Phenology characteristics and demographic structure of Aleppo pine in the Algerian mediterranean forest: The case study of El-Harhouria afforestation

AMINA BELDJAZIA[1], KHALED MISSAOUI[2], RAHUL GAWAI[3], AKRAM KOUT[4,5], MALIKA RACHED KANOUNI[6], AMEL NEGHNAGH[7], IBTISSEM SAMAI[8]

[1] University of Ferhat Abbas Setif 1, Faculty of Nature and Life Sciences, Departmnent of Plant Biology and Ecology, Setif, Algeria; e-mail: beldjaziaamina@yahoo.fr
[2] University of Ferhat Abbas Setif 1, Faculty Architecture and Earth Sciences, Laboratory Urban Project, City and Territory, Setif, Algeria; e-mail: missaouikhaled90@yahoo.com
[3] American University of Sharjah, Department of Civil Engineering, GIS and Mapping Lab, (GISML), Sharjah, United Arab Emirates; e-mail: rahul.unipunegis@gmail.com
[4] University of Ferhat Abbas Setif 1, Faculty of Nature and Life Sciences, Departmnent of based study, Setif, Algeria; e-mail: akram-kout@univ-setif.dz
[5] University of Constantine, Laboratory of Modelling and Implementation of Complex System, Constantine, Algeria.
[6] University of Larbi Ben M'hidi, Faculty of Exact Sciences and Life and Nature Sciences, Department of Life and Nature Sciences, Oum El Bouaghi, Algeria; e-mail: kmalikbio@yahoo.fr
[7] University Mohamed Boudiaf M'sila, Faculty of Sciences, Departement of Natural and life Sciences, Laboratory of Biodiversity and Biotechnological techniques for the valuation of plant resources, Algeria; e-mail: amelneghnagh3@gmail.com
[8] Badji Mokhtar University, Faculty of Sciences, Department of Biology, Laboratory Researches of Soil and Sustainable Development, Annaba, Algeria; e-mail: ibtissemecologie@yahoo.fr

ABSTRACT The structural characteristics of tree populations and their spatial distribution is an essential indicator of forest health. A subjective sampling of the Aleppo pine (*Pinus halepensis* Mill) of El-Harhouria afforestation in Algeria made it possible to establish the characteristics of this plant formation. In this case, five plots of 900 m² were subjected to the following dendrometric measurements: circumference, total elevation, slenderness coefficient, and density of trees. The diachronic measurement of the total photosynthesis (Normalized Difference Vegetation Index) was estimated with remote sensing methods based on Landsat images from 1986 to 2021. Data analysis showed that the average density of ligneous trees is 1,207 individuals per hectare including an average basal area of 41.95 m²/ha. The diameter and height structures of the wooded stands show a predominance of old individuals. In addition, NDVI values are correlated with the age of the trees, while low values were recorded in old trees.

KEY WORDS circumference – dendrometry – ligneous trees – *Pinus halepensis* – Normalized Difference Vegetation Index

BELDJAZIA, A., MISSAOUI, K., GAWAI, R., KOUT, A., KANOUNI, M.R., NEGHNAGH, A., SAMAI, I. (2024): Phenology characteristics and demographic structure of Aleppo pine in the Algerian mediterranean forest: The case study of El-Harhouria afforestation. Geografie, 129, 1, 43–59.
https://doi.org/10.37040/geografie.2024.004
Received February 2023, accepted February 2024

1. Introduction

Plants play a crucial role in maintaining the global climate by regulating the water and carbon cycles, as well as influencing the earth's albedo, which determines the level of surface reflectance and heat absorption. Additionally, they contribute significantly to feedback cycles (Kempes et al. 2011).

In this case it is very important to protect and utilize the natural resources in arational way not only as means of regulating, but as a source of wood to ensure this resource for wood raw material (Dau, Mati, Dawaki 2015).

Several variables such as characteristics of species, growth patterns, dimensions of the tree, location and type of environment, contribute to determine the level of service trees within ecosystems (Jose 2009; Rötzer et al. 2019). In an alarming situation of climate change and a decrease of biodiversity, it is necessary to maintain the ecosystem services provided by the forest ecosystem. Forest measurement are designed to survey the expansion, abundance, composition, and state of forest resources (Kangas, Gove, Scott 2006). In addition, remote sensing may be considered as an important approach for measuring tree health (Degerickx et al. 2018; Meng et al. 2018). According to the spectral vegetation index (SVI), biophysical parameters of vegetation can be estimated through multiple spectral bands to a single band (Myneni et al. 1995). Many different types of spectral vegetation index exist that combine the surface reflectance at two or more wavelengths in order to characterize property of the vegetation, the most common index is the Normalized Difference vegetation index (NDVI) (Sims, Gamon 2002).

Among the species of forest composition, it was found a large number of trees and shrubs in Algeria presented by 70 trees taxa of the Algerian spontaneous flora (Quezel 1976) distributed in several types of plant formation. As part of increasing the forest area, several afforestation programs have been carried out in Algeria since the 1970s, including the afforestation of El-Harhouria. The richness floristic of the El-Harhouria afforestation consists of the Aleppo pine as the main species. Sustainable use of these important ecosystem services requires sustainable forest planning and management. Learning structural and ecological characteristics of forests is indispensable for this purpose. The density, the structure in diameter, height and the spatial distribution of a population are very important parameters for characterizing the demographic population (Herrero-Jáuregui et al. 2012, Rached-Kanouni et al. 2020). Tree height constitutes a better indicator of forest productivity and growth demographics compared to circumference (Kempes et al. 2011, Rupšys 2016).

The Aleppo pine (*Pinus halepensis Mill.*) is recognized as a crucial element of the Mediterranean forest, playing a significant role in the majority of countries surrounding the Mediterranean Sea, especially in Algeria (Boudy 1950, Nahal

1962). This species is highly favored for its fast growth, resilience to dry conditions, and capacity to rehabilitate degraded areas and colonize barren land (Zavala, Zea 2004).

In Algeria, the Aleppo pine covers 35% of the wooded area in the northern region, totaling approximately 850,000 hectares. These forests hold significant ecological importance, as highlighted by Bentouati, Bariteau (2006) and Guit et al. (2015), and are also economically valuable. Forest productivity has traditionally been assessed using forest inventory data such as age and diameter. The primary aim of this research is to analyze and characterize the structure and dynamics of Aleppo pine populations within the El-Harhouria afforestation area (Setif, North East of Algeria) using dendrometric parameters and remote sensing techniques. Additionally, the adjustment of NDVI is crucial for gaining insights into changes in wood volume and evaluating forest responses to climate change in terms of both the scale and direction of ecosystem distribution changes.

