species.

Moreover, the level of horizontal structural diversity may vary depending on the vertical location within a stand (Brokaw and Lent, 1999). In Bialowieza primeval forests that are eutrophic, the lower layer is uniform and made up of one type of species, whereas the upper layer is diverse and includes a minimum of five species (Bielak and Brzeziecki 2017).

By modifying the supply, capture and efficiency of resource use and therefore the intra- and interspecific interactions, horizontal and vertical tree distribution patterns affect the main processes in forest stand dynamics. The rising diversity in both horizontal and vertical stand structure is closely associated with an increased species abundance (Pommerening, 2002; Scherer-Lorenzen *et al*., 2005). Depending on the type of spatial species intermingling, the stand dynamics may differ substantially, this will determine whether intra- or interspecific competition is the prevalent interaction between trees and, consequently, to what extent mixing effects can be expected (Pretzsch, 2009). Interactions and relationships among tree species are frequently researched in the air than in the soil. However, new studies indicate that niche partitioning and vertical stratification of root systems occurring (Fölster *et al*., 1991; Brown 1992), while this is not consistently true. (Meinen *et al*., 2009).

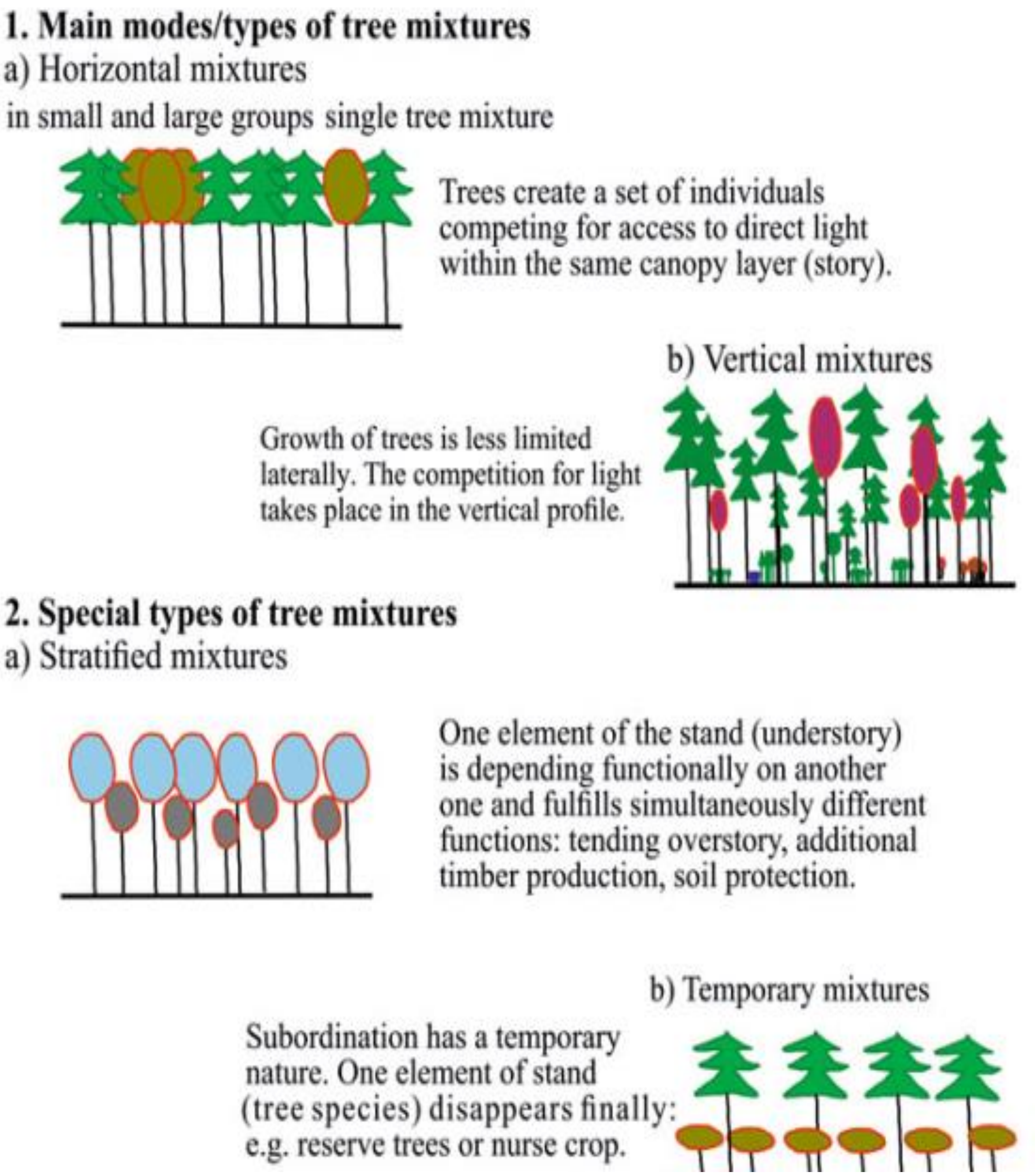


Figure 1. Types of tree species mixtures characterized by different spatial and temporal effects. (Adapted from Schütz, 2001)

6. Natural forest and planted forest

The FAO defines a forest as land covering an area of more than 1 hectare with trees reaching a height of over 7 meters and a forest cover of more than 10%, or with trees capable of reaching these thresholds in situ. Lands predominantly used for agriculture are excluded. Natural forest and planted forest have often been considered as two opposite poles of forestry, between which development projects swing back and forth (Loupe, 2011). Natural forest is a forest that has not undergone major transformation resulting from large-scale industrial exploitation. It is also known as "pre-industrial forest". Its description is not static, but takes into account its "variability", meaning the fluctuations it has undergone over time under the influence of natural processes (e.g. natural disturbances, mortality and regeneration). Its description is based on observations from forests that have not been managed to date or from historical studies covering large spatial or temporal extents.

In order to facilitate the operational management of the concept, the judgment of various experts is solicited in the development of simplified descriptions of the natural forest. Finally, this judgment will have to evolve, particularly following a profound modification of natural processes by global changes (climate change, pollution, invasive species, present or anticipated exotic insects and diseases) (Expert Group on Intensive Plantation Forestry, 2013).

The term reforestation implies the return to a previous state, as indicated by Touzet (1987). It is also reforestation and the surgical solution that is appropriate where careful management cannot succeed (Seigue, 1985, in Lahmer, 1996). Reforestation is an operation that consists of creating wooded areas or forests that have been removed by clear-cutting or destroyed by various causes in the past (overexploitation, forest fires, overgrazing, war...). Sometimes, its explicitly involves protective forests. Afforestation is the planting of trees on land that has been treeless for a long time.

7. Climate change and terrestrial ecosystems

There is strong scientific evidence that atmospheric CO_2 and global mean annual temperatures have been steadily increasing since 1880 (Stocker *et al*., 2013). Over Africa, drastic rises in land surface temperatures have been reported (Jones *et al*., 2012; Engelbrecht *et al*., 2015) and future projections indicate that temperature is continue to rise, at 1.5 to 2 times the global rate of temperature increase (Niang *et al*., 2014). Changes in rainfall patterns including increases in the frequency and intensity of drought events (Engelbrecht *et al*., 2013) as well the occurrence of El Niño events (Cai *et al*., 2014) are expected. These changes in temperature and rainfall combined with rising atmospheric CO_2 concentrations are likely to have profound implications for the terrestrial ecosystems of Africa (Scholes *et al*., 2004; Midgley & Bond, 2015). These impacts are likely to be confounded by multiple existing stressors such as land-use change, livestock grazing, fuel wood harvesting and invasions by alien species (Midgley *et al*., 2003; van Wilgen *et al*., 2008).

Understanding and predicting how climate change is likely to alter ecosystem structure and function is a key question in ecology and there is a growing research impetus to detect early signs of climate change impacts and to identify vulnerable regions. The response of vegetation to climate change depends on the magnitude of change, the relationships between the variables (e.g. temperature, rainfall and CO_2) and the historical environmental conditions (e.g. land-use change).

In Africa, changes and shifts in the distribution and dynamics of terrestrial ecosystems, including deserts, grasslands and shrublands, savannas have already occurring (Field *et al*., 2014). Increases in woody vegetation in central, eastern and sub-Saharan Africa have been well documented (Bond & Midgley, 2000; Wigley *et al*., 2009; Ward *et al*., 2012; Mitchard & Flintrop, 2013; Stevens *et al*., 2016) and modelling studies focusing on vegetation responses to climate change project that the extent of woody vegetation is likely continue to increase resulting in a variety of biome shifts (Scheiter & Higgins, 2009; Higgins & Scheiter, 2012).

Evidence suggests that as critical CO_2 levels are crossed, these may trigger vegetation structural switches with important consequences for both biodiversity and carbon storage (Bond & Midgley, 2000).

Uncertain in how climate is likely to change coupled with uncertainty in the mechanisms driving the change is currently limiting the ability to project future ecosystem change (Midgley & Bond, 2015). Evidence required to resolve divergences in model outputs is limited due to the lack of quantitative spatially explicit evidence the impact of climate on terrestrial ecosystems. In addition, the current understanding of the mechanism and extent of the influence of atmospheric CO_2 on ecosystem change is far from complete. Improved long term monitoring at regional spatial scales of changes in vegetation structure and dynamics combined with improved models of vegetation function is required in order to provide accurate assessments of current vegetation states and functions as well as future projections of change (Hill *et al*., 2011).

The necessity of such detailed information has increased not only to assist decision-making but also for improving climate models at regional and global scales.

Climate on earth has changed several times during the past millions of years, according to studies using a broad range of proxies such as ice cores, pollen, and tree rings (LaMarche, 1974; Dansgaard *et al*., 1993; Lara and Villalba, 1993; Briffa *et al*., 1995; Petit *et al*., 1999; Fowell *et al*., 2003). These changes have mainly been due to natural factors, such as solar cycles and biotic influences. Since the last century, however, one single species is shifting the natural atmospheric equilibrium: human impacts are causing an unprecedentedly quick elevation of atmospheric carbon-dioxide levels, leading to an elevation in the earth's average temperature. Although every living organism is affected by these changes, plants may be particularly at risk, as they are not able to migrate at the same timescale as the climate changes. Instead, plants largely have to rely on metabolic, physiological, and ecological strategies to compensate for environmental changes.

In an effort to secure understanding of how plants adapt to changing climate, a number of studies have considered changes in observables such as phenological characters and physiological rates, but due to methodological limitations, most of these studies only analyzed a limited period of a plant's life. These limitations make it difficult to obtain a complete picture of how species adapt in response to environmental changes. Furthermore, it is difficult to elucidate which responses are occurring in response to natural processes and which are related to anthropogenic influences. Quantitative models can help address these challenges, by integrating the impacts of a variety of environmental factors on the life cycle of a tree. This yields a particularly promising approach to studying the vegetation consequences of climatic changes.

Naturally, such models need to be informed by empirical data. For this purpose, and also to address the other questions above, it is important to obtain long-term records of how vegetation has changed in response to climatic conditions.

Dendrochronology (from the Greek dendros = trees, chronos = time, and logos = knowledge) is a well-established science that can be used to infer growth rates under different environmental conditions (Schweingruber, 1989; Stokes and Smiley, 1996). It provides accurate and long series of data that provide yearly records of changes in environment conditions at a study site. As one example, tree-ring width (one of the characters used in dendrochronology) shows strong correlations with temperature and precipitation across different landscapes throughout the world (Lara and Villalba, 1993; Briffa *et al*., 2001; Briffa *et al*., 2004).

Although most of dendroclimatic studies have considered trees of temperate species, some tropical tree species have been shown to be especially suited for this kind of study. Worbes (2001), Schöngart *et al*., (2002, 2004, 2005, 2006), and Oliveira *et al*., (2009) have all shown that many tropical species are particularly suited for dendroclimatological analyses (in addition to unpublished works on the genera Cedrela, Hymenaea, and Podocarpus that also show promising results).

Chapter 02: General conditions of forest study sites

1. Physical conditions

1.1. Location

The Hodna basin is located approximately within the following geographical coordinate ranges:

Longitude: 4°15' East and 5°06' West;

Latitude: 35°18' North and 35°32' South.

The Hodna basin is situated in northeastern Algeria (Fig. 2) and it constitutes 54% of the total area of the Algiers Hodna Soummam basin, it covers 07 wilayas in parts: Batna; M'sila; Bordj Bou Arreridj; Médea; Sétif, Bouira and Djelfa (Sahnouni, 2023).

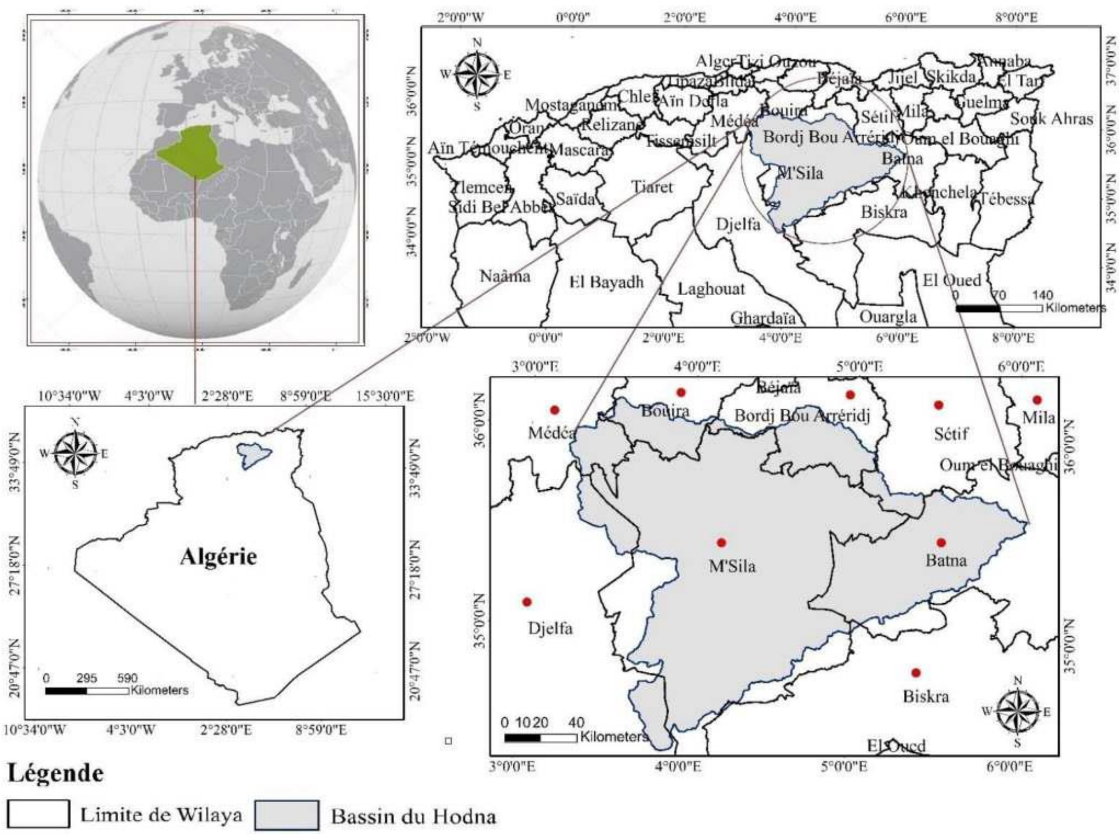


Figure 2. Location of the Hodna Basin (Sahnouni, 2023).

Our study focuses on two different regions that are part of the Hodna mountains, one located in the northeast (Boutaleb Forest) and the other in the southwest (Djebel Messaad).

Djebel Messaad is located in the M'sila province, which is one of the natural pine forest. This forest serves as a barrier between the northern region and the desert, making it susceptible to desert influences (Zedam *et al.*, 2016). According to the Djebel Messaad forest district (C.F.D.M), this forest is the largest in the M'sila province, covering a total of 33556 hectares within the Saharan Atlas. It is bordered by Boussaada to the north, Ain el Meleh to the south, and Medjedel to the west, with the highest point reaching 1675m (Fig. 3).The forest is currently divided into 12 cantons, generally bounded by the major ridgelines that characterize its relief. These cantons are shown in Tab. 2.

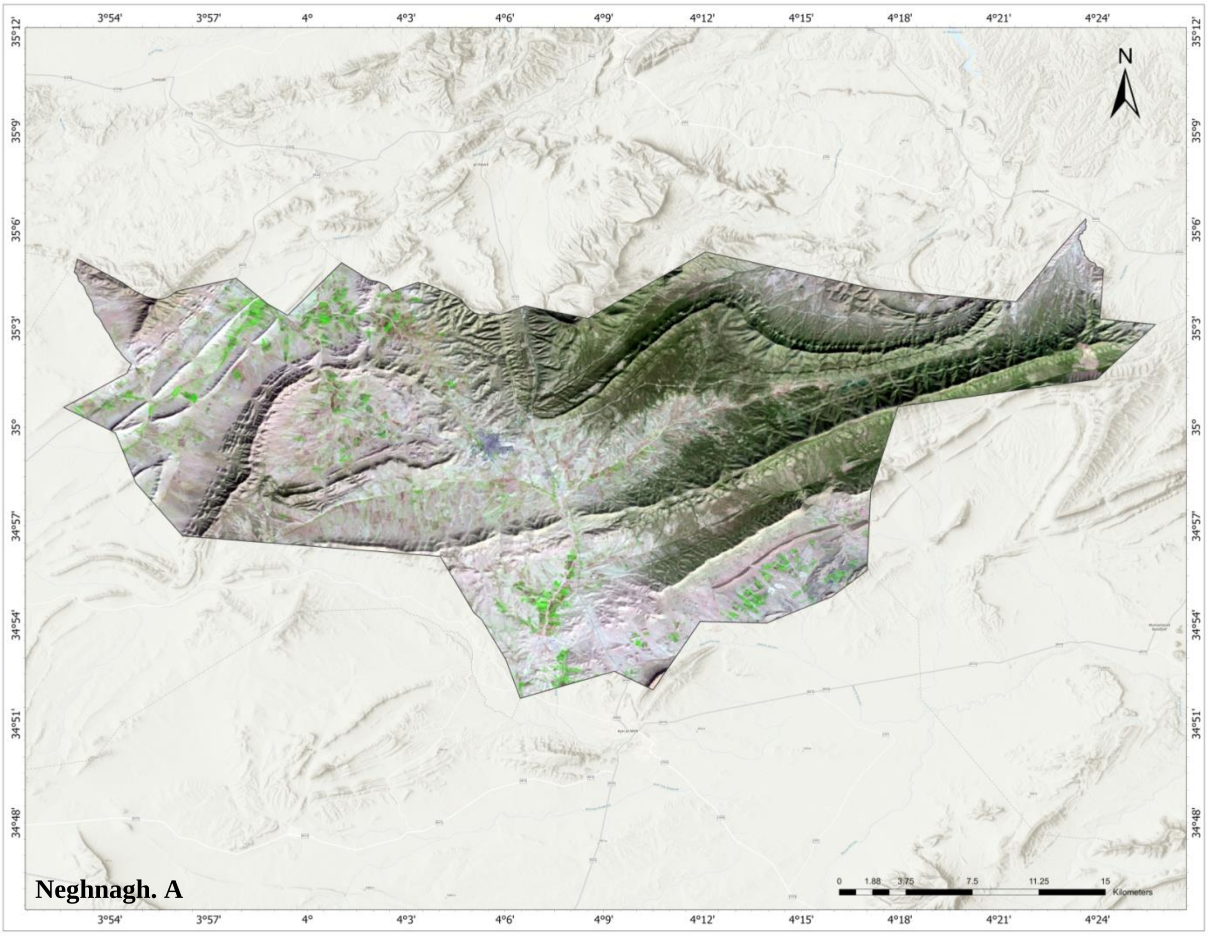


Figure 3. Location of Djebel Messaad forest over natural color composition map obtained from Landsat 8 satellite processed with ArcGis Pro.

Table 2. Cantons of Djebel Messaad (C.F.D.M 2012)

Canton	Surface area (Ha)
Fernane	5193
Djebel Fernane	1035.66
Draa Chehima	2182
Bouferdjoune	2159
Tsigna	3210
Okfiane	2312
Masmoudi	6430

Our second research site was Djebel Boutaleb forest, which is a part of the Hodna mountains range. Situated between the high plains of Setif to the north and the Hodna basin to the south, the massif covers a legal area of 28,427.17 hectares (Fig. 4).

Figure 4. Study area of Boutaleb location with wilayas over natural color composition map obtained from Landsat 8 satellite processed with ENVI 5.1 software.

The state forest of Boutaleb is located within six communes of Setif: Rasfa, Ain Azel, Boutaleb, Al Hamma, and Saleh Bey. Gosbet in the Batna province, and Magra in the M'Sila province. The management of the state forest of Boutaleb falls under the jurisdiction of the Setif forest conservation authority, with sub-districts including Ain Oulmane and Ras Isly-Hamma-Ain Azel, as well as thirteen specific areas for conservation. (Fig. 5).

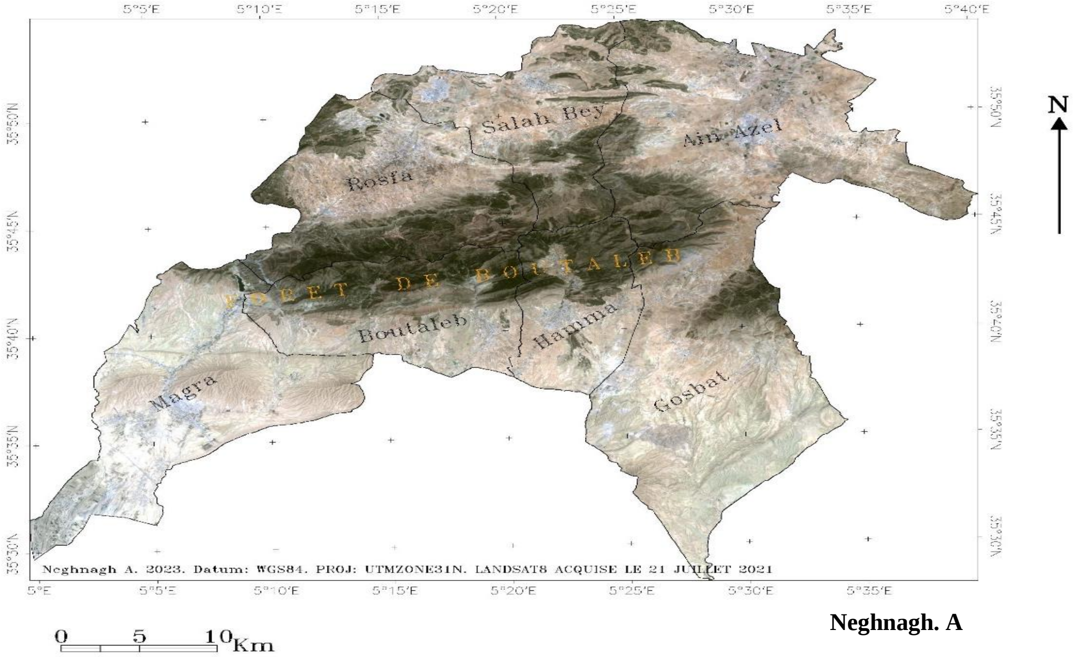


Figure 5. Study area of Boutaleb location with communes of Setif over natural color composition map obtained from Landsat 8 satellite processed with ENVI 5.1 software

1.2 Topograghy

Djebel Messaad forest contains numerous small mounds arranged in three main structures that run from Northeast to Southwest. Within these structures, three lines are of parallel ridges, with two major exposures facing opposite directions: northwest and southeast. Elevations in the area range from 1000 m to 1672 m (Fig. 6). The slopes of the land are relatively flat at lower altitudes and become steeper as altitude increases (Fig. 7).

Boutaleb massif is a large mountain range that extends from the Soubella gorges to Ain Azel. Its unique shape consists of folded ridges, giving it a distinctive mountainous appearance. The Boutaleb Mountain reaches high altitudes, with peaks ranging from 980 m to 1886 m, the highest one being Djebel Afghane (Fig. 6). This results in steep slopes, particularly in the southern part, which are prone to significant water erosion due to low vegetation cover, especially during summer rains (Fig. 7) (Madoui and Gehu, 1999).

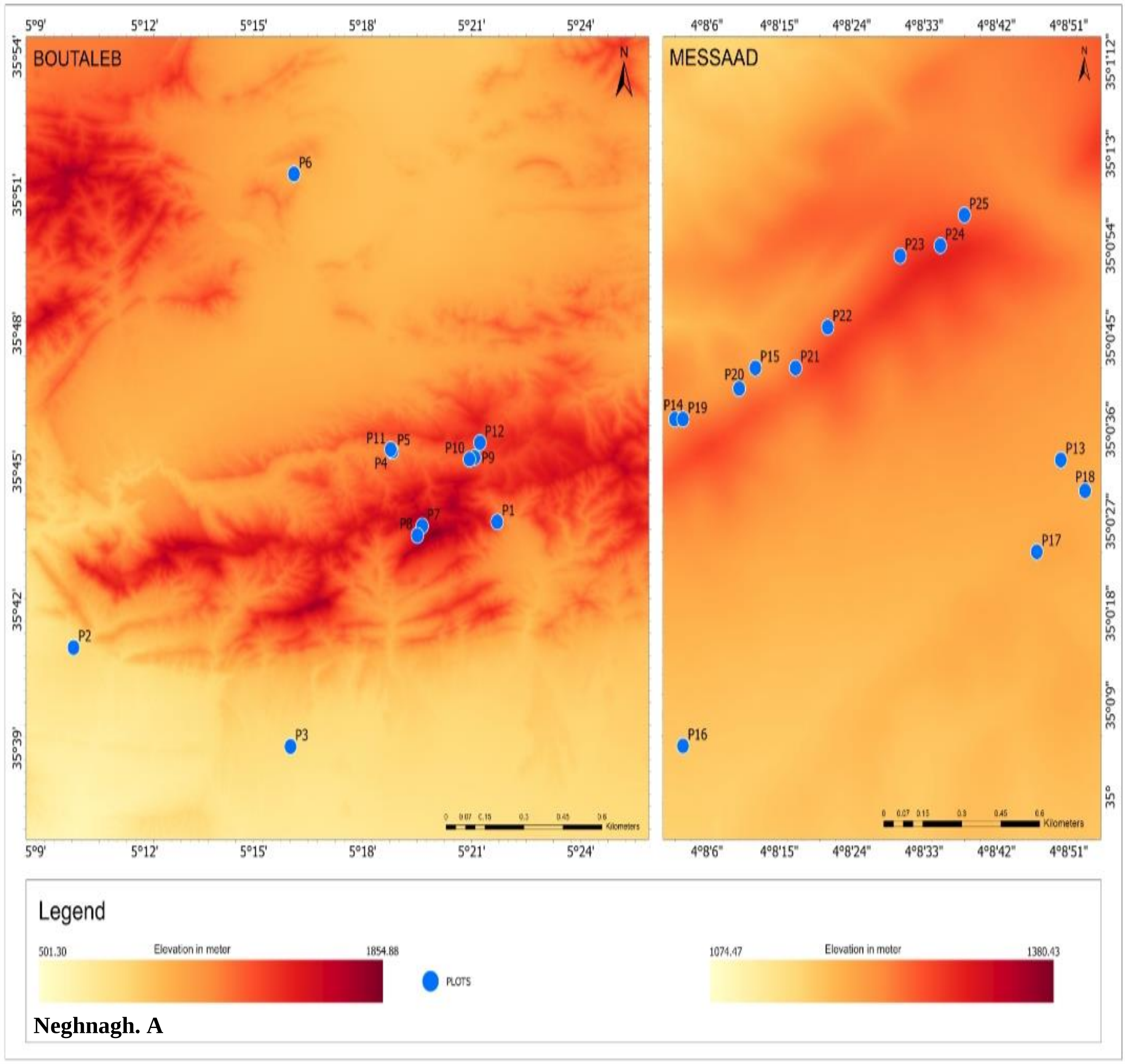


Figure 6. Elevation map of Djebel Boutaleb and Djebel Messaad processing with ArcGis Pro.

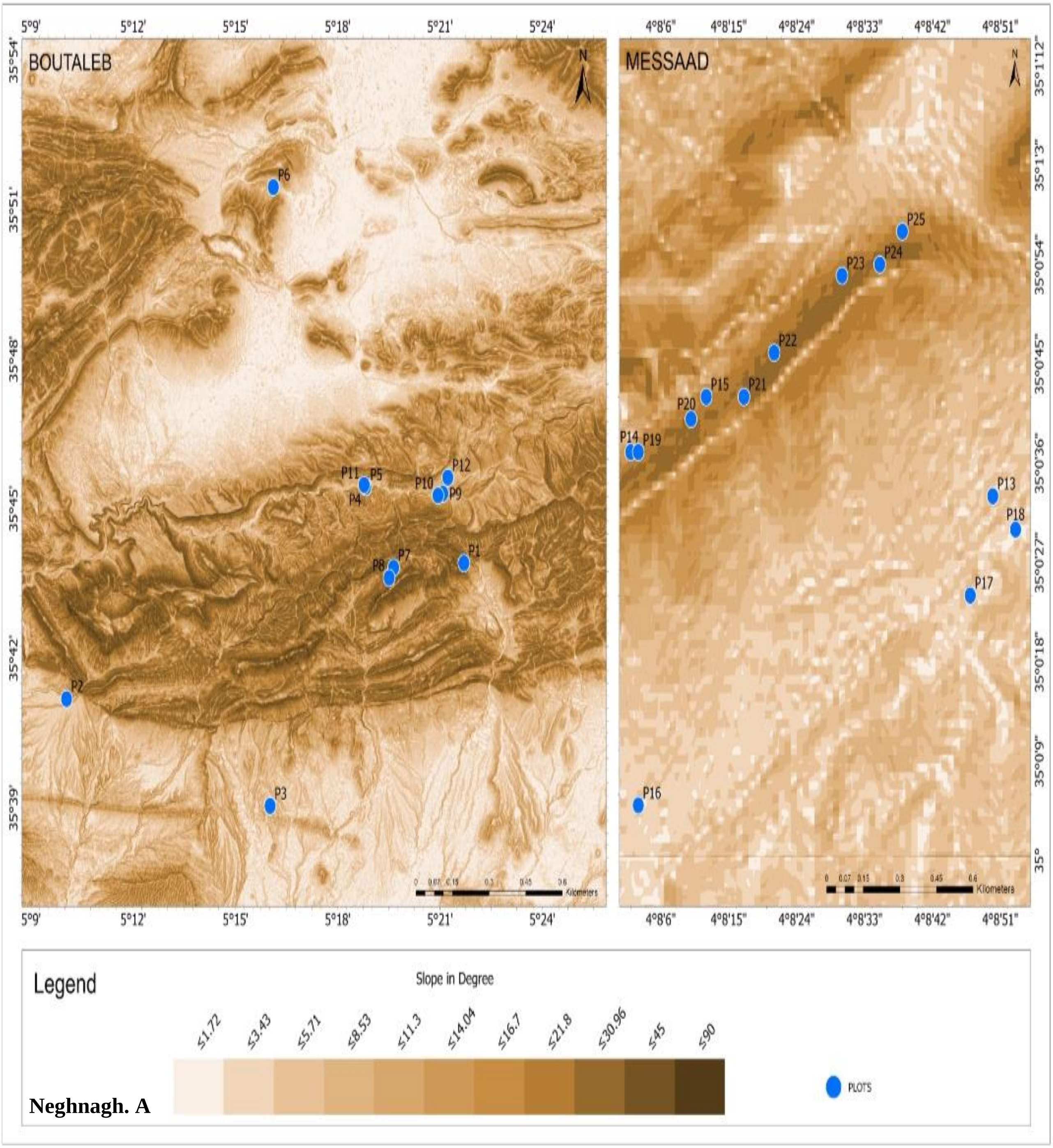


Figure 7. Slope map of Djebel Boutaleb and Djebel Messaad processing with ArcGis Pro.

In Djebel Messaad, we can identify the following lithological units:

- In the north, there is a syncline made up of sub-reef limestones and lithographic limestones (limestones and marl).

- In the south, there is an anticline and pre-inclinal made up of sandstone, clay marl, dolomite, and gypsum.

- In the east, there are continental tertiary deposits consisting of sand and red clay.

- In the west, there are continental quaternary deposits made up of silt and clay (C.F.D.M) (Fig. 8).

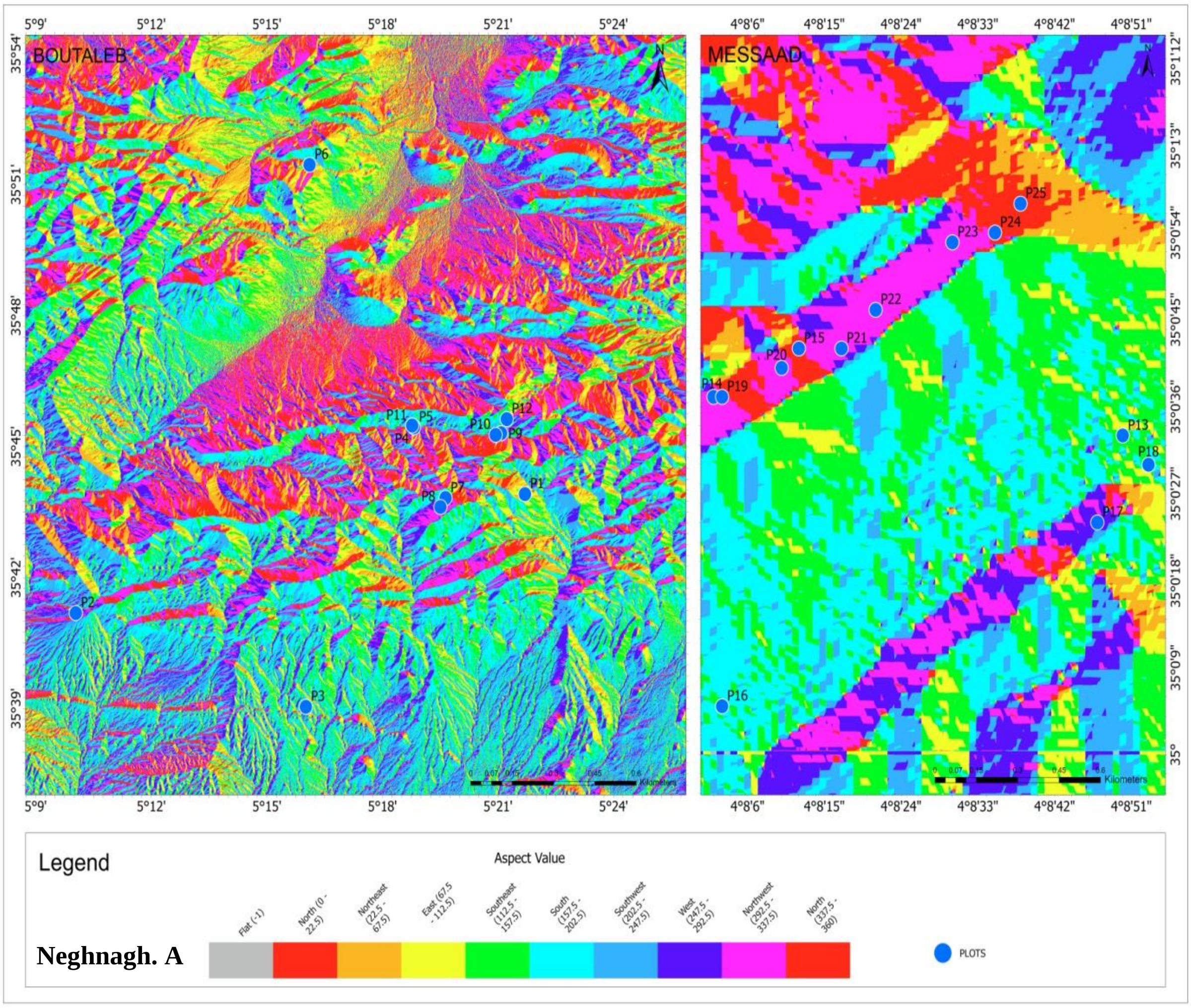


Figure 8. Aspect map of Djebel Boutaleb and Djebel Messaad processing with ArcGis Pro.

