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Assessment of Cork Oak Decline Using Digital Multispectral Imagery in Relation with *in Situ* Crown Condition

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Abstract

Cork oak in Mâamora forest is experiencing the dieback phenomenon. The evaluation of the latter in this forest has gained the importance over time and with the solicitation of managers to objectify its phytosanitary situation. Aiming at prioritizing management actions, remote sensing seems to be an effective tool to inquire about stands' health conditions and their evolution. To this end, this study aims at mapping and validating health status of cork oak stands in Mâamora. Sentinel 2 images in 2015 and 2020 were processed to calculate the differential normalized difference water index (NDWI), revealing vegetation moisture variation caused by drought. A statistical method based on thresholds was used to map cork oak dieback stands, those with no changes and those recovered. Results have shown that 54.63% of cork oak in Mâamora forest have not changed in terms of phytosanitary situation between 2015 and 2020, 31.10% of oak stands are afflicted by a slight decline and 12.97% by a severe decline. Areas with slight or strong recovery remain minimal and represent 1.04% and 0.25% respectively. Ground data indicated that the map generated displayed a good distinction between stands severely and slightly declined with a global accuracy of 66.66%. Therefore, further research elaborating an advanced vegetation index reflecting the various factors of dieback would be of much importance.

Keywords

Dieback, Cork Oak Forest, Mâamora, Satellite Images, Crown Condition

1. Introduction

Although its socio-economic and ecological importance, cork oak (*Quercus suber*

L.) forest is confronted, in the last few years, with a serious health problem threatening its survival (Sechi et al., 2002). It is, in fact, the dieback phenomenon which was reported in Portugal (Camilo-Alves et al., 2020; Sousa et al., 1995), Italy (Marras et al., 1995; Scanu et al., 2013), Spain (Acha & Newing, 2015; Garolera, 1988), France (Amandier & Vidal, 2007; Nageleisen, 1994; Terrin, 2018), Tunisia (Lahbib et al., 2005), Algeria (Bouhraoua et al., 2002) and in Morocco (Bakry & Abourouh, 1995; Boudy, 1948; Maghnia et al., 2019). In the latter country, the first dieback wave of cork oak was recorded between 1918 and 1928 (Boudy, 1948). Since then, the degradation of cork oak forest has been continuing with striking periods between 1943-1951 (Malecon & Marion, 1952; Boudy, 1948), 1981-1987 and 1991-1993 (Bakry, 1994). Mâamora forest with an area of 131,566 ha, 70,400 ha being occupied by cork oak (Belghazi & Mounir, 2015), is one of the largest forests containing this species in the Mediterranean region (Natividade, 1956). This forest is considered to be a typical example of cork oak dieback (Bakry, 1994; Harrachi, 2000) given that its density has decreased since more than two decades (Belghazi et al., 2011). This decline is the result of a combination of various factors; however, the unevenness of the climate is the main one (El Abidine, 2003). Besides this, factors were also reported 1) the stands ageing, 2) the infection of trees by *Hypoxylon mediterraneum* fungi, 3) the overgrazing caused by 230,000 cattle and sheep exceeding four times the capacity load of the forest, 4) the occurrence of fires and, 5) the periodic defoliation triggered by *Lymantria dispar* (Belghazi et al., 2011; Laaribya, 2006). It is very likely that the rise of temperature and the shifting of rainfall patterns will continue to occur, and that extreme weather events will be more frequent in the future (Allen et al., 2010; Church et al., 2013; Sterl et al., 2008). Dry periods were shown to have a significant effect on forests' vitality (Eggers et al., 2008; Lindner et al., 2010). Many studies were conducted to evaluate forest ecosystems' health status and to monitor them using remote sensing techniques (Coppin et al., 2004; Imanyfar et al., 2019; Lambert et al., 2013; Masek et al., 2008; Recanatesi et al., 2018). In Morocco, studies have more focused on symptomatologic criteria to evaluate the state of cork oak stands in Mâamora. Hence, of an essential importance is to characterize its dieback by making use of satellite images and infer the degree of concordance between the findings of this study based on these latter and the investigation in the field. In this respect, the aim of this paper is to detect and characterize the dieback of cork oak forest in Mâamora between 2015 and 2020. The present study is of an essential interest in the sense that it contributes to the amelioration of the decision-making, gives a clue to managers aiming at managing natural resources sustainably and determines spots highly affected by dieback requiring an urgent intervention in Mâamora.

2. Material and Methods

2.1. Study Area

Mâamora forest is located in the north west of Morocco between 6˚ and 6˚45' west longitude and 34˚ and 34˚20' north latitude (**Figure 1**). From the west to the East, five cantons are distinguished in this forest: A, B, C, D and E. The forest witnesses a gradual decrease of rainfall from canton A to canton E and it varies between 400 to 600 mm. Conversely, the average temperature increases from the West to the East. Bioclimate is sub-humid in the Western part and semi-arid in the Central and Eastern part.