2. Material and methods

2.1. Study area

The Setifois occupies a territory which extends from the chain of Babors, in the north, to the Hodna Mountains in the south, about 135 km away. Between these two mountainous entities the High Tellian Plains are found, dotted with more or less isolated mountains and depressions occupied by sabkhas. The southern foothills of the Babors chain at 2004 m above sea level are occupied by a series of more or less isolated massifs located in the eastward extension of the Bibans chain (Missaoui et al. 2020). The reforestation of El-Harhouria is in the commune of el-Ouricia, Daïra Ain Arnet which is located 7 kilometers west of the city of Setif. It is geographically located between 05°23' 05°24' East longitude and between 36°15' and 36°16' North latitude (Fig. 1). It occupies a total area of 22 ha 41 ar 25 ca with an average density of 2,000 subjects/ha. The altitude of this region varies between 900 and 1,200 m.

2.2. Climate of the study area

In Algeria, extensive research has been conducted on the growth of the Aleppo pine species, revealing a significant mortality rate. This alarming trend can be attributed to the fluctuating patterns of precipitation. Moreover, in northeastern Algeria, the expansion of vegetation is closely intertwined with climate changes. Through the implementation of various research methods, scientists have been

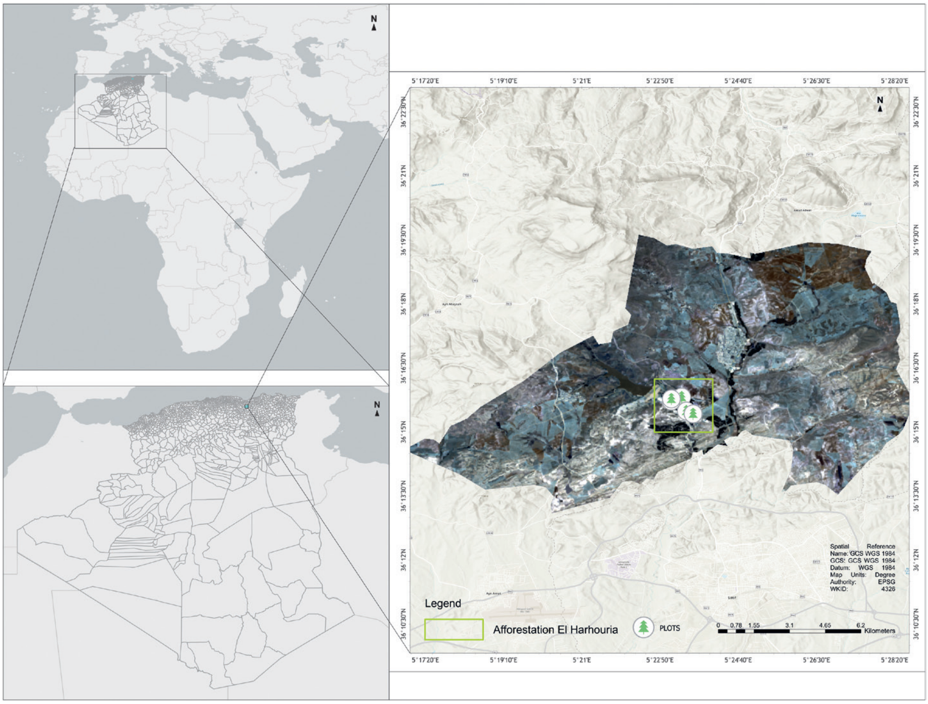


Fig. 1 – Location map of study area

able to identify several climatic, biological, and ecological phenomena and their subsequent impact on living organisms. It is evident that aridification is a looming concern in the forthcoming decades. Certain regions, currently experiencing a semi-arid climate, are projected to transition into an arid climate due to rising temperatures and a noticeable decline in precipitation. (Djellouli et al. 2020).

Examination of precipitation data collected from 1982 to 2020 at Setif station reveals that significant rainfall is recorded in May, averaging at 394.57 mm. The peak temperature is typically experienced in July, averaging at 26.55 °C. Conversely, the lowest temperatures are usually observed in February, with a monthly average of 1.2 °C.

2.3. Study plots

We have selected five plots of Aleppo pine with an area of 900 m^2 for each plot. All individuals are inventoried. The choice of this surface is accorded to the pixel resolution of Landsat 8 satellite image which is 30 m. All trees in plots are inventoried according to these parameters: diameter of the trees measured on bark at

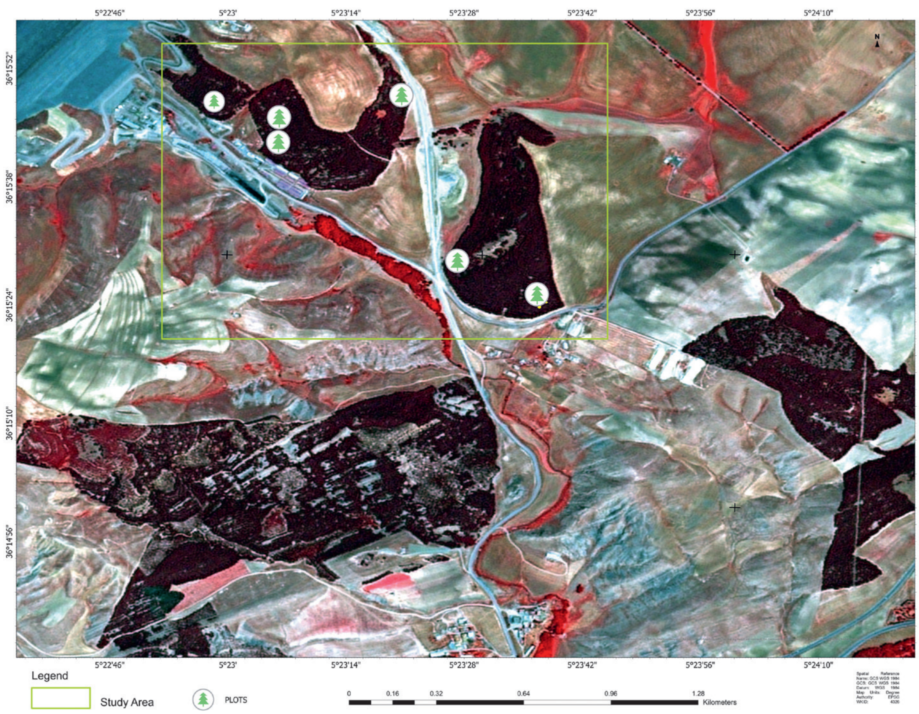


Fig. 2 – Plots location over Spot 5 satellite Image

breast height (1.30 m) from the soil and the total height (Ht). Informations of plot situation (longitude and latitude) were taken using a Global Positioning System (GPS; Fig. 2).

