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Spatial distribution of *Tetraclinis articulata* (Vahl) Mast. formations in north- western Algeria

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Abstract. *Tetraclinis articulata* (Vahl) Mast., syn. *Thuja articulata* Vahl, is mainly confined to the south-western Mediterranean region and considered to be endemic to North Africa (Morocco, Algeria, and Tunisia). This tree species is experiencing a significant regression of its range, in some cases irreversible. Currently, it is classified as an Ibero-Mauritanianelement. Our objective was to study the dynamics of land cover and even the possibilities of rehabilitation of this species. The forest formation based on *Tetraclinis articulata*, represented in this study by the areas known as Oued Fergoug and Béni-Khenies forests, has been subject to both regressive and progressive dynamics. An analysis and mapping of the vegetation over 48 years (1975-1994-2022) revealed that the forest cover, with an initial surface area of 3680.47 ha (61.36%) deteriorated dramatically in 1994 as a result of repeated fires and the drought that prevailed then, to 122.65 ha (2.04%) – a truly alarming situation. However, in 1994-2022 this forest formation experienced a significant biological recovery, so that the estimated vegetation cover is now 4292.64 ha (71.56%), with the appearance of dense woodland in an area of 13.18 ha.

Key words: drought, forest fire, forest cover, Oued Fergoug, Béni-Khenies, vegetation dynamics

1. Introduction

Mediterranean forests have a very high heritage value. They constitute important reserves of genetic, functional, and species diversity that should be conserved as much as possible, with a view to the sustainable management of this biological heritage and potential resources (Quézel & Médail 2003). Algeria is an integral part of the Mediterranean basin, one of the cradles of the oldest civilizations in the world and one of the regions where natural resources (fauna, soil, and vegetation) were subject to early stress (Louni 1994).

After gaining independence in 1962, Algeria inherited an estimated forest area of 3.2 million hectares (S.E.FOR 1980; Benabdeli & Belgherbi 2017). At present, according to sources from the General Directorate of Forests in Algeria, the country's forests cover some 4.7 million hectares.

In Oran Department, a region of north-western Algeria, there are only fragments of vast forest areas. *Pinus halepensis* Mill. is the tree species most commonly found there, usually accompanied by *Quercus ilex* L., *Q. suber* L., and *Cedrus atlantica* (Endl.) Manetti ex Carrière. However, there is also a very characteristic species of this region: *Tetraclinis articulata* (Vahl) Mast. (syn. *Thuja articulata* Vahl, commonly known as Barbary thuja, of the family Cupressaceae), which is almost endemic to North Africa (Quezel & Médail 2003). This species is particularly abundant in north-western Algeria. However, it exists as isolated individuals or in small clumps up to the entrance of Kabylie (Dellys and Lakhdaria), in the valley of the Sahel wadi to M'Chedellah as well as in the gorges of Kherrata. It is missing in the Constantine Tell and in the central and eastern parts of the Algiers Tell (Quézel & Santa 1962).

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Algeria's forestry potential has been over-exploited during the colonial period, resulting in a loss of regenerative capacity in many species. Boudy (1955), former Inspector General of Water and Forests, wrote "All these forests have another common feature: they were over-exploited during the period 1939-1946, to present only a few equipment reserves for the immediate future". After gaining independence, Algeria's forest heritage continued to deteriorate and it is now in a critical situation, under the influence of climate change, especially the extreme droughts (lack or irregular rainfall, high temperatures, etc.) and repetitive fires.

Tetraclinis articulata is a coniferous tree that can be found mixed with other tree species, such as *Olea oleaster*, *Ceratonia siliqua*, and *Sideroxylon spinosum*, but usually it forms communities where it is the dominant species, and sometimes even the only tree species. It is thermophilous and xerophilous, generally growing in coppice formations and rarely forest stands.

From an ecological point of view, *T. articulata* colonizes limestone and primitive rocks as well as sandstone and sandy sediments or superficial substrates, but avoids heavy soils and wetlands. It is mainly found in the Thermo-Mediterranean, but penetrates into the Meso-Mediterranean zone. From a bioclimatic point of view, it has a strong preference for the semi-arid bioclimate, but extends locally into the upper arid zone (Quézel & Médail 2003).