2.2. Satellite Images Processing

Sentinel 2 images of 2015 and 2020 were acquired from the United States Geological Survey (USGS) in the beginning of summer, mid-summer and at the end of this season (**Table 1**). This season was chosen in order to avoid the confusion of classification due to the presence of herbaceous and shrub vegetation out of summer. Image processing was carried out using QGIS 3.16. Since all retrieved images were of level 1C, radiometric and geometric corrections are included

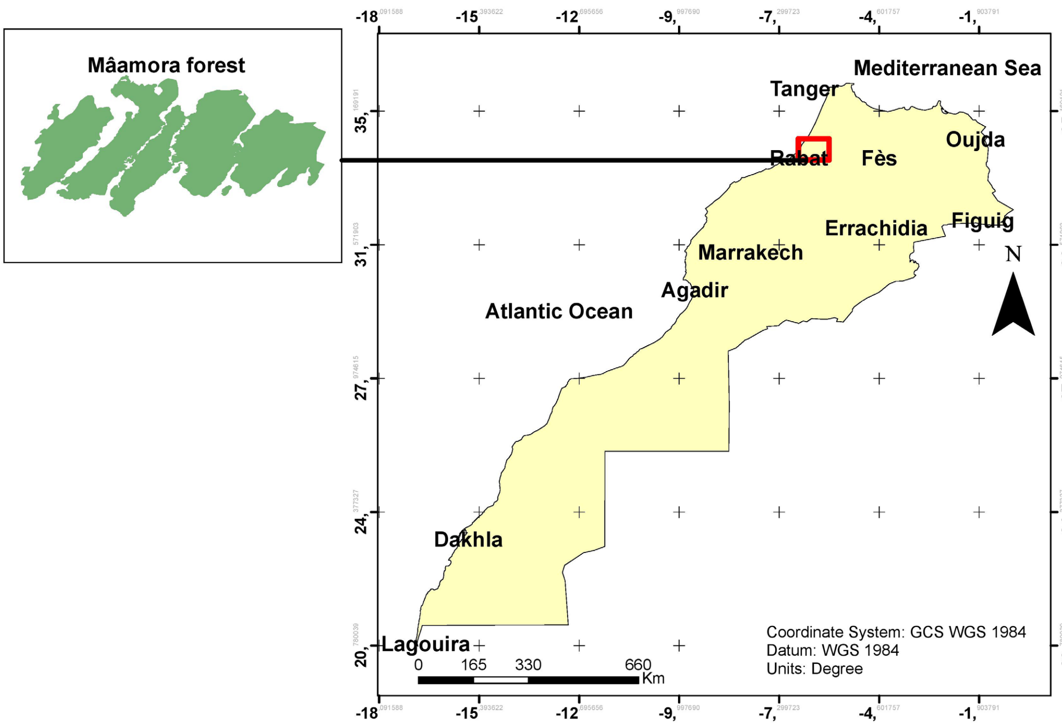

Figure 1. Location of Mâamora forest in Morocco.

Table 1. Data of satellite images used in the study.

Satellite	Sensor	Acquisition date
Sentinel 2	MSI	12.07.2015
		01.08.2015
		10.09.2015
		30.06.2020
		08.09.2020

(USGS, 2018). As for the atmospheric correction, it was done using the empiric algorithm of QUick Atmosphic Correction (QUAC). Given that the vegetation indexes were calculated on different years and for a good comparison of these spectral indexes (Chander et al., 2007; Chander & Markham, 2003), it was of essential importance to convert digital numbers DNs of each pixel to radiance and top-of-atmosphere (TOA) reflectance (Young et al., 2017). In the present study, the Semi-Automatic Classification Plugin (SCP) with QGIS was used to perfom this conversion.

2.3. Selection of Vegetation Indexes

The selection of spectral indexes was based on two criteria. The decline of cork oak forests is the result of the presence of pests favored by water deficit (Mattson & Haack, 1987a, 1987b) constituting, therefore, the main cause of trees' dieback (El Abidine, 2003). Leaves dry out drastically in dry conditions or due to pest infection (Wang et al., 2007). Hence, the first index should take into account the vegetation moisture. Furthermore, among the symptoms of cork oak dieback are recorded defoliation and branch mortality; this phenomenon may lead to trees mortality and thus to natural vegetation loss (de-densification). In this respect, the second index should take the vegetation density into consideration. The Normalized Difference Water Index (NDWI) fulfills the first criterion related to water stress and uses the band of Short-Wave Infrared (SWIR) (between 1500 and 1750 nm) which is the most sensitive to the variation of leaves water content (Jensen, 2000) and is negatively correlated to this parameter (Tucker, 1980). The combination of this channel with that of the Near Infrared (NIR) enhances the precision regarding vegetation moisture (Ceccato et al., 2001) and therefore provides information about its hydric status (Wang et al., 2007).

$$\mathrm{NDWI} = \frac{R_{NIR} - R_{SWIR}}{R_{NIR} + R_{SWIR}} \tag{1}$$

Bands 8 (NIR) and 11 (SWIR) of Sentinel-2 images were used in Equation (1).

