

Contribution of geomatics tools to the study of the spatio-temporal evolution of forest stands of the Maamora forest in the face of global changes

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Abstract. A better knowledge of the land use of an environment is based on the establishment and comparison of various spatio-temporal situations of the different components of this space. This work is part of a research on the dynamics of the Maamora forest. It aims to show the contribution of the use of geomatics tools in the evaluation of dynamics of forest cover and therefore the evaluation of the impact of global changes and previous forest management methods. The approach followed for the assessment of forest cover in 1984, 1994, 2004, 2014 and 2019, was based on satellite images of Landsat 5 and Landsat 8, with a spatial resolution of 30 m. The classification supervised by the "Support Vector Machine" (SVM) algorithm made it possible to develop forest cover maps for the dates selected and subsequently to evaluate the changes. The classification evaluation showed a Kappa coefficient over 87% and an overall accuracy over 90% for all the selected dates. The results showed a great dynamic of the forest cover between 1984 and 2019 with two significant periods. The first one is 1984-1994 when areas of cork oak and acacia fell respectively by 20% and 39% in favor of other introduced forest species, mainly eucalyptus and pines, which increased respectively by 28% and 74%. For the second period 1994-2019, there was a reversal trend of regression of cork oak's area towards an increase of 11%, while the area of eucalyptus plantations was generally stabilized and that of pines and acacia stands fell by 37% and 33% respectively. These results make it possible to provide decision-makers with tools for the future management of the space.

Keywords: Spatio-temporal evolution, Maamora forest, Global changes, Satellite images, SVM, Decision-makers.

1 Introduction

The Moroccan Forest estate covers more than 9 million hectares. It contributes 2.4% to the National GDP, taking into account the formal contribution and that of the income directly

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derived by the local population [1]. It has always constituted a multifunctional space (maintaining ecological balance, conserving biological diversity, satisfying product needs, offering recreation areas, etc.).

Forest ecosystems are very dynamic system [2]. They are continuously experiencing changes in composition and content under the influence of various factors: management methods, human activities, climate change, desertification, parasitic attacks, fires, etc. The combination of these factors directly and indirectly impacts the roles and missions of these forests.

Therefore, the monitoring of the evolution of these environments seems necessary to appreciate their dynamics and responses. It requires the implementation of new evaluation methods including space remote sensing, which is of exceptional interest. Thus, the best knowledge of the composition of these spaces is based initially on the establishment of maps of its various components. The comparison of various temporal situations will then allow the determination of the various changes undergone over time.

The Maamora forest, object of this study, is located on the Atlantic coast. It is considered the most extensive cork oak forest in the world [3]. It is a dynamic system, complex and sensitive to various factors such as climate, substrate, human pressure, grazing, diseases, management methods, etc. which continuously generate changes in its composition that are sometimes difficult to appreciate.

This work is part of a research on the dynamics of the forest cover of the Maamora. It aims to show the contribution of the use of geomatic tools (remote sensing and GIS), for the establishment of maps of the forest composition in different dates. It also aims to characterize the dynamics of the cover of this forest over a period of 35 years and to establish consequently an assessment of the impact of global changes and previous management policy on the forest. These objectives were achieved through a supervised classification of Landsat images via the SVM (Support Vector Machine) algorithm.

2 Material and methods

2.1 Study area

The The Maamora forest occupies a total area of 131,921 ha. It is in the North-West of the Moroccan Meseta bordering the Atlantic Ocean and it is in an elongated form from East to West over a length of 60 km and a width of 30 km from North to South [4]. It is divided, from West to East, into five cantons A, B, C, D and E (Fig.1).



Fig. 1. Situation map of the Maamora forest

Its relief appears flat as a whole [5] and the main soil types that predominate are essentially sand over clay [6]. This forest receives annually between 350 to 650 mm of rain and the average monthly temperatures vary from 12°C to 25°C [7]. The prevailing bioclimate is sub-humid with a warm winter in the West and semi-arid with a temperate winter in the center and in the East [5].