The *T. articulata* forest provides grazing for livestock and products for domestic use. It is considered to be a precious species, being a source of lumber, service wood, energy wood, sandarac gum, tar, and nectar-rich flowers (Hajib *et al*. 2013). Besides, various parts of this plant are used to treat intestinal infections, gastric pain, respiratory illnesses, diabetes, high blood pressure, and fever (Ilham *et al*. 2020; Zahir & Rahmani 2020).

Tetraclinis articulata currently occupies about 140 000 ha (Leutreuch-Belarouci 1991; Maatoug 2003; Ghailoule & Lumaret 2020), compared to 160 000 ha in the mid-20th century (Boudy 1950). Botanical studies of this species were not numerous: Terras *et al*. (2008); Hadjadj *et al*. (2009); Benabdellah *et al*. (2010); Haddouche *et al*. (2011); Hadjadj & Letreuch-Belarouci (2015); Ghaioule & Lumaret (2020). On the other hand, no research results on this species at the level of the wilaya of Mascara (part of the Oran region) have been published. This is the first study, aimed to provide reliable data and information that can be used to establish a strategy for the preservation and restoration of this species, so marginalized by the services concerned.

2. Material and methods

2.1. Study area

The study area covers 5998.04 ha, including the so-called Oued Fergoug forest and the Béni-Khenies forest, which are now nearly completely devoid of dense forest stands. It is located at the heart of the Béni-Chougrane mountain range (Fig. 1) and is bordered on all sides by