Normalized Difference Vegetation Index (NDVI) is used as an indicator of vegetation stress (Recanatesi et al., 2018). Some studies have indicated its effectiveness to discriminate health status of vegetation (Adams et al., 2000). Hence, NDVI meets the second criterion and presents an exponential relationship with vegetation density (Holben, 1986).

$$\mathrm{NDVI} = \frac{R_{NIR} - R_{R}}{R_{NIR} + R_{R}} \tag{2}$$

Bands 4 (R) and 8 of Sentinel-2 images were used in Equation (2).

2.4. Mapping Cork Oak Dieback

Aiming at mapping cork oak dieback in Mâamora, Wang et al. (2007) method was utilized. First, the differential NDWI of 2015 and 2020 was computed as follows:

$$\Delta\mathrm{NDWI} = \mathrm{NDWI}_{2020} - \mathrm{NDWI}_{2015} \tag{3}$$

Negative values of ΔNDWI reflect dying back trees indicating low leaf moisture. On the contrary, positive values represent trees recovery from previous stresses. Secondly, a statistical method was adopted based on thresholds to distinguish dying back cork oak, those recovered and those with no changes:

- Strong dieback: $\Delta NDWI < -2\sigma$;
- Slight dieback $-2\sigma < \Delta NDWI < -\sigma$;
- Cork oak with no changes: $-\sigma < \Delta NDWI < \sigma$;
- Slight recovery: $\sigma < \Delta NDWI < 2\sigma$;
- Strong recovery: $\Delta NDWI > 2\sigma$.

2.5. Validation Method

To validate the method used, three descriptors were considered to assess the vegetation health in the field. These parameters were examined in areas classified as severely and moderately affected by dieback in the generated map. This validation concerned 60 plots and in each one 10 cork oak trees were observed and rated. The number of plots was restricted to 60 due to the limited time and resources. The descriptors were: 1) branches mortality in the tree crown (the upper part of the crown excluding the lower and lateral parts undergoing natural competition phenomenon), 2) deficit in leaves as compared to a reference cork oak tree and 3) inappropriate pruning practiced by the human. The dieback index (ID) of Bouvarel (1984) was calculated for every plot taking into consideration the degree of defoliation of all the rated trees. This index was calculated as follows:

$$ID = \frac{(n_1P_1)+(n_2P_2)+(n_3P_3)+(n_4P_4)+(n_5P_5)}{N}$$

where n_1, n_2, n_3, n_4 and n_5: the number of trees rated in each class (1, 2, .., 4)

P_1, P_2, P_3, P_4 and P_5: weight of each class (Table 2).

N: Number of trees in the plot (=10).

Depending on the value of the ID, three dieback degrees were distinguished (Table 3).

Table 2. Weight assigned to each class of defoliation.

Foliage loss (%)	Defoliation class	Weight (P_i)
0 - 5	0	0
6 - 25	1	1
26 - 50	2	2
51 - 75	3	3
>75	4	4

Table 3. Dieback degree corresponding to the dieback index (Bouvarel, 1984).

Dieback index	Degree of dieback
ID < 1	Doubtful indexes of dieback
1 ≤ ID < 2	Moderate dieback
ID ≥ 2	Severe dieback

3. Results

3.1. Cork Oak Dieback Map

The calculation of NDWI of 2015 and 2020 enabled to produce histograms of images of the corresponding years (**Figure 2**). The image difference of the two