The Maamora forest has been the subject of five management plans since 1918 until now in addition to several interventions initiated in the form of specific projects and specific management plans [7]. Originally a cork oak forest, but for the country's needs for wood and paper; eucalyptus, pine and acacia were gradually introduced [8].

2.2 Methodology

To achieve the objectives set and to have decision-making tools for the future management of the forest, the methodological approach adopted was divided into two stages:

- **Consultation and exploitation of documentation and previous work** in relation to forest management, to obtain an overview of the area and identify the available data necessary for the achievement of the objectives set. The main documents consulted are the various reports and maps published within the framework of the 1972, 1992 and 2014 management plans, the 2001 eucalyptus, coniferous and acacia management plans, as well as other project reports.

- **Acquisition, processing, and classification of satellite images:**

The satellite images employed are Landsat images. The use of this satellite is because it offers recent images and other old with high spatial resolution of 30 m. They concern four images, covering the studied area, of the TM 5 sensor (Thematic Mapper): one for the year 1984, one for 1994 and two for 2004, and four images of the OLI 8 sensor (Operational Land Imager): two for the year 2014 and two others for the year 2019.

The total duration of the study, which is 35 years, is considered sufficient to understand the dynamics of forest stands especially as it covers the period of application of the last three management plans. The 10-years interval chosen between the first four dates (1984-1994-2004 and 2014) will make it possible to assess the impact at the mi-term and at the end of the implementation of previous development plans. As for the year of 2019, it was chosen to provide an updated situation following the application of the first five years of the current management plan. The months in which the images were taken, were chosen between June and October to minimize classification confusions due to the abundance of herbaceous vegetation outside these months and to have images devoid of cloud cover as much as possible.

After the necessary pre-processing of the downloaded images, the isolated bands were combined to obtain multi-band images offering the possibility of carrying out more processing. Subsequently, a supervised classification was performed using the SVM (Support Vector Machine) classification algorithm. SVM methods was officially introduced by Boser, Guyon, and Vapnik (1992) during the 5th Annual Association for Computing Machinery Workshop on Computational Learning Theory [9].

Although initially designed for binary classifications, SVMs have been adapted to the problem of multiclass classification [10]. Their uses in various fields, particularly in the land use classification and in the study of biophysical parameters, as in the case of this study, have been elucidated by Mountrakis et al. [11].

SVMs have often been found to provide higher classification accuracies than other widely used pattern recognition techniques, such as the maximum likelihood and the multilayer perceptron neural network classifiers. Furthermore, SVMs appear to be especially advantageous in the presence of heterogeneous classes for which only few training samples are available [12].

The choice of the SMV method using Landsat images is also justified, in this study, firstly by the monospecific composition of the homogeneous areas and the lack of mixing of the species, and secondly by the differentiated structure of stands (natural stands and plantations) and their botanical classification (leafy stands and resinous stands) thus allowing to give distinct reflectance that facilitate the classification.

The first classification step consisted in identifying the classes to be retained having to indicate the species present in the forest in addition to the other areas. For each of them, a sufficient and representative number of areas of interest was provided, by referring to the previous management documents, particularly stand type maps and action plans, that provide information on the existing forest strata at the homogeneous extents level. In addition, visual interpretation of images and available earth monitoring tools were used to delineate areas of interest. These various documents and procedures were also used to verify and control the results of the classification.

Subsequently, the algorithm learned the areas of interest data and proceeded to separate the pixels then their assignments to the classes selected based on the spectral information contained in these pixels. After completion of the classification operation itself, control and validation tests were carried out based on areas of interest that were not used for the classification, for calculating the overall accuracy and the Kappa coefficient. At the end, the areas of the various forest stands were generated.

Also, to assess and quantify the changes experienced by these stands during key periods, forest cover change maps were created from the classifications made and the statistics of these changes were generated according to change matrices.