2.4. Imagery data

We have chosen three years of Landsat satellite images acquired in 1986, 2007 and 2021 obtained from the United States Geological Survey (USGS) to study the dynamics of the forest, with the 30 m spatial resolution.

2.5. Data processing and analysis

2.5.1. Dendrometric parameters

The dominance is utilized to evaluate the basal area of a stand, representing the overall surface area of a tree trunk at a height of 1.30 m from the ground. This measurement indicates the amount of forest canopy cover (Kakaï, Sinsin, Palm 2008) as calculated by the following formula:

$N = n/s$

Which n is the number of individuals found in the plot, s is the size of the plot (in hectare).

We use the dominance to assess the basal area of a stand, which is the total surface of a tree trunk at 1.30 m in height from surface area. It reflects the quantity of forest filling (Kakaï, Sinsin, Palm 2008) according to this formula:

$G = \Sigma g_i = \pi / 4\Sigma di^2$ (m^2/ha)

The unit of this parameter is m^2/ha, di is diameter situated at 1.30 m from the soil of each rod (in meter).

2.5.2. Weibull distribution

The demographic structure of the species is analyzed according to the diameters of the trees (defined from a threshold of 5 cm) and the height of the trees; the latter defined from a threshold of 1.30 m, with an amplitude of 2 m. The above mentioned diameter and height classes were used to construct distribution histograms. Observed structures are fitted to the theoretical Weibull distribution with three parameters using the MINITAB 18 software (Rondeux 1999; Goba et al 2019) with this 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, Beers, Kershaw 2003; Kakaï, Bonou Lykke 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 with population including a predominance of old individuals. Moreover, if c is between 1 and 3.6, this means that recent individuals or slight diameter individuals are predominant in this population.

2.5.3. Spectral vegetation index

Spectral vegetation indexes are equations which utilize multispectral data of remote sensing, to quantum chlorophyll and vitality of vegetation (Xue, Su 2017). In order to assess vegetation health, we use the Normalized Difference Vegetation

Index (NDVI) calculated according to the Near-Infrared (NIR) and RED spectral bands of Landsat imagery. It measures the activity of photosynthesis so that vegetation greenness following this formula (Rouse et al. 1973):

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)}$$

The spectral characteristics of field information can vary due to various factors such as environmental reactions, changes in materials, seasonal variations, pollution in the area, and the influence of nearby objects (Bao et al. 2013). To calculate vegetation indices, we utilized Google Earth Engine, a cloud-based platform that offers a vast collection of satellite images. We specifically employed LandSAT 5 and LandSat 8 images, which are atmospherically corrected surface reflectance level 1 images. After exporting the resulting images, we performed spatial statistics using ArcGIS Pro. The study plots' GPS locations were used to extract values using the point extraction tools in ArcGIS Pro, specifically for the years 1986, 2007, and 2021. Finally, cartographic maps were created using ArcGIS Pro, incorporating NDVI raster maps and vector data for plot locations.

3. Results and discussion

Dendrometric approaches are the most useful to illustrate density in forest stands in which simple parameters like tree diameter and height stand utilized as a proxy for more complex morphological and physiological variables (Del Rio et al. 2018).

Our results of the main characteristics of the Aleppo pine stand in each plot, highlights an average diameter among 15.08 and 24.33 cm in the state of high poles with young forest. The measure of tree density with a diameter at breast height greater than 5 cm varies from 822 to 1,500 individuals per hectare. Intraspecific variation allows that the youngest plot is the second where the average diameter is 15.08 cm and we found a lot of young trees (Table 1).

Basal area varies in the same direction as density and mean diameter. The 4 plots (2, 1, 3 and 5), having a mean diameter among 15.08 and 24.33 cm and

Table 1 – Measurements of stand properties

Plot	D (cm)	H (m)	H/D	N/ha	G (m^2/ha)
P1	15.31	9.35	62.34	989	19.62
P2	15.08	9.24	65.63	822	15.60
P3	19.80	11.46	62.81	1,256	41.85
P4	21.04	15.02	85.70	1,500	58.79
P5	24.33	14.56	65.90	1,467	73.90