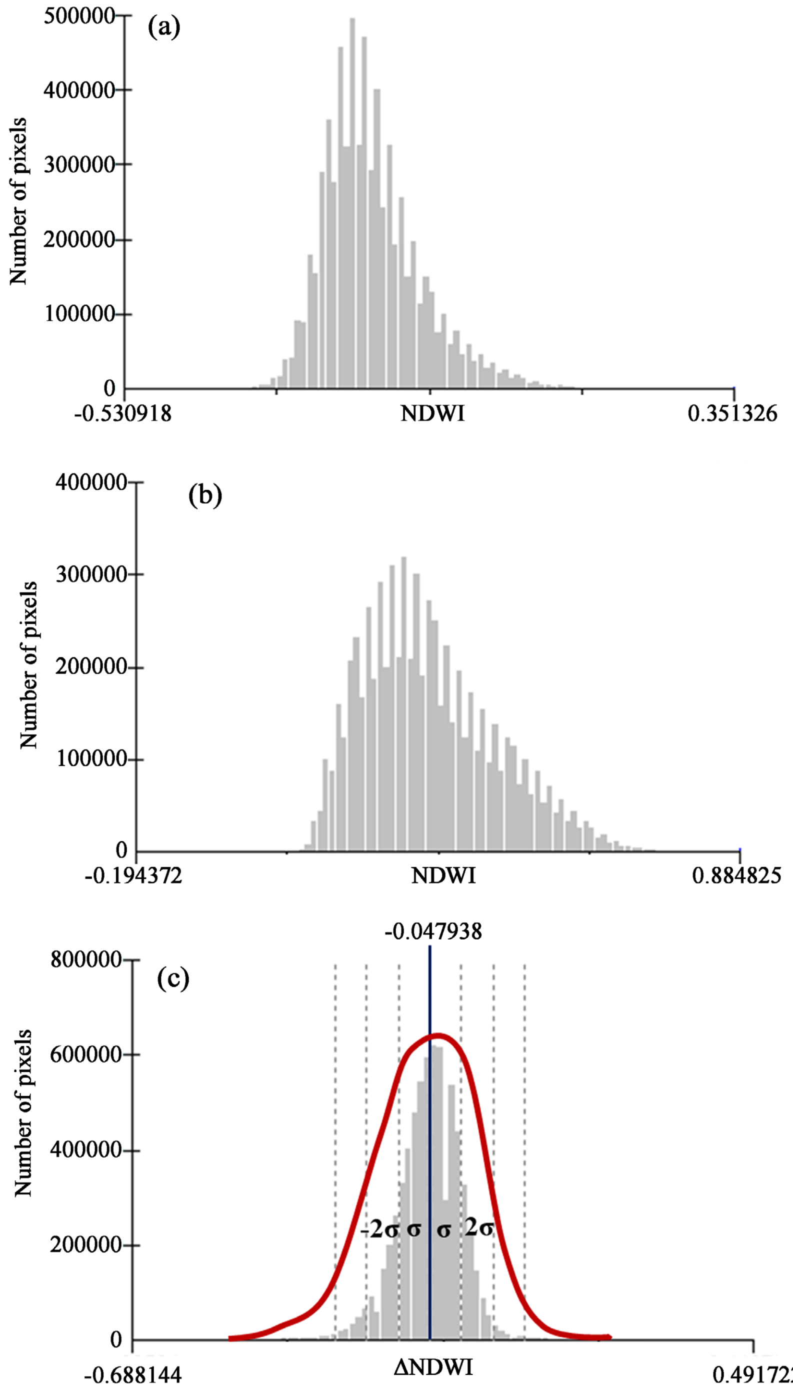

Figure 2. Histogram of images of NDWI in 2015 (a), 2020 (b), and ΔNDWI (c), histogram of the difference between images of 2015 and 2020. The bell-shaped curve in red represents the normal distribution of the ΔNDWI histogram. The solid blue line represents the mean of ΔNDWI and σ refers to its standard deviation.

years generated a ΔNDWI histogram that is normally distributed with a mean and a standard deviation of −0.05 and 0.04 respectively (ΔNDWI~ N (−0.05, 0.04)) (**Figure 2(c)**). The statistical method used allowed to generate a map describing the evolution of cork oak dieback, between 2015 and 2020, of Mâamora forest (**Figure 3**). Areas occupied by each class were calculated, and it turns out that more than the half of the area of cork oak did not record a change in terms of health status between 2015 and 2020 and it is of the order of 36,892.9 ha, constituting 54.63% of the total area (**Table 4**). Oak stands affected by a severe decline represent 8757.7 ha, making 12.97% of the total area and those afflicted by a slight dieback form 21,002.4 ha, representing 31.10%. Surfaces of cork oak witnessing slight and strong recovery remain minimal and represent only 1.04%