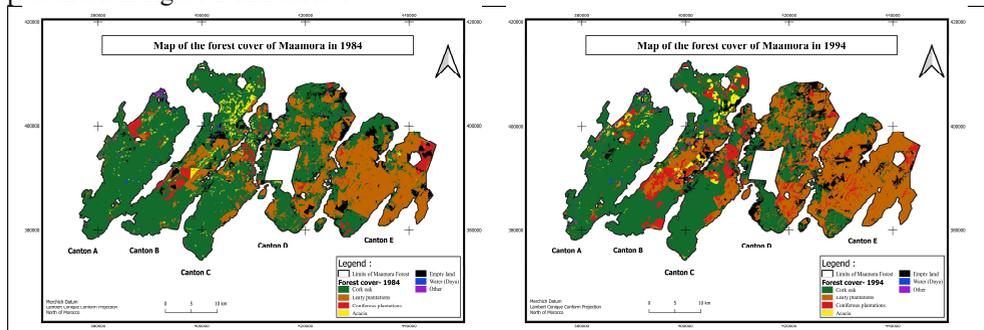
The processing and editing of the images were carried out using open-source software (Quantum GIS).

3 Results

3.1 Forest cover maps

The results of the SVM supervised classification of the Maamora forest for the years 1984, 1994, 2004, 2014 and 2019 made it possible to distinguish seven classes of forest cover: Cork oak, Leafy reforestation, Resinous reforestation, Acacia, Empty Land, Water (Dayas) and Others which brings together all the other covers different from those mentioned above, including roads, buildings, wood and cork deposit, etc.

The results as well as the parameters for assessing the quality of this classification are presented in figure 2 and table 1.



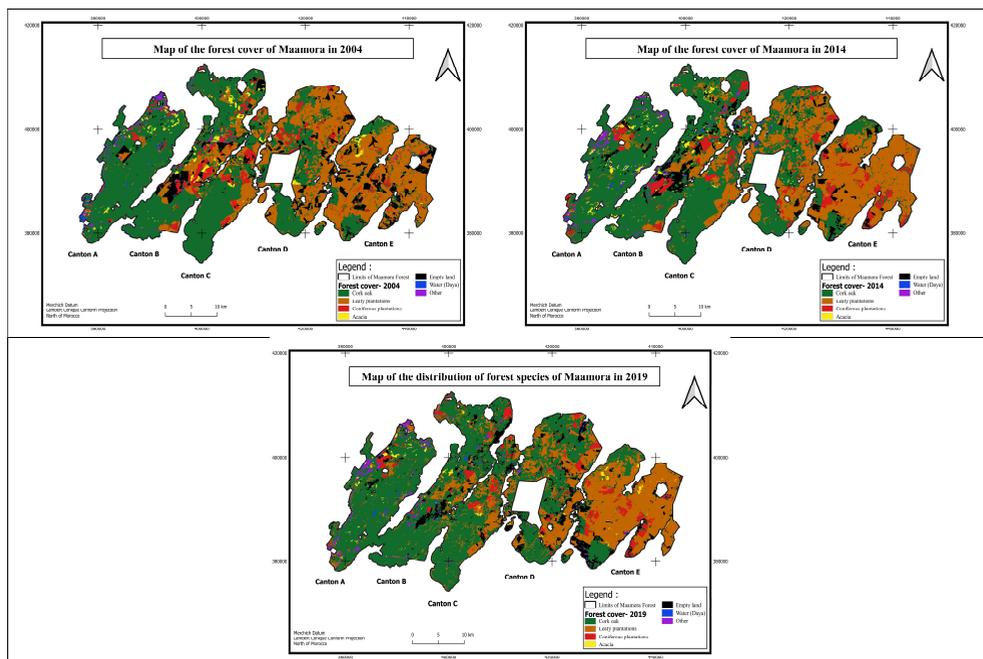


Fig. 2. Maps of Maamora forest covers for the years 1984, 1994, 2004, 2014 and 2019

The qualitative examination of the results presented in figure 2 shows that, for the various dates selected, the forest formations based on cork oak are dominant, occupying the western part of the forest. Leafy plantations, which consist of eucalyptus reforestation, are mainly located in order of importance, in cantons E and D. As for coniferous plantations, made up of pine reforestation, acacia formations and empty spaces, they are in the form of tasks at the level of the five cantons.