Fig. 1. General view of the study area in north-western Algeria

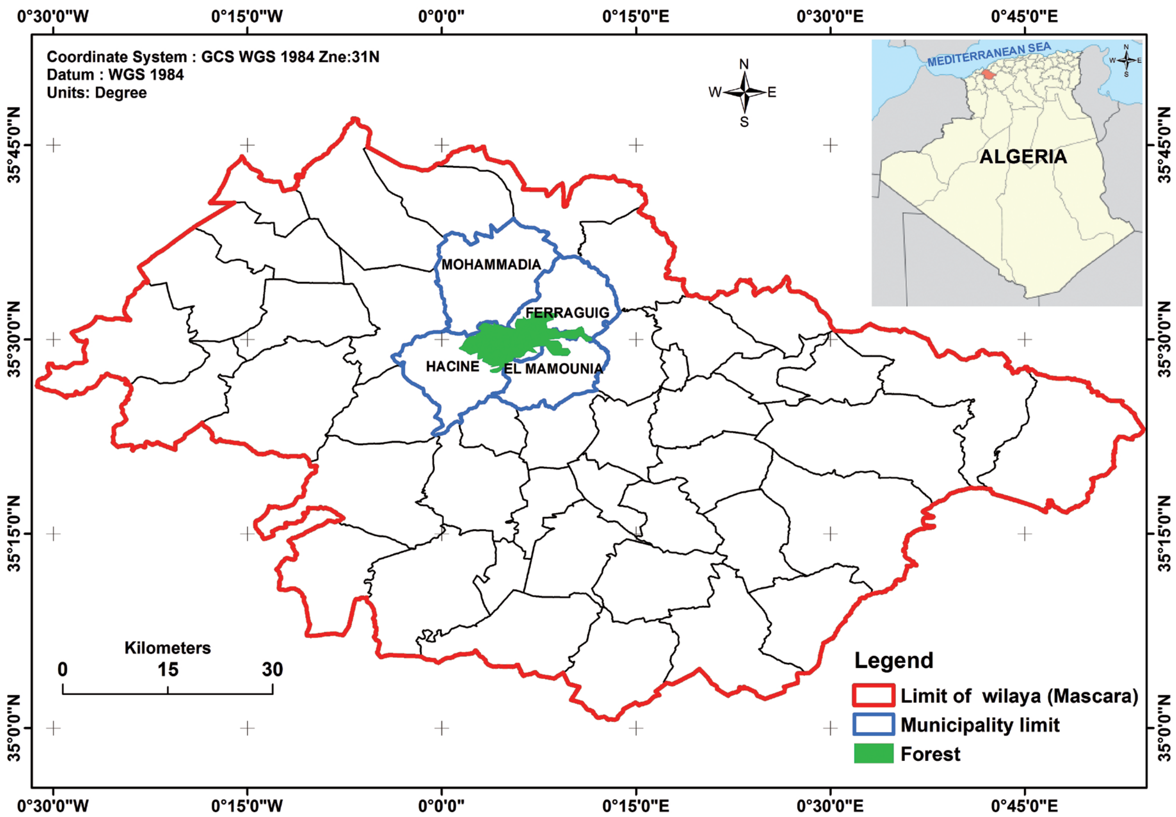

Fig. 2. Geographical location of the study area

agricultural land (Fig. 2). Altitudes vary from 100 m to 600 m, as the area has a more or less uneven terrain, and 70% of the surfaces have a slope of 25%.

Due to its geographical position, the study area represents a downstream point in the watershed. It is drained by several wadis, including Oued Fergoug, Oued Tarzout, and Oued El Hammam. A wadi (or Oued) is a valley of an ephemeral watercourse, wet during the cold and rainy in winter, but hot and dry in summer.

The lithology of the study area is characterized by a diversity of surface formations, with a predominance of marly and clayey soils sensitive to water erosion (Dalloni 1940, 1953). The types of soil encountered are: grey or black vertisols occupying the lowlands, flat areas, and slopes; brown calcareous soils occupying fairly large areas on the hills; and poorly developed soils occupying the top of the slopes (Boukhari *et al*. 2016).

The study area is subject to a semi-arid Mediterranean climate, a temperate to cool variant, with an average annual rainfall of around 300-350 mm. The average maximum temperature of the hottest month is 35.54° and the average minimum of the coldest month is 2.69°C (Belgherbi & Benabdeli 2010, 2016; Belgherbi *et al*. 2018).

From the floristic point of view, the forest is dominated at the level of the tree stratum by a single species *T. articulata* (Fig. 3) and a very small contribution of

Fig. 3. View of the various strata of the dominant tree species *Tetraclinis articulata*

Explanations: A – first background, tree seedlings (natural regeneration); B – second background, young, shrub-like trees; C – last background, older trees

Pinus halepensis (reforestation). The other strata are composed of *Nerium oleander* L., *Pistacia lentiscus* L., *Olea europaea* L., *Calycotum spinosa* L., *Rosmarinus* sp., *Artemisia* sp., *Stipa tenacissima* L., and others.

2.2. Data and application model

Vegetation dynamics was analysed by the use and manipulation of 2 sources of data: cartographic documents (topographic maps covering the study area) and satellite images. The 2 different maps are on a scale of 1:50000. The 3 satellite images, with 30-m resolution, include Landsat 2 for the year 1975, Landsat 5 for the year 1994, and Landsat 9 for the year 2022. The software used to study the dynamics are: ENVI 5.3 and ArcGIS 10.3.

The satellite images were chosen to coincide with the summer period in order to eliminate the influence of annual vegetation and to assess the dynamics of perennial vegetation, including the dominant species (*T. articulata*) in relation to environmental factors. In the dry season, the contrast between annual vegetation and perennial and evergreen vegetation is the strongest and therefore the most detectable (Haddouche 2009).

The method used in the current study aims to identify the changes in land cover. It is based on the comparison of classifications, using the pixel-by-pixel approach from pseudo-spectral bands resulting from the application of the normalized difference vegetation index (NDVI) (Rouse *et al*. 1974). Many authors (Mihi *et al.* 2019; Hereher & El-Kenawy 2021; Shao *et al.* 2022) recommend the use of NDVI as a good indicator for vegetation analyses in arid and semi-arid environments. It is calculated using the formula: NDVI=(NIR–Red)/(NIR+Red), where Red and NIR stand for the spectral reflectance in the red (visible) and near-infrared regions, respectively.

We established a supervised classification from 88 points (Fig. 4) carried out in the field following simple random sampling. The other trips were carried out in order to validate the cartographic results and/or correct the approval with the reality of the field. It is based on the comparison of supervised pseudo-band classifications (ACP-NDVI). It can be used to provide detailed information on the evolution of changes and the mutation of occupancy classes, and to prepare occupancy and change maps (Yuan *et al*. 2005).