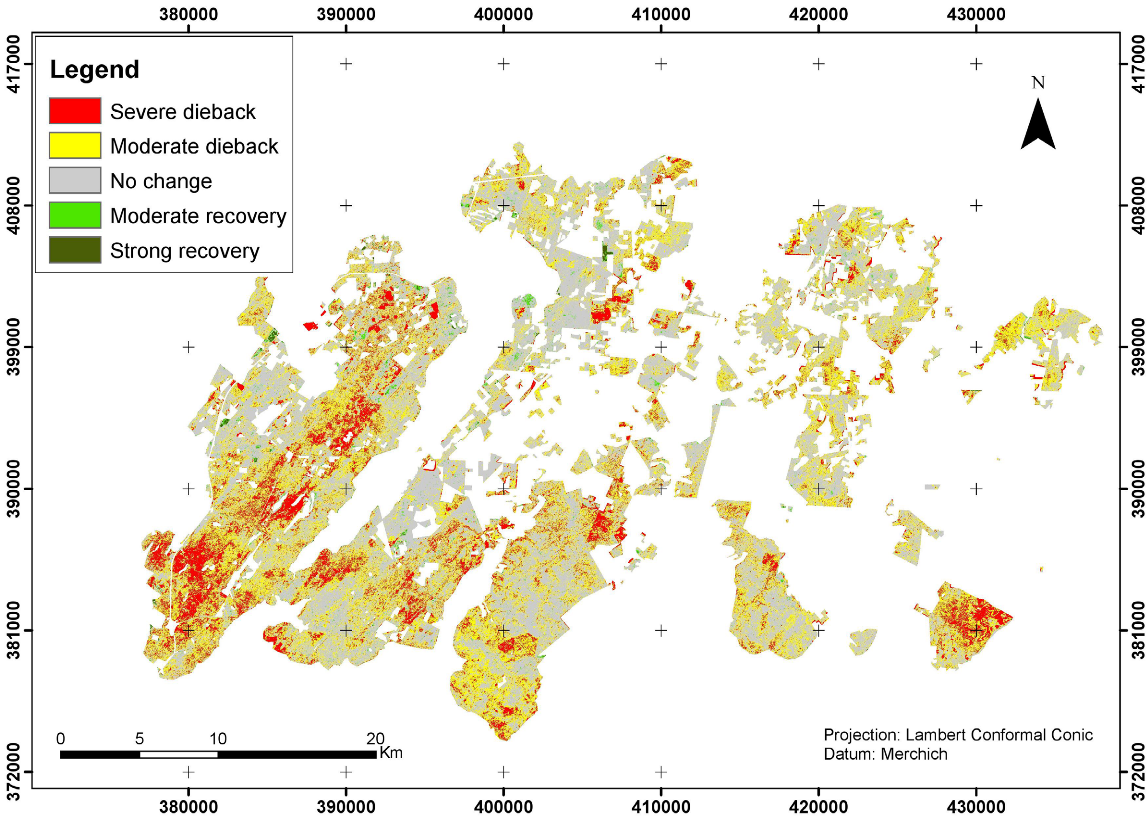

Figure 3. Map illustrating the evolution of cork oak dieback in Mâamora forest between 2015 and 2020.

Table 4. The different degrees of cork oak dieback in Mâamora forest and their corresponding areas in hectare and percentage.

Health status	Area (ha)	Percentage (%)
Severe dieback	8757.7	12.97
Moderate dieback	21,002.4	31.10
No change	36,892.9	54.63
Moderate recovery	702.9	1.04
Strong recovery	171.9	0.25

and 0.25% respectively.

3.2. Cork Oak Dieback per Canton

In cantons B, C and D, a large proportion of the area occupied by cork oak has not experienced a change between 2015 and 2020 (Figure 4). Canton A and E are the most afflicted by the decline phenomenon for the reason that 19.33% and 18.46% of stands are strongly dying back, and 3.29% and 39.96% are moderately dying back respectively. Conversely, B and D cantons are the least affected by the decline with a rate of the order of 9.71% and 6.61% respectively.

3.3. Cork Oak Density Assessment in 2020

According to the NDVI map (Figure 5), the maximum value of this index is 0.89 while the minimum is −0.19. High values correspond to dense and healthy vegetation with a high reflectance, appearing light in the image. From the results, it is obviously clear that from the west to the east the pixel tends to be dark. This means that the density and the sanitary state of the forest exacerbate as per continentality. From the field, cork oak canopy density less than 10% was assigned to pixels with a value of NDVI between 0 and 0.2, between 10% and 40% to 0.2 and 0.4 and the density higher than 40% was attributed to pixels with a value larger than 0.2 (Figure 6). Stands with the latter density account for less than one-third of the total area occupied by cork oak (Table 5). The dominant class of the canopy density in Mâamora is between 10% and 40%, making 62.13% of the total surface.