According to Kanev's study (1972), Boutaleb massif consists of a large anticlinal whose east-west direction axis in the western part of the massif and it is slightly curved toward the northeast in the central and eastern zone. The Lyasian heart of this anticlinal emerges in three distinct islets that are from West to East: the core of djebel Soubella and Bou- Ich, Bou-Hellal and finally Afghan. They are covered by a Jurassic series from the full Cretaceous to the Cenomanic. In the north-west part of the massif, a sub-horizontal transgressive simonian comes to cover the above-mentioned formations. Finally, a continental and neogenous oligocene deposit belt runs at the foot of this anticlinal in an almost continuous inflorescence (Kanev, 1972).

1.3 Geology

According to the conservation of the forests of Djebel Messaad (C.F.D.M), the soils belong to three types of soils:

- Rough eroded mineral soils
- Calcimorphic soils (steppe brown, rendzine, degraded rendzine, limestone brown)
- Evolved soils to mull (brown to calcareous mull)

According to Kanev's (1972) work on the Boutaleb Domanial Forest and the soil map developed by Boydgiev (1975) as part of the Hodna, F.A.O. project, the region can be divided into two series: raw mineral soils and calcimagnesic soils.

- Raw mineral soils: lithosols and regosols.
- Calcimagnesic soils: brown limestone soils and brown calcareous soils.

1.4 Hydrography

Djebel Messaad area is characterized by the following hydraulic resources: deep drilling, traditional drilling, water dams, pastoral drills, wells, water ponds and dams (Tab. 3).

Table 3. Water resources in Djebel Messaad (C.F.D.M).

Water resources	**2013**	**2014**	**2015**	**2016**	**2017**
Deep drilling	230	234	248	250	260
Traditional drilling	98	101	101	101	102
Water dams	0	0	0	0	0
Pastoral drills	12	12	122	12	12
Wells	2	2	2	2	2
Water ponds	0	0	0	0	0
Dams	1	1	1	1	1

The hydrographic network of the Boutaleb forest massif is very dense, but lacks permanent surface water. Most of the watercourses in the massif are temporary and dry up in the summer, except for Oued Faragh, which has a permanent flow and joins Oued Soubella to the west, eventually flowing into the Hodna chott. The main Oueds are listed in tab. 4, with irregular flow rates and significant flow only on rainy days. Over 80% of the Boutaleb massif is part of the Hodna watershed, with all tributaries flowing into the Hodna chott during the rainy season. The massif contains two sub-drainage basins: the Southern Hodna Mountains sub-watersheds and the sub-watershed of the Setifien highlands in the North (Bousselam watershed).

Table 4. The main wadis of the Boutaleb massif.

North flank wadis	**South flank wadis**
Oued Ras Isly	Oued El Hamma
Oued Messaoud	Oued Tebesbes
Oued Meadouma	Oued Tirhirin
Oued Farag	Oued Anoual
Oued Annfif Attafi	Oued Tafrent
Oued Soubella	

1.5 Climatology

In the Mediterranean region, climate is a determining factor in the establishment, organization and maintenance of ecosystems. Thus, one of the essential aims of Mediterranean ecology is to find the best relationship between different plant formations and climate.

According to phytogeographic subdivisions of Algeria (Quezel and Santa, 1962), Djebel Messaâd belongs to the saharian atlas steppe area of Maghreb sector and Mediterranean region. The climate is Mediterranean and predominantly continental. Its characteristics include:

- The mean temperature of the coldest month (m) = -1,01 °C,
- The mean temperature of the warmest month (M) = 32,47°C,
- The mean annual rainfall: 411,14 mm/year
- Emberger quotient (Q2) = 41,89.

These data indicates that this forest is part of the Mediterranean semi-arid bioclimatic zone, characterized by cold winter.

From a climatic point of view of Boutaleb forest, and after extrapolation from old data by Seltzer (1946) and more contemporary data (Madoui, 1995), rainfall ranges from 300 to 700 mm, the minimum temperature of the coldest month (m) at the high point can reach -4.8°C in the south of the massif and -3.3°C in the north. The average maximum temperature of the warmest month (M) at the highest point does not exceed 25°C in the north and 29°C in the south, while it can reach 31°C in the north and 34°C in the south at lower elevations. The bioclimate is semi-arid at lower elevations, with mild winters in the north and cold in the south, while subhumid with extremely cold winters dominates the higher elevations. Low altitudes experience a five-month long dry season, while high altitudes have a three-month long dry season. (Madoui, 2013) (Fig. 9).

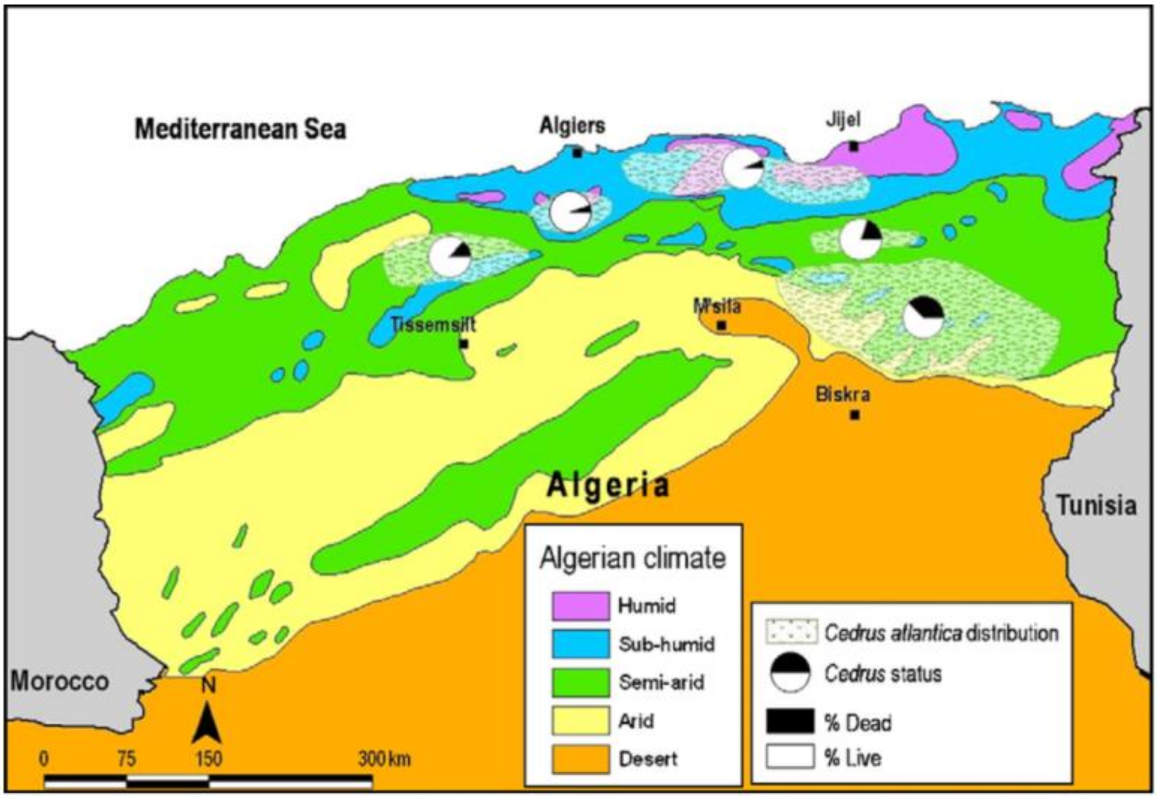


Figure 9. Map of climatic zones in northern Algeria and distribution of mortality of Cedrus atlantica.

2. Biodiversity

1.2 Flora

Algeria's geographical location between two floral empires, Holarctis in the north and Paleotropis in the south, results in a diverse flora with over 4000 taxa, spread across 131 botanical families and 917 genera with 464 are national endemic taxa, including 387 species (Yahi & Benhouhou, 2011).

Steppe vegetation is a defining feature of Chott El Hodna (Le Houérou, 1995). Salt-tolerant, perennial species that are casulescent dominate the area. (Kaabeche *et al*., 1995), and annuals (Zedam, 2015).

Aleppo pine forests are found in the Hodna Mountains at altitudes ranging from 800 to 1,500 meters. Above an average elevation of 1,400 meters, the highest peaks are covered in Cedar forests that are more or less damaged. The majority of the mountainous zone is covered with matorral forests, which are more or less wooded and include Holm oak, Prickly juniper, and matorral with Phoenician juniper and lentisk (Le Houérou *et al*., 1975).

Djebel Messaad is a natural Aleppo pine forest with vegetation consisting of *Pistacia lentiscus*, *Rosmarinus offcinalis*, *Globularia alypum*, *Hertia cheirifolia*, *Dorycnium suffruticosum*, *Fumana ericoides*, *Stipa tenacissima*, *Cistus libanotis*. Part of the forest belongs also to the association *Juniperetum phoenicea* characterised by *Artemisia herba alba*, *Lygeum spartum*, *Helianthemum cinereum*, and *Quercus ilex* in relatively cool regions or sites less affected by agriculture and animal grazing, thereby including *Cistus villosus*, *Jasminum fruticans*, *Muscari atlanticum*, *Dactylis hispanica* and *Ampelodesma mauritanica* (El-Attoui, 1996). It is a degraded, clear forest with a low density and a significant scrubland. The steppe is a low, discontinuous formation, without trees and shrubs; it is typical of the high Plateaus. Grass steppe made up of Alfa (*Stipa tenacissima*) and *Aristida pungens*. *Artemisia herba alba* steppe and Crassulacea steppe is made up of species typical of the wadi spreading zone (*Emphorbia sp*., *Péganum sp*.) (Benderradji *et al.*, 2018).

The vegetation of Boutaleb state forest has been strongly influenced by human activity at all levels, which has led to its richness. During the 1990s, 423 species were inventoried, 3% are endemic and 61% represents the Mediterranean type (Madoui, 1995, 2003a). Arboreal vegetation is represented by coniferous forests of varying densities. This vegetation consists mainly of *Cedrus atlantica Manetti* and *Pinus halpensis Mill*. Cedar forests are the main high-altitude forest formations, found on the northern slopes from 1,400 m upwards. Along with cedar, they include *Quercus rotundifolia*, *Acer monspessulanum* and *Juniperus oxycedrus*. Pine forests appear at altitudes of 1000 m and above. Another type of arborescent vegetation is found mainly along the Oueds (Oued Fraregh, Oued Afghan ect.), the hygrophilous forests (riparian forests) consisting of: *Populus alba*, *Populus nigra* and *Salix pedicellata*.

1.2 Fauna

Chott El Hodna is a natural area with great importance for animal species (Cuvier's Gazelle *Gazella cuvieri*, Houbara Bustard *Chlamydotis undulata*), endemic to North Africa and endangered species listed by the International Union for Conservation of Nature (IUCN). The fauna is rich and diverse in both qualitative and quantitative terms, with 119 species of birds, 20 species of mammals and 10 species of reptiles (Ladgham Chicouche & Zerguine, 2000).

The faunistic inventory in Djebel Boutaleb is based on data collected by Setif Forestry Department and existing bibliography from the universities of Setif and M'sila, supplemented by field observations and information. The wildlife potential of the Boutaleb massif is significant and varied represented by different species of birds (*Milvus migrans*, *Neophron* *percnopterus, Aguila rapax, Alectoris Barbara, Apus melba, Dendrocopos major…),* mammal fauna (*Sus scrafus, Hyena hyena, Felis sylvestris, Mustella nivalis, Vulpes vulpes, Mus musculus, Felis sylvestris…)* and reptile species (*Varanus griseus, Natrise viperina, Chamaeles vulgaris, Cerastes cornutus, Testodus grasea*).

Chapter 03: Material and methods

1. Data Collection and Processing

The characteristics of vegetation and moisture parameters are multiple and generally non-stationary, whether spatially or temporally. Their observation therefore requires the implementation of measurement devices, either in situ, in which case we speak of 'field observations', or from space, in which case we speak of 'remote sensing observations'.

1.1 Field data

In situ measurements related to the biophysical characteristics of trees correspond to a spatial sampling of the study area. The Boutaleb forest and Djebel Messaad are two important forest in Hodna that aims to understand the quantity, quality, and patterns of soil occupation. The ground data used in this study are from the 25 sample plots inventory in 2022 and 2023 with the support of the forestry services, and all sample plots plotted in fig. 10 were in size 30m x 30m, or 900m^2. In our study, the trees that are inside the plots are taken into account.

The observation is made from the first tree in a clockwise direction (Fig. 11).

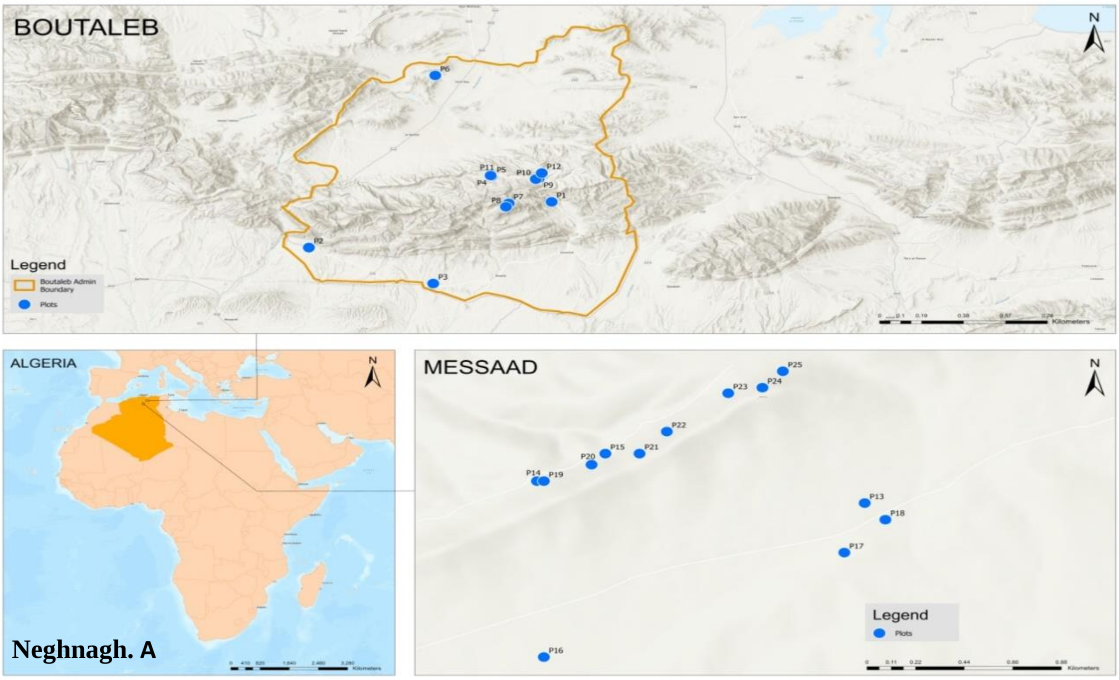


Figure 10. Plots location processing with Google Earth engineering.

Figure 11. Plots delimitation.

The study area is rich in forest resources, and the dominant tree species in the screened sample plots mainly include five species: *Pinus halepensis, Cedrus atlantica, Quercus ilex, Cupressus sempervirens, Juniperus oxycedrus*. The data include the location, date, species composition. For each sample plot, the main investigation includes diameter at breast height, tree height and species, which the purpose is to understand the actual state of the vegetation.

1.1.1 Measurements of total height

The height of trees is determined by the vertical distance from the ground to the top of the tree. The Measure Height application was used to measure the height of all trees in the plots.

1.1.2 Measurements of circumference

We used a tape measure to measure the circumferences at a height of 1.30 meters above the ground, approximately chest height (Fig. 12).

Figure 12. Measurement of the circumference of observed trees.

1.1.3 Measurements of crown diameter

There is no universally accepted method for determining crown diameter or calculating mean diameter from measurements. In our study, we measured crown diameter by projecting the edges of the crown onto the ground and measuring the length between the two edges.

1.2 Remote sensing data

The Landsat-8 satellite includes 11 bands, while the OLI Land Imager has nine bands and an imaging width of 185 km. The panchromatic band's range has been altered compared to Landsat-7 ETM's sensor, with a narrower range for improved differentiation of vegetation from other areas. 11 images covering the study between 2014-2024, processing with Google Earth Engine platform, the image information is shown in tab. 5. The Satellite imagery product is created by correcting radiometrically and refining geometrically using ground control points and digital elevation models.

Table 5. Informations on the optical (Landsat 8) data used in the study.

Acquisition Time	**Band**	**Spatial Resolution**
03/2014	Bands 3-4-5-6	15 m
03/2015	Bands 3-4-5-6	15 m
03/2016	Bands 3-4-5-6	15 m
03/2017	Bands 3-4-5-6	15 m
03/2018	Bands 3-4-5-6	15 m
03/2019	Bands 3-4-5-6	15 m
03/2020	Bands 3-4-5-6	15 m
03/2021	Bands 3-4-5-6	15 m
03/2022	Bands 3-4-5-6	15 m
03/2023	Bands 3-4-5-6	15 m
03/2024	Bands 3-4-5-6	15 m

2. Data Processing and analyses method

2.1 Stand density

In the ecosystems of Boutaleb and Djebel Messaad, stand density is determined using dendrometric approaches. This method involves measuring simple variables such as tree diameter and height to estimate more complex morphological and physiological characteristics of the stand. Maximum density data for individual species in monoculture stands are used as a reference point for calculating stand density in mixed-species stands. This data were obtained from several measurements on different plots. In order to calculate stand density in mixed-species stands based on species-specific maximum densities, we have used method that consists to compute the relative density contribution of each component species separately and then combine them. This include the relative density (S) as computed from the partial relative basal areas of pure stands (del Río and Sterba, 2009; Condés *et al*., 2013).

$$S = \Sigma\ Gi/Gi,max$$

or the relative density index (RDI) as computed from the partial relative densities computed from number of trees per hectare (e.g. Hein and Dhôte 2006; Waskiewicz *et al*., 2013).

$$RDI = \Sigma\ Ni/Ni,max$$

The formulation of S is to be preferred, because it preserves the area contribution of the individual species (Prodan, 1959; Sterba *et al*., 2014).

The characterization of a stand is determined by its abundance, a key parameter according to Ramade (2009). This factor helps in evaluating the density of stands within the forest, as noted by Rabiou et al., (2015a). Abundance is typically measured using a specific formula:

$$\boldsymbol{N = n/s}$$

Which n: is the number of individuals found in the plot;

s: is the size of the plot (in hectare);

The dominance is utilized to evaluate the basal area of a stand, which represents the total surface area of a tree trunk at a height of 1.30m from the ground. This measurement reflects the amount of forest cover according to the formula proposed by Kakaï et *al*., in 2008.:

$$\mathbf{G = \Sigma g\mathit{i} = \boldsymbol{\pi}\ /4\Sigma di^2 \quad (m^2\ /ha)}$$

The unit of this parameter is **: m² /ha**

di: diameter situated at 1.30 m from the soil of each rod (in meter);

2.2 Vegetation structure (Height/Diameter)

The diameter at breast height (D) and tree height (H) are crucial factors for calculating tree volumes and forest production (Luo *et al*., 2020). The demographic composition of the species is assessed based on tree diameters and heights. These diameter and height categories were utilized to create distribution histograms. The observed structures were matched to the theoretical Weibull distribution with three parameters using MINITAB 18 software (Rondeux, 1999; Goba *et al*., 2019) with the function f(x):

$$f(x) = \frac{c}{b}(x - a/b)^{c-1} exp\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

Where: x is the diameter of the shafts; (a) is the positional parameter; (b) is the scale or size parameter; (c) is the shape parameter related to the observed structure.

Lot of forms of the distribution is related to the shape value parameter (c) (Husch et *al*., 2003; Kakaï et *al*., 2016); for «c» the shape, parameter (or Weibull slope) defined the structure tested and « b » the scale parameter linked to the middle value of the probability distribution of the variable « x ». The amount of c < 1, "reversed J" distribution is marked by various species or uneven-aged population, although a value of c > 3.6 is associated to population including a predominance of old individuals. Moreover, if c is between 1 and 3.6, this mean that recent individuals or slight diameter individuals are predominant at this population (Beldjazia *et al*., 2024).

2.3 Health status of trees

The trees were diagnosed for their sanitary state using the DEPEFEU method, which includes a visual inspection of various structures, identification of parasites or pathogens, and evaluation of risks and maintenance expectations. This work provides detailed observations, a synthesized diagnosis, and recommendations for proper conservation or site security. The assessment of crown condition using specific protocols helps characterize the decline stages of each tree. The DEPEFEU, DEPERIS, and ICP forests protocols were used to assess the health status of Boutaleb and Djebel Messaad forests, specifically the condition of hardwood and softwood/coniferous crown trees.

2.3.1 DEPEFEU Protocol

The DEPEFEU protocol evaluates dieback in hardwood forests by analyzing various aspects of the crown's condition, based on a system developed by Nageleisen in 2010 (Tab. 6). This protocol focuses on observing symptoms in the soil to determine the health of the crown. Three main criteria are used: crown transparency, perennial organ death, and leaf mass distribution. Each criterion is further divided into sub-categories, with specific symptoms to be observed in the top crown of adult trees in the dominant stage to assign a dieback rating.

Table 6. Symptomatological criteria to be observed in the upper part of the tree crowns for scoring dieback (Nageleisen, 2005).

Transparency	Appreciate the overall transparency but also the presence of window (hole in the canopy showing a spot of sky) or indentation in the perimeter of the canopy	Window TF
		Indentation TE
		Overall transparency TG
Mortality of perennial organs	Distinguish the twigs (Ø < 3 cm) from the branches (Ø > 3 cm) and assess the significance of this mortality in relation to the entire observed crown.	Twigs MR
		Branches MB
		Overall mortality MG
Leaf mass	Estimate the overall loss of fine branching in the notable crown as well as the presence of whip-like branches or leaves clustered in bundles in the upper periphery of the crown.	Whips F
		Packet distribution P
		Loss Thin branches PR

2.3.2 DEPERIS Protocol

The DEPERIS tree dieback method relies on two consistent symptoms to assess the health of tree crowns: branch mortality and lack of branching (or absence of needles for softwood trees). These criteria work together to provide a comprehensive evaluation of tree health (Vallet *et al*. 2006).

2.3.3 The ICP method

The protocol, developed as part of the International Cooperative Programme for Forests (ICP Forests), involved observing each tree in three ways: noting the observation conditions, assessing the crown condition, and describing any damage (Eichhorn *et al*., 2010). The observation conditions included visibility, which ranged from 1 (fully visible crown) to 4 (not visible crown), and social status, which ranged from 1 (dominant or free-growing tree) to 4 (dominated trees) (Braem, 2009).

2.4 Vegetation survey from Remote Sensing

Our interest is to analyze, first, the evolution of vegetation in Boutaleb and Djebel Messaad forests, which they are located in the wilayas of Setif and M'Sila. The bands of the Landsat images provide adequate information on the vegetation cover, due to their fine spatial resolution (30 m). Then, using the same dataset, we study the vegetation dynamics of the forest ecosystem using vegetation indices.

2.4.1 Color composition

By combining three spectral bands and assigning each one to a primary color (red, green, or blue), we created a color image using color composition. This process results in a Color Composite Image. The visible and near-infrared bands of the electromagnetic spectrum of the Landsat images (6, 5 & 4), provide best information on the vegetation cover, due to their colors.

2.4.2 NDVI

The Normalized Difference Vegetation Index (NDVI) is a combination of visible red (R) and a near infrared (NIR) bands of the electromagnetic spectrum of Landsat image. It varies in value from –1.0 to 1.0. NDVI is employed to assess the vigor of vegetation on the Earth. The equation used for the NDVI calculation is

$$NDVI = (NIR - R)/(NIR + R),$$

Where NIR and R are the values of pixels in these bands, respectively (Lemenkova, 2021).

We calculated the NDVI of each date using ArcGIS Pro software for the period between 2014 and 2023.

2.4.3 NDMI

The Normalized Difference Moisture Index (NDMI) is a remote sensing index used to assess vegetation's moisture content. It is calculated using the reflectance values NIR and mid-infrared (MIR) wavelengths, which are sensitive to water in plant tissues. It ranges in value from −1 to 1, with negative values indicating dry conditions and positive values indicating moist conditions. NDMI values close to 0 indicate intermediate moisture levels. The NDMI is calculated using the following equation (Delgado-Moreno and Gao, 2021):

$$NDMI = (NIR - MIR) / (NIR + MIR)$$

The NDMI of each date was calculated using ArcGIS Pro software for the period between 2014 and 2023.

2.4.4 Evapotranspiration

The average annual evapotranspiration from 2014 to 2024 was extracted from the MODIS product, which provides the annual total of evapotranspiration (in kg/m^2) at a resolution of 500 m. The obtained values of evapotranspiration were log-transformed prior to the following statistical analyses.

2.4.5 Indirect interpretation of remote sensing images

The most effective interpretation of satellite images combines the use of computer-assisted methods and visual analysis. Visual interpretation allows for the safest analysis of image structures (Girard C-M and Girard M-C, 1973; Girard M-C, 1986); on the other hand, it is by using the computer's capabilities that texture interpretation is done most rigorously (Girard MC. and Girard C-M, 1989; Bonn *et al*., 1989).

3. Statistical analyses

Variations in mean diameter, height and number of trees values among the 25 plots from 543 trees were analyzed with separate analyses of variances, followed by Difference tests for multiple comparisons at $p < 0.5$ using XLSTAT.

All following analyses were separately conducted for each combination of Boutaleb and Djebel Messaad forests. We accounted for the effects of environmental factors on the distribution of vegetation by applying linear regression models with the different indices calculated from spatial analysis as the dependent and the two dendrometric variables (diameter and height) as independent predictor variables.

Chapter 04: Results and Discussion

1. Floristic richness and health state of the arborescent stratum

Boutaleb forest massif is an important and well individualized link in the eastern part of the Hodna mountain range. The vegetation of Boutaleb forest has been strongly influenced by human activity at all levels, which has led to its richness. It is represented by coniferous forests of varying densities. This vegetation consists mainly of *Cedrus atlantica* Manetti and *Pinus halpensis* Mill. Pine forests appear at altitudes of 1000 m and above, and can be found in two forms: natural and wooded. The natural form is either pure or mixed with Holm oak, Cedar or *Juniperus oxycedrus* (Fig. 13, 14).

Figure 13. Boutaleb forest massif.

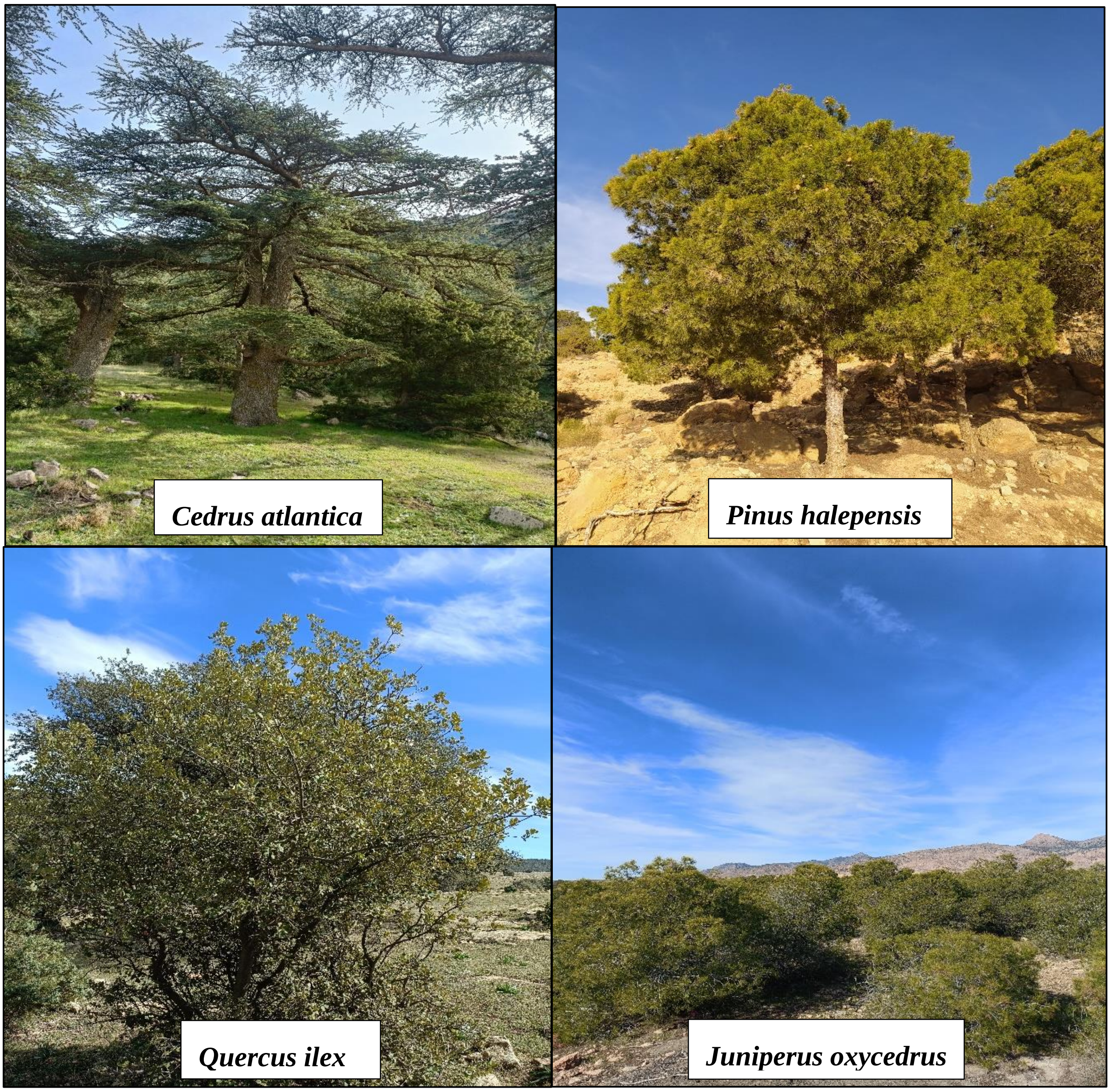


Figure 14. Forest formations of Boutaleb massif.

Figure 15. Mixed formation of Aleppo pine, holm oak and cedar in the Boutaleb forest.

Djebel Messaâd is still covered with forest of the Mediterranean type with an altitude ranging from 1200 to 1600 m. The forest consists of Aleppo pine and Juniper with an approximate surface area of 33500 hectares. It is a degraded, open forest with a low density and significant scrub (Fig. 16).

Figure 16. Forest formations of Djebel Messaad.

1.1 Characterization of forest

Monitoring and managing trees is crucial for preserving species and habitat diversity through successional processes. Diversity of tree species contributes significantly to the diversity of forest ecosystems. Tree density is essential to describe tree populations and forest stands.

Statistical analyses show that the number of trees of djebel Boutaleb forest range from 11 to 78 individual per 900 m^2. The mean stand density was 357 individuals per hectare, the highest stand density was observed in the second plot (866 individuals/ha), whereas the lowest stand density was observed in plot number eight (122 individuals/ha) and the others plots showed moderate densities. It means that stand density increased with increasing number of species (Fig. 17).

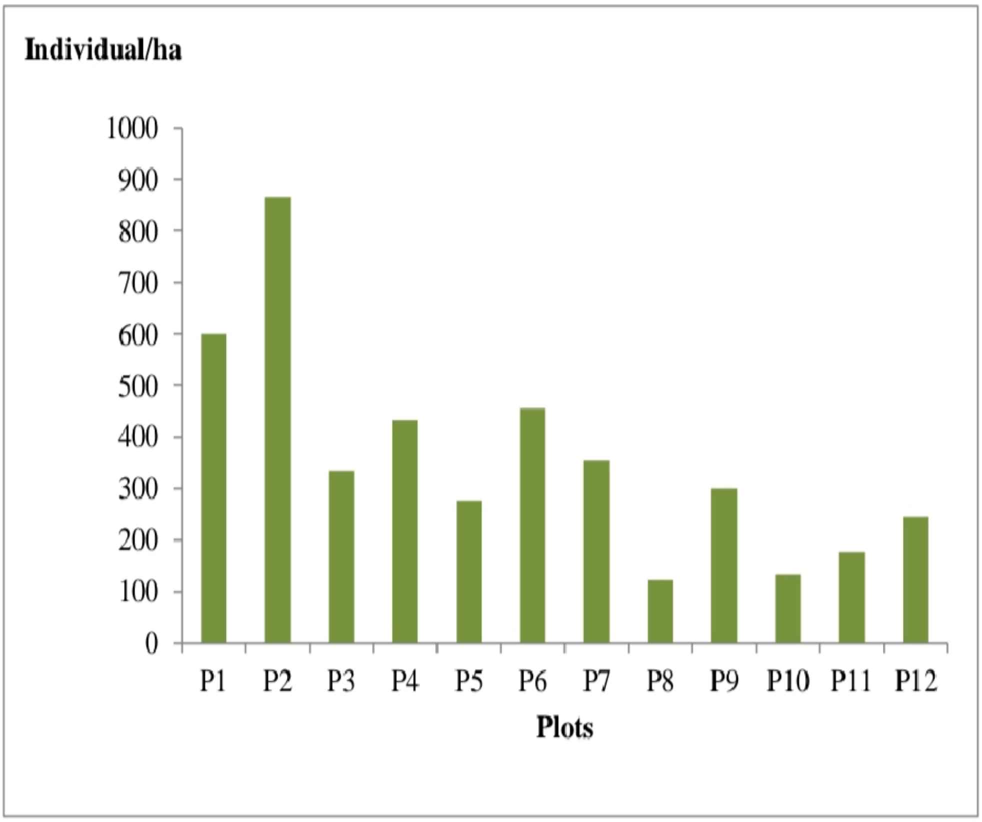


Figure 17. Distribution of stand density by plot in Boutaleb forest.

The comparison between the plots of Boutaleb forest shows that the number of trees is greater in the second plot, due to location and forest type (mono-species reforestation of Aleppo pine). However, the other plots are mixed formations (*Pinus halepensis*, *Cedrus atlantica*, *Juniperus oxycedrus, Cupressus semperviren, Juniperus phoenicea, Quercus ilex and Phillyrea* *angustifolia*). The dominant species in terms of number of individuals is Aleppo pine, which constitutes 46% of all trees observed, followed by Holm oak, Prickly juniper, Atlas cedar, Mediterranean cypress, Narrow-leaved mock privet and the Phoenician juniper in a smaller proportions (Fig. 18).