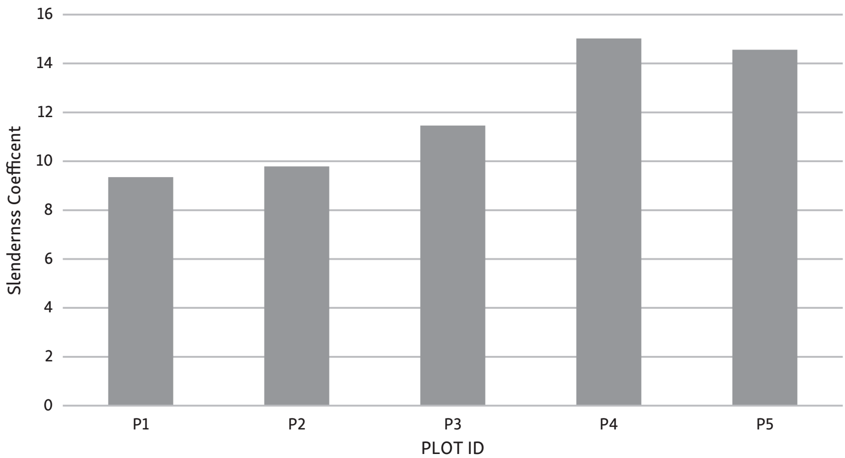


Fig. 3 – Slenderness coefficient per plot

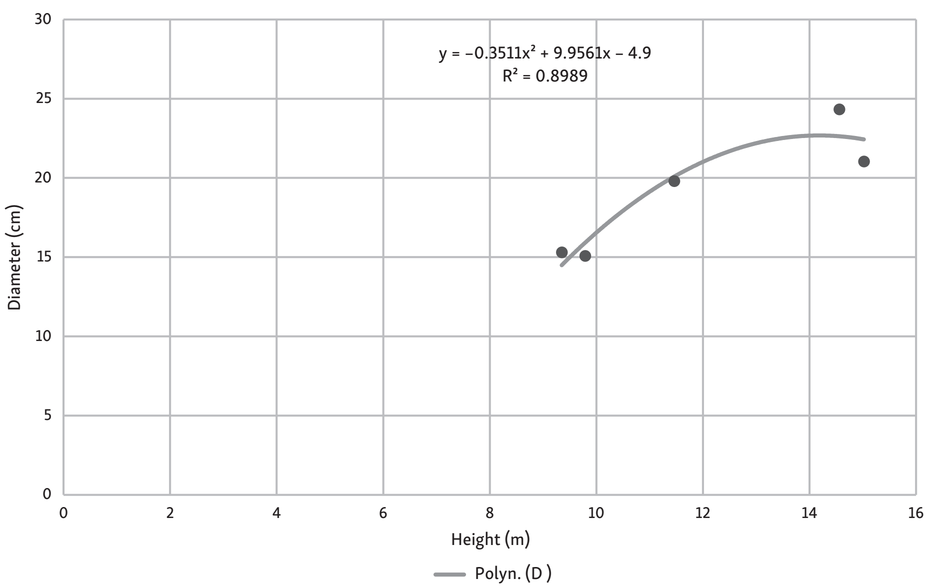


Fig. 4 – Slenderness coefficient of the average diameter

have average slenderness coefficient among 62.34 and 65.90%. Plot 4, which has an average diameter of 21.04 cm (average slenderness coefficient = 85.70%), the ratio H/D is changeable (Fig. 3). This data lets us conclude that the slenderness coefficient is a function of the diameter of the tree and therefore the age of the tree (Kakaï, Bonou Lykke 2016).

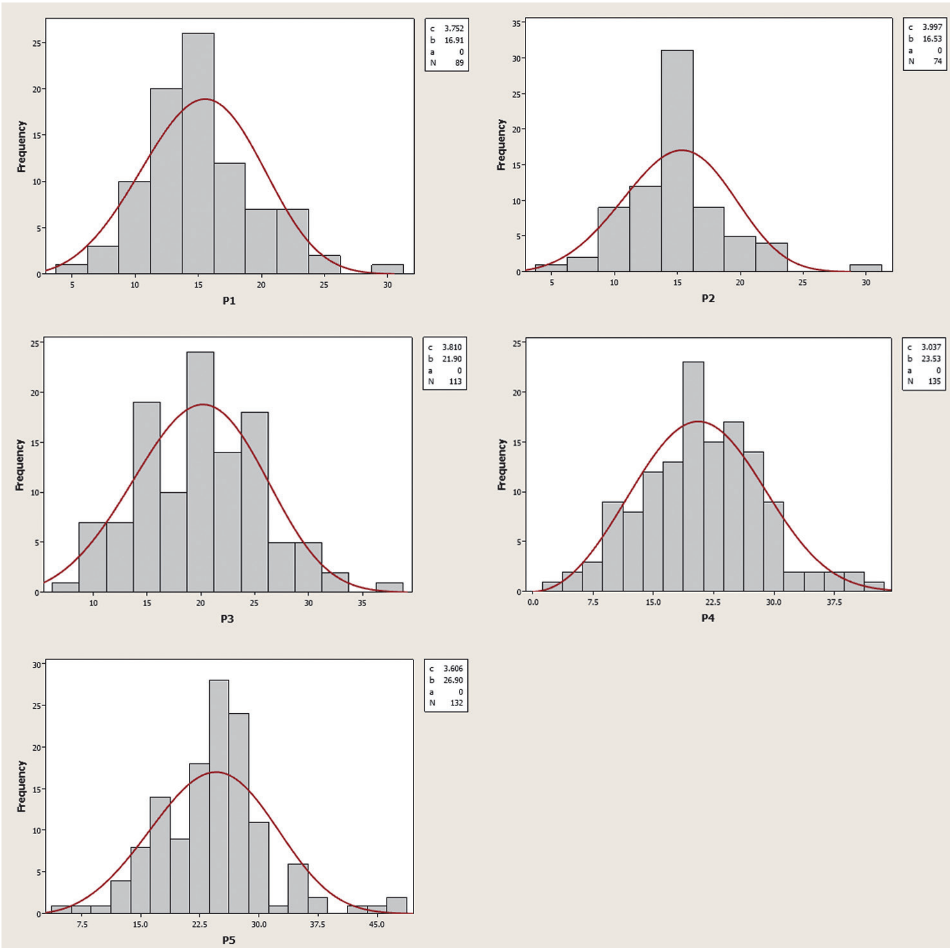


Fig. 5 – Structure of Aleppo pine diameters

According to the slenderness coefficient, which a strong negative trend is a function of the average diameter. The trend curve explains that only 8.34% of our values are not demonstrated in this curve. These 8.34% surely correspond to the level from 15.08 cm to 15.31 cm interval. And therefore average diameter is associated to an average height of the natural regeneration state (Fig. 4).

In fact of forest management, stands require control of the structure in diameter and height of woody species, which are characteristics of the settlements vitality. It is obvious that the demographic structure of stands can be described and analyzed using other distributions such as the Weibull distribution quite commonly cited in specialized forestry literature (Rondeux 2021). This distribution is used to assess the structure of the vegetation. Furthermore, the definition