3.4. Cork Oak Density per Canton in 2020

Going from the west towards the east, meaning from canton A to E, the class of density higher than 40% curbs. More than the half of the area occupied by cork

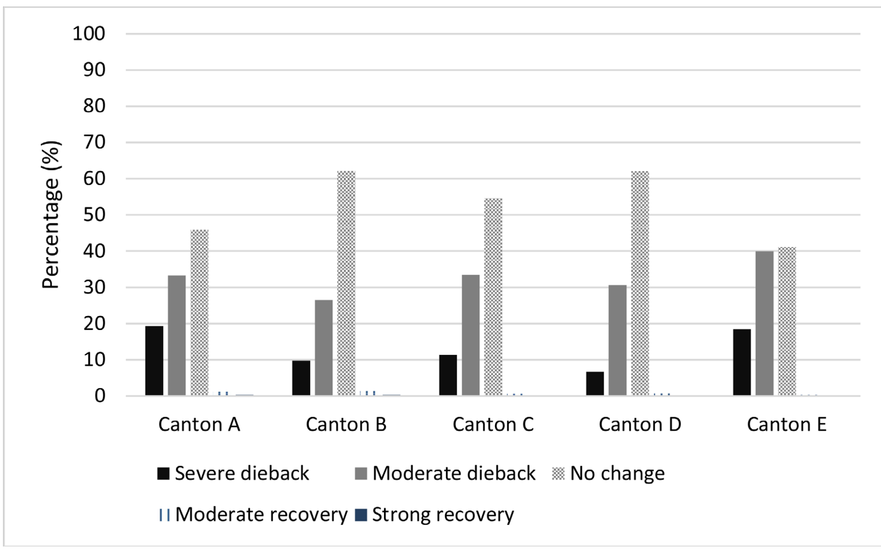

Figure 4. Different health status classes of cork oak per canton (A, B, C, D and E) in Mâamora forest in 2020 and their corresponding areas in percentage.

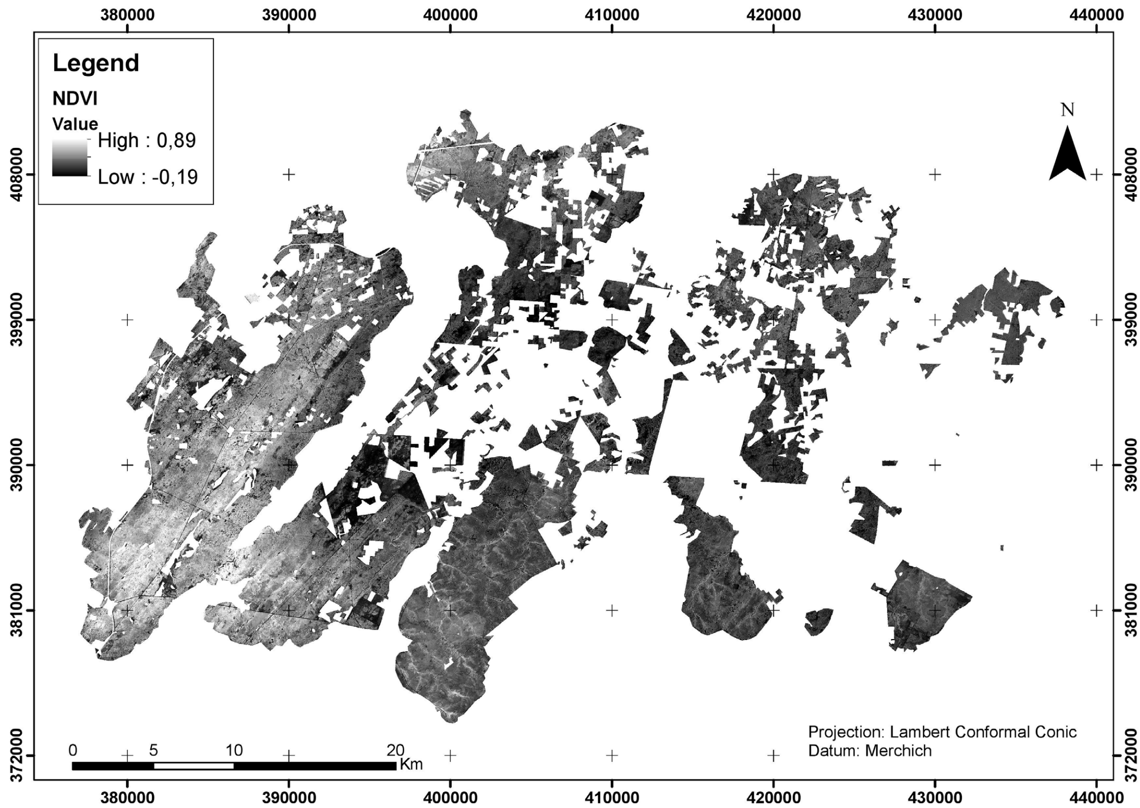

Figure 5. Normalized difference vegetation index (NDVI) map of cork oak in Mâamora forest in 2020.