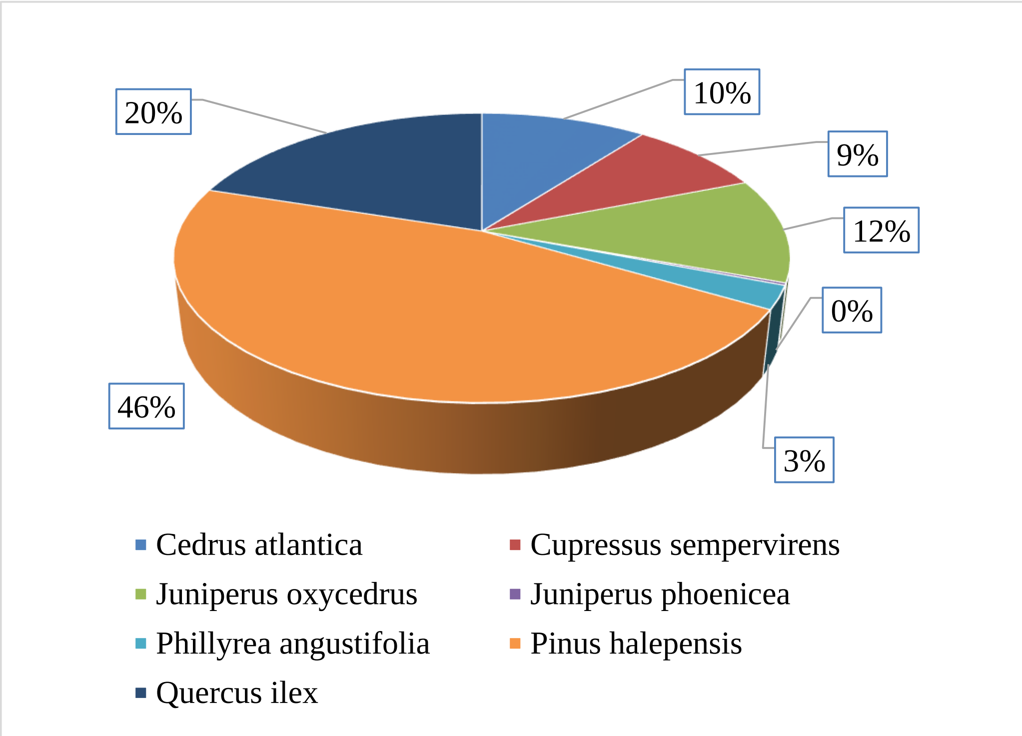


Figure 18. Pie Chart of the distribution of number of species in Boutaleb forest.

In Djebel Messaad Aleppo pine natural forest, The average stand density was 134 individuals per hectare, the first and the third plots have the highest density (167 individuals/ha), plot eleven have the lowest density (100 individuals/ha), and the remaining plots have moderate densities (Fig. 19).

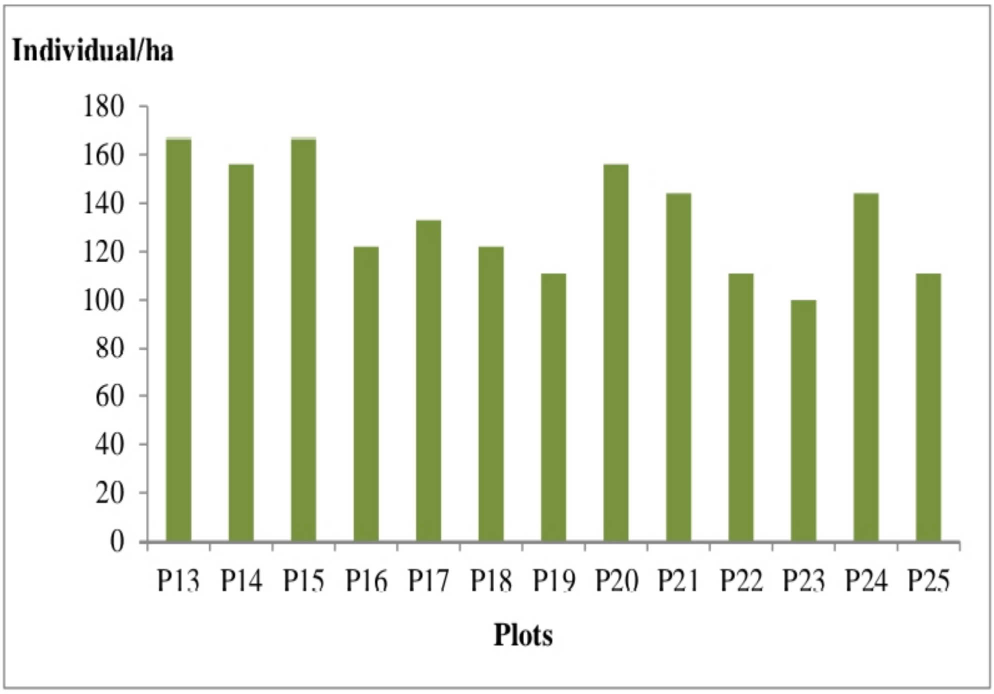


Figure 19. Distribution of stand density by plots in Messaad forest.

Density refers to the abundance of an organism within a specific area. In plant ecology, density is commonly defined as the number of individuals within a given area (Bonham, 2013). In forestry, the term is used more extensively to encompass not just the number of trees, but also their size and other features, in order to determine the level of site resources used and crowding. (Dean & Baldwin, 1996). Ideally, a measure of density should be able to accurately describe and forecast tree population dynamics, such as self-thinning, in both pure and mixed stands. (E.g. del Río *et al*., 2001).

Multiple different measures of density have been employed in Boutaleb and Djebel Messaad forests; however, their interpretation becomes more challenging. It has found that the the Boutaleb forest has twice as many trees per hectare as the Djebel Messaad forest.

1.2 Visibility

The visibility of a crown corresponds to the conditions under which the assessable crown can be seen from the ground. It is a limiting factor and a source of error in the characterization of the crown. In fact, when the visibility of the crown is decreased due to competing hoops, the observable part is assumed to represent the entire crown. In some cases of non-visibility, observers obtained all quotations relating to defoliation, discoloration and observable fructification (Braem, 2013).

The analysis of trees visibility focused on Boutaleb forest showed that 60% of the total number of individuals have a completely visible crown and 27% of the crowns are partially visible. The remaining 10% of crowns are backlight and 3% are not visible (Fig. 20).

The closer a tree is between other trees, the less visible it is. In dense stands, where the crowns are entangled, it becomes very difficult to see the upper part of the crown (Braem, 2013). Therefore, almost all trees are under some form of thinning.

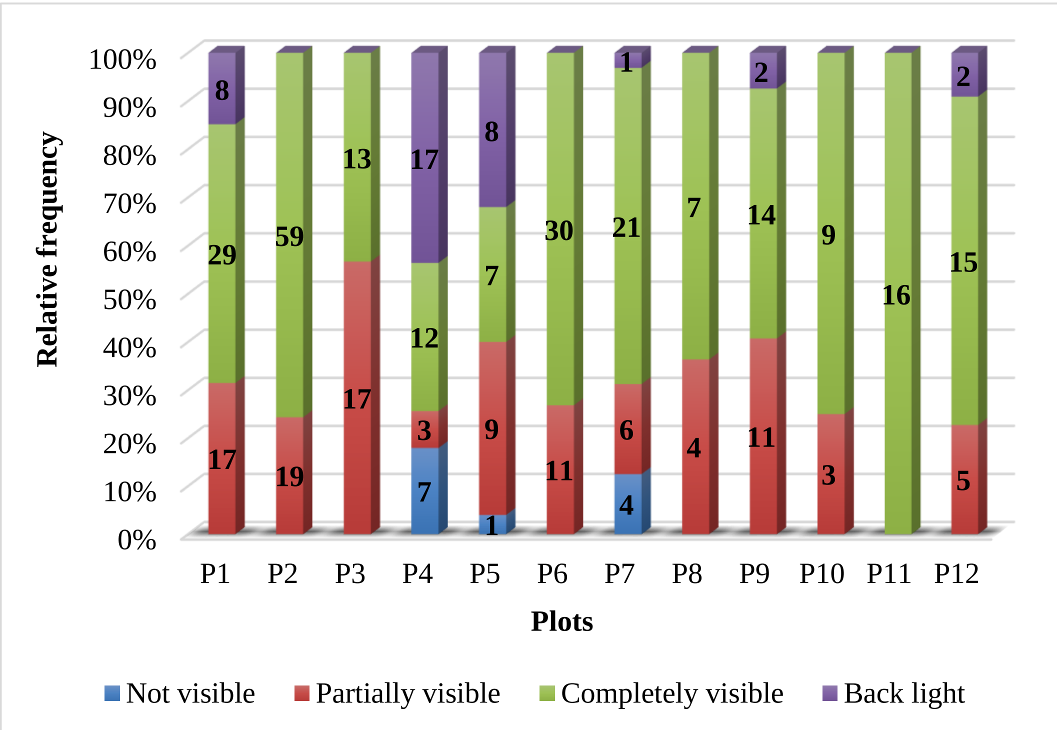


Figure 20. Distribution of trees according to the level of visibility in Boutaleb forest.

The following fig. 21 shows that 33% of the total number of individuals of Messaad forest stands has a completely visible crown and 69% of the crowns are partially visible. The remaining 21% of crowns are backlight and 2% are not visible.

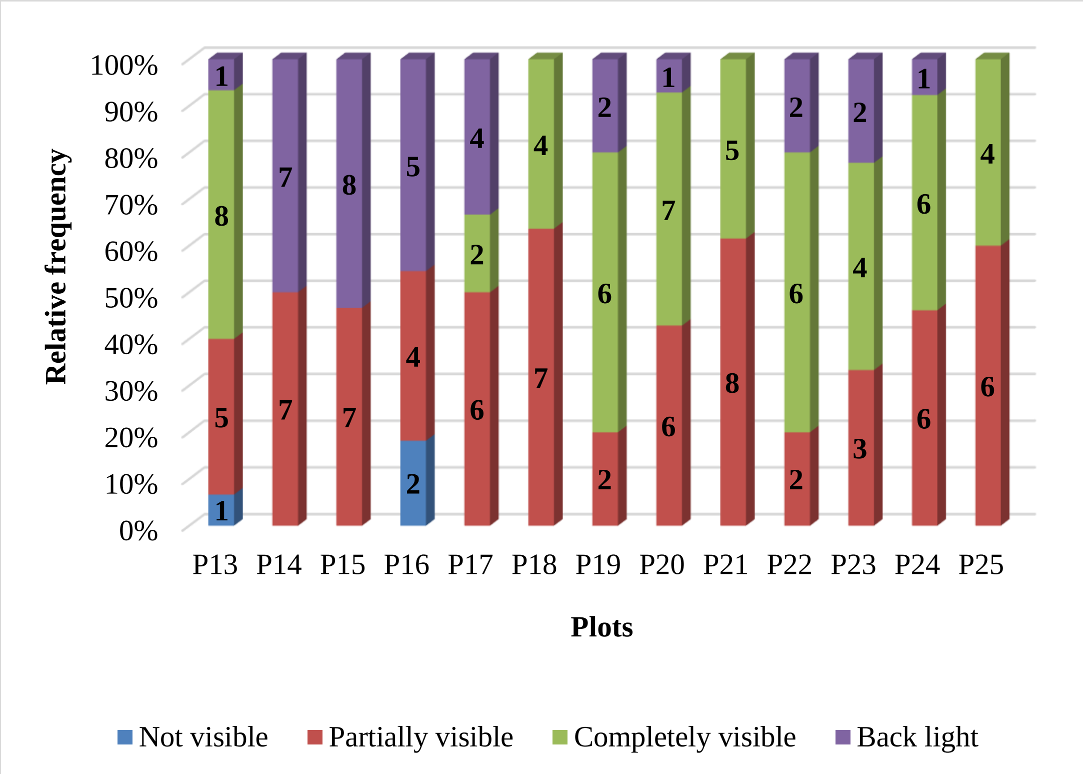


Figure 21. Distribution of trees according to the level of visibility in Messaad forest.

The analysis of variance of the visibility is highly significant among the different species for all plots (Tab.7).

Table 7. Analysis of variance (Visibility).

Source	**DDL**	**Sum of Squares**	**Average Squares**	**F**	**Pr > F**	**Significance Codes Value Pr**
Model	6,000	30,123	5,021	10,212	**<0,0001**	***
Error	378,000	185,840	0,492			
Corrected Total	384,000	215,964				

Calculated against the model Y=Average(Y)

*Significance codes: 0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

The comparison of the averages reveals the existence of three homogeneous groups, the first corresponds to *Juniperus phoenicea* with completely visible, and the second group corresponds to *Pinus halepensis, Cupressus sempervirens, Cedrus atlantica, Juniperus oxycedrus and Quercus ilex* that are partially visible. In the last group, we found *Phillyrea angustifolia* with partially visible but backlight (Tab. 8).

Table 8. Analysis of differences (Newman-Keuls test) between modalities with a 95% confidence interval (Visibility).

Modality	Estimated means	Standard error	Lower bound (95%)	Upper bound (95%)	Groups
Juniperus phoenicea	1,000	0,701	-0,379	2,379	A
Pinus halepensis	1,307	0,052	1,204	1,410	AB
Cupressus sempervirens	1,333	0,122	1,093	1,573	
Cedrus atlantica	1,500	0,111	1,282	1,718	
Juniperus oxycedrus	1,822	0,105	1,617	2,028	
Quercus ilex	1,857	0,080	1,700	2,014	
Phillyrea angustifolia	2,400	0,222	1,964	2,836	B

1.3 Social status

According to the standardized protocol, social status is a comparative assessment of the position a tree holds in relation to nearby trees. Knowing social status allows us to better interpret a tree's crown condition (Eichhorn *et al.*, 2010).

Many factors such as competition from surrounding trees, silviculture practices, site conditions, and tree genetics influence the social status of trees. (Braem, 2009).

Fig. 22 shows that the most of trees in Boutaleb forest are dominant or co-dominant, representing respectively 44% and 30% of the total of trees. Nearly 18% are subdominant and 8% are dominated.

According to Braem (2009), dominant trees are supposed to be more sensitive to stress than co-dominant trees, which are better integrated into the canopy mass.

Based on our experiment results, it can be concluded that approximately 1/4 of trees in the 12 plots of Boutaleb forest are supposed to be more sensitive to stress, while 3/4 are less sensitive.

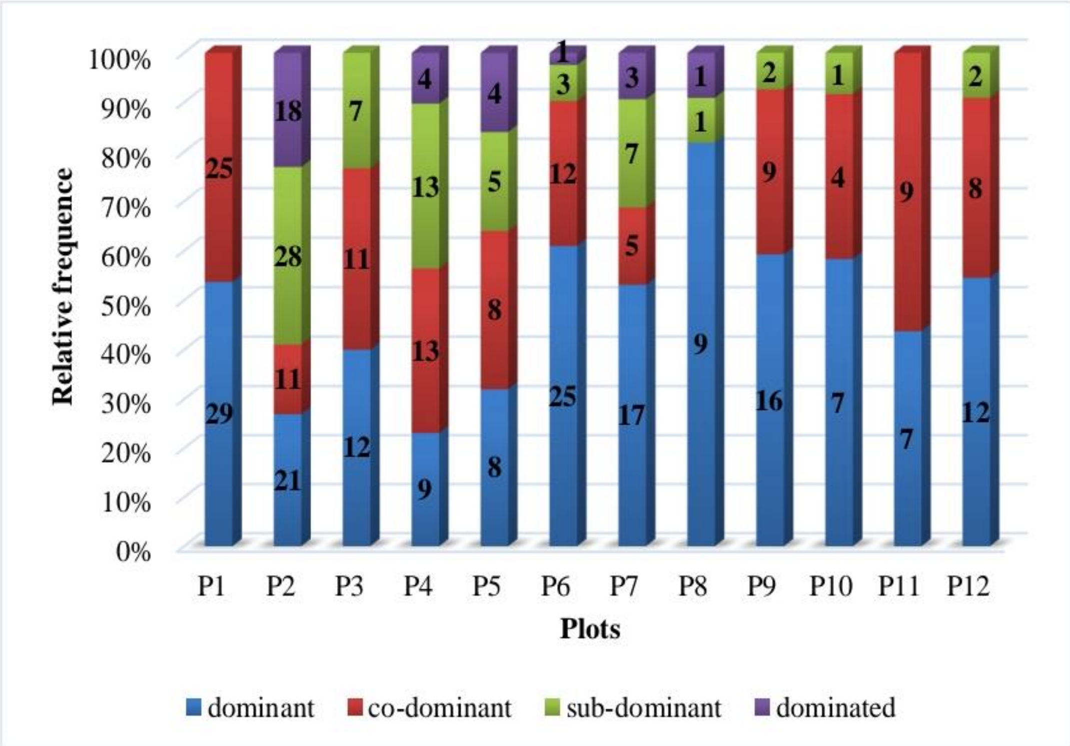


Figure 22. Distribution of trees according to social status in Boutaleb forest.

Fig. 23 demonstrates that most of trees of djebel Messaad forest are dominant or co-dominant, accounting for 45% of each. Nearly 9% are subdominant, while 1% are dominated**.**

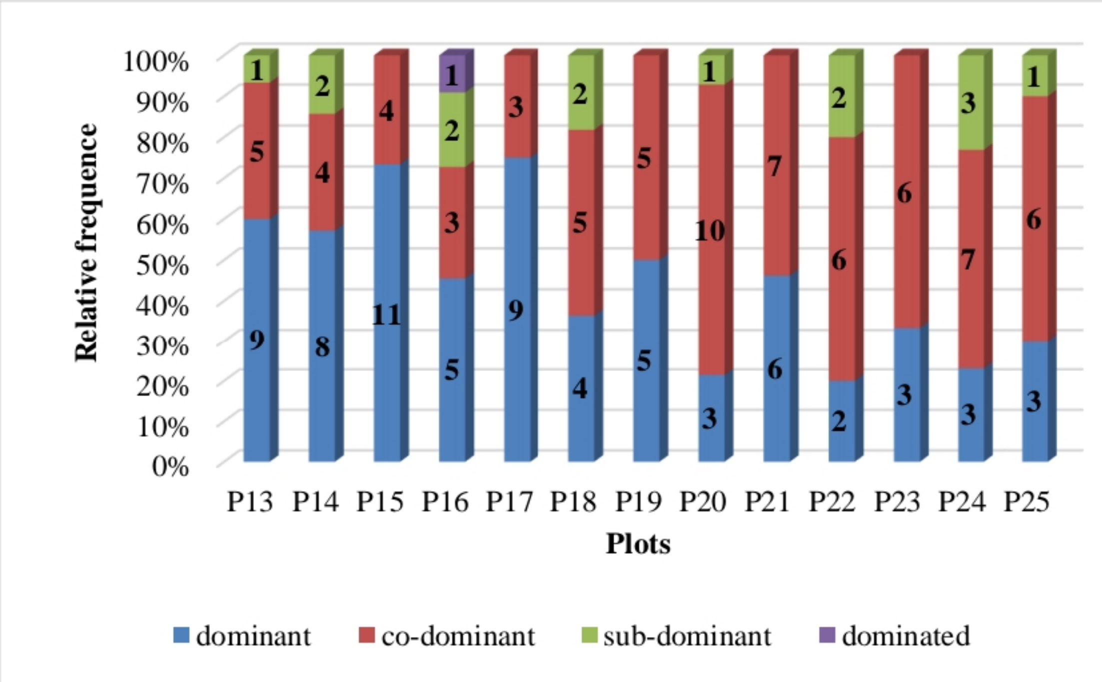


Figure 23. Distribution of trees according to social status in Djebel Messaad forest.

In order to compare the social status among the different species of forest we have use the analysis of variance. Statistical analysis is highly significant for all plots (Tab. 9).

Table 9. Analysis of variance (Social status)

Source	**DDL**	**Sumof Squares**	**Average Squares**	**F**	**Pr > F**	**Significance Codes Value Pr**
Model	6,000	20,571	3,428	3,879	**0,001**	***
Error	378,000	334,063	0,884			
Corrected Total	384,000	354,634				

Calculated against the model Y=Average(Y)

*Significance codes:0 < *** < 0.001 < ** < 0.01 < * < 0.05 < . < 0.1 < ° < 1*

Statistical analysis shows the presence of three homogeneous groups where the first group A corresponds to *Juniperus phoenicea*, *Cedrus atlantica* and *Cupressus sempervirens* with the lowest average, and *Phillyrea angustifolia* in the last group with the highest average (Tab. 10).

Table 10. Analysis of differences (Newman-Keuls test) between modalities with a 95% confidence interval (Social status)

Modality	Estimated average	Standarderror	Lowerbound (95%)	Upperbound (95%)	Groups
Juniperus phoenicea	1,000	0,940	-0,848	2,848	A
Cedrus atlantica	1,450	0,149	1,158	1,742	
Cupressus sempervirens	1,515	0,164	1,193	1,837	
Pinus halepensis	1,961	0,070	1,823	2,099	A B
Quercus ilex	1,961	0,107	1,750	2,172	
Juniperus oxycedrus	2,044	0,140	1,769	2,320	
Phillyrea angustifolia	2,600	0,297	2,015	3,185	B

1.4 Health status of Leaves

The leaf is an important organ of plants that exchanges water and air with neighboring environment. Leaves have a variety of morphologies, and their characteristics have a direct impact on plant physiological and biochemical processes, revealing their adaptation methods for resource acquisition. There are multiple leaf morphological traits, including leaf size, leaf shape, leaf margin (with or without teeth) and leaf type (i.e. single vs. compound leaf). We focused on leaf discoloration; it is defined as any alteration (tint or distribution) of the normal foliage color of the species observed (Braem, 2010). This criterion is noted in percent and corresponds to the amount of foliage affected in relation to the global observed crown. It is evaluated according to the scale described in the table below:

Table 11. Discoloration classes (Braem, 2010).

Levels	**% of leaves/needles**	**Degrees of discoloration**
1	0-10 %	Normal
2	> 10 et <= 25 %	Visible
3	> 25 et <= 60%	Moderate
4	> 60 %	Severe
5	Fallen tree	Fallen tree

In Boutaleb forest, trees with normal discoloration accounted for 67% of the observed trees, 26% had visible discoloration, 14% had moderate discoloration, 1% had severe discoloration and 2% were dead trees (Fig. 24).

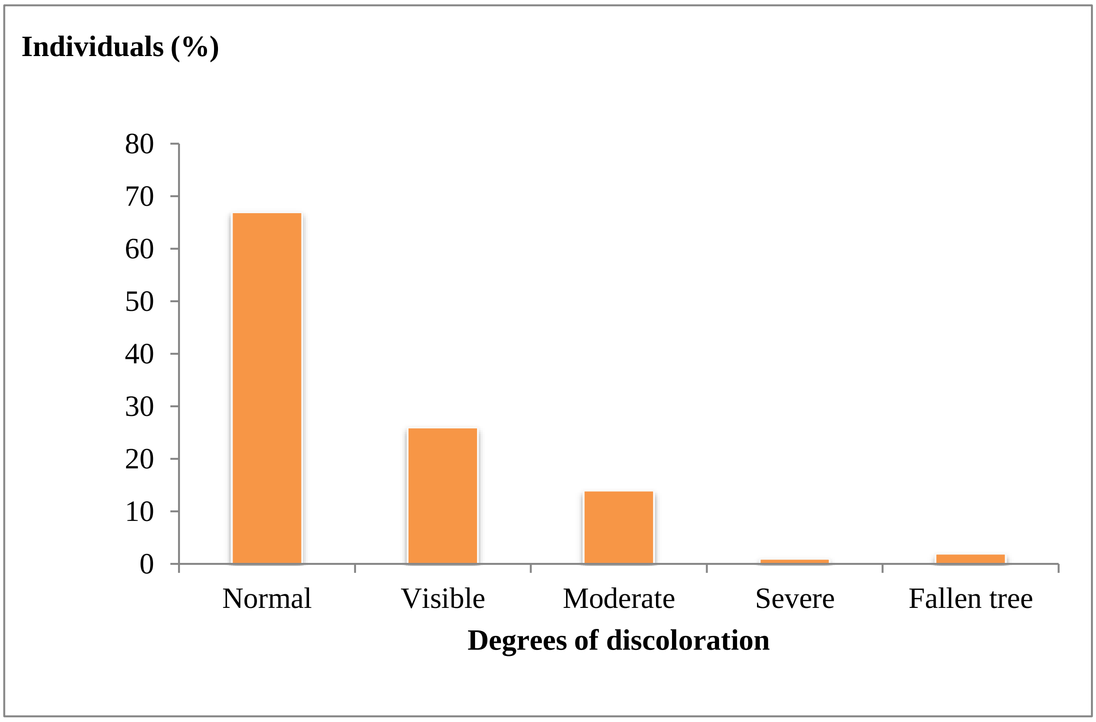


Figure 24. Distribution of the mean of sampled trees by level of discoloration of leaves in the Boutaleb forest.

Analysis of the results obtained from the thirteen stations of Djebel Messaad forest shows that the majority of trees have normal coloration, with a rate of 92%. Trees with visible discoloration account for 4%, 3% have moderate discoloration and 1% are dead trees (Fig. 25).

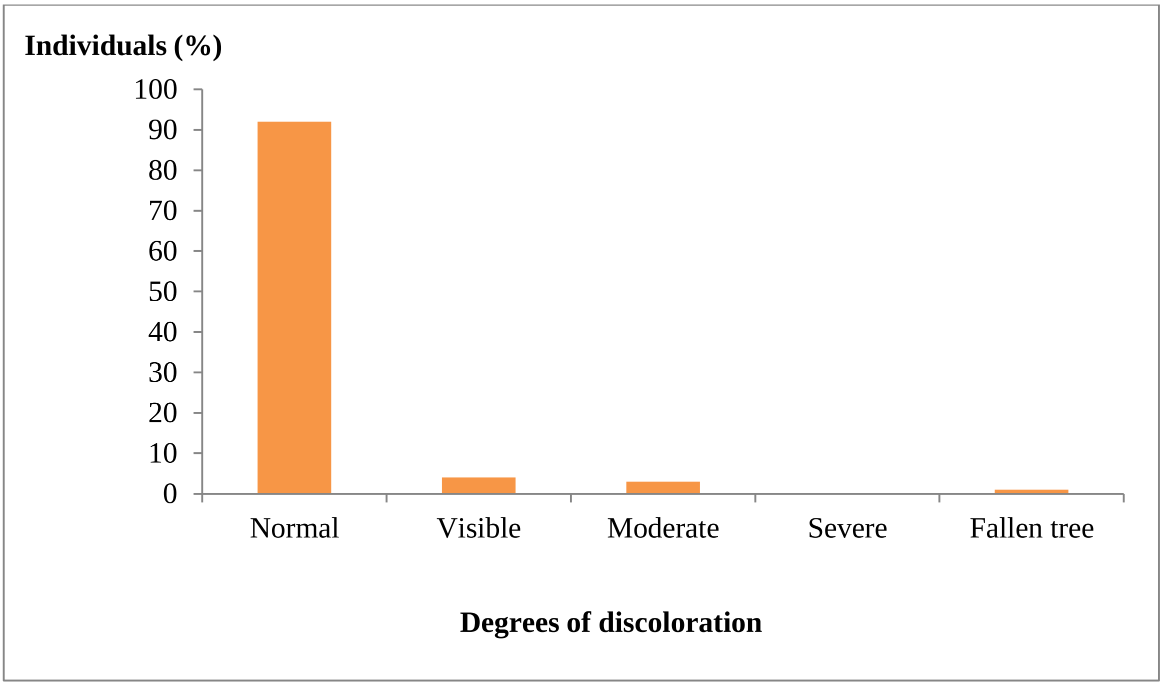


Figure 25. Distribution of the mean of sampled trees by level of discoloration of leaves in Djebel Messaad forest.

1.5 DEPEFEU

In order to characterize the health status of the plots studied, we will analyze the data concerning the appearance of the crowns. The graph in figure 26 shows that the majority of trees are in class 1; their percentage is 64%. A significant proportion of trees are in classes 2 and 3 (19% and 16% respectively) and the percentage of trees in class 4 is low (1%). Plot 2 is characterized by the highest rate of healthy trees (19%) where symptoms are totally absent, while the crowns of plots 8 and 10 are dying and show 3%. The health of the other plots is quite average.

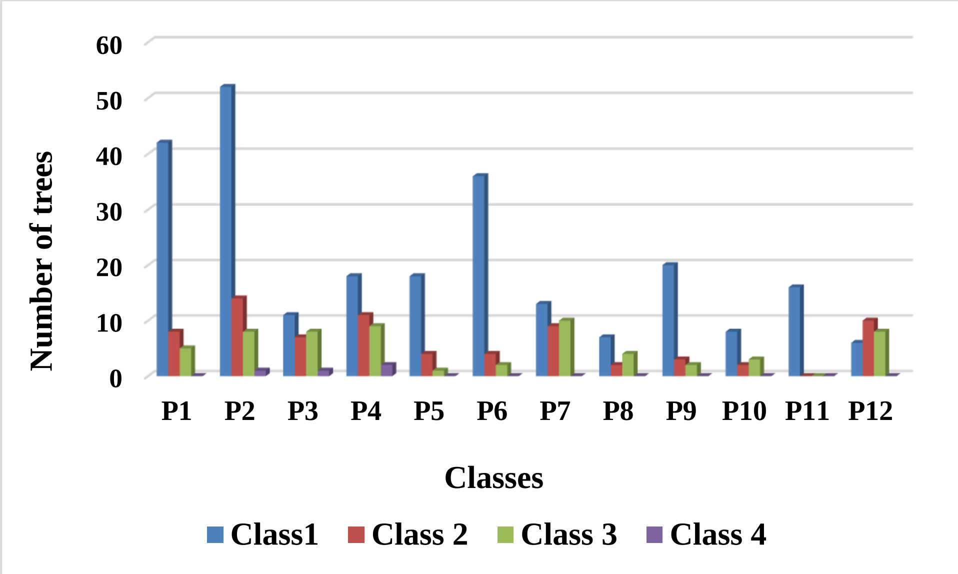


Figure 26. Number of trees from the DEPEFEU classes for the plots in Boutaleb forest.

Overall, the results show that Aleppo pine (P2) in its wooded state has the highest score, while holm oak (P8 and P10) has the lowest. Our results are in line with those of Bley, 2011, who found that the crown condition of softwoods is generally better than that of hardwoods in Paimpont forest.

2. Analysis of dendrometric parameters

Dendrometric parameters are the most useful indicators for measuring the qualitative and quantitative development of forest communities (Oosterhoorn & Kappelle, 2020). The aboveground biomass of trees can be estimated by measuring the height and diameter (Chenge, 2021).

2.1 Diameter distribution

The statistical analyses show that the average of DBH of all plots from minimum to maximum ranged from 5.22 cm to 49.60 cm in Boutaleb forest (Fig. 27). However, in Djebel Messaad, the mean diameter is between 16.39 cm and 38.03 cm (Fig. 28).

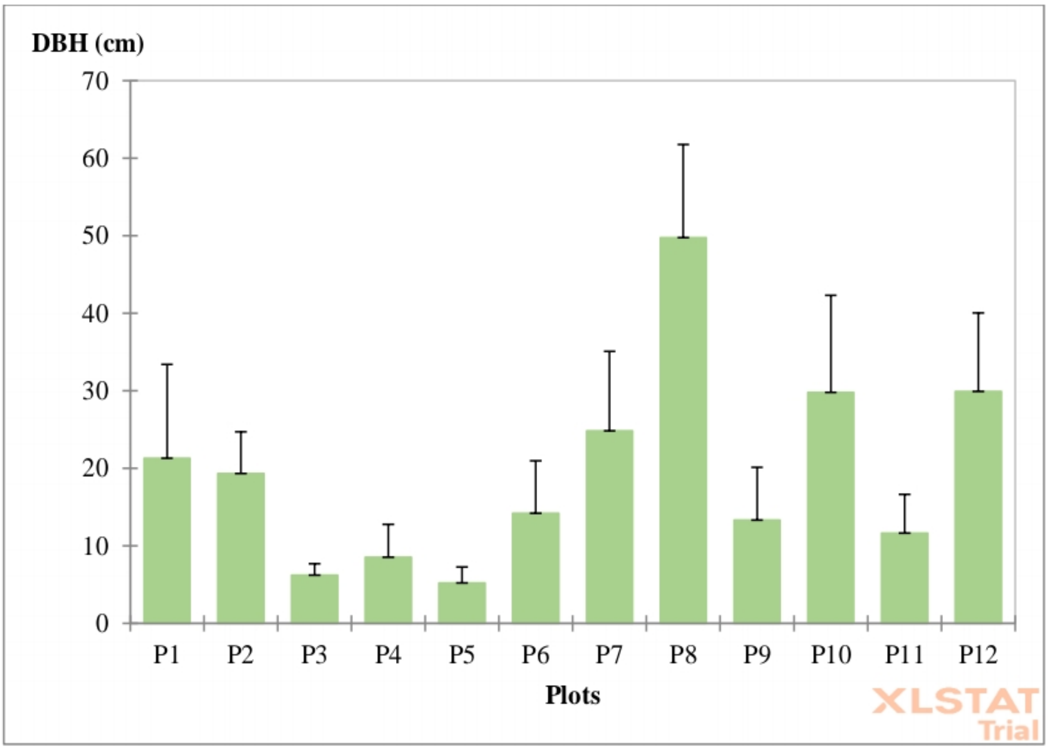


Figure 27. Diameter means of Boutaleb forest over plots

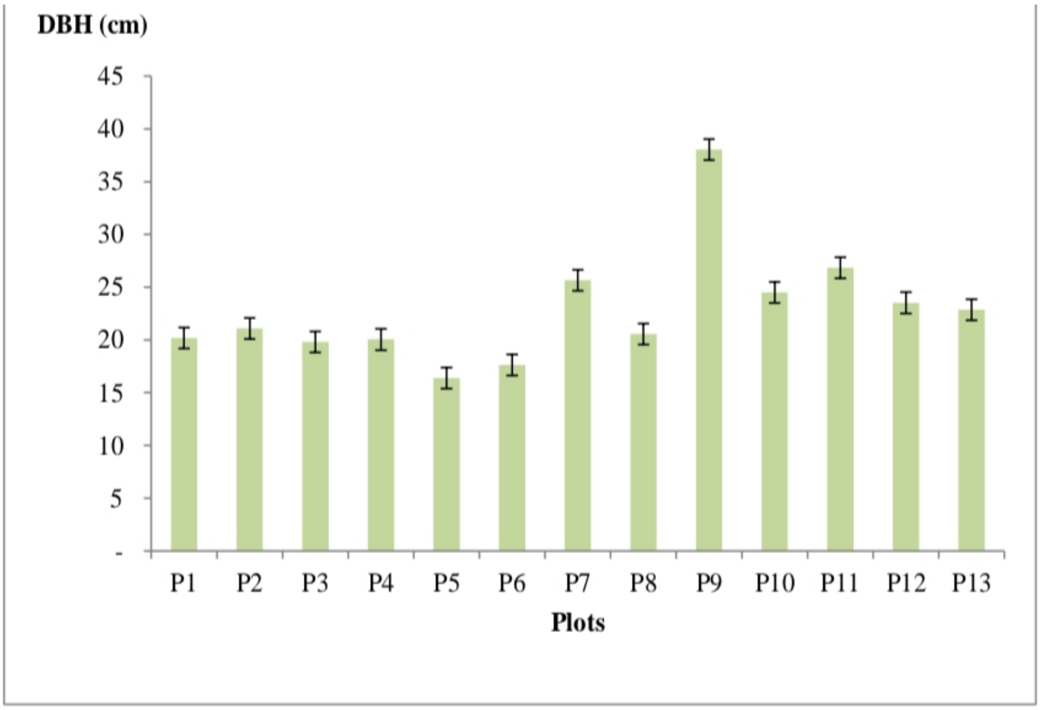


Figure 28. Diameter means of Djebel Messaad over plots

The Friedman test showed that the forest diversity effect on the average diameter to be significant in Boutaleb forest and Djebel Messaad (Tab. 12).