The advantage of this type of multispectral classification called "pixel to pixel" lies in the fact that it allows us to remain close to the original information contained in the image (Le Hégarat-Mascle 2003). According to Sader *et al*. (2001), Franklin *et al*. (2002), Hoang (2007), transformations of raw images into vegetation indices are the techniques most used to detect changes in this type of work.

Fig. 4. View of various types of land cover in the study area: bare ground and sparse woodland

Table 1. Dynamics of land use in the study area (5998.04 ha) between 1975, 1994 and 2022

Type of land cover	Situation in 1975		Situation in 1994		Situation in 2022		Difference [ha] 1994-2022	Difference [ha] 1975-2022
	Area [ha]	%	Area [ha]	%	Area [ha]	%		
Water body	145.30	2.42	0006.85	0.12	0.00	0.00	-6.85	-145.30
Barren land	1632.27	27.21	5868.55	97.84	1705.39	28.43	-4163.16	73.12
Shrubs and grassland	3719.00	62.00	0122.29	2.04	3691.17	61.54	3568.88	-27.83
Sparse woodland	501.47	8.37	000.36	0.01	588.29	9.81	587.93	86.82
Dense woodland	0.00	0.00	000.00	0.00	13.18	0.22	13.18	13.18

3. Results

The comparative analysis aimed to detect changes (progressive and/or regressive) of the forest cover based on *T. articulata*. The studied forests in 1975 covered an area of 5998.31 ha but were in fact constituted in the majority by shrubs and grassland (3719 ha, i.e. 60% of the total) or barren land (1632.39 ha, 27.21%). The rest was divided between sparse woodland (501.4 ha, 8.37%) and a water body (145.30 ha, 2.42%), namely the Oued Fergoug dam reservoir (Table 1, Fig. 5).

The situation of the forest stands of *T. articulata* in 1994 was very worrying. The investigations, compared with the situation in 1975, demonstrated a dramatic deterioration of the forest cover, to only around 122.65 ha (2.04% of the total area), in favour of bare soil, covering 5868.55 ha (97.84%) (Table 1, Fig. 6).

After the disastrous situation in 1994, the forest cover underwent a positive evolution, with a very significant biological recovery noticeable in 2022. Our comparative study shows that the forest area is now dominated by shrubs and grasslands (3691.17 ha, 61.54%), followed by sparse woodland (588.29 ha, 9.81%) and dense