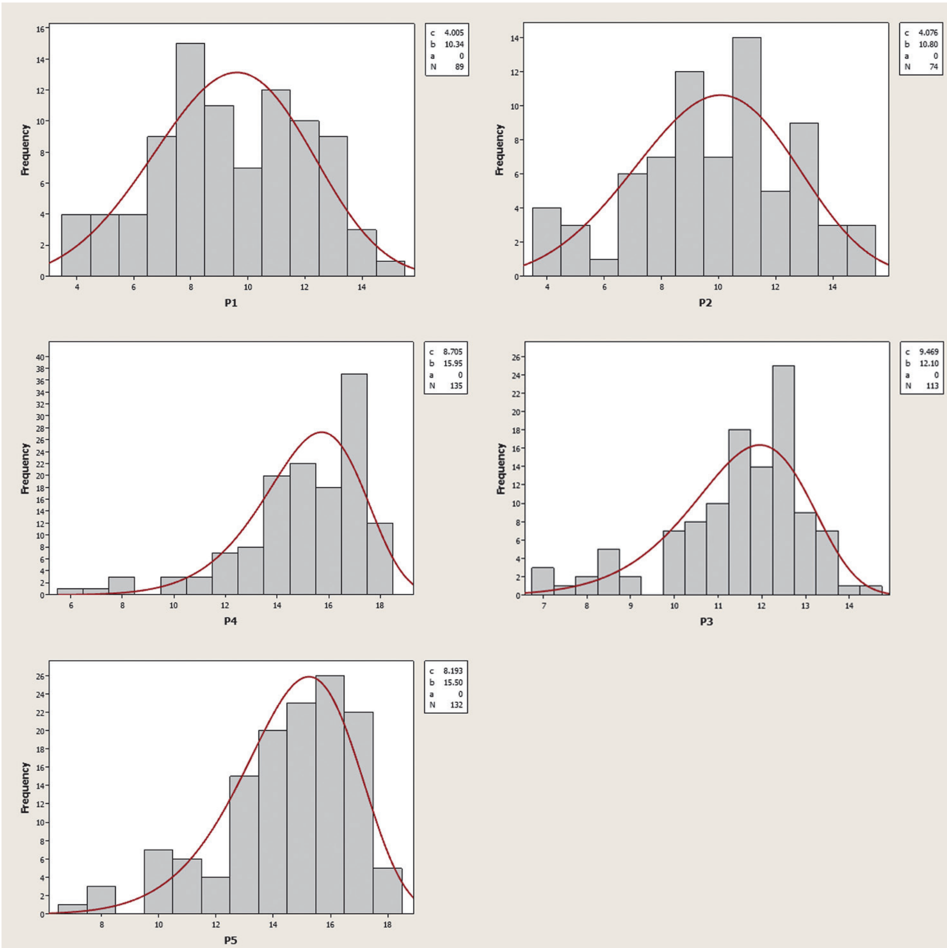


Fig. 6 – Structure of Aleppo pine heights

of management options for a stand first assumes the establishment of these structures in diameter and height (Kakaï, Bonou Lykke 2016). We found a similar distribution of the trees in three plots (P1, P2 and P3) depending on diameter of the Aleppo pine stands in the El-Harhouria afforestation. The values of the shape coefficient c of the Weibull distribution are among 3.752 and 3.997 (Fig. 5). The distribution is left asymmetrical or negative asymmetrical, properties of monospecific stands associated with a dominance of old individuals or wide diameters (c > 3.6). Analysis of the diameter structures of plots 4 and 5 show the appearance of bell-shaped structures, with values of *c* between 1 and 3.6 being obtained. They are characteristic of abundance of young trees or small diameters.

The partition of the individuals inventoried by classes of total height at 2 m amplitude for the different plots is illustrated in Figure 6. The shape parameter *c* is between 4.005 and 9.469 in the El-Harhouria afforestation. It is therefore evident that the height distribution of the Aleppo pine population is left-skewed or negative-skewed. The modal classes are respectively 8 to 14 m for plots 1, 2 and 3 and 12 to 18 m for plots 4 and 5. Individuals taller than 18 m are low revealed in this forest.

The diameter and height structures of the wooded stands show a predominance of old individuals ($c > 3.6$) for the different plots of the study area. The diameter structures, established on the basis of the distribution of individuals into classes of diameter (5–10 cm), are characterized by a large number of adult trees. Furthermore, the demographic structure of trees in height classes highlights the abundance of medium-sized trees (8 to 16 m).

These structures show a negative development of the *Pinus halepensis* populations in this area, where the renewal of the population is risky. Contrary to previous results, those of Hani, Rached-Kanouni, Menasri (2021), where the diameter and height structures of natural stands show an abundance of young trees ($c < 1$; $1 < c < 3.6$) for the different exposures of the Benis Oudjana forest in Algeria. Diameter structures, established on the basis of the distribution of individuals into diameter classes (5–10 cm), are characterized by a large number of small trees and a regular reduction in the number of individuals from one class to the next. The abundance of medium size individuals (2 to 8 m) a positive structures evolution of the stands of *P. halepensis* in this afforestation where the regeneration of the stand is assured because of its extraordinary power of expansion and its low requirements (Quezel 1986, Bentouati 2006, Feeley et al. 2007). Spatial diachnronic analysis of the study area showed that NDVI varied from year to year (Fig. 7). We have observed important values of NDVI in the year of 1986 that varied from 0.01 to 0.55. This corresponds to the beginning years of plantation. In 2007 a significant increase was observed (NDVI varied from 0.18 to 0.76) which revealed a good productivity of the Allepo pine trees. Whereas spatial reflectance curve of the NDVI in 2021 indicate that NDVI values have been considerably reduced, so a decrease of the photosynthesis in these trees.

The temporal dynamics of NDVI enhances data content required for improved management decisions. The NDVI wavelengths decreased relative to the health state of Allepo pine formation.

Our findings provide information that we can use NDVI across the years to see specific plant parameters. A decrease of NDVI values in the year of 2021 is due to the predominance of the old trees that is demonstrated by the diameter and height structures of the wooded stands.

In order to compare NDVI values from plots to another, diachronic study was established (Fig. 8 and 9). Results showed that plot 3 presents a very important values to other plots according to the years.