Table 12. Friedman Test of diameter values in the study area

	Boutaleb forest	Djebel Messaad
Q (Observed value)	662,384	51.417
Q (Critical value)	19,675	21.026
DDL	11	12
p-value (unilateral)	**<0,0001**	**<0,0001**
Alpha	0,05	0.05

In other words, our results support the hypothesis that a more complex forest structure, include trees of different status and diameter (Fig. 29).

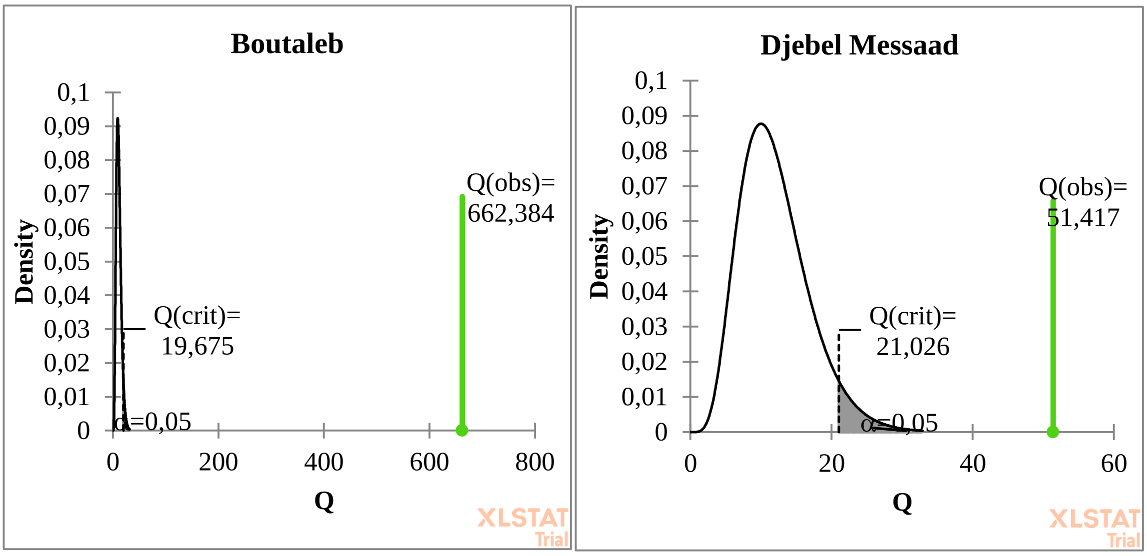


Figure 29. Friedman test of diameter values in the study area

The Multiple Pair Comparisons by Nemenyi Test show the presence of 12 groups. The group “A” presents the lowest value while the highest value is for the group “J” (Tab. 13).

Table 13. Multiple Pair Comparisons by Nemenyi Test of diameter values in Boutaleb forest.

Plots	Average rank	Groups									
P5	1,513	A									
P3	2,385	A	B								
P4	3,436		B	C							
P11	4,487			C	D						
P9	5,506				D	E					
P6	6,051				D	E	F				
P1	7,173					E	F	G			
P2	7,737						F	G	H		
P7	8,603							G	H	I	
P10	9,404								H	I	
P12	10,103									I	J
P8	11,603										J

The highest values were corresponding to *Atlas cedar* formation in Ghbaret agueni, which we have the presence of just trees of *Atlas cedar*. In the other case, the lowest values were affect the *Pinus helepensis* trees and *Juniperus oxycedrus*.

In Djebel Messaad, the Multiple Pair Comparisons by Nemenyi indicate the presence of five groups. The highest values are for group “A” and the lowest are for group “C” (Tab. 14).

Table 14. Multiple Pair Comparisons by Nemenyi Test of diameter values in Djebel Messaad forest.

Plots	Average rank	Groups
P1	3,571	A
P2	4,500	
P3	4,857	A B
P4	5,643	A B C
P5	5,964	
P6	6,143	
P7	7,071	
P8	7,429	
P9	7,750	
P10	8,071	
P11	9,429	B C
P12	10,179	
P13	10,393	

The presence of different groups in Boutaleb forest (ten groups) is due to trees diversity form. However, in Djebel Messaad, diameter was taken in Pinus halepensis trees.

2.2 Height distribution

The statistical analyses show that the mean of height of all plots from minimum to maximum ranged from 2.41m to 8.37 m in Boutaleb forest (Fig. 30). However, in Djebel Messaad, the mean height is between 5.45 m and 13.25 m (Fig. 31).

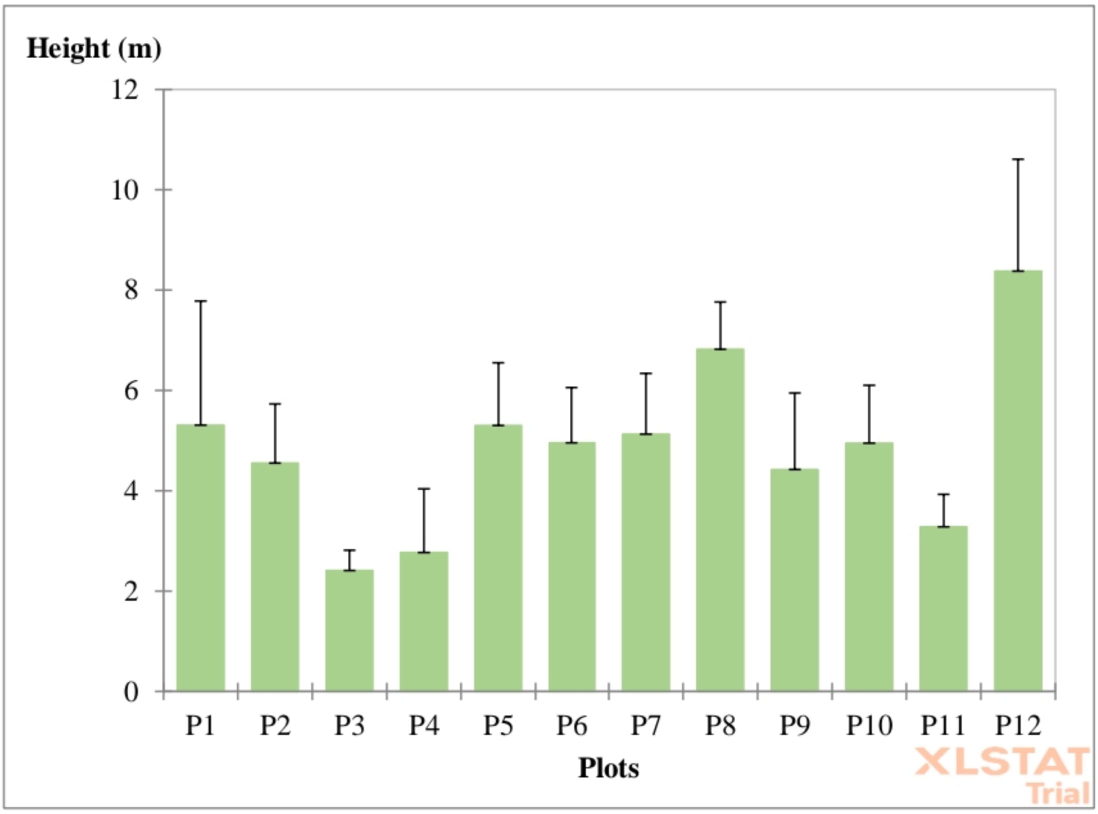


Figure 30. Height means of Boutaleb forest over plots.

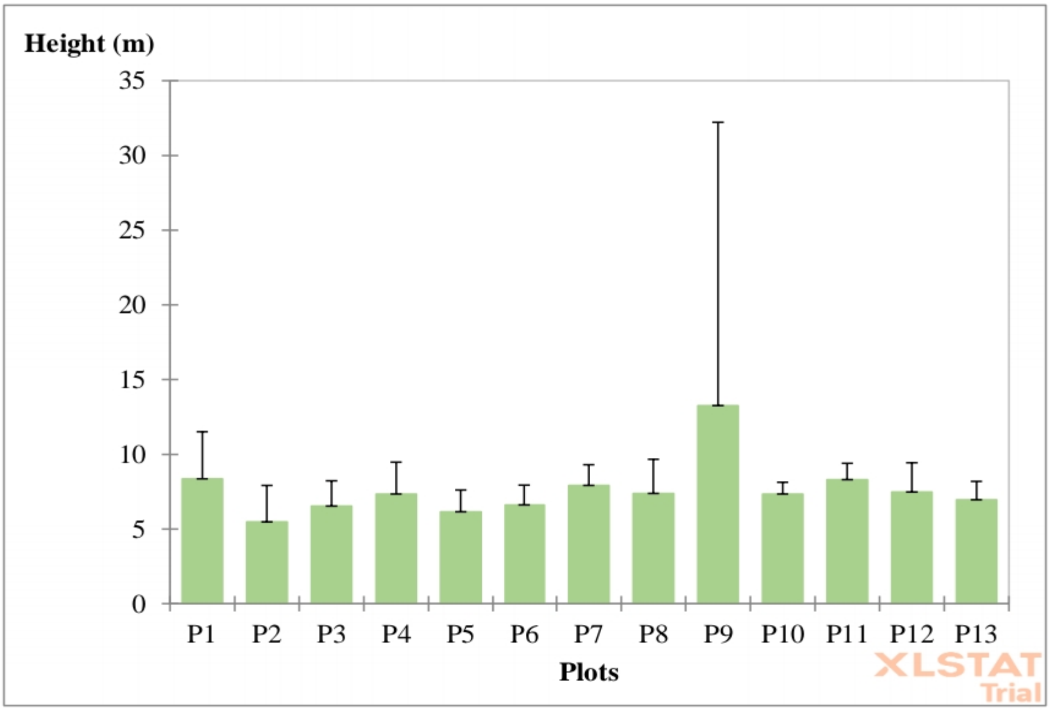


Figure 31. Height means of Djebel Messaad over plots.

The Friedman statistical test results shows a significative difference between plots from the two sites (Tab. 15).

Table 15. Friedman Test of height values in the study area.

	Boutaleb forest	Djebel Messaad
Q (Observed value)	553,746	37.001
Q (Critical value)	19,675	21.026
DDL	11	12
p-value (unilateral)	**<0,0001**	**0.000**
Alpha	0,05	0.05

According to the box plot, we can see that the average height varies from plot to other and from site to another (Fig. 32).

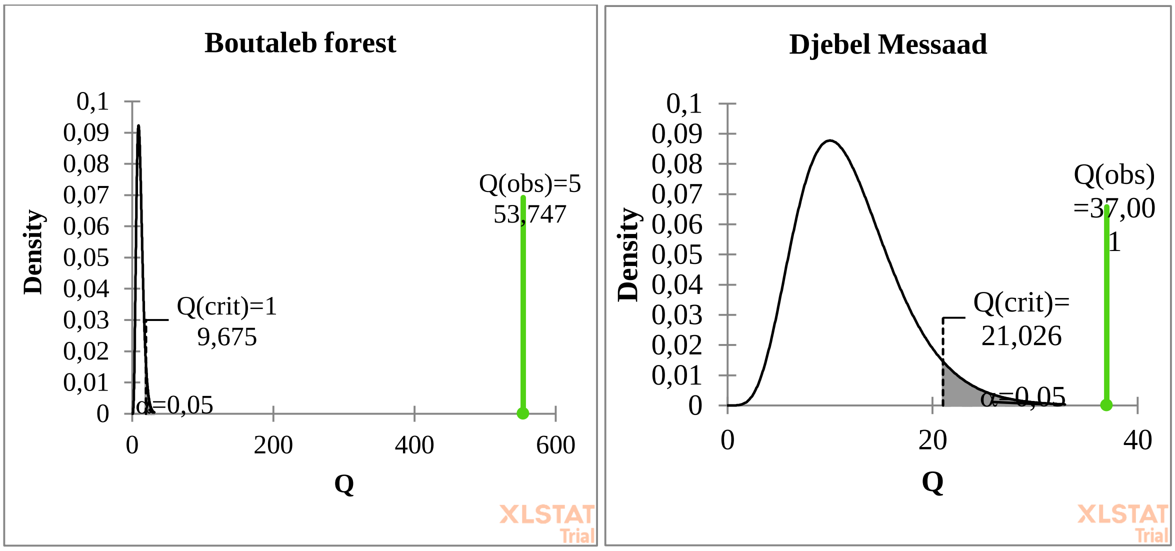


Figure 32. Friedman test of height values in the study area

In order to study the effect of trees diversity on height parameter in forest, a Multiple Pair Comparisons by Nemenyi test was applied. The results show the presence of nine different groups in Boutaleb forest where the lowest values are in *Quercus ilex* and *Juniperus oxycedrus* trees, meanwhile the highest values were in *Pinus halepensis* of natural formation and *Atlas cedar* trees (Tab. 16).

Table 16. Multiple Pair Comparisons by Nemenyi Test of height values in Boutaleb forest between modalities with a 95% confidence interval.

Plots	Average rank	Groups
P3	1.673	A
P4	2.422	A B
P11	3.827	B C
P9	5.199	C D
P10	6.288	D E
P2	6.346	
P6	6.955	
P1	7.654	E F
P7	7.712	
P5	8.410	F
P8	10.340	F G
P12	11.154	G

In Djebel Messaad, the Multiple Pair Comparisons by Nemenyi Test of height values highlights five homogenous groups (Tab . 17).

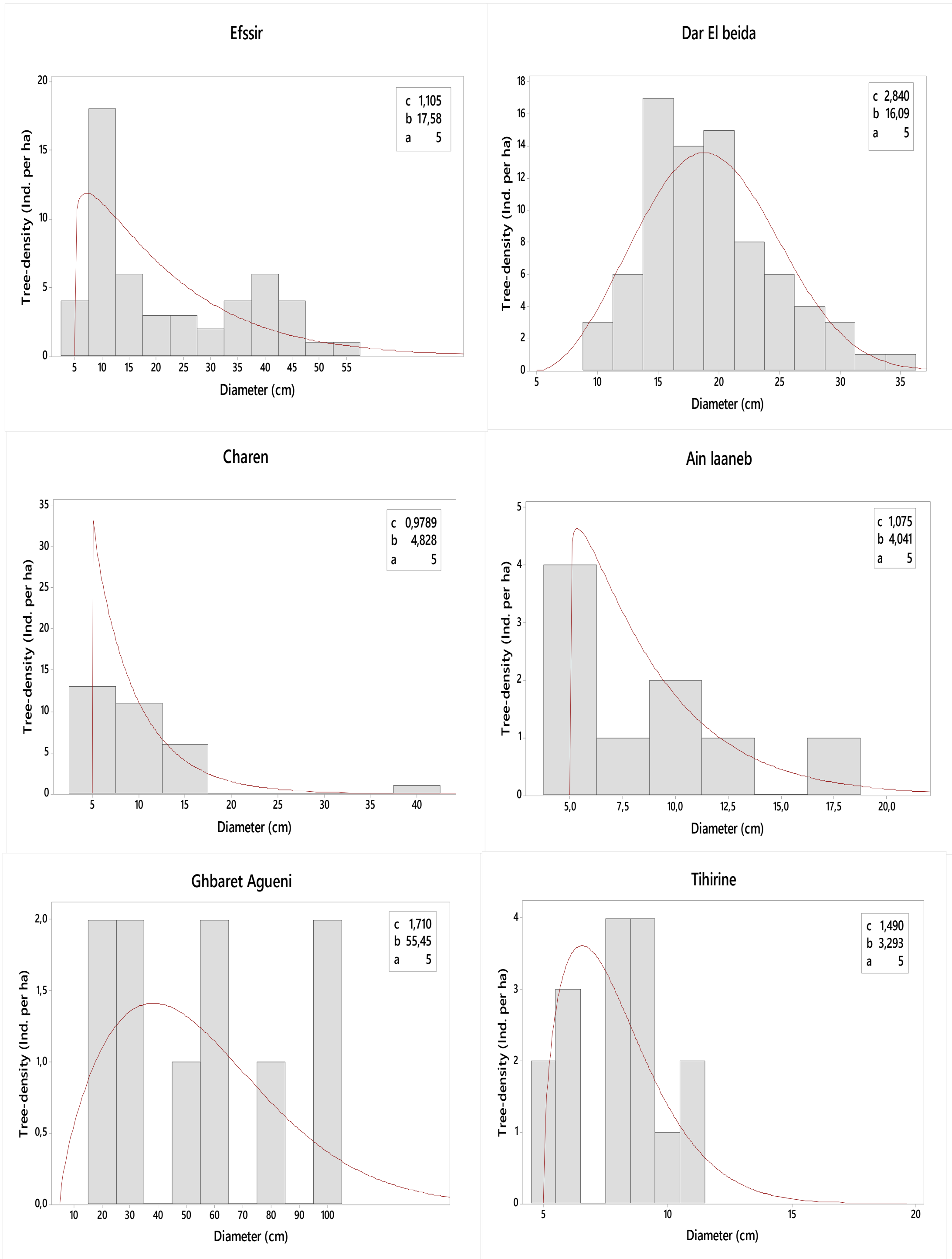
Table 17. Multiple Pair Comparisons by Nemenyi Test of height values in Djebel Messaad between modalities with a 95% confidence interval.

Plots	Average rank	Groups
P2	4,467	A
P5	4,533	A
P6	5,000	A B
P3	5,567	A B C
P13	6,500	
P8	7,033	
P10	7,033	
P4	7,167	
P12	7,333	
P1	8,600	
P7	8,667	
P9	9,333	B C
P11	9,767	C

3. Diameter and height structure

3.1 Diameter structure

The demographic structure of the different plots is examined in conformity with diameter of trees (defined from a threshold of 5 cm) as well as the height of trees of different species, using Weibull distribution (see fig. 33 and 34).



Efssir
c 1,105
b 17,58
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Dar El beida
c 2,840
b 16,09
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Charen
c 0,9789
b 4,828
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Ain laaneb
c 1,075
b 4,041
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Ghbaret Agueni
c 1,710
b 55,45
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Tihirine
c 1,490
b 3,293
a 5
Tree-density (Ind. per ha)
Diameter (cm)

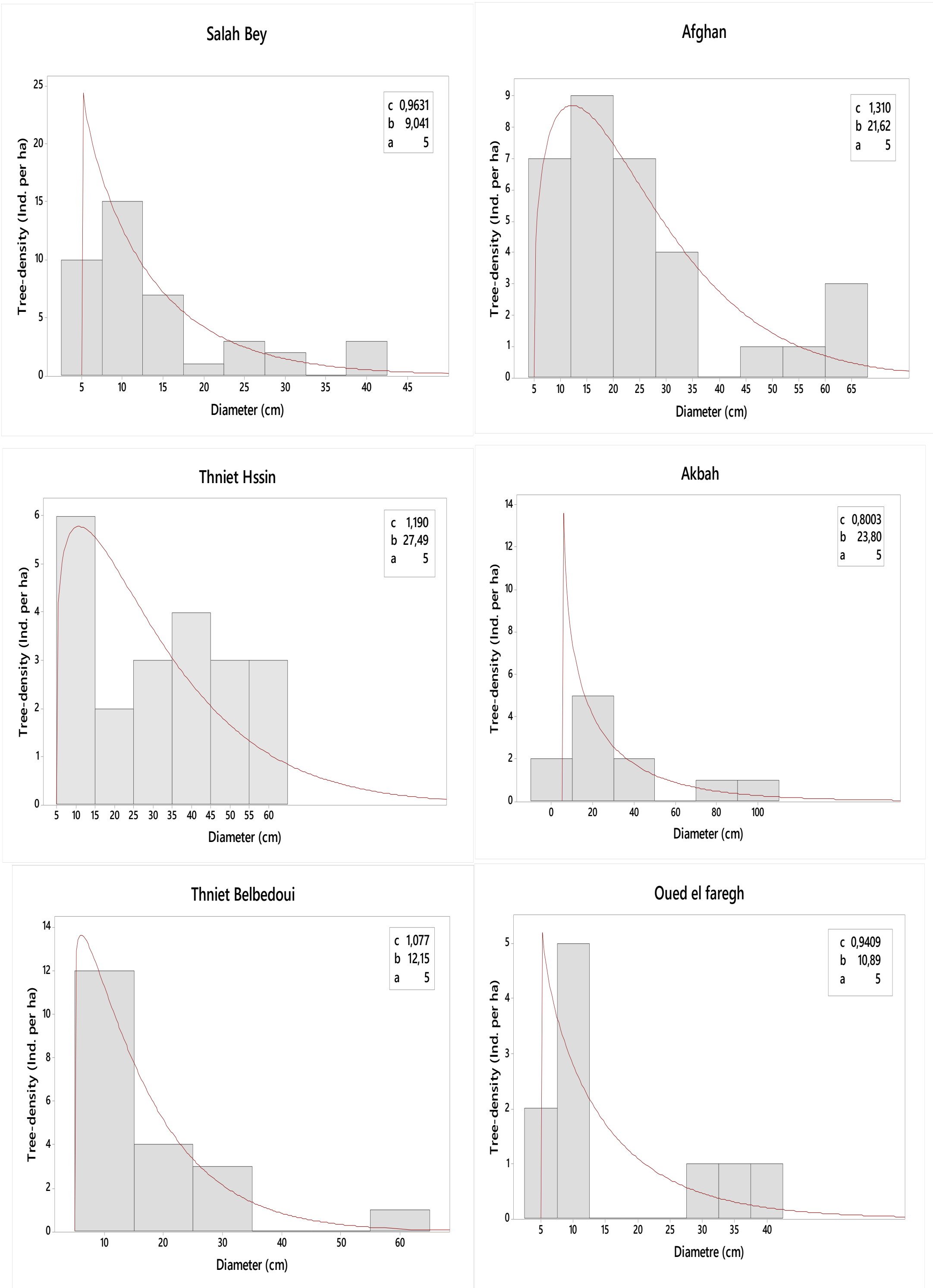
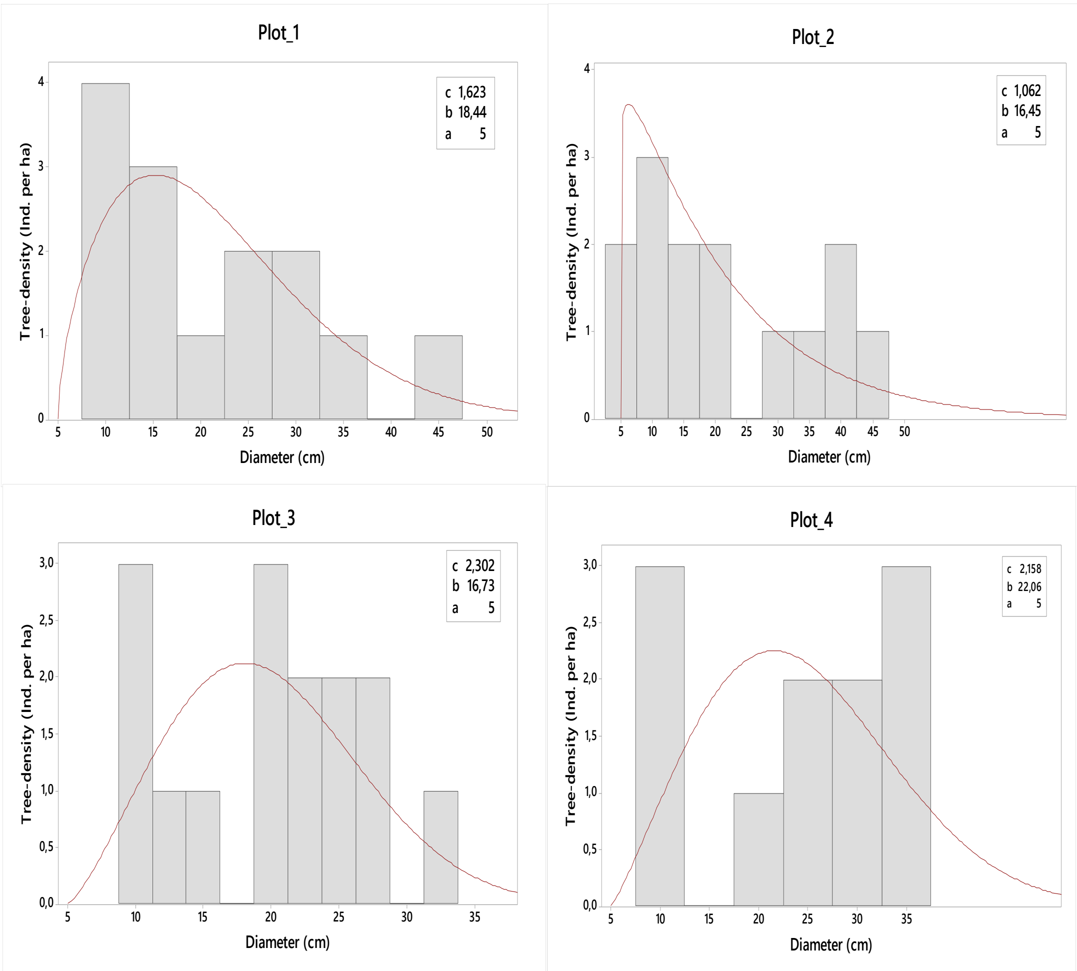
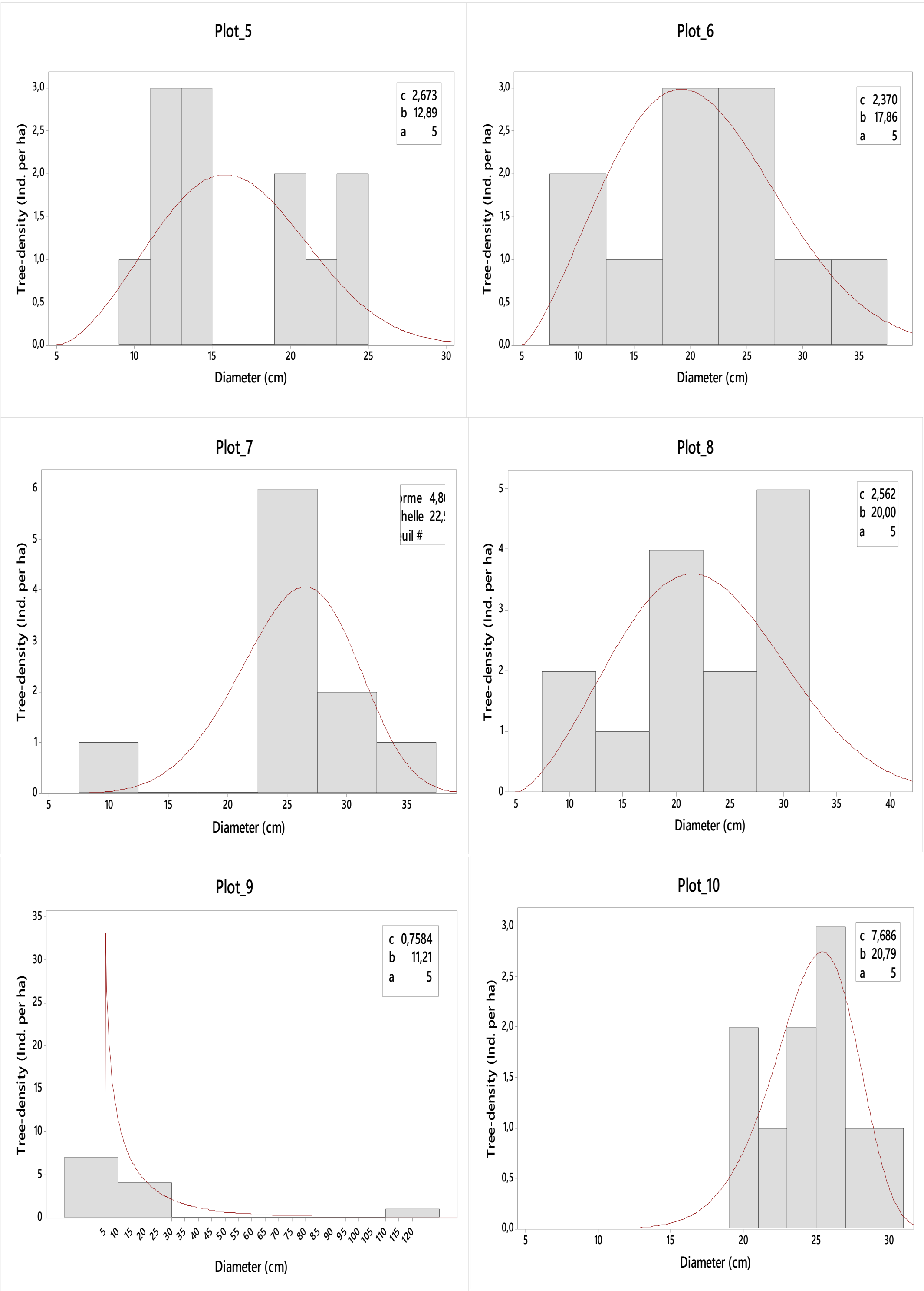


Figure 33. Diameter structure of Boutaleb forest stands.

We note from the fig. 31 that the shape parameter C is taking a value less than one (C< 1) in four plots (Charen, Salah bey reforestation, Akbah and Oued el faregh). This structure is therefore regressive and characteristic of natural stands with high regeneration potential. The plots Efssir, Ain laaneb, Ghbaret agueni, Tihirine, Afghan, Thniet hssin and Thniet belbedoui show a distribution with a shape similar to an "L" curve, with a shape parameter 1<C<2. This exponentially decreasing distribution characteristic of populations with strong regeneration potential but presenting survival challenges during the transition between stages of development. The value of the shape parameter C is 2.840 suggesting a positive asymmetric distribution, characteristic of monospecific populations with predominantly small-diameter individuals.





Plot_5
c 2,673
b 12,89
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Plot_6
c 2,370
b 17,86
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Plot_7
Tree-density (Ind. per ha)
Diameter (cm)
Plot_8
c 2,562
b 20,00
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Plot_9
c 0,7584
b 11,21
a 5
Tree-density (Ind. per ha)
Diameter (cm)
Plot_10
c 7,686
b 20,79
a 5
Tree-density (Ind. per ha)
Diameter (cm)

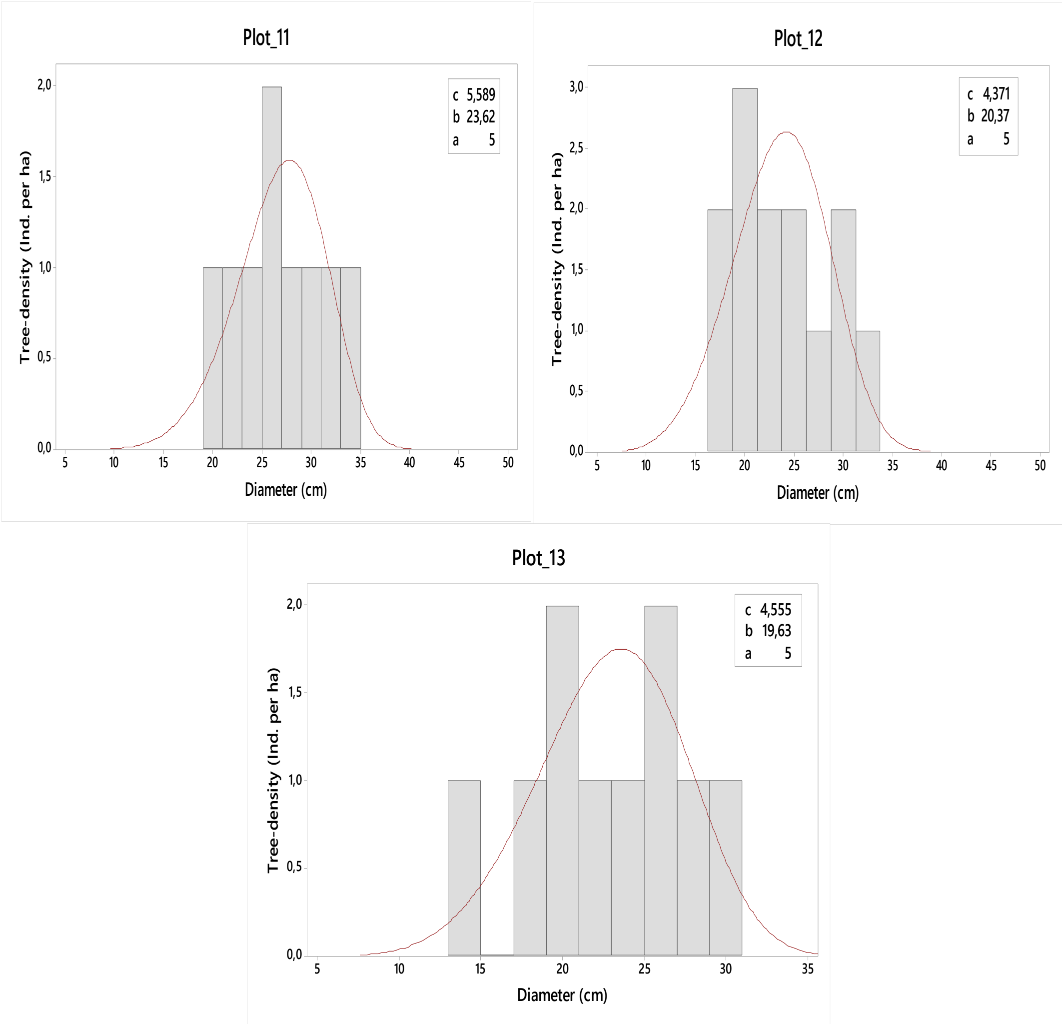
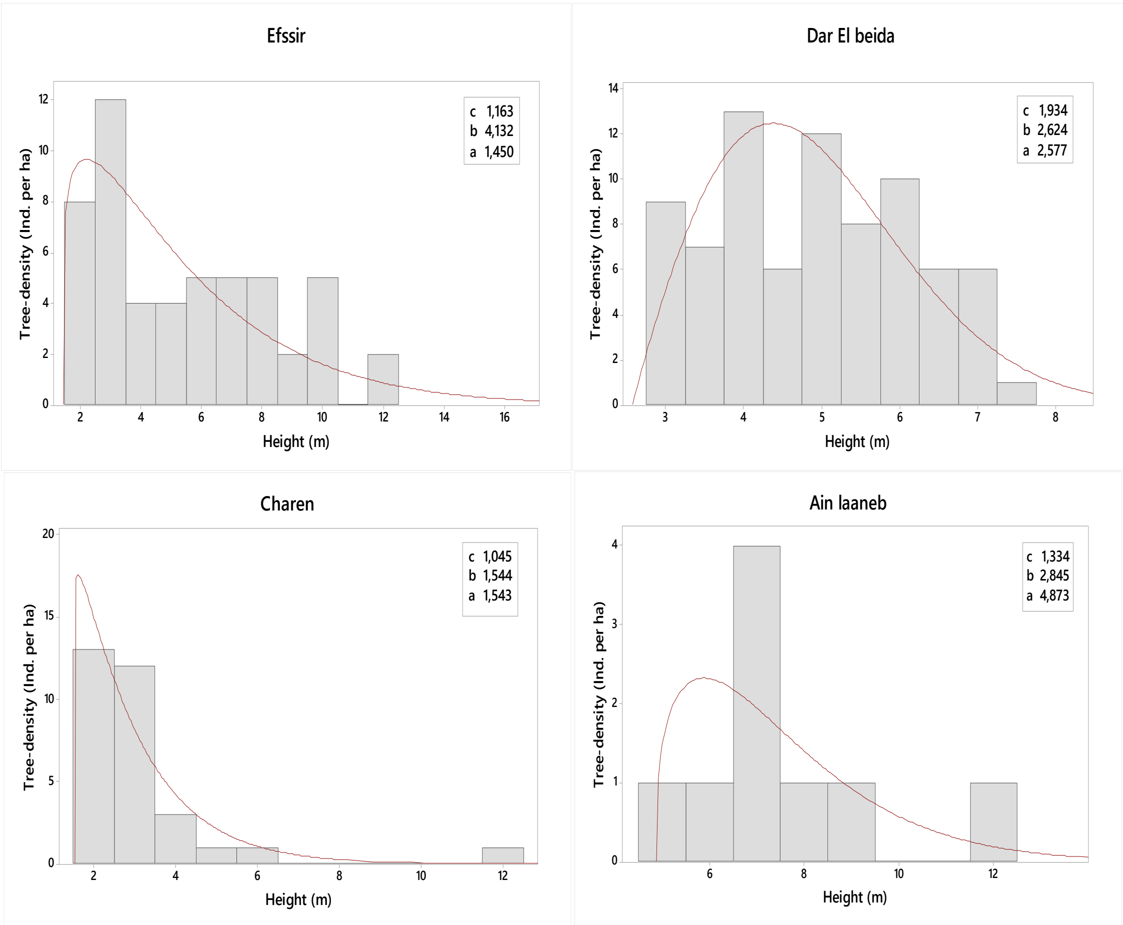


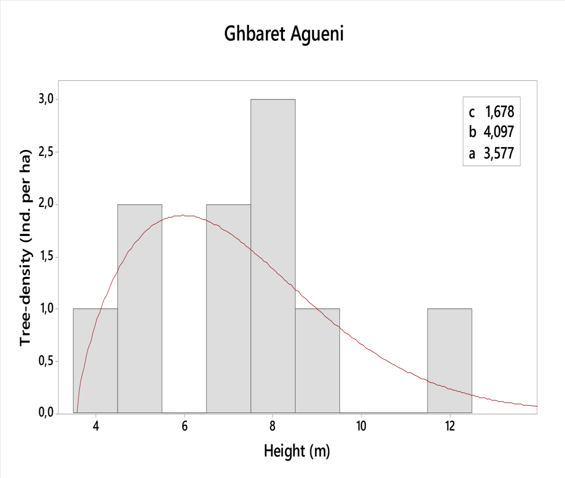
Figure 34. Diameter structure of Djebel Messaad forest stands.