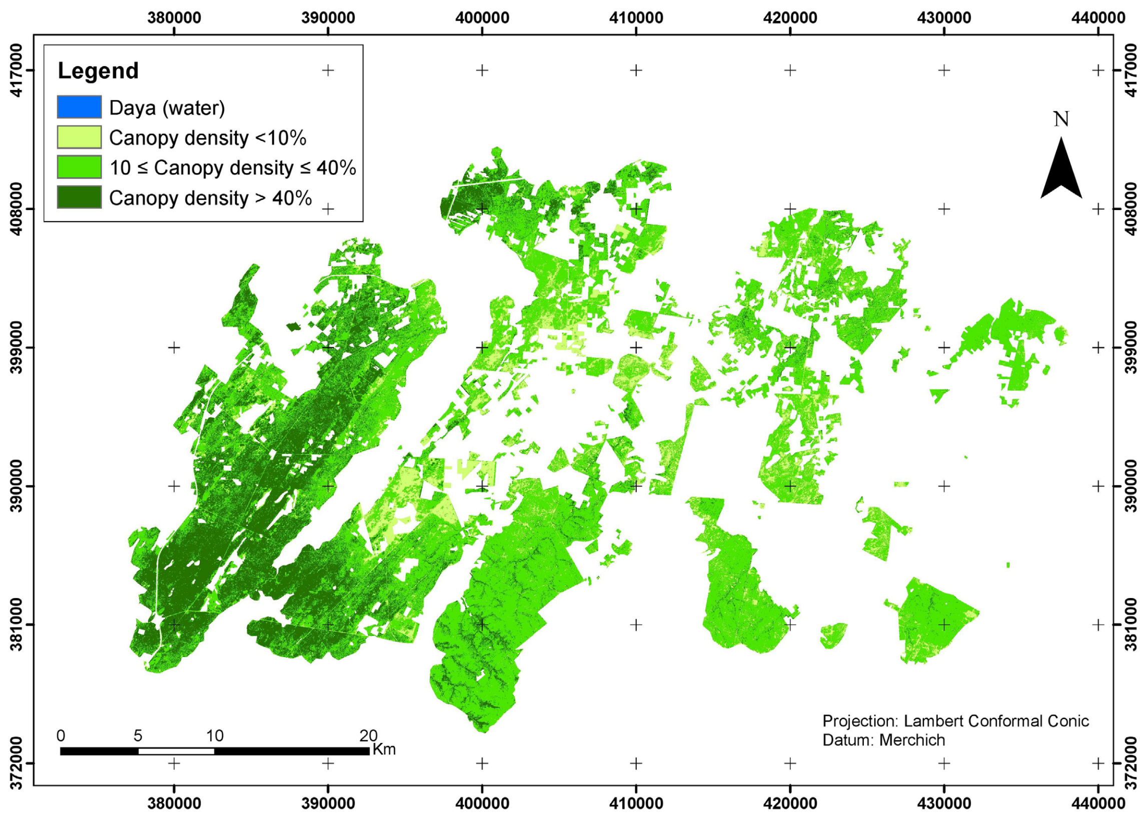

Figure 6. Map of canopy density of cork oak in Mâamora forest in 2020.

Table 5. Areas of the different canopy density classes of cork oak in Mâamora forest in 2020 and their corresponding percentages (%).

Density class	Area (ha)	Percentage (%)
Canopy density < 10%	7781.4	11.52
Canopy density between 10% and 40%	41,956.1	62.13
Canopy density > 40%	17,790.3	26.34

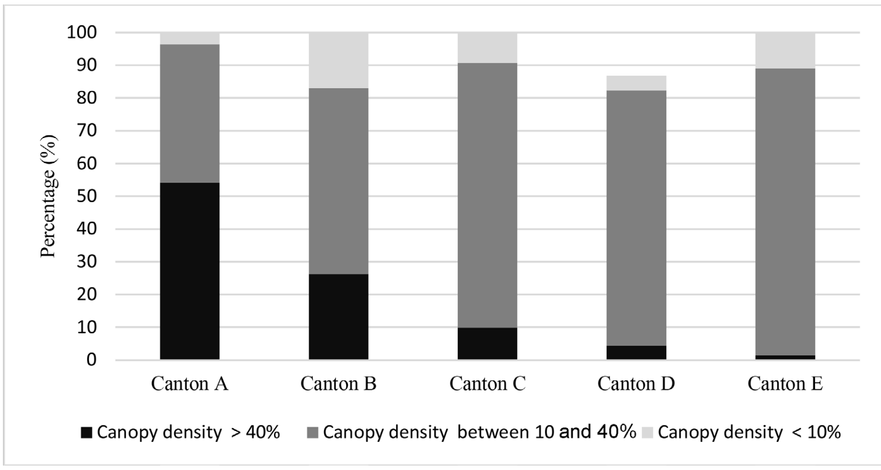

Figure 7. Canopy density classes of cork oak in Mâamora in the five cantons (A, B, C, D and E).

oak has a density larger than 40% in canton A. The same class of density constitutes only 26% in the neighboring canton B (Figure 7). Canton E, with its eastern position is individualized regarding stands density.