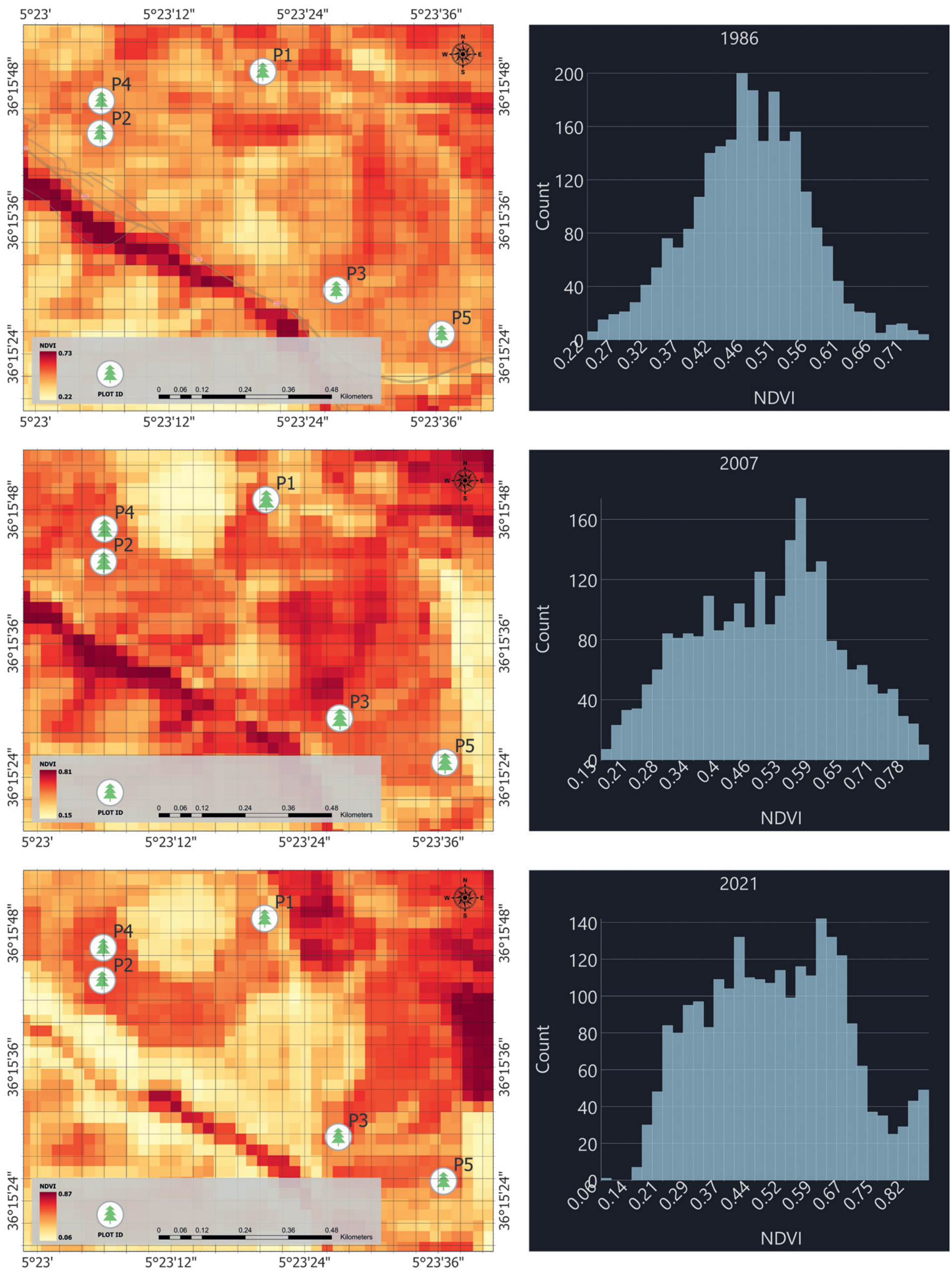


Fig. 7 – Spatial diachnronic analysis of NDVI

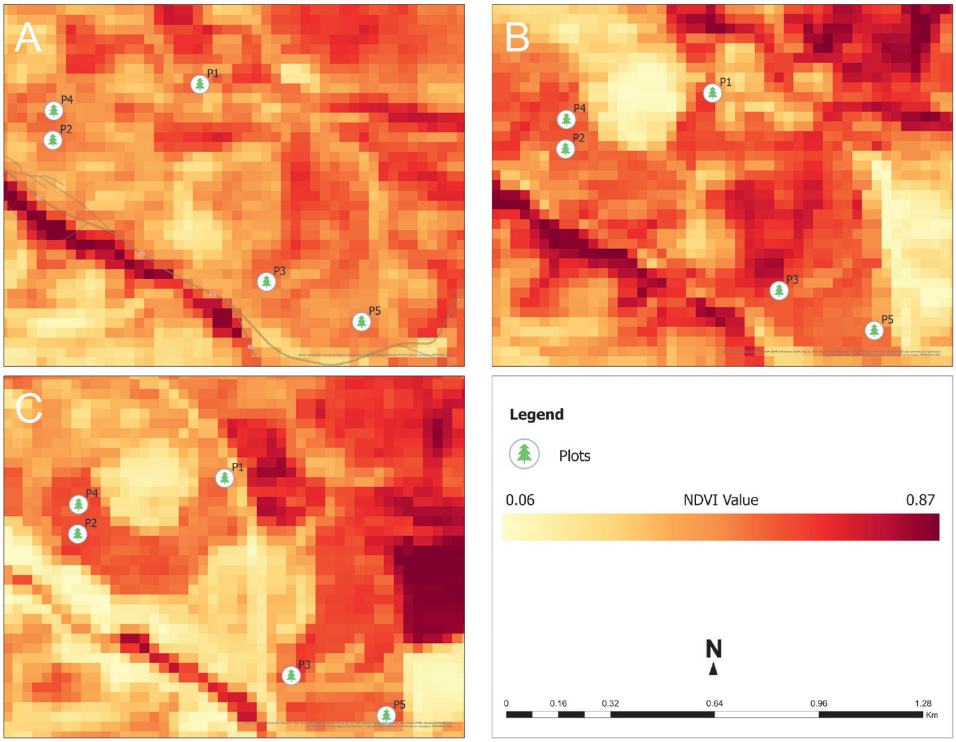


Fig. 8 – The NDVI map for different years. A – 1986, B – 2007, C – 2021.

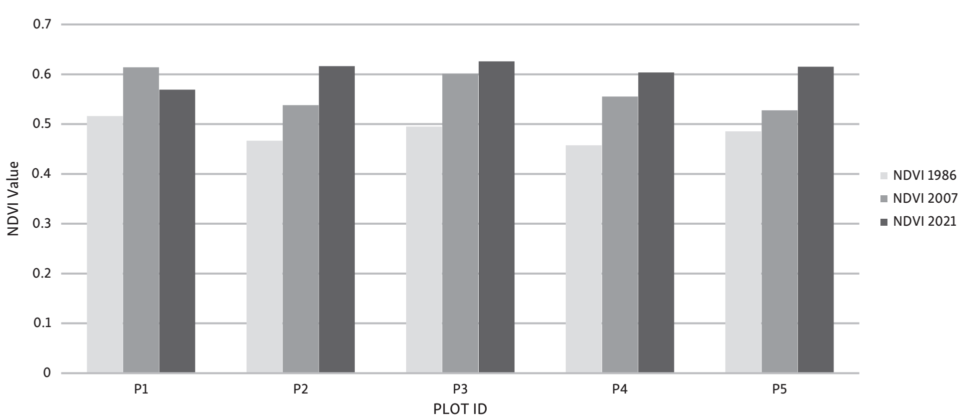
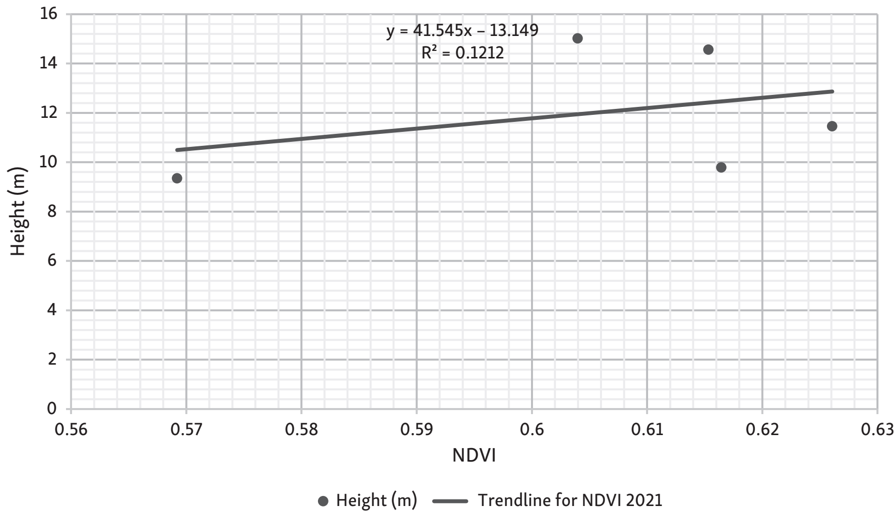