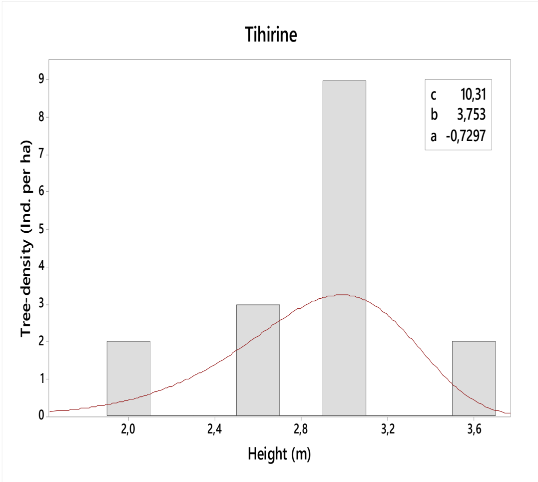
A Weibull theoretical distribution of Djebel Messaad forest (Fig. 34) stands with shape parameter C<1 is for plot 9 characterized by a high density of regeneration, which decreases with the transition to older age classes. When considering a group of individuals of the same species, the expected diameter structure should also have an "inverted J" shape. An exponentially decreasing distribution when C=1 in plot 1 and plot 2, characteristic of populations with high potential for regeneration but with a problem of survival during the transition between stages of development. The plots 3, 4, 5, 6 and 8 presents a positive asymmetrical or straight asymmetrical distribution with shape parameter 1<C<3.6 , characteristic of monospecific artificial stands with a relative predominance of young, small-diameter individuals. It can also be characteristic of populations with low regeneration potential due to exogenous actions, especially in small diameter classes. A left-handed asymmetry in diameter structure implies the predominance of large-diameter individuals in plot 7, 10, 12 and 13; the shape parameter of the Weibull distribution takes on a value greater than 3.6 in this case. Consistent management of such plantations could consist in thinning the high forest to bring the stand back to its normal structure. In the case of populations of natural species, such a distribution is a signal of a decline in species density linked to a regeneration problem.

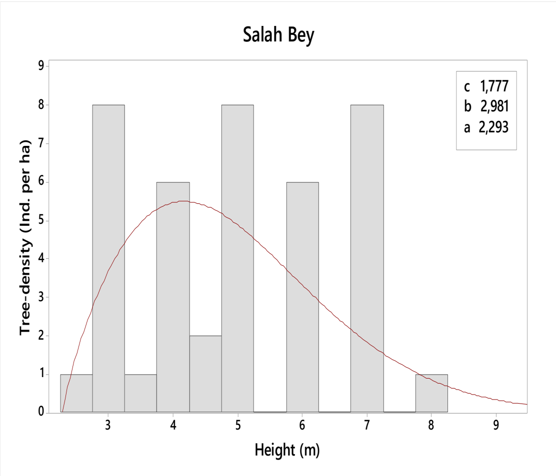
3.2 Height structure

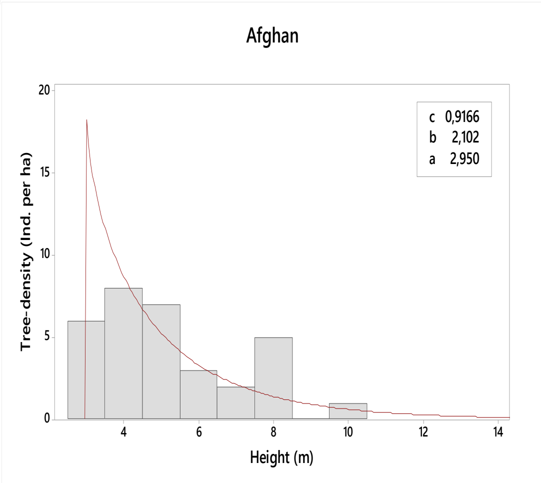
The structure of the inventoried trees by total height of Boutaleb and Djebel Messaad forests using Weibull distribution is showed in fig. 35 and fig. 36.

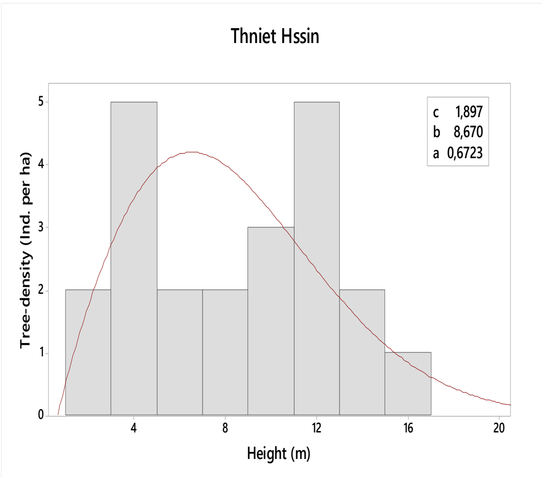


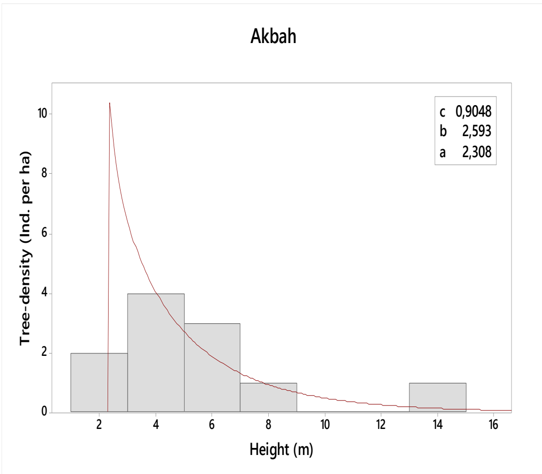

Ghbaret Agueni
c 1,678
b 4,097
a 3,577
Tree-density (Ind. per ha)
Height (m)


Tihirine
c 10,31
b 3,753
a -0,7297
Tree-density (Ind. per ha)
Height (m)


Salah Bey
c 1,777
b 2,981
a 2,293
Tree-density (Ind. per ha)
Height (m)


Afghan
c 0,9166
b 2,102
a 2,950
Tree-density (Ind. per ha)
Height (m)


Thniet Hssin
c 1,897
b 8,670
a 0,6723
Tree-density (Ind. per ha)
Height (m)


Akbah
c 0,9048
b 2,593
a 2,308
Tree-density (Ind. per ha)
Height (m)

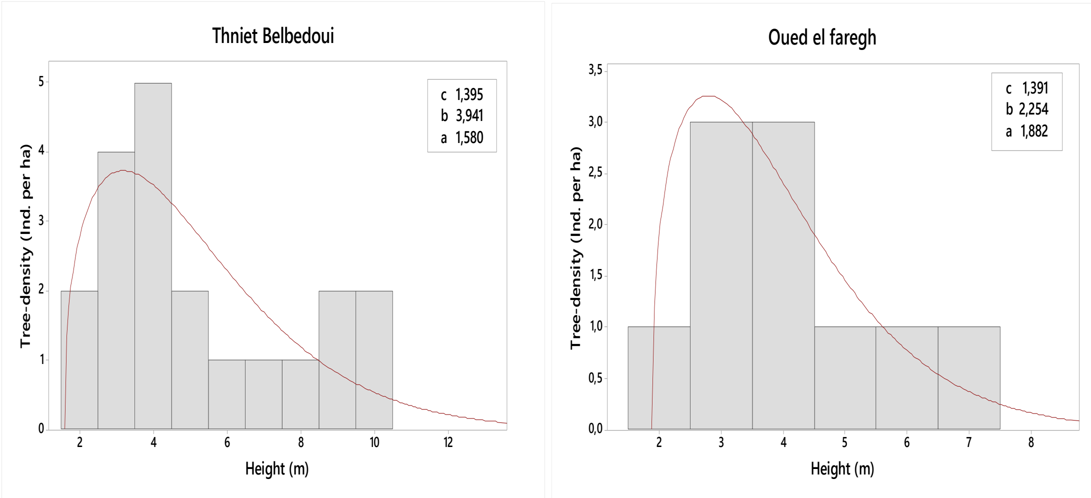
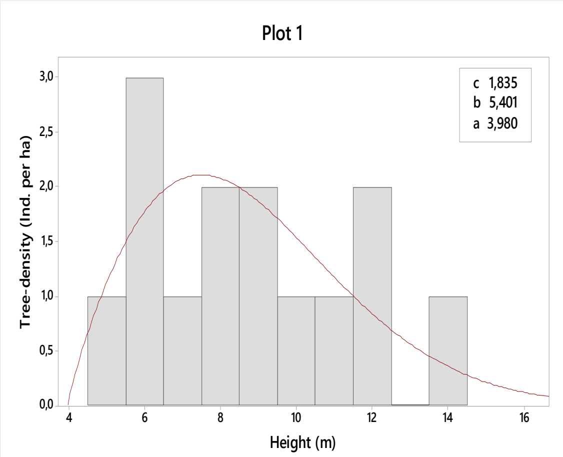
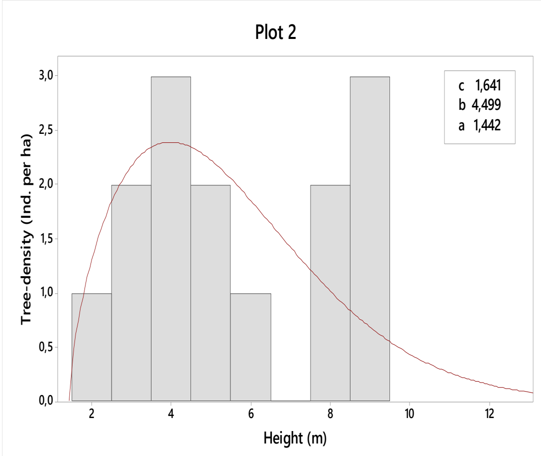


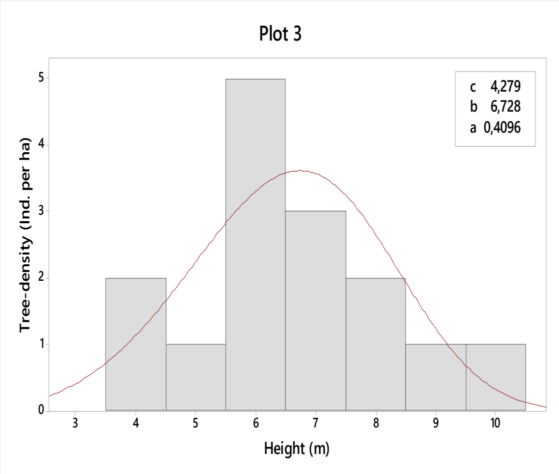
Figure 35. Height structure of Boutaleb forest stands.

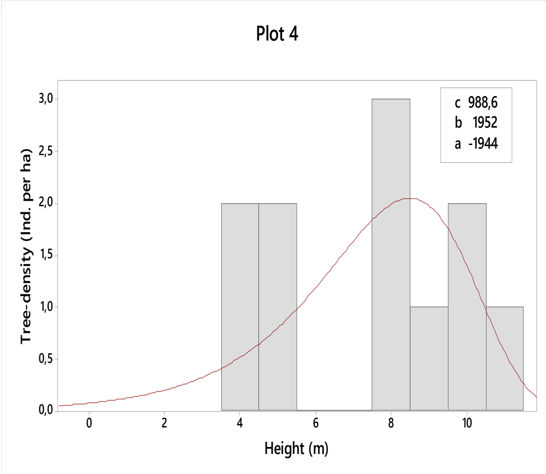
The shape parameter C is less than 1 in two plots Afghan and Akbah, the distribution is "inverted J", characteristic of multispecific or uneven-aged stands which is related to the presence of three different tree species in the same plots (*Cedrus atlantica*, *Quercus ilex and Juniperus oxycedrus*). The plots Efssir, Dar el beida, Charen, Ain laaneb, Ghbaret agueni, Salah bey reforestation, Thnniet hssin, Thniet belbedoui and Oued el faregh presents a positive-asymmetrical distribution with a shape parameter between 1 and 3.6, characteristic of monospecific stands with a predominance of young individuals or small heights. The shape parameter (c) is greater than 3.61 for Tihirine plot. It is therefore clear that the distribution is left asymmetrical or negative asymmetrical, characteristic of mono-specific of *Pinus halepensis* stands with a predominance of older individuals with high heights.

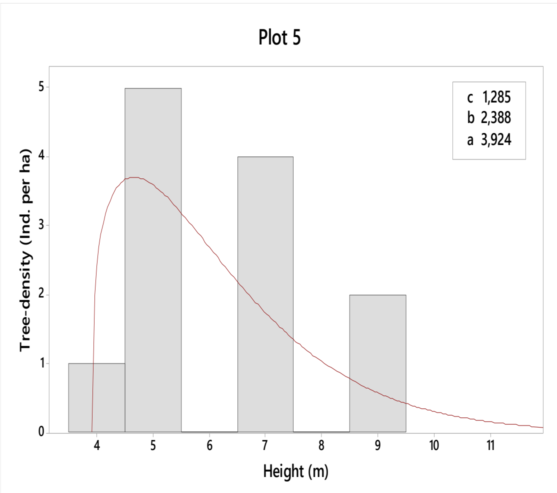
For Djebel Messaad forest stands, a straight asymmetry indicates the predominance of young individuals in the stand; in this case, the C parameter of Weibull distribution is between 1 and 3.6 for the plots 1, 2, 5, 6, 8, 10, 11 and 12. This straight asymmetrical distribution is typical of monospecific artificial stands with a relative predominance of young, small-height individuals. It can also be characteristic of populations with low regeneration potential due to exogenous influences, especially in small height. The shape parameter (C) is greater than 3.61 for plots 3, 4, 7, 9 and 13, characteristic of monospecific stands with a predominance of older or high heights individuals.

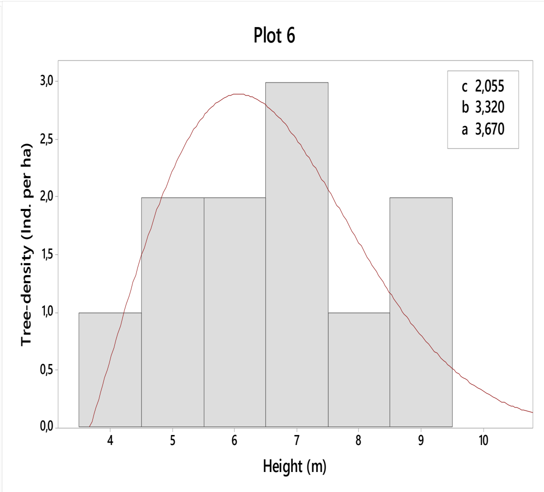

Plot 1
c 1,835
b 5,401
a 3,980
Tree-density (Ind. per ha)
Height (m)

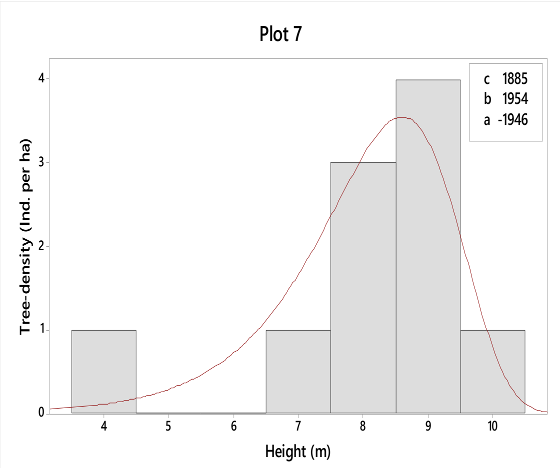

Plot 2
c 1,641
b 4,499
a 1,442
Tree-density (Ind. per ha)
Height (m)

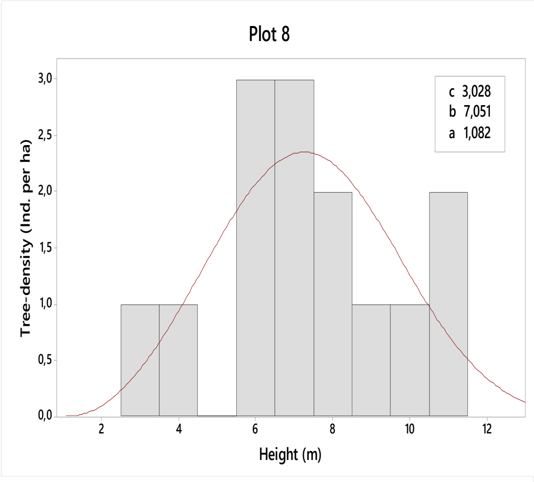

Plot 3
c 4,279
b 6,728
a 0,4096
Tree-density (Ind. per ha)
Height (m)

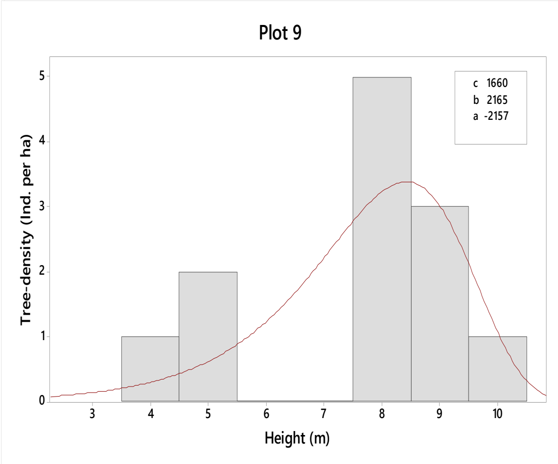

Plot 4
c 988,6
b 1952
a -1944
Tree-density (Ind. per ha)
Height (m)

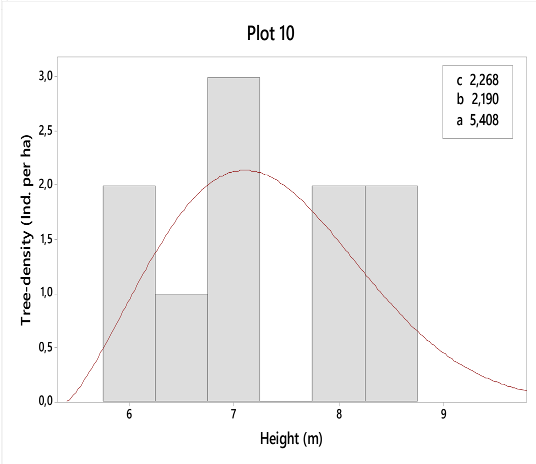

Plot 5
c 1,285
b 2,388
a 3,924
Tree-density (Ind. per ha)
Height (m)

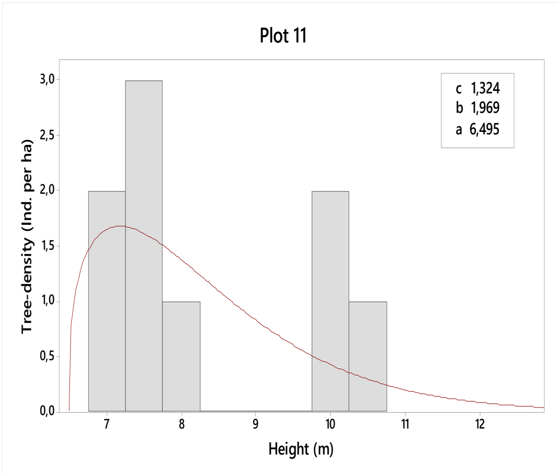

Plot 6
c 2,055
b 3,320
a 3,670
Tree-density (Ind. per ha)
Height (m)

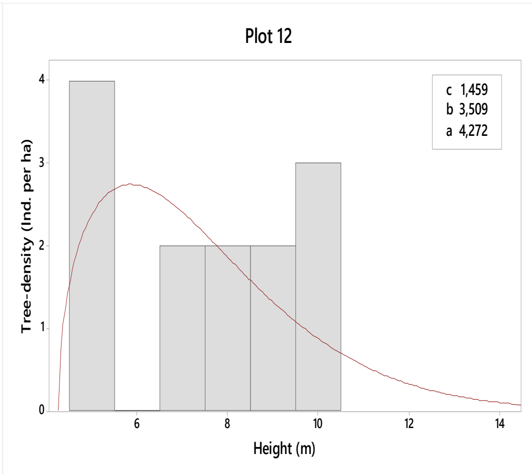

Plot 7
c 1885
b 1954
a -1946
Tree-density (Ind. per ha)
0 1 2 3 4
4 5 6 7 8 9 10
Height (m)


Plot 8
c 3,028
b 7,051
a 1,082
Tree-density (Ind. per ha)
0,0 0,5 1,0 1,5 2,0 2,5 3,0
2 4 6 8 10 12
Height (m)


Plot 9
c 1660
b 2165
a -2157
Tree-density (Ind. per ha)
0 1 2 3 4 5
3 4 5 6 7 8 9 10
Height (m)


Plot 10
c 2,268
b 2,190
a 5,408
Tree-density (Ind. per ha)
0,0 0,5 1,0 1,5 2,0 2,5 3,0
6 7 8 9
Height (m)


Plot 11
c 1,324
b 1,969
a 6,495
Tree-density (Ind. per ha)
0,0 0,5 1,0 1,5 2,0 2,5 3,0
7 8 9 10 11 12
Height (m)


Plot 12
c 1,459
b 3,509
a 4,272
Tree-density (Ind. per ha)
0 1 2 3 4
6 8 10 12 14
Height (m)

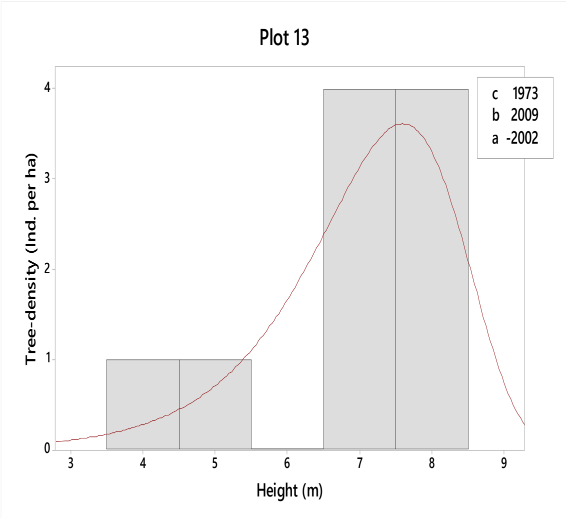
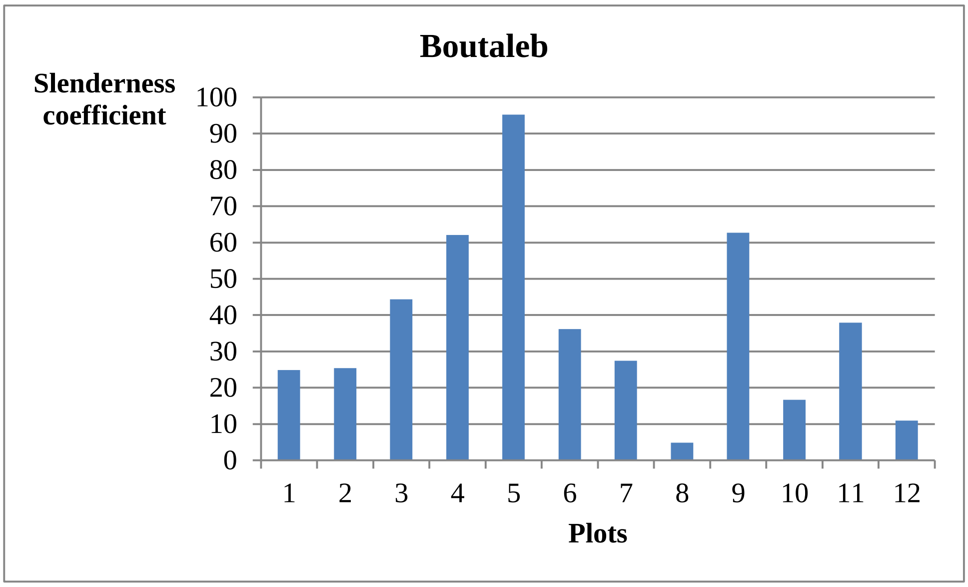


Figure 36. Height structure of Djebel Messaad forest stands.

4. Height and diameter correlation

The alliance between dendrometric variables (height (H) and diameter at breast height of trees (DBH)) is a key factor for the characterization and the growth of forest stands. It is the most commonly used measurement of tree size to describe the strategies of tree species.

The slenderness coefficient indicates that we have a strong negative trend, which is a function of the average diameter (Fig. 37). The trend curve shows that only 20.2% of our values from Djebel Messaad and 50% of values from Boutaleb forest are not demonstrated in this curve. In addition, the mean diameter is linked with the mean height. (Fig.38 and fig.39).



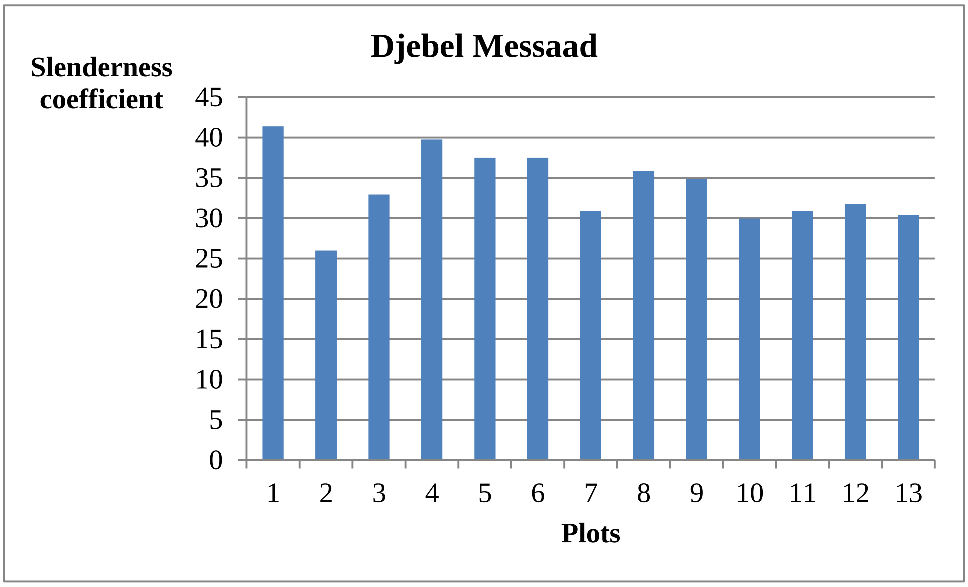


Figure 37. Slenderness coefficient of the study area.

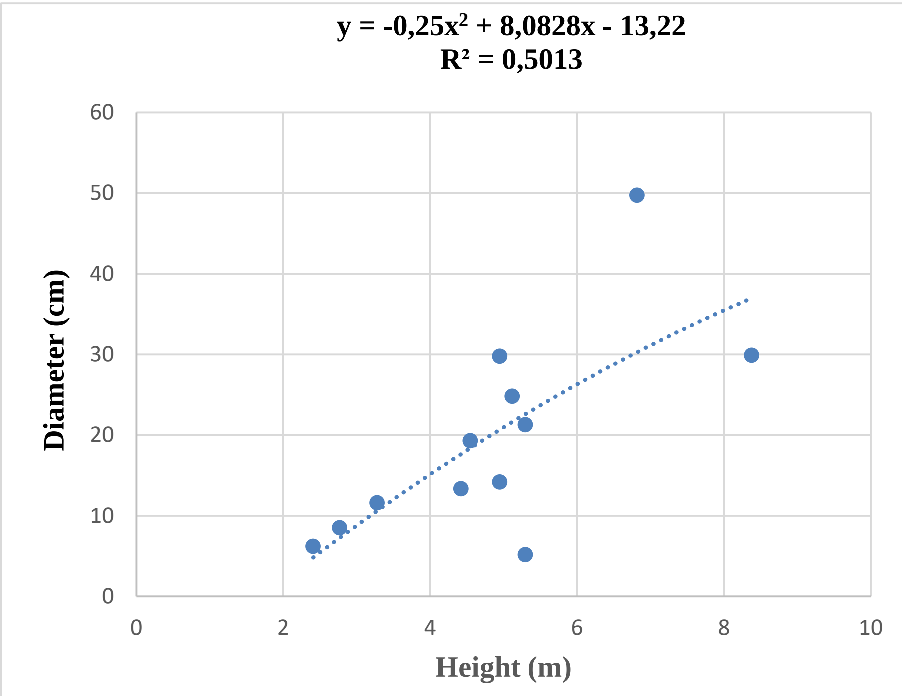


Figure 38. Correlation between DBH and height of Boutaleb forest stands.

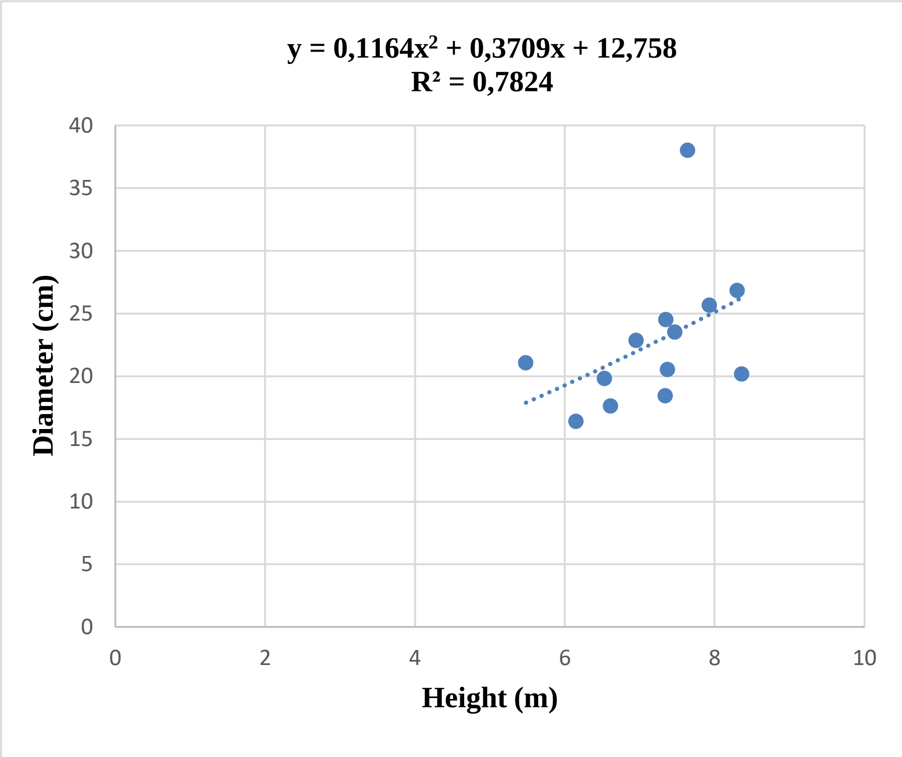


Figure 39. Correlation between DBH and height of Djebel Messaad forest stands.

5. Study of vegetation in the forest ecosystems of Hodna through remote sensing.

5.1 Analyses of the dynamics of plant formations

Landsat 8 (6-5-4) color composites acquires in two different dates 2014 and 2021 for Boutaleb forest, 2014 and 2023 for Djebel Messaad forest, obtained after image processing, are shown in figures 40, 41, 42 and 43.

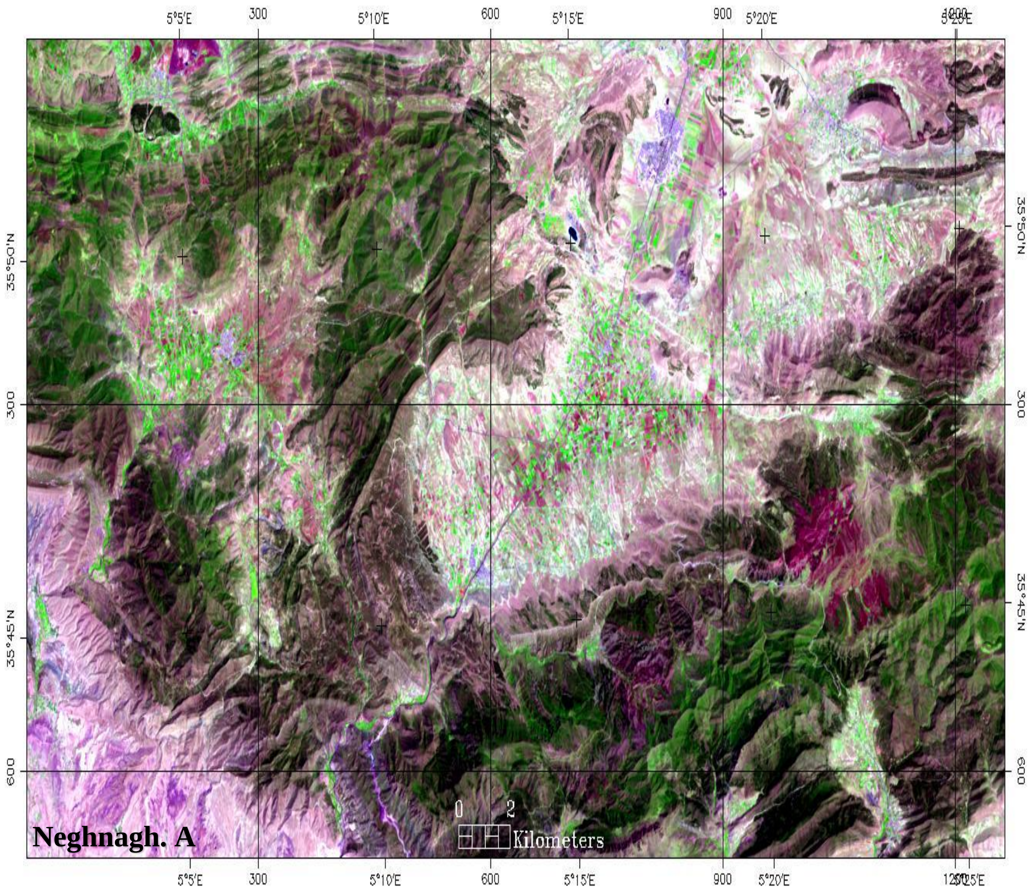


Figure 40. FCC of the bands 6, 5, 4 of Landsat 8 image 16/05/2014 of Boutaleb forest.