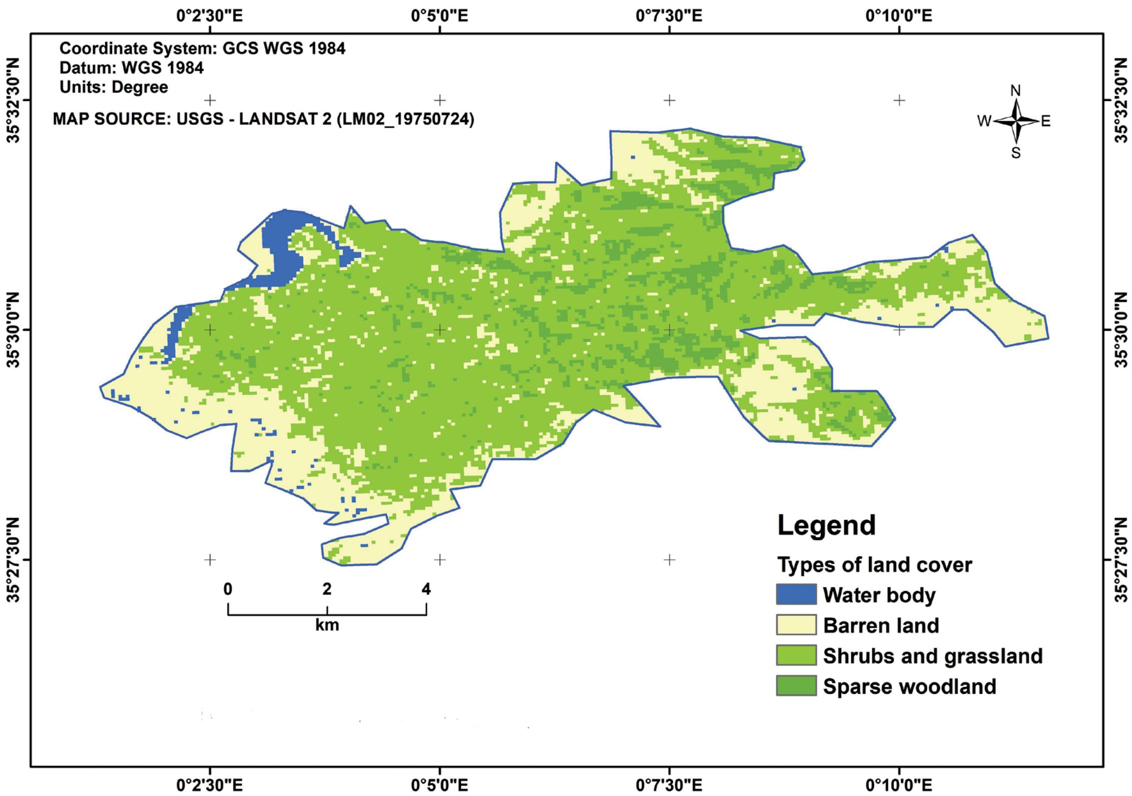

Fig. 5. Map of land cover in the study area in 1975

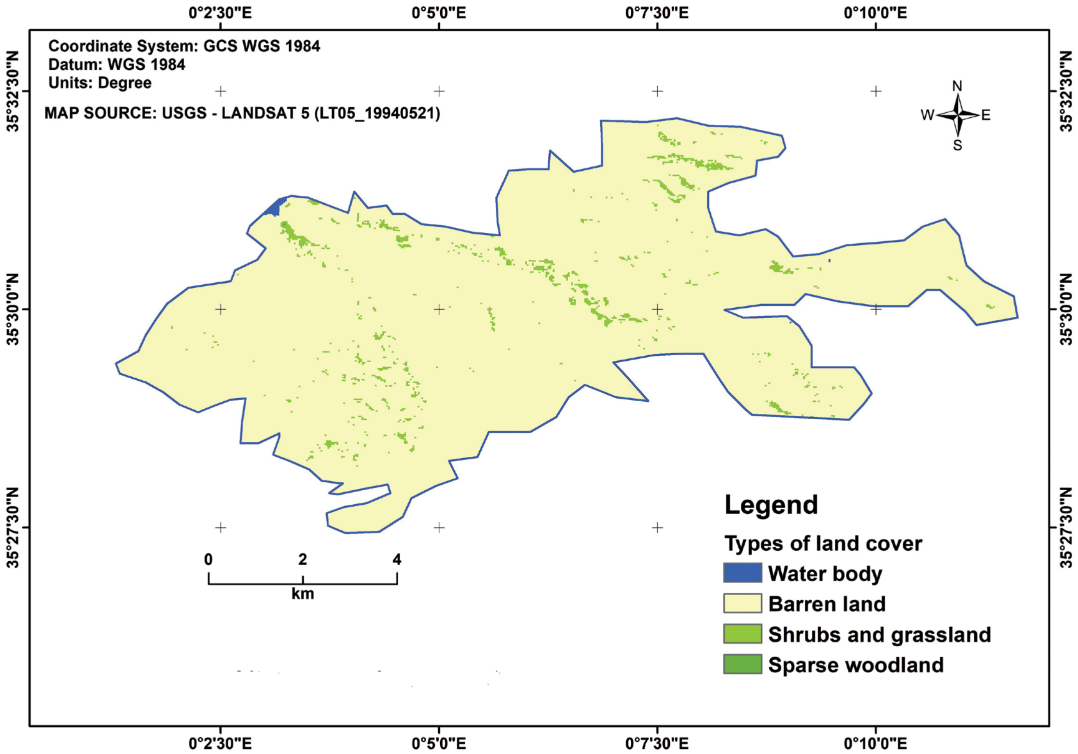

Fig. 6. Map of land cover in the study area in 1994

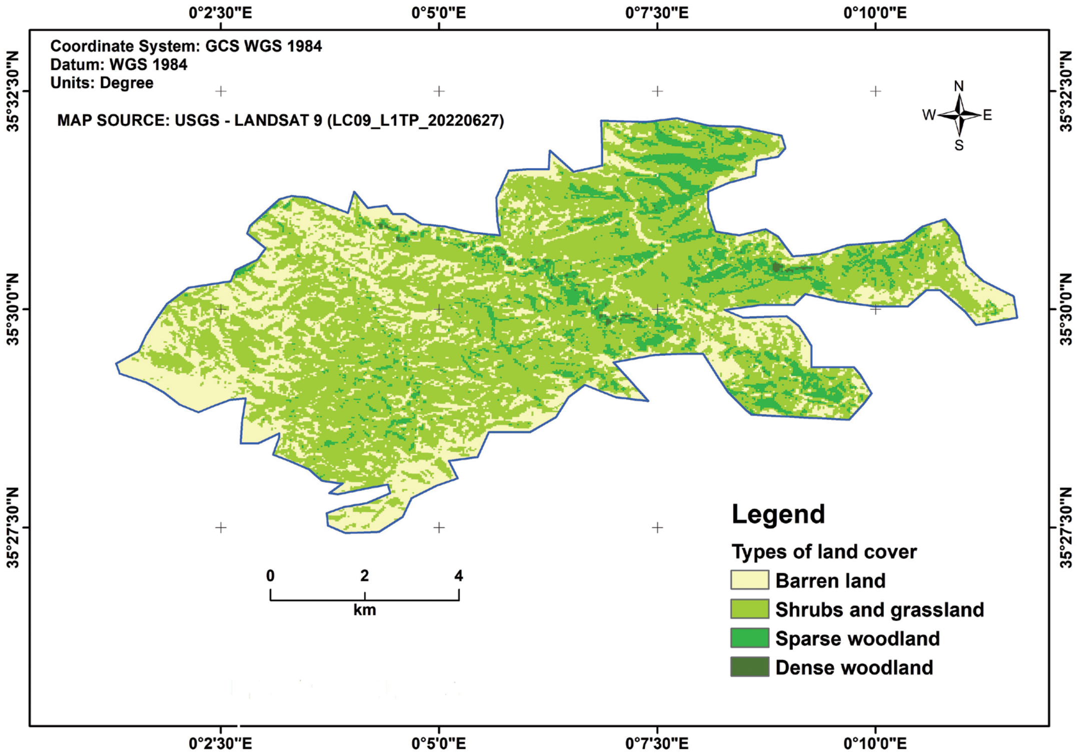

Fig. 7. Map of land cover in the study area in 2022

woodland (13.18 ha, 0.22%), where the major tree species is *T. articulata*. Barren land covers 1705.39 ha (28.42%). It should be noted that the complete drying of the Oued Fergoug dam reservoir took place before 1994.

These results show vegetation recovery in the study area, and positive dynamics in 2022 within an area of 4292.65 ha, i.e. 71.57%, for all types of vegetation (Table 1, Fig. 7).

4. Discussion

The situation of the *T. articulata* formations in 1975 clearly illustrates that the latter suffered a more or less advanced degradation. The forest cover was represented by shrubs and grassland or sparse woodland (68.37% in total). In fact, after the colonial period, Algeria inherited a fragile and very degraded forest heritage. The years just before independence (1958-1962) were marked by fires that ravaged a very large area (around 200 000 ha), causing enormous damage. The major dramatic fires, annually covering at least 100 000 ha in Algeria, coincided with troubled times (rebellions, war) (Boudy 1952; Sari 1976; Belgherbi 2002; Meddour-Sahar *et al.* 2008; Puyo 2008). Fire was, on certain occasions, used as a weapon of war (Guillerm & Trabaud 1980; Trabaud 1980).

The degradation of the forests of the Oranian Tell therefore appears, in the final analysis, to be a recent fact, directly linked to the development of colonization. It was the "settler colonization" type, as it unfolded throughout the Algerian Tell and particularly from the Oran region, over the last hundred years (Benchetrit 1966).

The forest cover in 1994 was degraded enormously, leaving nearly 98% of the ground bare in both former forests. The data concerning fires in 1975-1994 revealed a burnt area of 2650 ha, i.e. over 44% of the study area, in a single year (1994).

The use of climate data from the reference station shows an average annual rainfall of around 311 mm during the study period. The driest year was 1981, with an average of 171, and the wettest year was 1990, with an average of 475 mm. The average monthly precipitation for the 3 months coinciding with high-risk period for forest fires is 2.95 mm (4.84 mm in June, 2.12 mm in July, and 1.88 mm in August). These climatic data show that the study area has experienced a period of severe drought, which has only aggravated the fire situation.