3.5. Validation Results

Investigations on the field have exhibited that in the severe dieback class, 48.89% of the rated trees were severely pruned afflicting 1/4 to 1/2 of the whole tree, 35% experienced branch mortality affecting between 1/4 to 1/2 of the whole tree branches and 34.44% have lost between 1/2 and 3/4 of their leaves. Plots observed in the moderate dieback class have indicated that 55.33% of cork oak trees were slightly pruned, 71.33% have branch mortality in less than 1/4 of the tree branches and 47% have lost between 1/4 and 1/2 of their leaves. In order to determine the contribution of remote sensing in monitoring health status of cork oak, a comparison between data collected in the field, used to calculate the index of Bouvarel, and those obtained by satellite images was made resulting in an overall accuracy of 66.66%.

4. Discussion

The relatively low overall accuracy (66.66%) might be explained by the confusion in the classification because of: 1) the presence, in some plots, of *Halimium halimifolium*, a shrub layer which even if in a good state, was classified as moderately declined, 2) the presence of huge quantities of dry branches derived from pruning operation and left on the ground, which in their turn affect the reflection. Phytosanitary issues are triggered by droughts and are exacerbated by insects and fungi (Bakry & Abourouh, 1995). According to some studies, the appearance of pests in forests coincides with heat and drought periods (Mattson & Haack, 1987a, 1987b). This parasitism impairs the tree and reduces its full resumption. In Morocco, droughts occurred in 1975 led to the mortality of a large number of trees either planted or those existing in natural forests (El Abidine, 2003). Nageleisen (1993) has highlighted that cork oak is in a worrying situation in the Mediterranean region. Moreover, the decline of this specie was observed since the 80s in the Western Mediterranean (Delatour, 1983) and was linked to an important surge of *Platypus cylindrus* population (Ferreira & Ferreira, 1989). Thus, this pest insect with the fungi it transports contributed to the decline recorded in Portugal (Sousa et al., 1995), Spain (Soria et al., 1994), France (Durand et al., 2004) and in Morocco (Bakry et al., 1999). In this latter, during drought spells, infections by *Lymantria dispar* had a destructive effect on cork oak (El Hassani et al., 1994). *Biscogniauxia mediterranea* is a pathogen which attacks cork oak trees in the Mediterranean region causing its decline and the frequency of infection was observed to increase in dry and warm periods (Desprez-Loustau et al., 2006; Henriques et al., 2012). In the United States of America and in Europe, attacks by *Armillaria* sp. on oak trees were associated to drought effects (Houston, 1992). In Italy, Vannini and Mugnozza (1991) pointed out the effect of water deficit which has increased *Quercus cerris* sensitivity to *Hypoxylon mediterraneum*. This correlation is explained by the fact that water stress favors, from the one hand, the survival of pathogens and insects creating thus conducive environment for their development, and from the other hand, the trophic conditions at the tree level (El Abidine, 2003). Under water limitations, the concentration of solutes within the plant tends to increase improving the insects' diet and increasing pathogen attacks (Mattson & Haack, 1987a). In addition to these factors, human pressure plays a substantial role in the degradation of Mâamora forest including the increase of the population living nearby to 341,400 inhabitants (HCEFLCD, 2015), the overgrazing which hampers the natural regeneration to occur (Belghazi et al., 2011), the uncontrolled and inappropriate pruning operations practiced even in the dearth period to feed the livestock (Laaribya, 2006) and cork harvesting executed by unqualified workforce. The two latter practices lead to the emergence of lesions which impair the tree resulting in physiological stress and parasite infections (Ben Jamaa & Hasnaoui, 1996) and thus tree decline.

5. Conclusion

Prolonged drought characterized by a rainfall deficit which deviates from the normal precipitation combined with biotic and other abiotic factors induced the decline of cork oak in Mâamora forest. This phenomenon was mapped using a statistical method based on the variation of the normalized difference water index which shows the degree of dieback and recovery of cork oak from 2015 to 2020. The results were compared with those of the diagnosis in the field based on some symptomatologic criteria and it is concluded that the overall accuracy of the remote sensing-based analysis is 66.66%. Therefore, a further study focusing on developing a vegetation index combining the different factors of dieback would be of great importance.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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