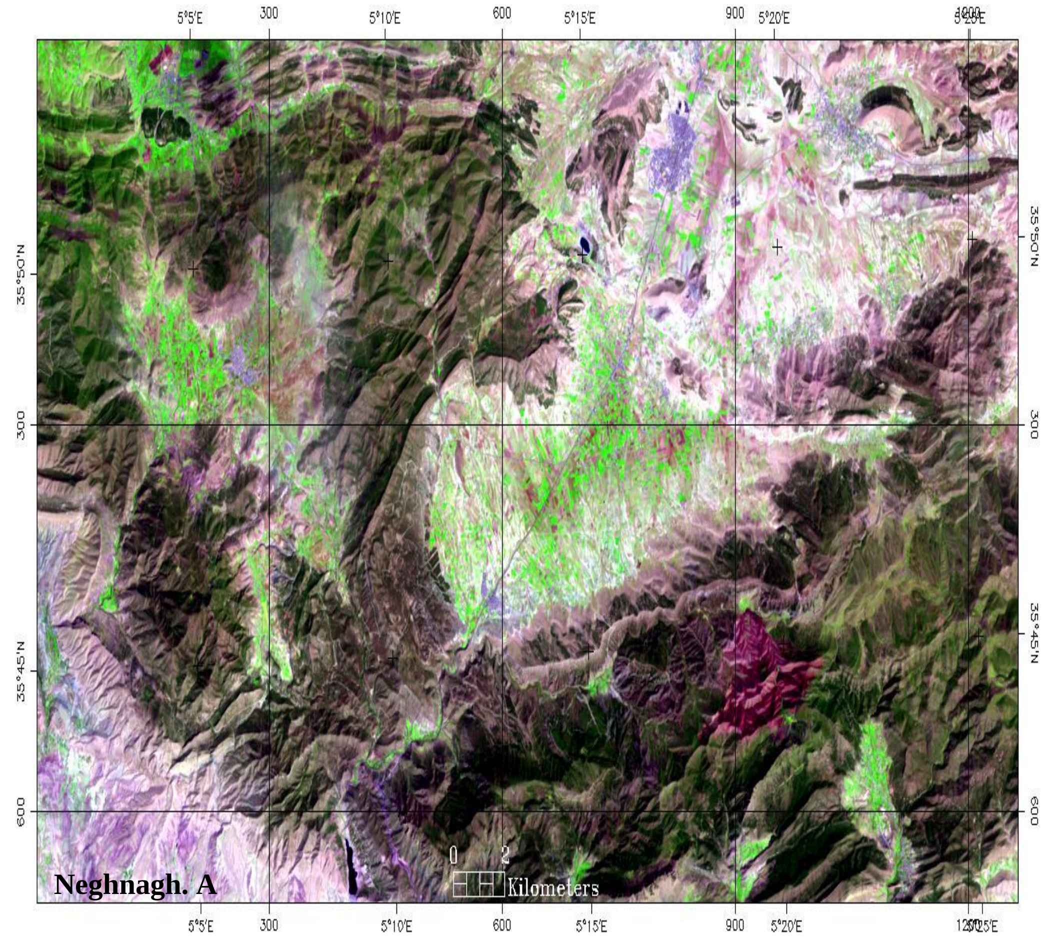


Figure 41. FCC of the bands 6, 5, 4 of Landsat 8 image 01/04/2021 of Boutaleb forest.

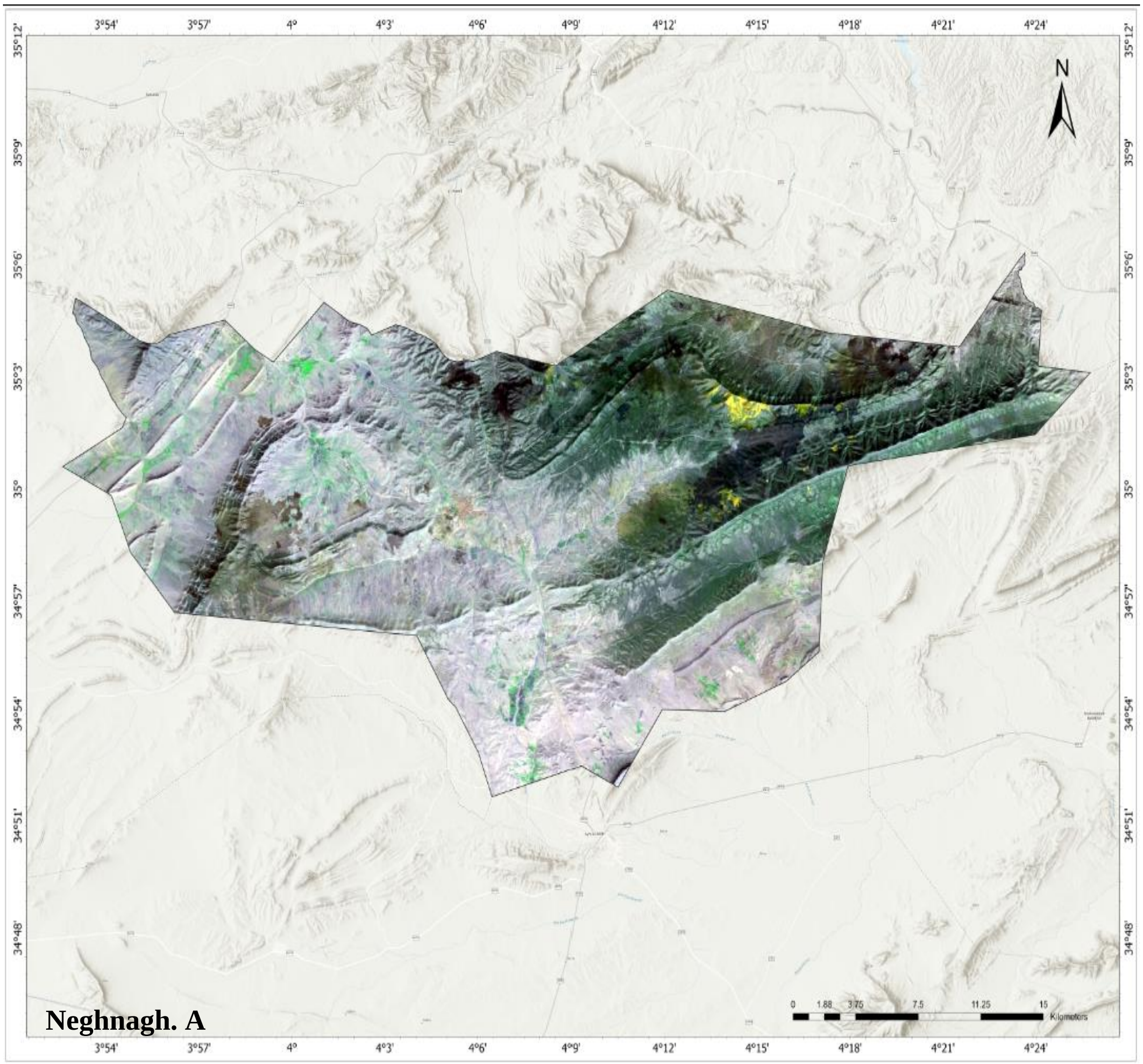


Figure 42. FCC of the bands 6, 5, 4 of Landsat 8 image for the year 2014 of Messaad forest.

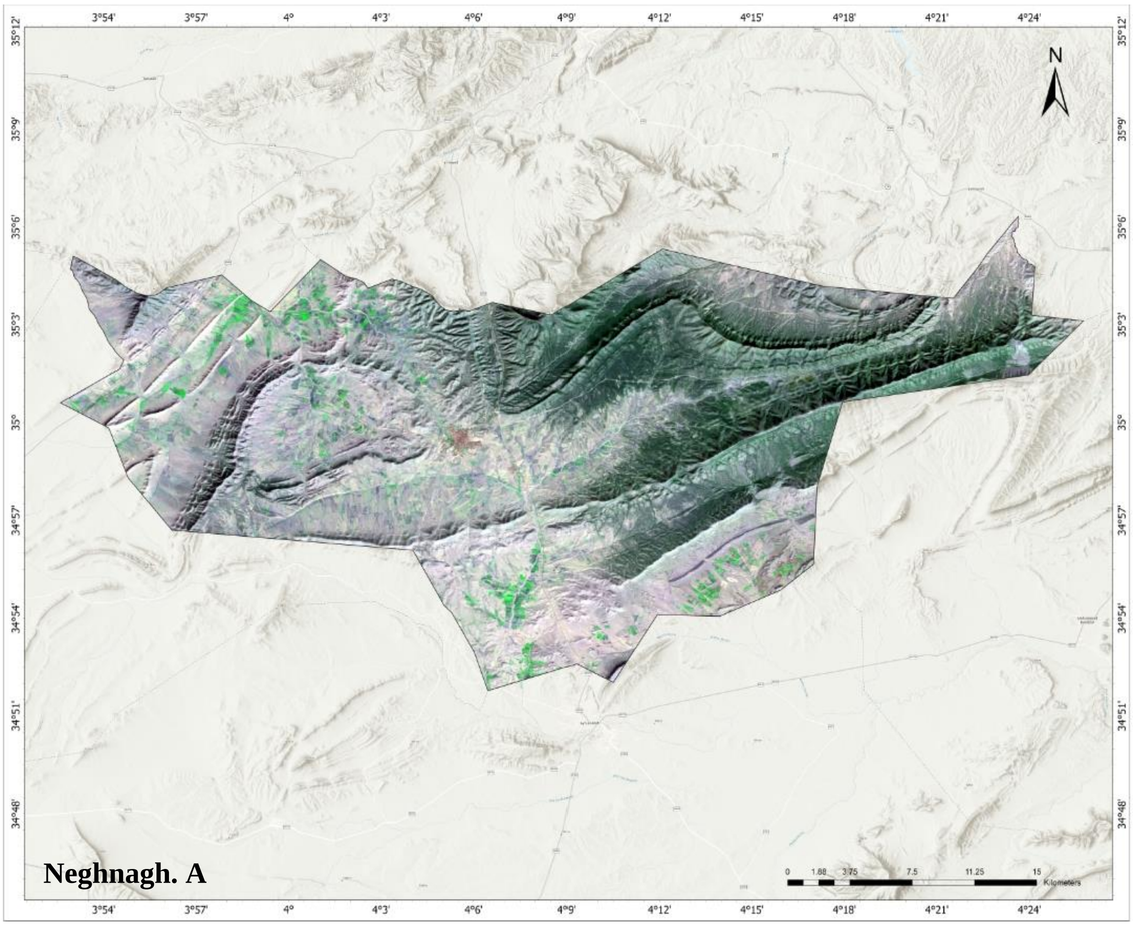


Figure 43. FCC of the bands 6, 5, 4 of Landsat 8 image for the year 2023 of Messaad forest.

The thematic classes identifiable on the color composites are divided into four groups:

- Bare soils appear in shades ranging from pink to mauve;
- water bodies are shown in dark blue;
- forests, in dark green;
- Constructions (buildings) in white.

If we compare figures 40 and 41 of the color composites of the Boutaleb forest for the years 2014 and 2021, we can see a slight decrease in dark green and pink colorations, corresponding to forests and bare soils. There is also an increase in white, corresponding to new building installations.

Comparing the figures 42 and 43 of Djebel Messaad forest color composites of the years 2014 and 2022, we notice a decrease in dark green or olive green coloration corresponds to forests and an increase in pink coloration corresponds to bare soils.

The choice of bands, including two in the infrared and one in the red, allowed for the discrimination of different vegetation types and their differentiation from other land uses. Indeed, chlorophyll, a characteristic pigment of vegetation, reflects in the infrared (Pony *et al.*, 2000). Several authors such as Koné *et al*. (2007) and Dibi N'Da *et al*. (2008) have used infrared bands in their color compositions to map land use and vegetation.

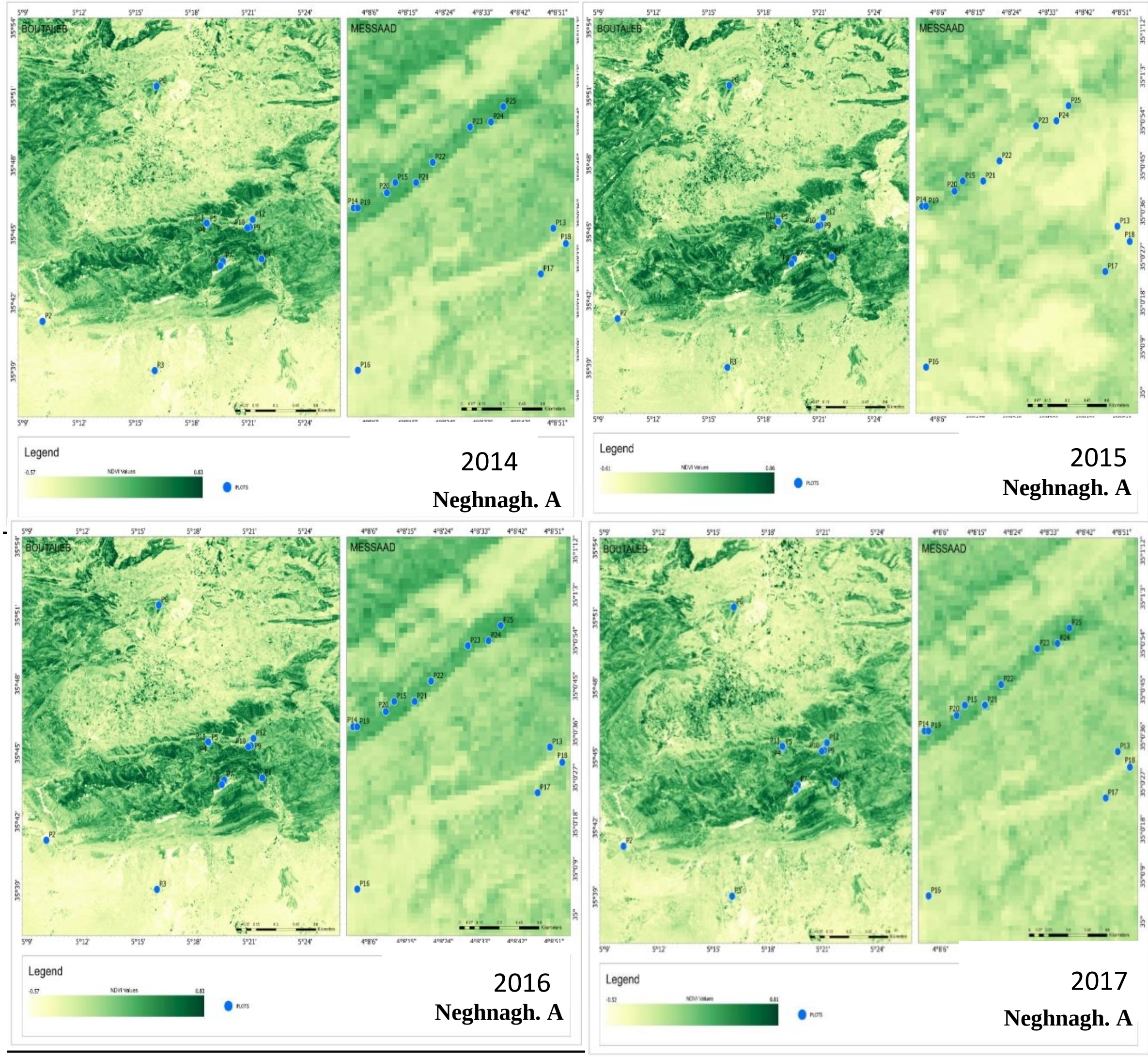
Statistical analysis of the colored compositions shows that the vegetation area is decreasing. Additionally, by testing different color composites, various phenomena can be detected more accurately, which makes them useful in a variety of practical applications.

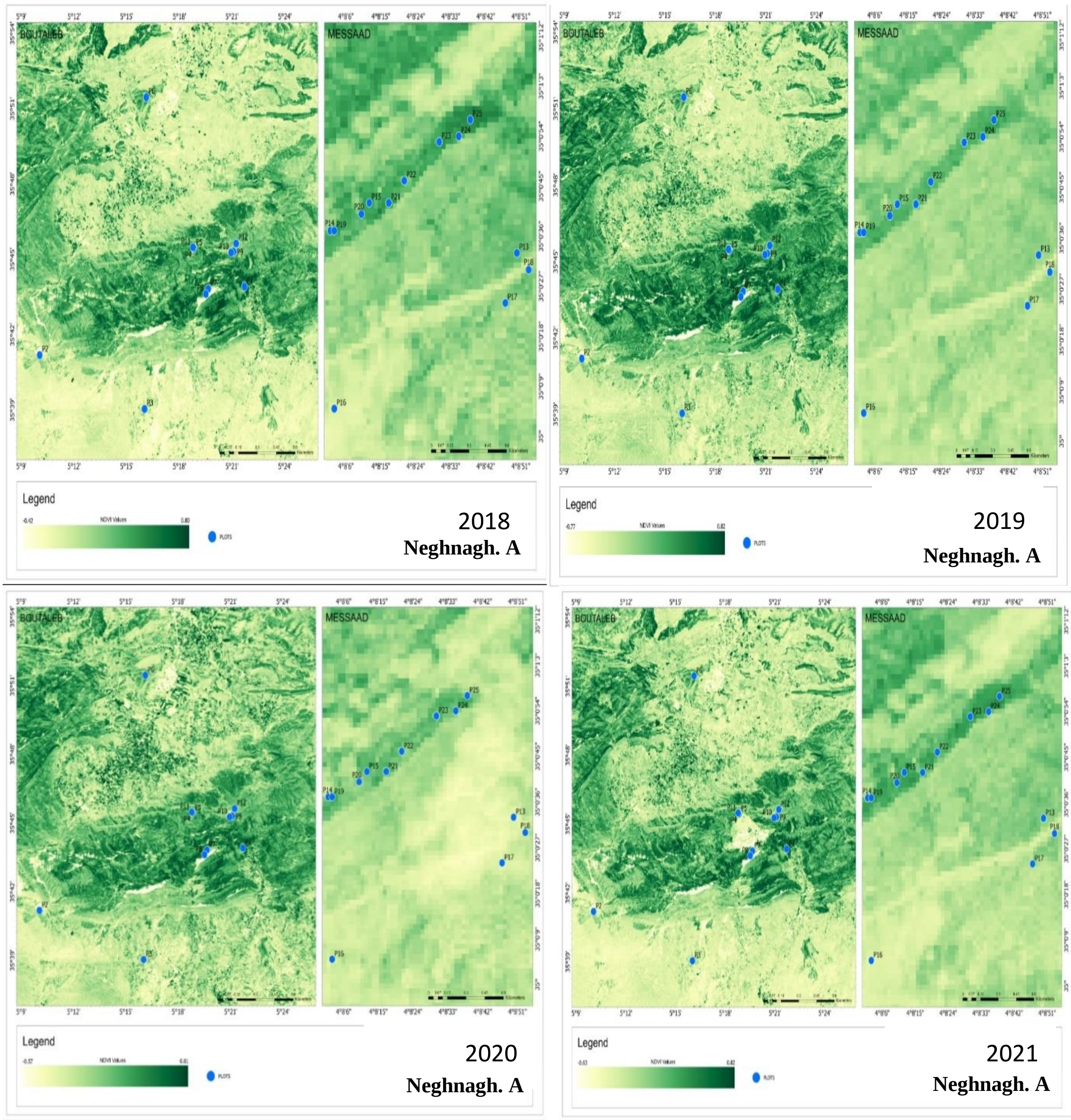
To mention some of them: indirect parameters of soil types that can be evaluated using color composites of the images, relief parameters reflected in vegetation types, as well as hydrologic parameters (river drainage network: density and curvature), and soil types (Lemenkova, 2021).

5.2 Calculation of the Normalized Difference Vegetation Index (NDVI)

The analysis of forest degradation and land use changes are major examples of the application of this approach. It is indeed possible to compare images from different years. These images should be taken at the same time of year, in order to minimize the expression of variables such as light quality, observation geometry, and, in the case of plant ecosystems, differences in community behavior throughout the year (Singh, 1986; Mouat *et al.*, in Beldjazia, 2016).

Eleven values of NDVI were taken using ArcGIS Pro software between the period 2014 to 2024. The values of NDVI range from -1 to +1, with negative values corresponding to surfaces other than vegetation cover, such as snow, water, or clouds, for which reflectance in the red band is higher than in the near infrared. For bare soil, where reflectance is roughly the same in the red and near infrared bands, NDVI values are close to 0. Vegetation formations have positive NDVI values, typically ranging from 0.1 to 0.7, with higher values corresponding to denser vegetation cover. NDVI varies significantly over the study period. A general observation shows that all NDVI curves, for different classes, exhibit the same behavior (Fig. 44).


BOUTALEB
MESSAAD
Legend
NDVI Values
PLOTS
2014
Neghnagh. A
2015
Neghnagh. A
2016
Neghnagh. A
2017
Neghnagh. A


BOUTALEB
MESSAAD
Legend
2018
Neghnagh. A
BOUTALEB
MESSAAD
Legend
2019
Neghnagh. A
BOUTALEB
MESSAAD
Legend
2020
Neghnagh. A
BOUTALEB
MESSAAD
Legend
2021
Neghnagh. A

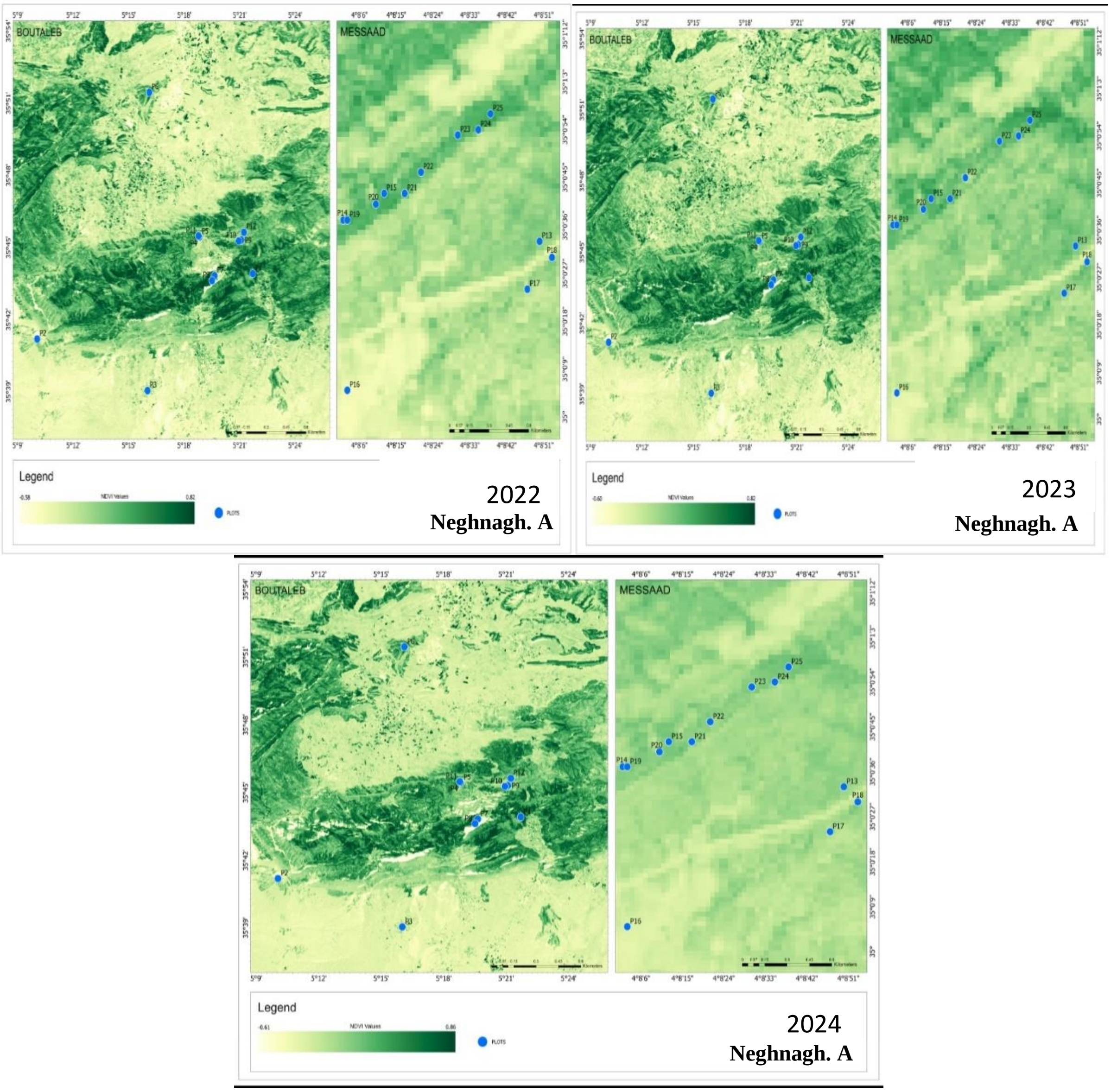


Figure 44. NDVI maps of Boutaleb and Djebel Messaad forests for the period 2014-2024.

The NDVI is a measure of the balance between the energy received and the energy emitted by objects on the earth. When applied to plant communities, this index establishes a value measuring the intensity of green in a given area, indicating the amount of vegetation present, as well as its health or growth vigor. The NDVI is a dimension less index, in practice, values below 0.1 correspond to water bodies and bare soils, while higher values indicate strong photosynthetic activity, typical of shrublands, temperate forests, wetlands, and agricultural lands. The calculation of the normalized vegetation index shows a decrease in vegetation cover density in the Hodna region.

The values of NDVI time series were statistically tested using the Friedman statistical test (Tab. 18).

Table 18. Friedman Test of NDVI values in the study area.

Parameters	Boutaleb	Djebel Messaad
Q (Observed value)	51.588	55,357
Q (Critical value)	19,675	21,026
DDL	11	12
p-value (unilateral)	**<0,0001**	**<0,0001**
alpha	0,05	0,05

The Friedman test shows that there is a significative difference between plots from the two study areas (Fig. 45).

The Multiple Pair Comparisons by Nemenyi Test show the presence of 5 groups. The group "A" presents the lowest value while the highest value is for the group "C" (Tab. 19).

The *Pinus halepensis* formation in their wooded state was affected by the lowest values, whereas the highest values corresponding to mixture formation of *Pinus halepensis, Quercus ilex* and *Juniperus oxycedrus* in their dense state, and also in *Cedrus atlantica* formation.

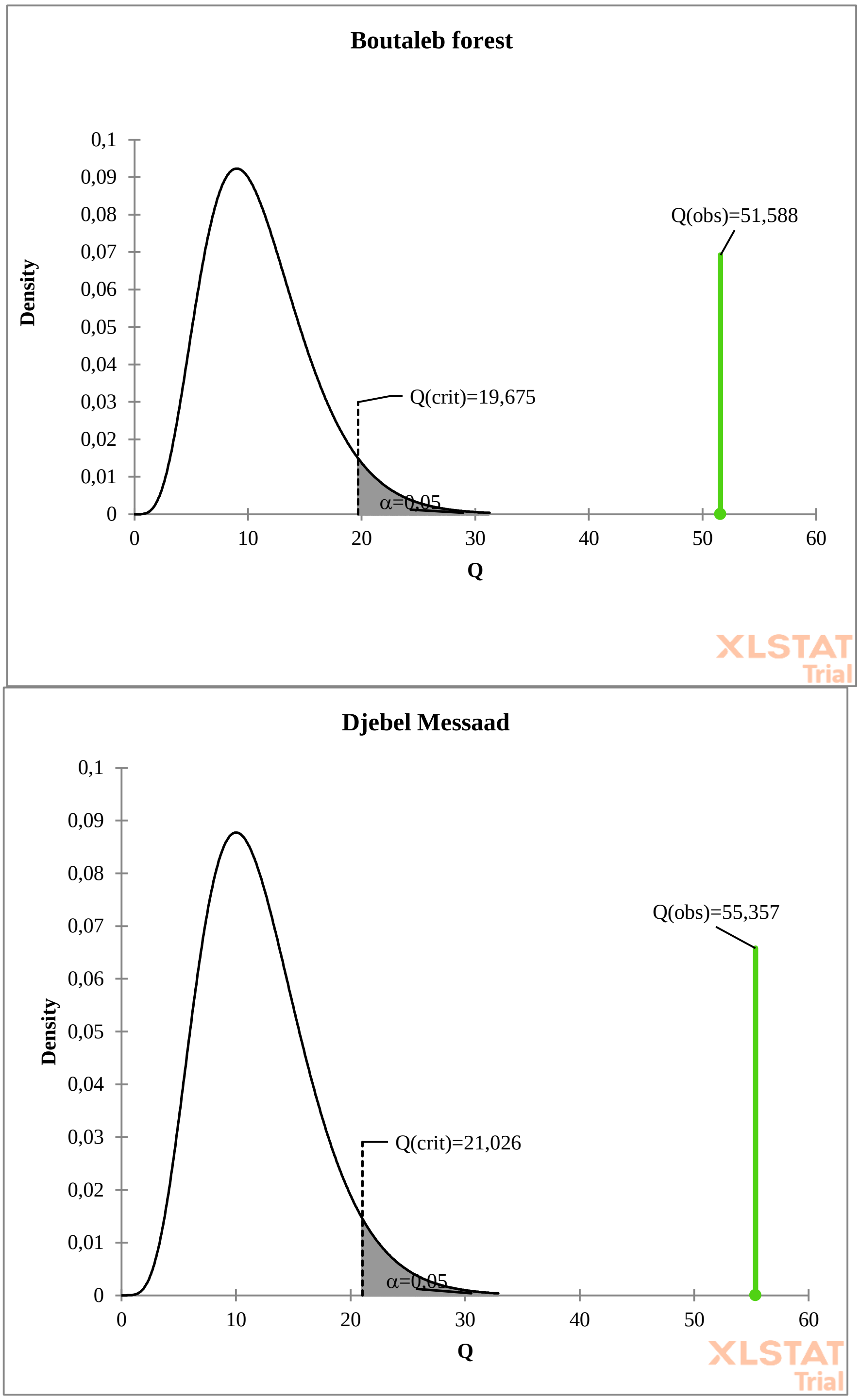


Figure 45. Friedman test of NDVI values in the study area.

Table 19. Multiple Pair Comparisons by Nemenyi Test of NDVI values in Boutaleb forest.

Plots	Average rank	Groups
P2	2,727	A
P6	3,500	A B
P3	3,773	
P12	6,000	A B C
P5	6,182	
P4	6,273	
P10	6,591	
P7	7,500	
P9	8,136	B C
P11	8,136	
P8	8,318	
P1	10,864	C

In Djebel Messaad, the Multiple Pair Comparisons by Nemenyi indicate the presence of five groups. The highest values are for group "C" and the lowest are for group "A" (Tab. 20).

Table 20. Multiple Pair Comparisons by Nemenyi Test of NDVI values in Djebel Messaad.

Plots	Average rank	Groups
P4	2,727	A
P5	3,545	A B
P6	4,591	A B C
P1	4,727	
P2	6,091	
P7	6,591	
P9	7,727	
P10	7,818	
P13	8,818	B C
P3	9,318	C
P11	9,500	
P8	9,773	
P12	9,773	

According to the box plot, we can see that the average of NDVI values varies between 0.19 and 0.38 for the different sampled plots of Boutaleb forest. The maximum mean value is for plot 1, the minimum value is for plot 2. The comparison of the interquartile ranges show that NDVI data of the majority of plots are more dispersed (Fig. 46).

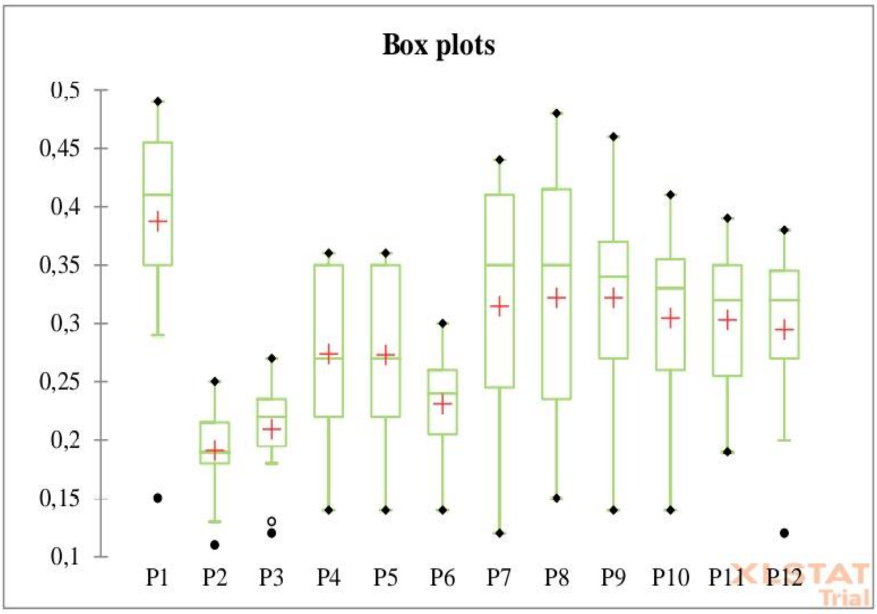


Figure 46. Box plots of NDVI values of Boutaleb forest stands.

The box plots of Messaad forest stands show that the average of NDVI values varies between 0.19 and 0.26. The maximum mean values are for plot 8 and 12, the minimum values are for plot 4. The comparison of the interquartile ranges show that NDVI data of the majority of plot are less dispersed (Fig. 47).

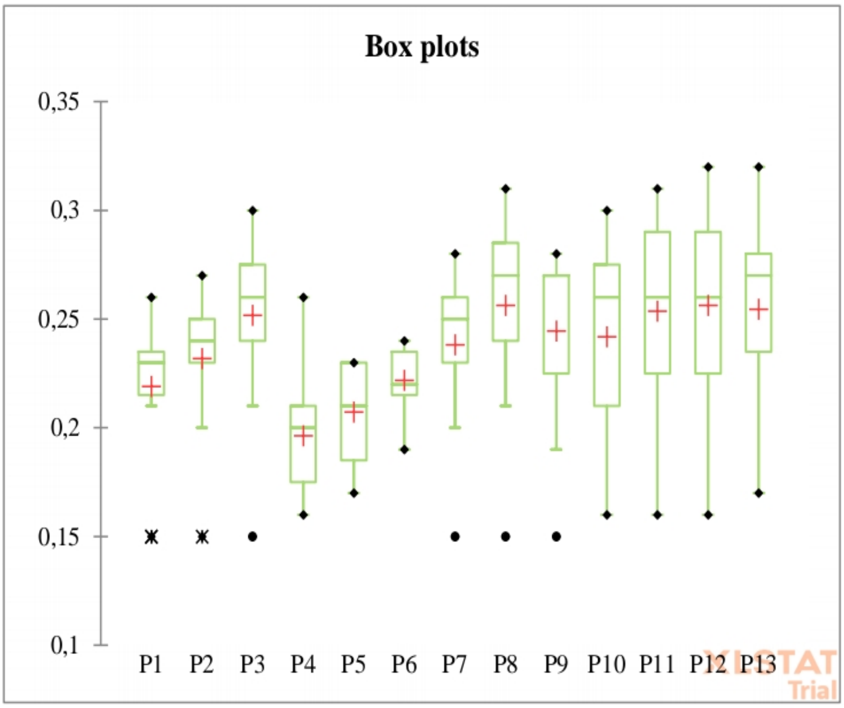


Figure 47. Boxplots of NDVI values of Djebel Messaad forest stands.