Fig. 9 – Diachrnonic NDVI values at plot level



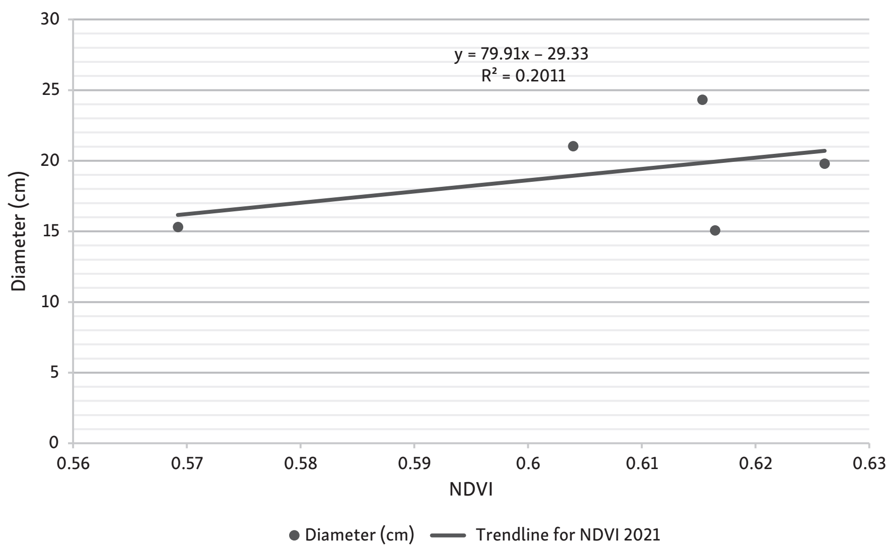


Fig. 10 – Correlation coefficient according to linear regression between the NDVI values and dendrometric parameters

Our results reveal an agreement between values of dendrometric (height and diameter) measured at pixel level (where the trees sampled) and using a spatial values of NDVI for all variables (Fig. 10).

Our analysis shows positive correlation between integrated NDVI and tree production, diameter increase, and so the increase of photosynthetic activity. Also, tree height increase is best related with integrated NDVI of different plots of Aleppo pine. It was found that NDVI can help to better evaluate the condition of the tree growth than other types of indices. This is due to the polyfunctionality of NDVI, which achieves good results in different environments; it also serves as a point of comparison with other indices (Kim et al. 2017; Haghighian, Yousefi, Keesstra 2020).

4. Conclusion

This study revealed the opportunities of Aleppo pine which can provide services to the forestry sector in Algeria. Wooded species are used in reforestation with the aim of producing lumber. The choice of species is to contribute to enhancing the various qualities of wood, and also to diversifying wood production and soils protection of certain arid zones. Demographic and structural characterization of Aleppo pine indicate that the pine forest of the El Harhouria afforestation is good with high density. The combined information from tree dendrometric and remote sensing is statistically significant to reconstruct stand-level sensitivity for high-elevation Aleppo Pine forests during the last century. The demographic structure and spatial diachnronic analysis of the NDVI reflectance wavelenghts indicates that the old individuals are more abundant, and the natural regeneration of this forest is weak. This is associated with less productivity where strengthening strategies and sustainable management of this area must be developed.

References

BAO, Y., HAN, J., HU, F.B., GIOVANNUCCI, E.L., STAMPFER, M.J., WILLETT, W.C., FUCHS, C.S. (2013): Association of Nut Consumption with Total and Cause-Specific Mortality. The new England Journal of Medicine, 369.

BENTOUATI, A., BARITEAU, M. (2006): Réflexion sur le dépérissement du Cèdre de l'Atlas des Aurès (Algérie). Forêt Méditerranéenne, XXVII, 4, 317–322.

BOUDY, P. (1950): Economie forestière Nord-Africaine. Tome 2. Monographie et traitement des essences forestières. Edit. Larose, Paris, France.

DAU, J.H, MATI, A., DAWAKI, S.A. (2015): Role of Forest Inventory in Sustainable Forest Management: A Review. International Journal of Forestry and Horticulture (IJFH), 1, 2, 33–40.

DEGERICKX, J, ROBERTS D.A., MCFADDEN, J.P., HERMY, M., SOMERS, B. (2018): Urban tree health assessment using airborne hyperspectral and LiDAR imagery. International Journal of Applied Earth Observation and Geoinformation, 73, 26–38.

DEL RIO, M., PRETZSCH, H., ALBERDI, I., KAMIL, B., BRAVO, F., BRUNNER, A., CONDES, S., DUCEY, M.J., FONSECA, T., VON LÜPKE, N., PACH, M., PERIC, S., PEROT, T., SOUIDI, Z., SPATHELF, P., STERBA, H., TIJARDOVIC, M., TOME, M., VALLET, P., BRAVO-OVIEDO, A. (2018): Characterization of Mixed Forests. In: Bravo-Oviedo, A., Pretzsch, H., Del Río, M. (eds.): Dynamics, Silviculture and Management of Mixed Forests. Managing Forest Ecosystems, 31, Springer Link.

DJELLOULI, Y., LOUAIL, A., MESSNER, F.R., MISSAOUI, K., GHARZOULI, R. (2020): The natural ecosystems of eastern Algeria facing the risk of climate change. Geo-Eco-Trop., 44, 4, 609–621.