The hyper-arid climate remains a determining factor of forest fires in Algeria, as it accentuates and accelerates their triggering, spread, and combustion of the forest cover. It is above all on the meteorological conditions noted during the year that the areas covered by fires depend (Trabaud 1980), and their number decreases significantly as a function of the increase in the amount of precipitation (Trabaud 1983).

The target area of this study requires protection, ensuring soil stabilization and therefore reducing the sedimentation of solids towards the Oued Fergoug dam. The disastrous and repetitive fires during this period, by degrading and reducing the forest cover, have aggravated erosion and the dam is now completely silted up. The value of erosivity factor remains very high, considering that most of the rains are torrential and the study area remains bare for a long period of the year, with the topography of an uneven terrain (Belgherbi & Benabdeli 2021).

Between 1994 and 2020 (26 years) the forest cover was subject to fairly spectacular development and biological recovery. This progressive dynamics has been achieved both quantitatively and qualitatively. The forest vegetation cover is now estimated at 4292.64 ha (71.56%) over an area of 5998.04 ha, with the appearance of dense woodland. The analysis of the data concerning the fires during this period shows that the forest stands of *T. articulata* only suffered in total a few fires with an estimated damage of 40 ha in 6 locations. The climatic data for this period show that the average annual rainfall was around 513.67 mm (the driest year was 1998, with an average of 315.7 mm, and the wettest year was 2018, with an average of 698.7 mm). The average annual precipitation for the 3 months with a high risk of forest fires was 15.30 mm (36.89 mm in June, 7.67 in July, and 1.36 mm in August).

In comparison with 1975-1994, it appears that in 1994-2022 the forest formation suffered only minimal fires and that the climatic situation of the region was more favourable, with higher rainfall. These investigations demonstrate once again that fires are the most dangerous factor for forest ecosystems in Algeria, causing enormous damage that can reach irreversible destruction of the latter. The studies carried out on fires converge in the fact that all fires are linked with human activity but the causes remain for the most part unknown, which indicates a weakness in the identification of the sources of fire (Rebai 1986; Favre 1992; Dimitrakopoulos 1995; Madoui 2002). The results obtained are very interesting and allow us to assess the renewal rate of *T. articulata,* thanks to its regenerative capacity.

The present work demonstrates clearly an example of a positive evolution of a very degraded or nearly exterminated forest formation towards a paraclimacic formation, and this follows the protective measures established by the forest services concerned. This protection has made it possible, on the one hand, to minimize any negative human impact, including fires, and on the other hand, to ensure a biological recovery of the floristic composition accompanying *T. articulata* as well as the sexual and asexual regeneration of this species.

5. Conclusions

This study, including the mapping of vegetation dynamics in Algeria, has provided a historical (1975, 1994) and current view (2022) of the state of the *T. articulata* forest formation. This formation protects the soil against erosion and preserves the watershed and the Oued Fergoug dam reservoir, so it has been defended to minimize the harmful anthropozoogenic actions and ensure a biological rise. After 1994, this forest formation recovered its vitality, most of the bare soil being was revegetated, and the dominant species caught up thanks to its potential for natural regeneration (sexual and asexual),and ecological succession allowed this forest formation to achieve its protection objectives.

Our results clearly demonstrate that the degradation of forest ecosystems in Algeria is caused by fires. These fires are linked with human activity but their causes remain unknown. The study shows that the forest dynamics in Algeria is not always regressive but with a few means and more attention, a positive evolution can be achieved.

It is difficult to envisage a rehabilitation program for an ecosystem without identifying the determining causes of this catastrophic situation, to understand how this ecosystem behaves both in its composition and in its dynamics. Once the degradation process has been described and understood, it will be possible to propose a pragmatic and – above all – realistic strategy for preserving and restoration of threatened forest ecosystems (Benabdeli & Belgherbi 2016).

It is essential to set up a management plan with short, medium, and long-term actions to ensure the functions of protection, preservation, and restoration of this forest formation, with priority given to an appropriate schedule of silvicultural work and, above all, to involving the local population in forest management.

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