Over the ten years, the response of plant communities appears more like those of a region with irregular precipitation in our study area (Fig. 48, 49).

The study of land surface phenology typically involves tracking changes over time in NDVI data, which has been accessible since the introduction of the first earth observation satellites. By monitoring NDVI time series, researchers can gather insights into various phenological stages, such as the emergence (green wave) or decline (brown wave) of vegetation. These stages are indicated by corresponding increases or decreases in NDVI values.

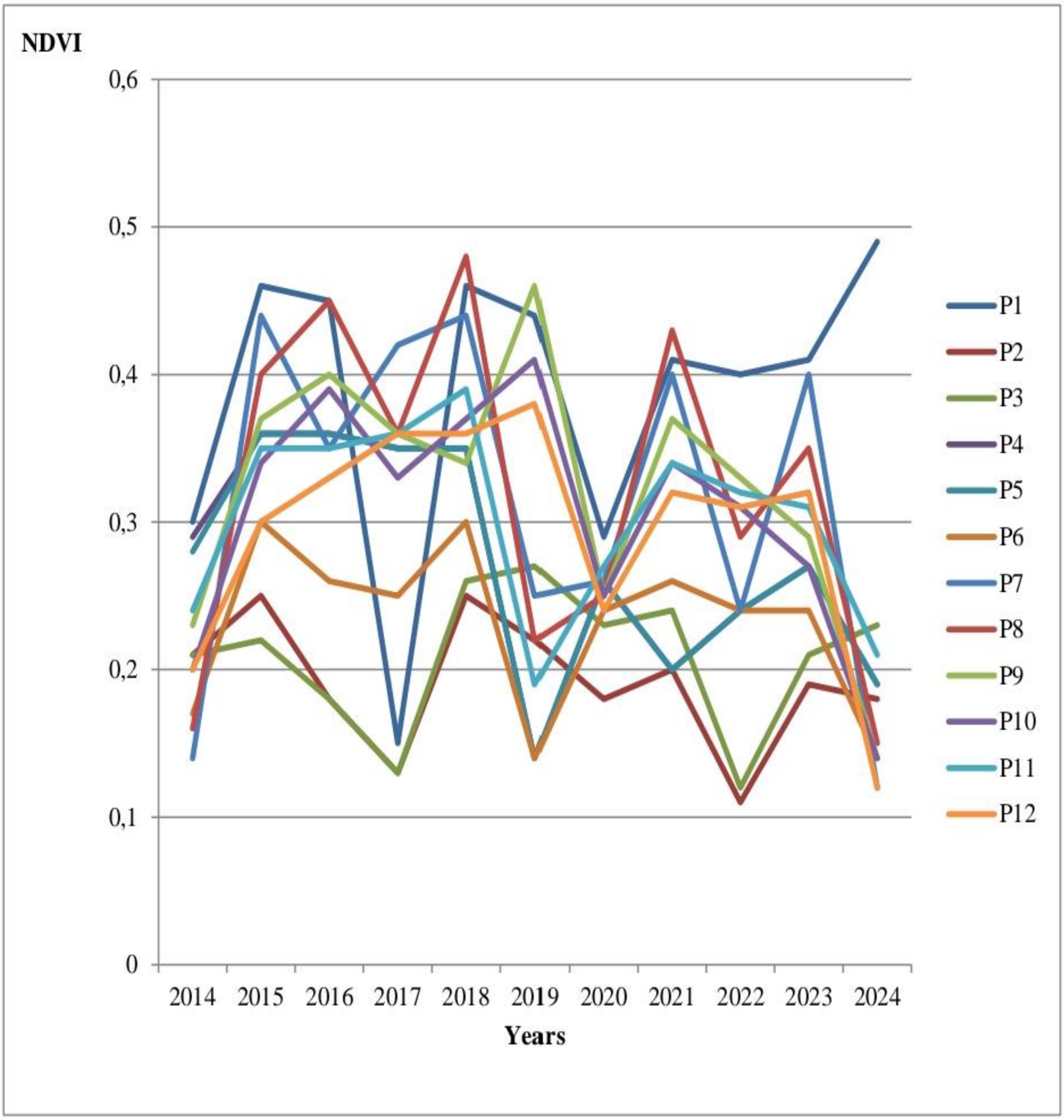


Figure 48. NDVI behavior of the same plots for various vegetation categories of Boutaleb forest.

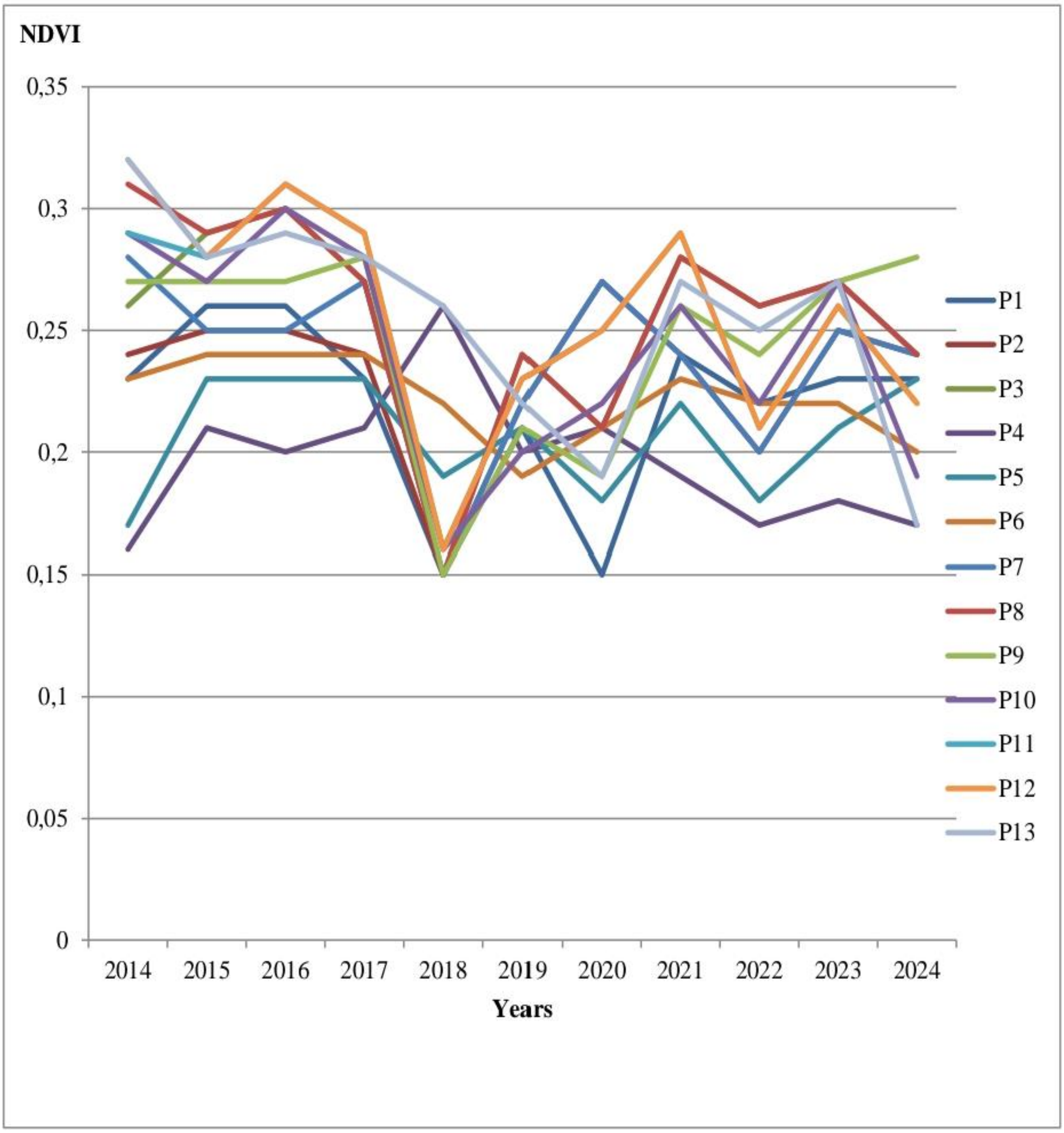
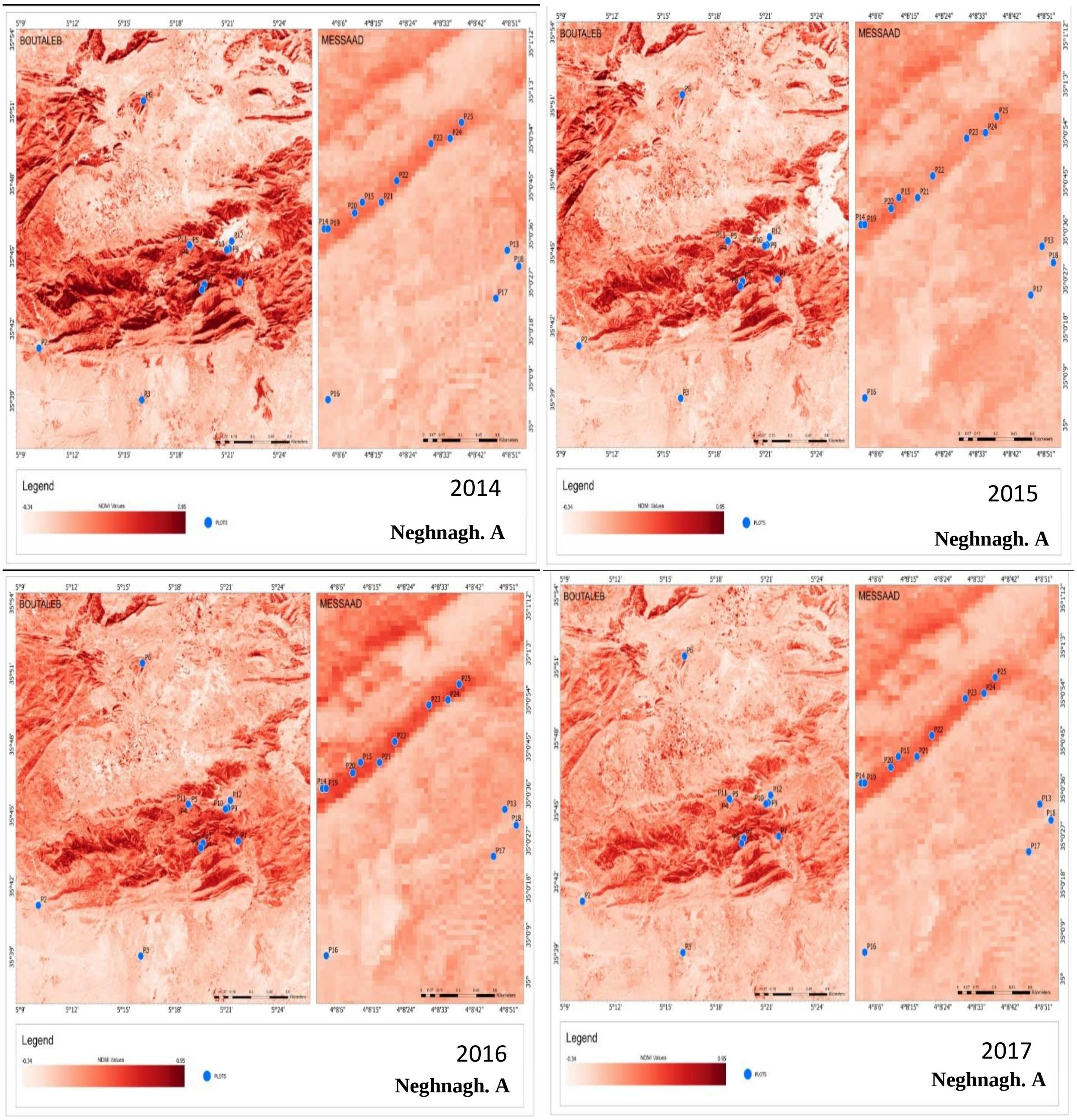


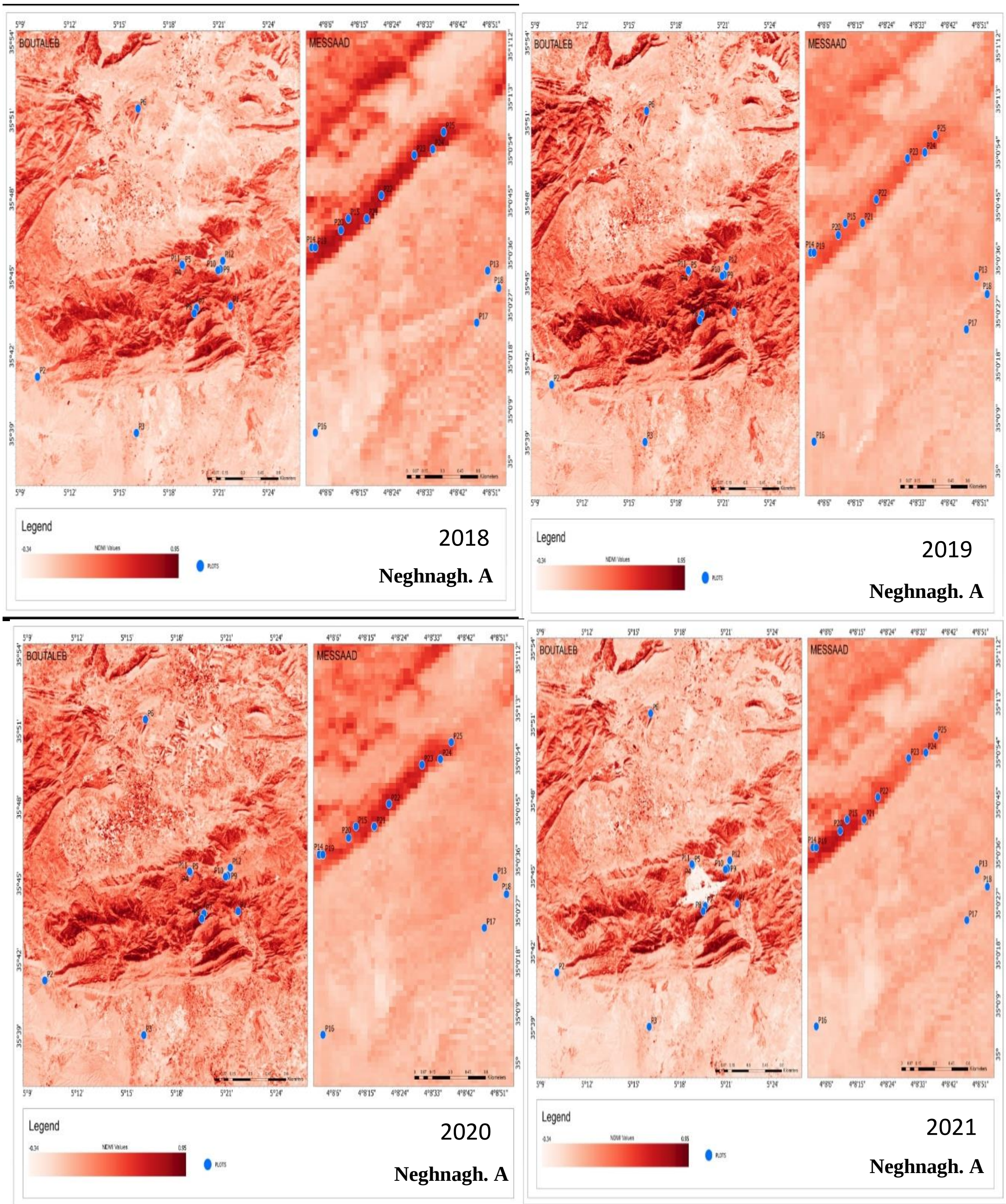
Figure 49. NDVI behavior of the same plots for various vegetation categories of Djebel Messaad.

It was found that NDVI has been sensitive to canopy background modification in arid and semi-arid territories. (Huete *et al.*, 1997). The growth of individual trees is influenced by a combination of climate, site conditions, and competition factors. These influences can vary according to species and tree dimensions (Jiang *et al.*, 2018).

5.3 Calculation of the Normalized Difference Moisture Index

Water is essential for the growth and development of all plants. Scientists use the NDMI index to measure the moisture content of plants, which in turn affects their basic physiological processes, such as photosynthesis. The NDMI was calculating using ArcGIS Pro software for the period (2014-2024) (Fig. 50).




BOUTALEB
MESSAAD
Legend
NDMI Values
2018
Neghnagh. A
BOUTALEB
MESSAAD
Legend
2019
Neghnagh. A
BOUTALEB
MESSAAD
Legend
2020
Neghnagh. A
BOUTALEB
MESSAAD
Legend
2021
Neghnagh. A

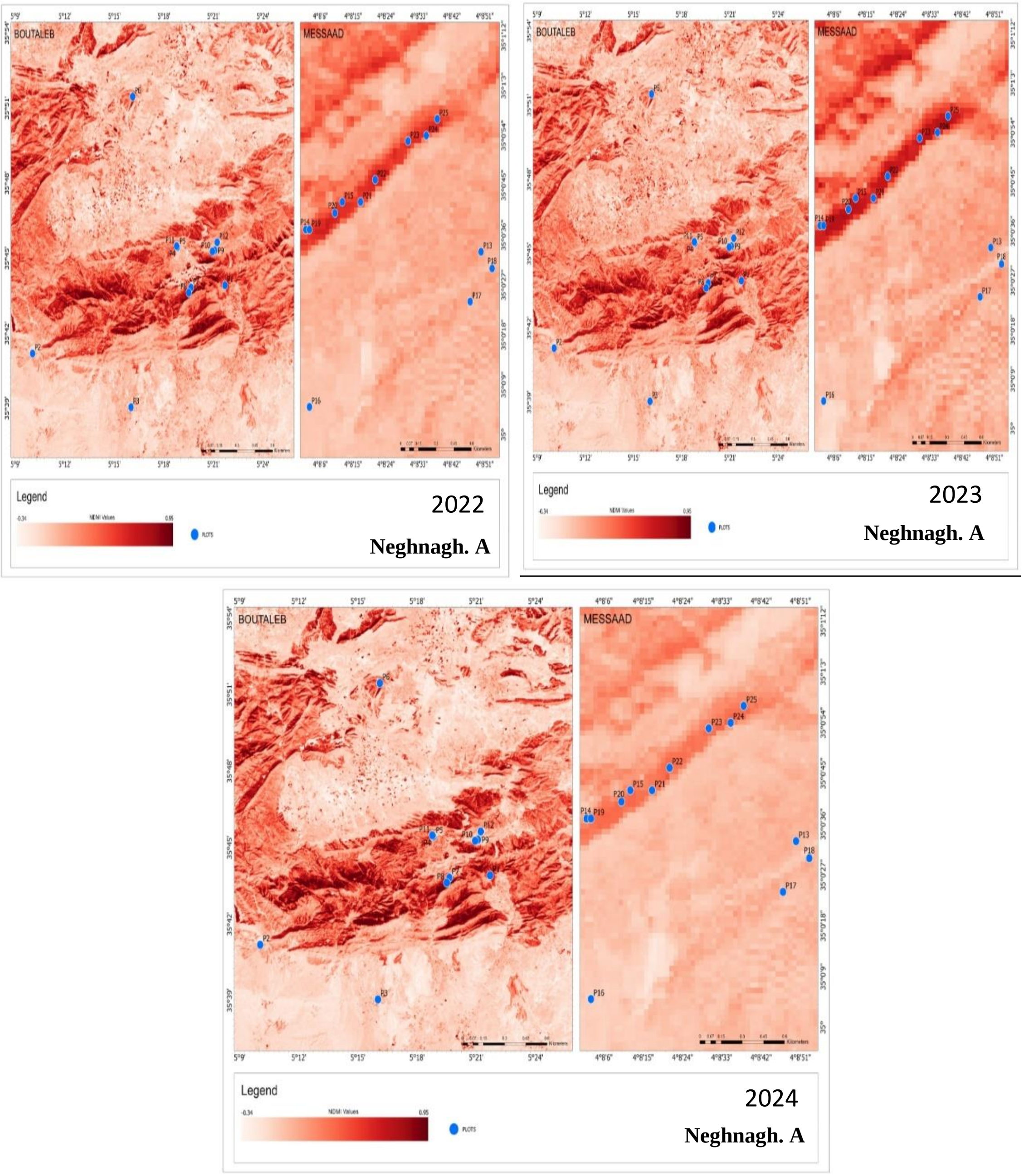


Figure 50. NDMI maps of Boutaleb and Djebel Messaad forests for the period 2014-2024 processing with ArcGis software.

The statistical analyses according to Friedman test indicate a significative difference between the plots over the study area (Tab. 21) (Fig. 51).

Table 21. Friedman Test of NDMI values in the study area.

Parameters	Boutaleb	Djebel Messaad
Q (Observed value)	72.467	55,167
Q (Critical value)	19,675	21,026
DDL	11	12
p-value(unilateral)	**<0,0001**	**<0,0001**
alpha	0,05	0,05

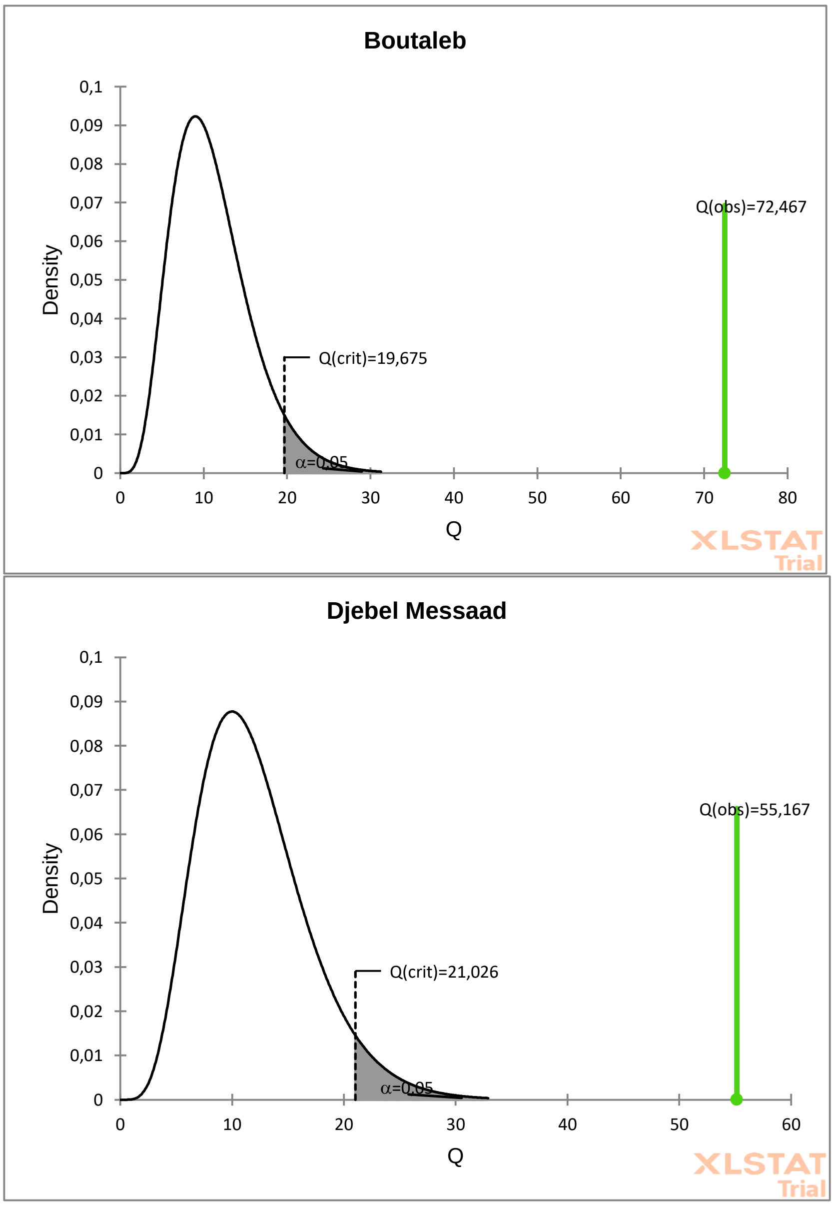


Figure 51. Friedman test of NDMI values in the study area.

In Boutaleb forest, the Multiple Pair Comparisons by Nemenyi Test show the presence of 7 groups. The group “A” presents the lowest value while the highest value is for the group “D” (Tab. 22).

Table 22. Multiple Pair Comparisons by Nemenyi Test of NDMI values in Boutaleb forest.

Plots	Average rangs	Groups
P2	2,409	A
P3	3,500	
P6	4,500	
P12	5,273	A B
P5	5,364	
P4	5,682	
P11	5,727	A B C
P10	6,500	A B C D
P9	7,455	
P1	9,818	B C D
P8	10,773	C D
P7	11,000	D

However, in Djebel messaad, the statistical comparison highlight 7 homogeneous groups, with the first corresponding to plot 4 and the last including plot 8 with the highest values (Tab. 23).

Table 23. Multiple Pair Comparisons by Nemenyi Test of NDMI values in Djebel Messaad.

Plots	Average rangs	Groups
P4	2,682	A
P5	3,227	A B
P6	4,727	A B C
P1	5,591	A B C D
P13	5,773	
P10	7,455	
P7	7,591	
P2	7,773	
P11	8,364	B C D
P9	8,409	
P12	8,864	C D
P3	10,136	
P8	10,409	D

The box plots of NDMI of Boutaleb forest stands show that the average NDMI values varies between -0.01 and 0.21. The maximum mean value is for plot 7, the minimum value is for plot 2. The comparison of the interquartile ranges show that NDMI data of the majority of plots are less dispersed (Fig. 52).

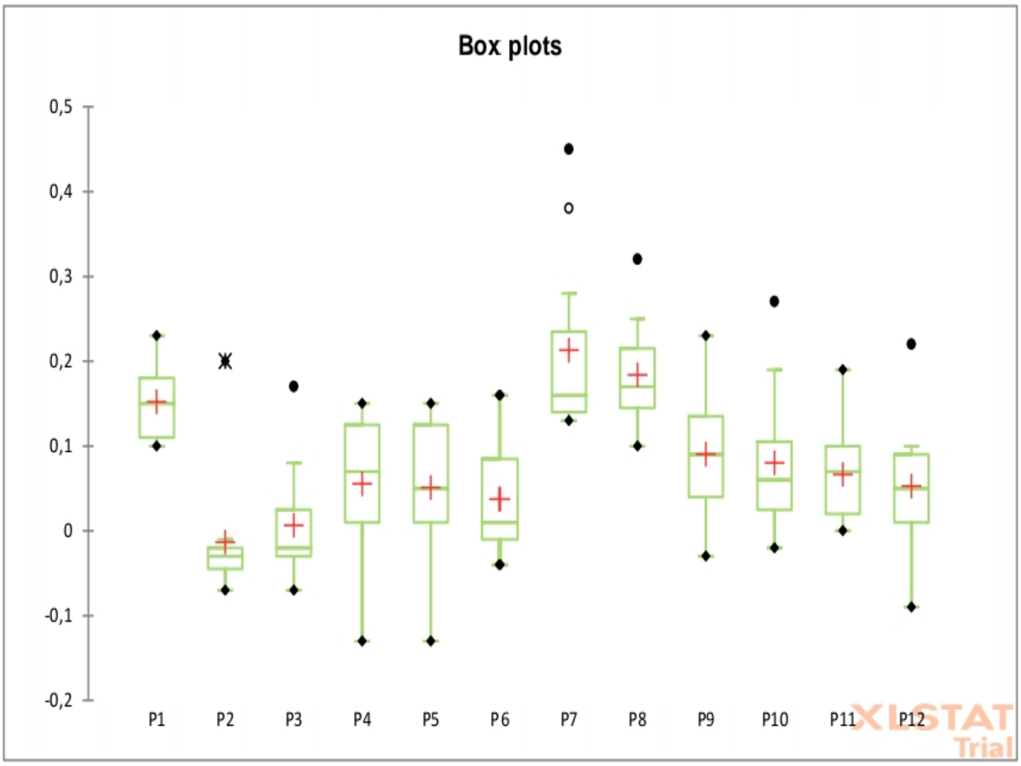


Figure 52. Box plots of NDMI values of Boutaleb forest stands.

According to the box plot of NDMI of Djebel Messaad forest stands, we notice that the mean of NDMI values varies between -0.03 and 0.03 for the different sampled plots. The maximum mean value is for plot 8, the minimum value is for plot 4. The comparison of the interquartile ranges show that NDMI data of the majority of plot are less dispersed (Fig. 53).

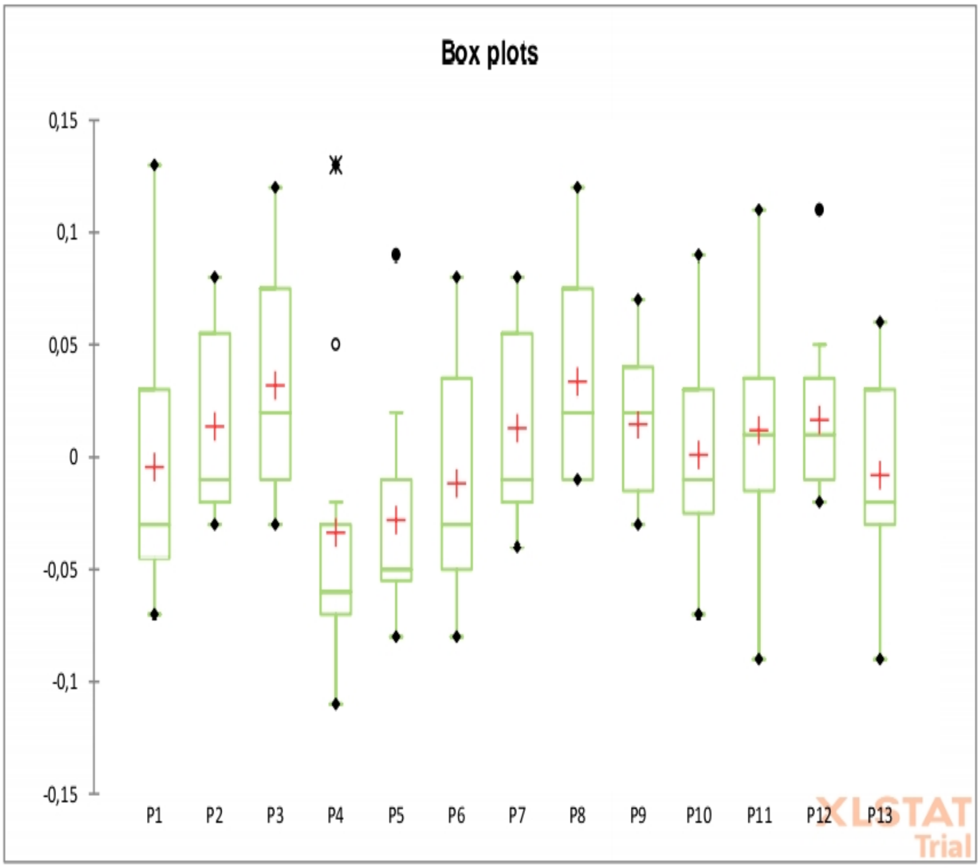


Figure 53. Box plots of NDMI values of Djebel Messaad forest stands.

We have found that NDMI values varies from year to year due to the growth process of vegetation. In this research, we investigated how vegetation types and amounts explain the average NDVI and NDMI and how changes in mean of those two indices represent various vegetation types at different distances. The spatiotemporal analyses show the dynamics of changes in NDMI indicators.

The graphs display how the indicators change over the years and how the growth processes in plants are activated. We notice that the values of NDMI are more significant in Boutaleb forest stands than Djebel Messaad forest stands (Fig. 54 and 55).

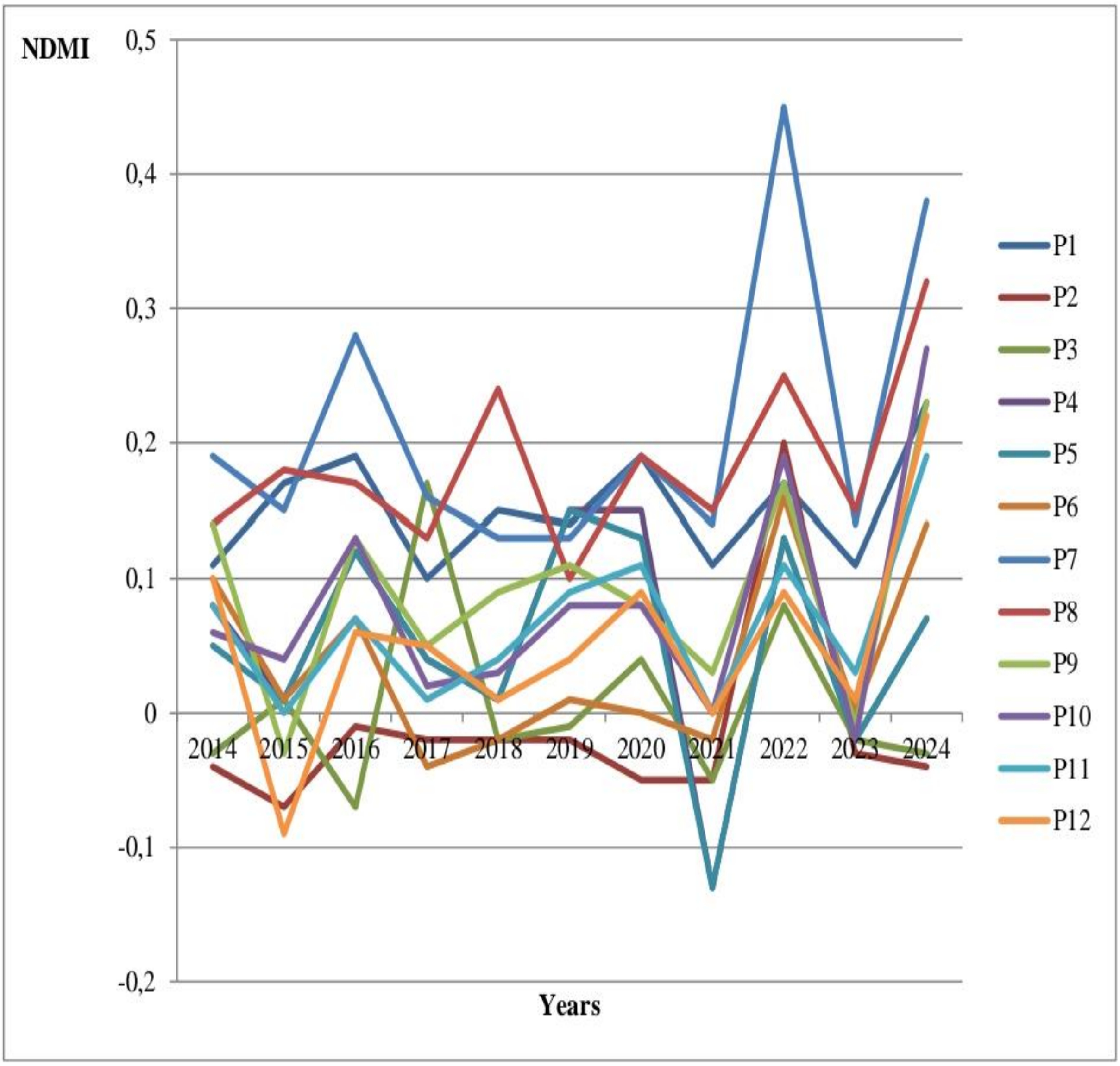


Figure 54. NDMI behavior of the same plots for various vegetation categories of Boutaleb forest.