FEELEY, K.J., JOSEPH WRIGHT, S., NUR SUPARDI, M.N., KASSIM, A.R., DAVIES, S.J. (2007): Decelerating growth in tropical forest trees. Ecology Letters, 10, 6, 461–469.

GOBA, A.E., KOFFI, K.G., SIE, R.S., KOUONON, L.C., KOFFI Y.A. (2019): Structure démographique et régénération naturelle des peuplements naturels de Pterocarpus erinaceus Poir. (Fabaceae) des savanes de Côte d'Ivoire. Bois et Forêts des Tropiques, 341, 5–14.

GUIT, B., NEDJIMI, B., GUIBAL, F., CHAKALI, G. (2015): Dendroécologie du Pin d'Alep (*Pinus halepensis* Mill.) en fonction des paramètres stationnels dans le massif forestier de Senalba (Djelfa – Algérie). Revue d'écologie (Terre Vie), 70, 32–3.

HAGHIGHIAN, F.; YOUSEFI, S.; KEESSTRA, S. (2020): Identifying tree health using Sentinel-2 images: A case study on Tortrix viridana L. infected Oak trees in Western Iran. Geocarto International, 37, 1, 304–314.

HANI, I., RACHED-KANOUNI, M., MENASRI, A. (2021): Tree Species Diversity and Spatial Distribution of Aleppo Pine Stands in Northeastern Algeria. South-East European Forestry, 12, 1, 35–41.

HERRERO-JAUREGUI, C., GARCIA-FERNANDEZ, C., SIST, P.L., CASADO, M.A. (2012): Recruitment dynamics of two low-density neotropical multiple-use tree species. Plant Ecology, 212, 9, 1501–1512.

HUSCH, B., BEERS, T.W., KERSHAW JR., J.A. (2003): Forest Mensuration. Hoboken, NJ, USA, John Wiley, 4th edition.

JOSE, S. (2009): Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems, 76,1, 1–10.

KAKAÏ, R., BONOU, W., LYKKE, A.M. (2016): Approche méthodologique de construction et d'interprétation des structures en diamètre des arbres. Annales des Sciences Agronomiques 20, 95–105.

KAKAÏ, G.R.L., SINSIN, B., PALM R. (2008): Étude dendrométrique de Pterocarpus erinaceus Poir. des formations naturelles de la zone soudanienne au Bénin. Agronomie Africaine, 20, 3, 245–255.

KANGAS, A., GOVE, J.H., SCOTT, C.T. (2006): Introduction. In: Kangas, A., Maltamo, M. (eds.): Forest Inventory. Springer, 3–11.

KEMPES, C.P., WEST, G.B., CROWEL, K., GIRVAN, M. (2011): Predicting maximum tree heights and other traits from allometric scaling and resource limitations. Plos One.

KIM, H.W.; KIM, J.H., LI, W., YANG, P., CAO, Y. (2017): Exploring the impact of green space health on runoff reduction using NDVI Urban Forestry & Urban Greening, 28, 81–87.

MENG, R., DENNISON, P.E., ZHAO, F., SHENDRYK, I., RICKERT, A., HANAVAN, R.P. (2018): Mapping canopy defoliation by herbivorous insects at the individual tree level using bitemporal airborne imaging spectroscopy and LiDAR measurements. Remote Sensing of Environment, 215, 170–183.

MISSAOUI, K. GHARZOULI, R. DJELLOULI, Y. MESSNER, F. (2020): Phenological behavior of Atlas cedar (*Cedrus atlantica*) forest to snow and precipitation variability in Boutaleb and Babors Mountains, Algeria. Biodiversitas, 21, 239–245.

MYNENI, R.B., HALL, F.G., SELLERS, P.J., MARSHAK, A.L. (1995): The interpretation of spectral vegetation indexes. IEEE Transactions on Geoscience and Remote Sensing, 33, 2, 481–486.

NAHAL, I. (1962): Le pin d'Alep, Etude taxonomique, phytogéographique, écologique et Sylvicole. Annales de l'Ecole Nationale des Eaux et Forêts, 19, 4, 533–627.

QUEZEL, P. (1976): Les forêts du pourtour méditerranéen. Forêts et maquis méditerranéens: écologie, conservation et aménagement. Note technique MAB, 2, 9–33.
QUEZEL, P. (1986): Les pins du groupe «*halepensis*». Ecologie, végétation, écophysiologie Options Méditerranéennes. Série Etude CIHEAM, 86, 1, 11–24.
RACHED-KANOUNI, M., HANI, I., BOUSBA, R., BELDJAZIA, A., KHAMMAR, H. (2020): Structural variability of Aleppo pine stands in two forests in northeastern Algeria. Biodiversitas, 21, 6, 2848–2853.
RONDEUX, J. (1999): La mesure des peuplements forestiers. Gembloux, Belgique, Les Presses agronomiques, Gembloux.
RONDEUX, J. (2021): La mesure des arbres et des peuplements forestiers. Presses Universitaires de Liège, Presses Agronomiques, Gembloux.
RÖTZER, T., RAHMAN, M.A., MOSER-REISCHL, A., PAULEIT, S., PRETZSCH, H. (2019): Process based simulation of tree growth and ecosystem services of urban trees under present and future climate conditions. Science of the Total Environment, 676, 651–664.
ROUSE, J.W., HAAS, R.H., SCHELL, J.A., DEERING, D.W. (1973): Monitoring vegetation systems in thegreat plains with ERTS. Third Earth Resources Technology Satellite-1 Symposium, 1, 309–330.
RUPSYS, P. (2016): New insights into tree height distribution based on mixed effects univariate diffusion processes. Plos One, 11, 12, 0168507.
SIMS, D.A, GAMON, J.A. (2002): Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages. Remote Sensing of Environment, 81, 2–3, 337–354.
XUE J., SU, B. (2017): Significant remote sensing vegetation indices: A review of developments and applications. Journal of Sensors, 2017, 1353691.
ZAVALA, M., ZEA, E. (2004): Mechanisms maintaining biodiversity in Mediterranean pine-oak forests: insights from a spatial simulation model. Plant Ecology, 171, 197–207.

ORCID

AMINA BELDJAZIA
https://orcid.org/0000-0002-9607-4543

KHALED MISSAOUI
https://orcid.org/0000-0003-2043-364X

RAHUL GAWAI
https://orcid.org/0000-0002-7417-3655

AKRAM KOUT
https://orcid.org/0000-0001-8868-8986

MALIKA RACHED KANOUNI
https://orcid.org/0000-0002-8957-5710

IBTISSEM SAMAI
https://orcid.org/0000-0002-7792-2260