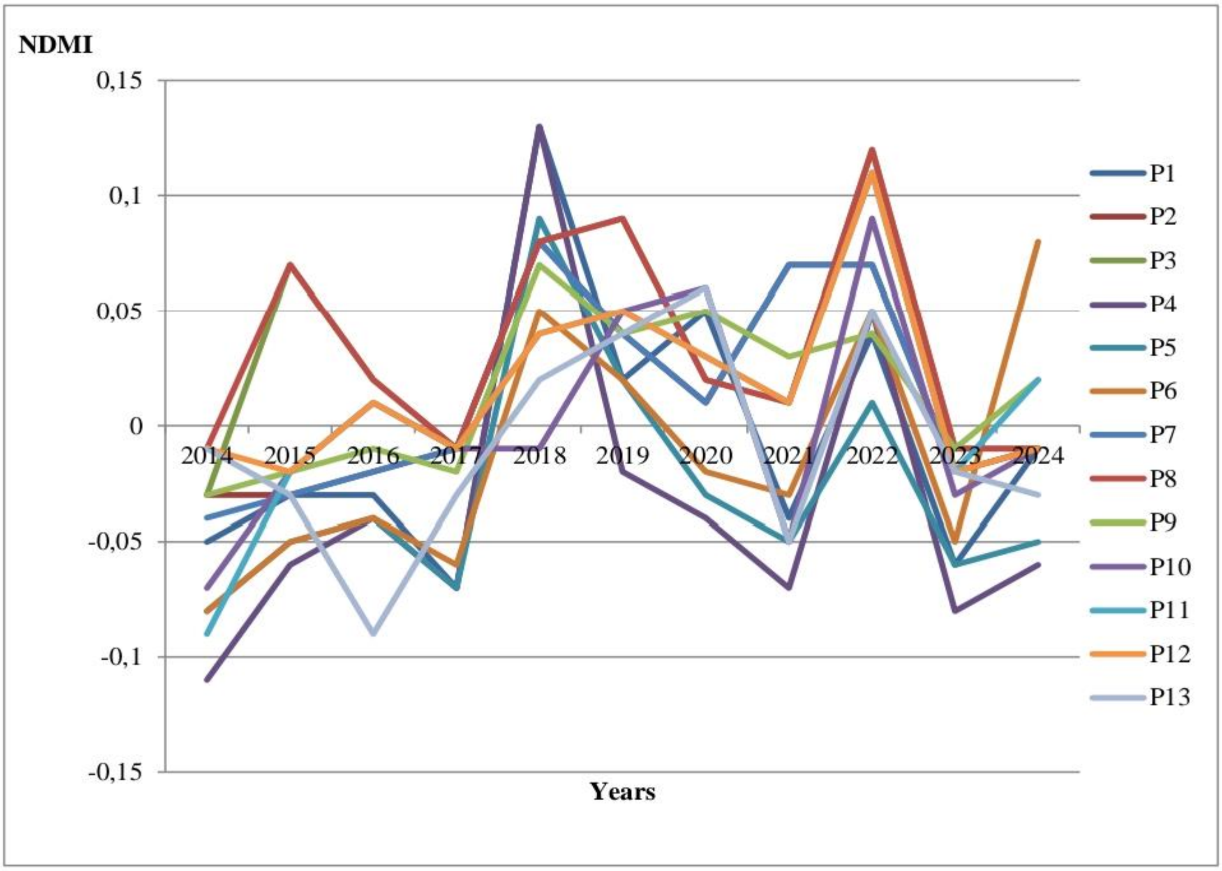


Figure 55. NDMI behavior of the same plots for various vegetation categories of Djebel Messaad.

Over 11 years, the study of vegetation phenology involves examining the recurring cycles of vegetation and how they are influenced by climate. This area of research has gained attention from the scientific community due to its importance in understanding global change. By accurately tracking phenological phases, researchers can estimate the carbon and water cycles spatiotemporal dynamics. While many ground-based phenological studies have been conducted (Ahas *et al.*, 2002; Schwartz *et al*., 2006), challenges in consolidating data across plant species and events have limited their usefulness for detecting vegetation changes. However, with the raising availability of satellite information, land surface phenology has identified by NASA as a valuable tool for monitoring vegetation (Friedl *et al.,* 2006).

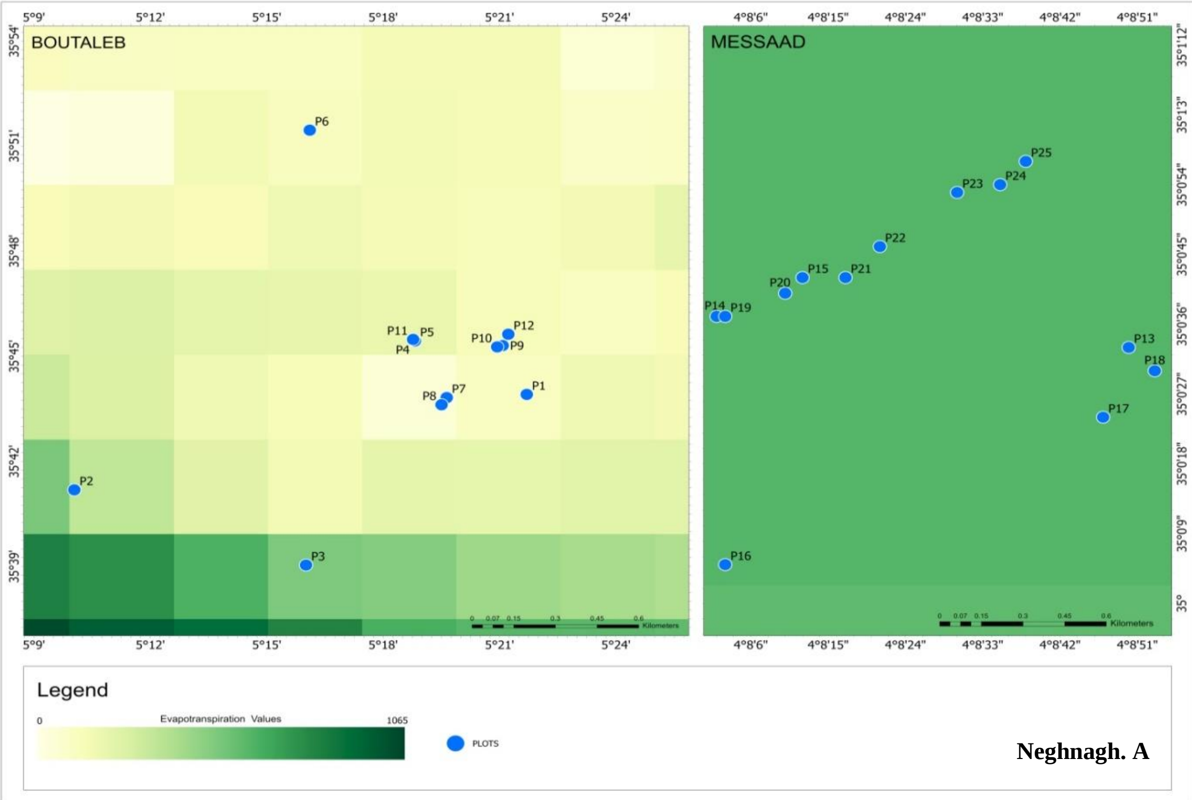
NDMI is used to indicate water stress level in plants (Gao, 1996). It helps to survey drought stress and the amount of vegetation moisture (Nasiłowska and Kubiak, 2016). The NDMI indicators are strongly correlated with dry matter in leaves (Wang, 2011).

5.4 EvapoTranspiration

EvapoTranspiration (ET) is a term used to describe the depletion in water from the earth's surface to the atmosphere by the combined process of both evaporation from the open water bodies, bare soil and plant surfaces, etc… and transpiration from vegetation or any other moisture living surface. The presence of water within a system or across a boundary, as well as the energy required changing liquid water into vapor, and a means of moving water from the earth's surface to the air, are essential conditions for evapotranspiration to occur. Other factors influencing ET rates mainly include solar radiation, wind speed, vapor pressure deficit and air temperature, etc... (Bi, 2010).

In total, Evapotranspiration map show a different values between the years and species formation, where we have obtain a very high values in Djebel Messaad (Fig. 56).

ET rates for vegetated surfaces are closely related to plants assimilation rates and can serve as an indicator of plant water stress (Jackson *et al.*, 1981). Hence, precise regional ET estimates are in land surface water and energy budget modeling across various temporal and spatial scales.



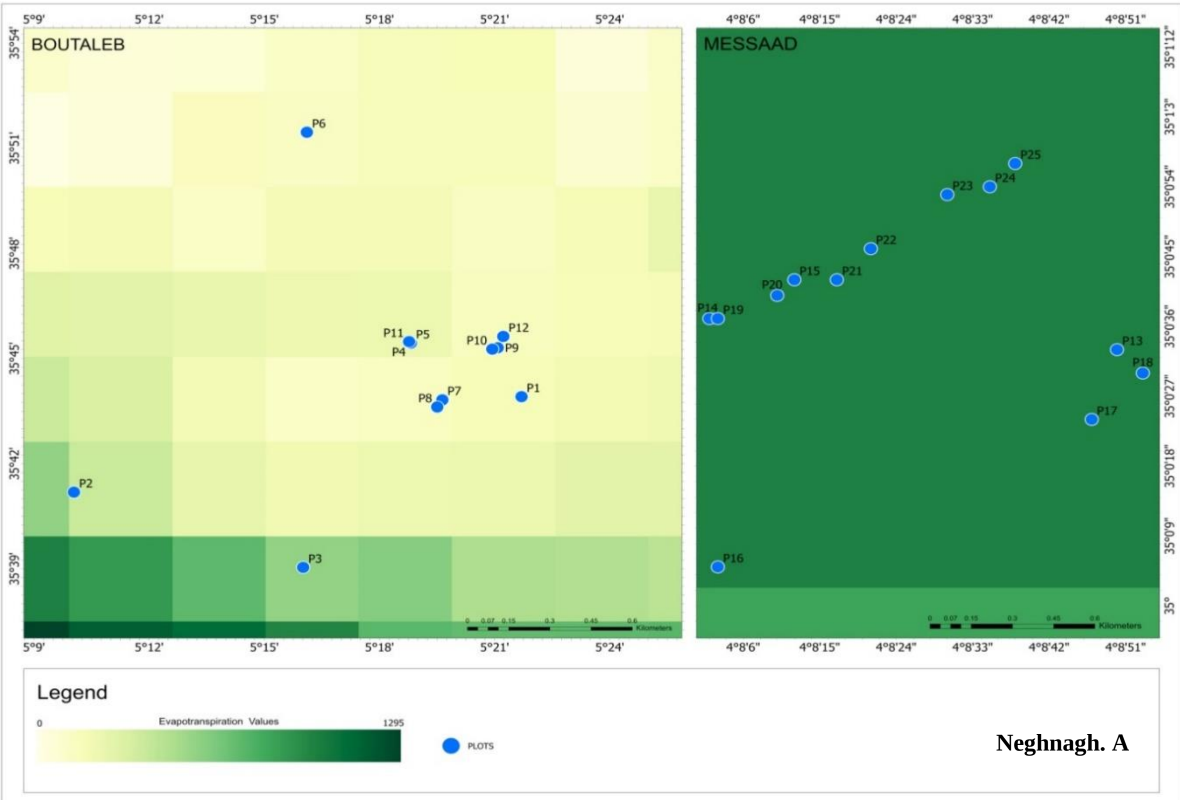


Figure 56. EvapoTranspiration maps of Boutaleb and Djebel Messaad forests for the period 2014-2023 processing with ArcGis software.

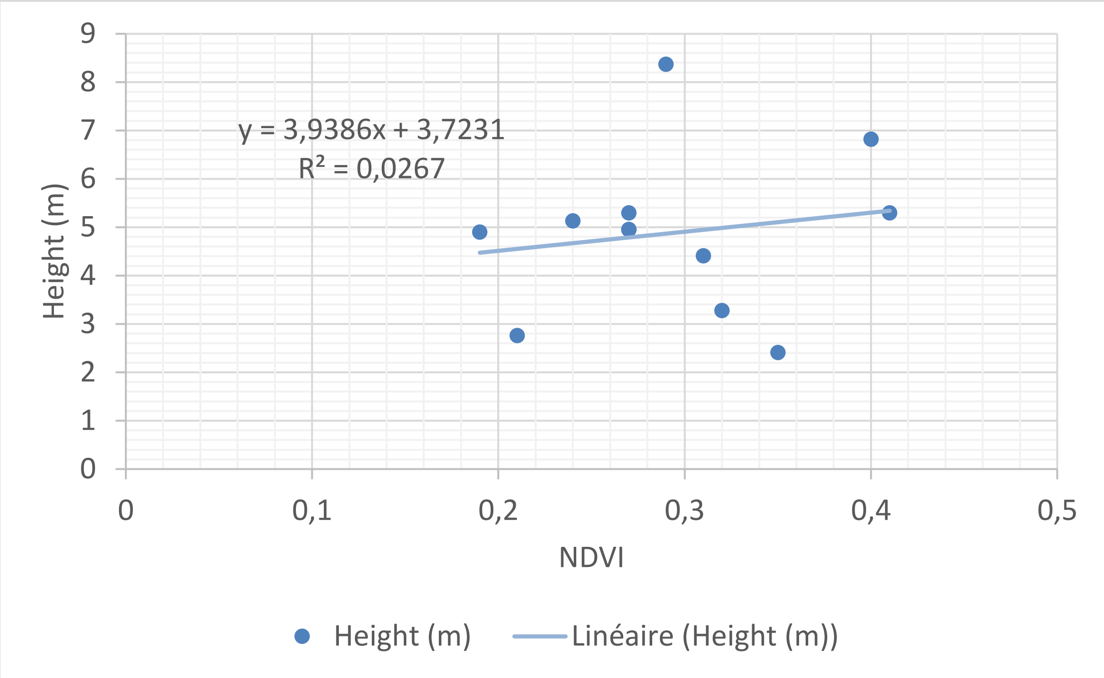
Descriptive statistical analysis of evapotranspiration values shows that it varies from one formation to another, with maximum values in the Djebel Messaad stations (Tab. 24). It appears that the floristic diversity in Boutaleb forest and the presence of a mixed floristic community between deciduous and coniferous trees result in lower values compared to those of Djebel Messaad. Additionally, the geographical location plays a very important role in this variable. Comparing the values of the year 2014 and those of the year 2023 shows that there is a tendency towards an increase due to the climatic variations experienced in this region during the last decade.

Table 24. Descriptive statistical analysis of evapotranspiration.

Statistic	2014	2024
Nb. Of observations	25	25
Minimum	0,000	0,000
Maximum	100,000	100,000
1 st Quartile	24,183	3,846
Median	100,000	100,000
3third Quartile	100,000	100,000
Sum	1580,392	1420,192
Mean	63,216	56,808
Variance (n)	1703,944	2121,573
Variance (n-1)	1774,941	2209,972
Ecart-type (n)	41,279	46,061
Ecart-type (n-1)	42,130	47,010

6. Relationship Between Spectral Data and Dendrometric Variables

Correlations was made to examine the relationships between forest stand attributes such as average height and diameter, and the reflectance values obtained from Landsat 8 spectral bands, as well as vegetation indices like NDVI and NDMI. Additionally, the study aimed to investigate how the age of the vegetation stand affects these correlations. The findings indicated that vegetation indices and NDMI exhibited stronger correlations with basal diameter compared to other variables (Fig. 57, 58, 59, 60).



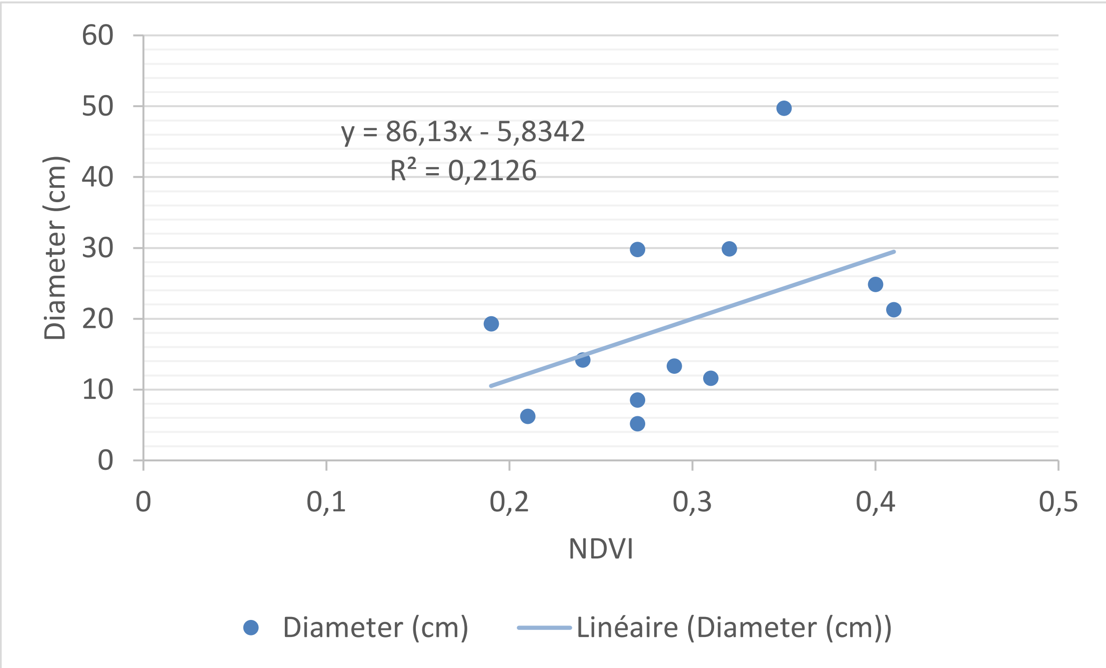


Figure 57. Correlation coefficient according to linear regression between the NDVI values and dendrometric parameters in Boutaleb forest.

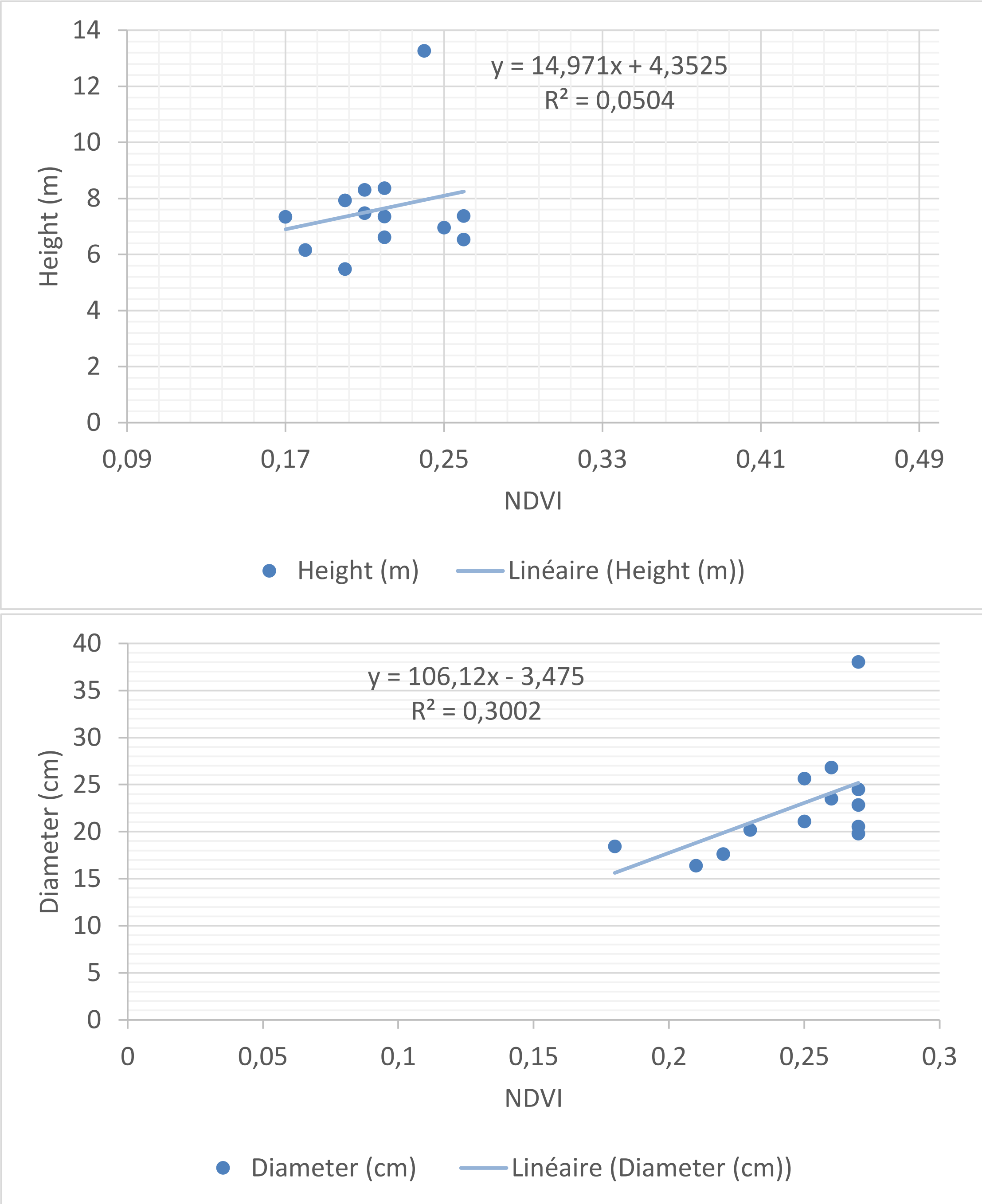


Figure 58. Correlation coefficient according to linear regression between the NDVI values and dendrometric parameters in Djebel Messaad forest.

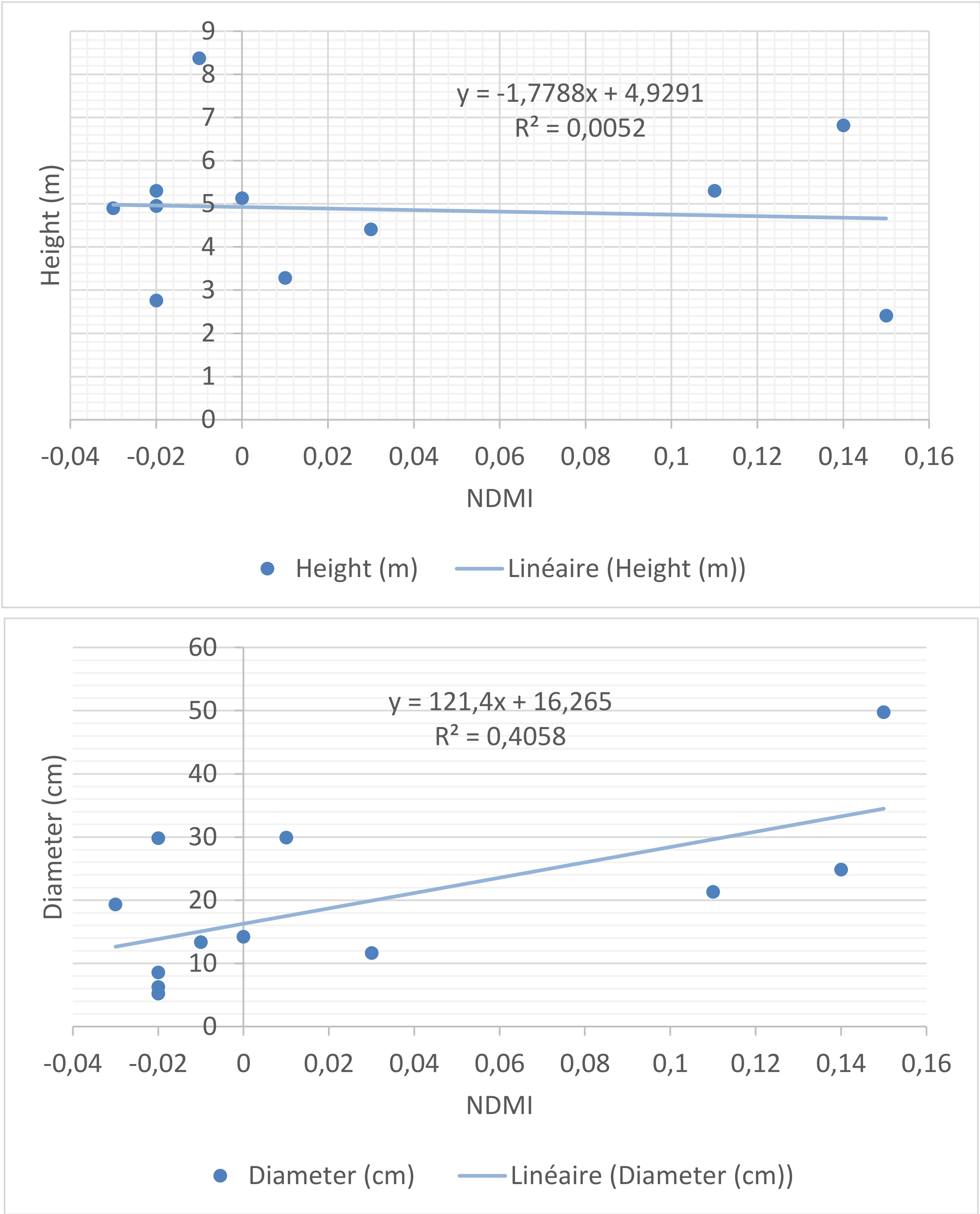


Figure 59. Correlation coefficient according to linear regression between the NDMI values and dendrometric parameters in Boutaleb forest.

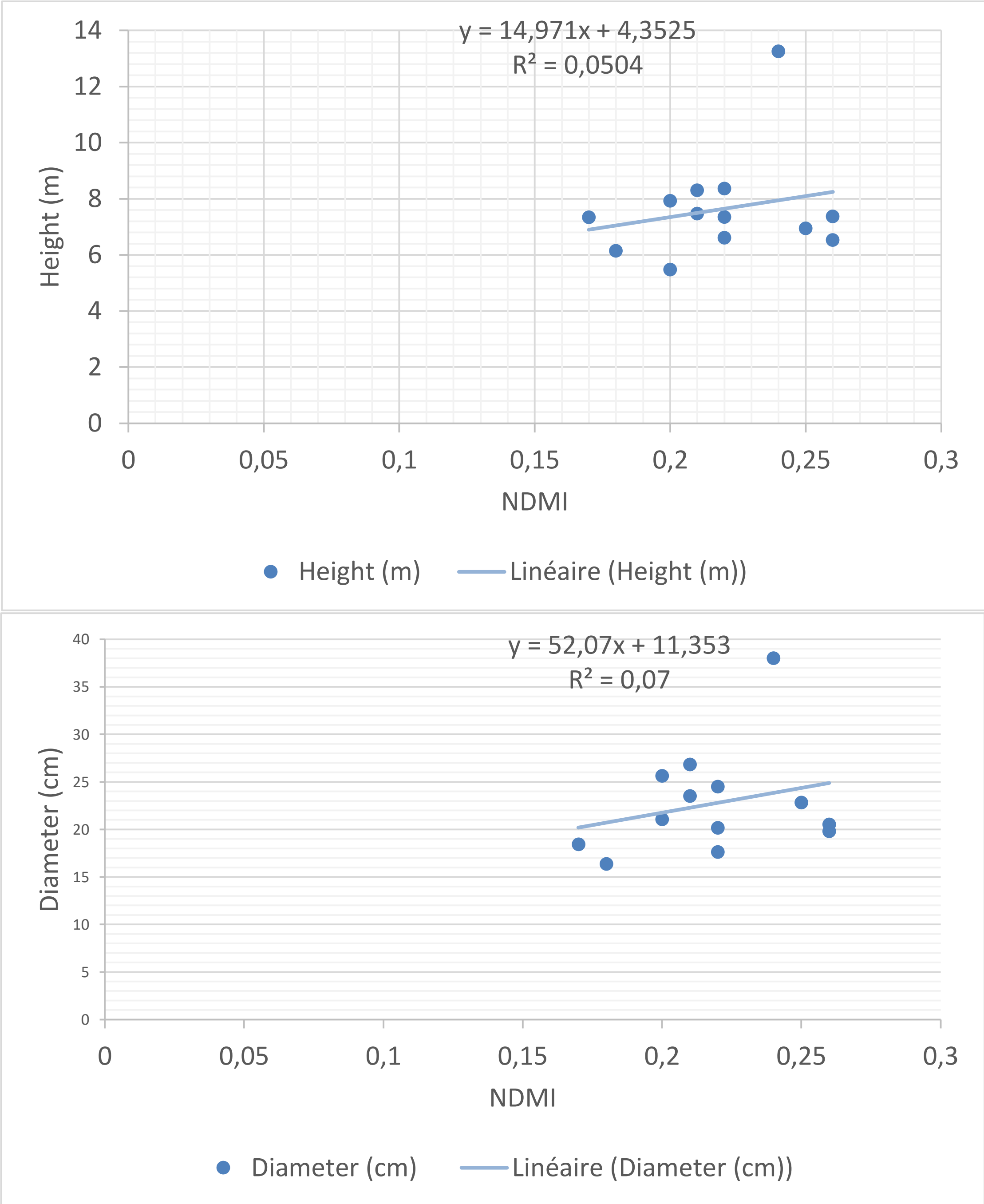


Figure 60. Correlation coefficient according to linear regression between the NDMI values and dendrometric parameters in Djebel Messaad forest.

Several studies have shown that geotechnologies have the potential to enhance traditional forest inventory methods by providing valuable information on forest growth. This is mainly accomplished by utilizing data gathered by sensors installed on artificial satellites (Halme & Tomppo, 2001; Mäkelä & Pekkarinen, 2004; Hall *et al.*, 2006; Tomppo *et al.*, 2009; Viana et *al.*, 2012). The consistent and systematic observation of forest growth using remotely sensed images allows for a more detailed understanding of variations in growth and yield across the forest plantation area. This data can be collected from every pixel across different sections of the electromagnetic spectrum (Ponzonietal, 2015).

To link dendrometric parameters with spectral information in order to create prediction models, Berra *et al.* (2012) and Pacheco *et al.* (2012) utilized correlation analysis. Their findings suggest that remote sensing data show promise in accurately predicting forest dendrometric variables.

Our research found a positive correlation between NDVI and NDMI indices and tree diameter. Vegetation indices that use infrared spectral bands are more resistant to atmospheric dispersion (Jensen, 2009), which may explain why these indices show stronger correlations with tree measurements compared to indices using visible bands.

The limited correlation between dendrometric characteristics and spectral data in Djebel Messaad forest may be due to the minimal impact of this band to vegetation analysis, as the reflectance values of NDVI and NDMI show little variation with increasing vegetation cover (Meng *et al.,* 2009).

Conclusion

Hodna Mountains are a mountain range in Algeria located in the center-east of the country. They mark the transition from the Tellian domain to the north and the Sahara to the south. The climate is Mediterranean attenuated by the Saharan influence. This climatic diversity leads to the confrontation of two main types of plant communities; a steppic community in the plains and slopes of the mountains up to depressions and a forest and preforest community at high altitudes.

In Northeast of Algeria, in the wilayas of Sétif and M'sila, the two forest massifs of Boutaleb forest and Djebel Messaad forest represent a mountainous ecosystem. They afford a remarkable diversity of flora, with several plant formations, including Aleppo pine, Atlas cedar, Juniper, Holm oak and mixed formations of these species.

This research leads to study and analyze the dynamics and biophysical characteristics of forest and preforest formations. The study was based on several databases, including:

A study of the sanitary state of the forest stands using ICP protocol including the observation conditions of visibility (observation of crown), social status (the dimensions and position of a tree in relation to neighboring trees) and the health status of leaves.

A dendrometric study consists of the measurement of total height, circumferences and crown diameter of 387 individuals in Boutaleb forest and 157 individuals in Messaad forest.

Remote sensing, which enabled a spatially and temporally well-adapted approach, and cartographic data.

The health check of the 25 plots in the study area shows that there is a high proportion of two species (Aleppo pine and Holm oak). The analysis of the visibility of trees of the two forests show that whole crown is visible which means that there is a weak competition between trees. Information on social status is useful as an aid to interpreting crown condition and increment data for the individual trees. Most trees are dominant, they are supposed to be more sensitive to stress. Other important damage characteristic is foliar discoloration, in most cases, a yellowing of leaves. In our case, the majority of trees of Boutaleb and Messaad forests present a normal coloration.

The results obtained through dendrometric measurements indicates that the density of the feet of trees in a planted forest is more important compared to the natural state. The mean stand density was 357 individuals per hectare in Boutaleb forest, while it was 134 individuals per hectare in Messaad forest.

Height and diameter at breast height indicate that the growth is more remarckable and strongly correlated with the quality of the station. The average diameter varies between 6.21 cm and 49.74 cm for the different sampled plots of Boutaleb forest whereas the mean diameter for Messaad forest stands varies between 15.71 cm and 39.95 cm. The average height varies between 2.41 m and 8.37 m for the different sampled plots of Boutaleb forest and the average height of Messaad forest plots ranges from 5.47 m to 8.3 m.

Species demographic structure was examined according to the diameters and heights of all observed trees using Weibull distribution. The structure is therefore regressive for Boutaleb forest, characteristic of natural stands with high regeneration potential, small diameter and high heights individuals. The structure in Messaad forest stands is characterized with populations of strong capacity for regeneration but with a problem of survival during the transition between stages of development and a predominance of older and high heights individuals.

Remote sensing technics are used for the survey of vegetation based on vegetation indices such as NDVI, NDMI and the colored composition. The results obtained from the Landsat 8 images show that, over the years, the diachronic study of vegetation productivity (NDVI) and vegetation humidity (NDMI) varies from one type of plant formation to another. The mean of NDVI values varies between 0.19 and 0.38 for the different sampled plots of Boutaleb forest while Messaad forest stands show a range of NDVI values varies between 0.19 and 0.26. NDMI of Boutaleb forest stands show that the average values varies between -0.01 and 0.21, while the mean NDMI values of Messaad forest plots varies between -0.03 and 0.03.

Descriptive statistical analyses of evapotranspiration shows a difference in values between years and species formations with maximum values in Djebel Messaad stations. The presence of mixed floristic diversity in Boutaleb forest result in lower values compared to Djebel Messaad forest, which is monospecific. A plant’s transpiration rate is controlled by the surrounding environment, which is largely determined by the local climate.

Spatio-temporal linkage between dendrometric parameters and remote sensing technics provide different approaches that allow evaluating the productivity of ecosystems. In this study we reported a positive relationship between NDVI, NDMI indices and tree diameter.

In terms of future outlook for this work, there are a number of aspects which, for one reason or another, have not been addressed. Research focusing on the mechanisms of forest therapy needs to be prioritized. Collaborations between different disciplines need to be strengthened to quantitatively study the health benefits of specific forest environmental factors. The government can train forest guides who are familiar with the forest environment so they can guide the public to deeply integrate themselves into the forest and maximize the health benefits of nature.

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