Table 1. Overall Accuracy and Kappa Coefficient of the SVM classification

| Years | Overall Accuracy (%) | Kappa Coefficient (%) |
|-------|----------------------|-----------------------|
| 1984 | 90.02 | 87.80 |
| 1994 | 92.01 | 89.90 |
| 2004 | 91.63 | 89.47 |
| 2014 | 92.35 | 91.20 |
| 2019 | 93.77 | 92.84 |

The evaluation of the results was done with the objective of assessing the quality of this classification and its ability to differentiate between the previously defined classes. Thus, the values of the overall accuracy and of the Kappa coefficient, presented in Table 1, are very satisfactory and allow to validate the results obtained. They are greater than 90% for the overall accuracy and 87% for the Kappa coefficient for the selected dates.

3.2 Quantitative evaluation of the evolution of the forest cover

The quantitative results of the SVM classification for the various dates selected are presented in Table 2.

Table 2. Evolution of the area of the forest cover of Maamora between 1984 and 2019

| Years | 1984 | | 1994 | | 2004 | | 2014 | | 2019 | |
|-------------------------------|---------------|------------|---------------|------------|---------------|------------|---------------|------------|---------------|------------|
| | Area (ha) | % |
| Cork oak | 76098 | 58 | 61079 | 46 | 64119 | 49 | 65487 | 50 | 67563 | 51 |
| Leafy plantations | 32855 | 25 | 41929 | 32 | 41561 | 32 | 42231 | 32 | 41427 | 31 |
| Coniferous plantations | 5953 | 5 | 10340 | 8 | 8596 | 7 | 9663 | 7 | 6544 | 5 |
| Empty land | 8122 | 6 | 11985 | 9 | 11027 | 8 | 7993 | 6 | 10626 | 8 |
| Water (Dayas) | 780 | 1 | 602 | 0 | 1165 | 1 | 605 | 0 | 761 | 1 |
| Acacia | 5471 | 4 | 3362 | 3 | 2800 | 2 | 3228 | 2 | 2269 | 2 |
| Other covers | 2642 | 2 | 2624 | 2 | 2651 | 2 | 2714 | 2 | 2731 | 2 |
| Total | 131921 | 100 |

The quantitative evaluation of the evolution of the area of the different Maamora forest cover during the period 1984-2019, showed that the cork oak formations occupied an area of 76,098 ha in 1984 that is 58% of the total area of the forest. This area regressed massively by more than 15,000 ha to reach 61,079 ha in 1994, equivalent to 46% of the forest area. From 1994 to 2019, there has been a reversal of this regression trend towards an increase in the area of around 6,484 ha, i.e. an average annual gain of around 260 ha/year, to reach in 2019 an area of 67,563 ha representing 51% of the total area.

For the eucalyptus plantations, it is an inverse evolution of that of the cork oak which was observed during the period 1984-1994 when an increase in the area of this introduced species was detected, going from 32,855 ha in 1984 to more of 41,900 ha in 1994 i.e. 32% of the area. During the period from 1994 to 2019, the area of eucalyptus has been stable around 32% of the area of the forest.

The area of resinous reforestation composed of pines has known in turn during the period 1984-1994, an increase of 4,387 ha, that is to say an average annual gain of about 440 ha/year. This area subsequently fluctuated between 1994 and 2019 with an overall downward trend going from 10,340 ha at the start of the period to 6,544 ha in 2019.

Acacia formations, for their part, generally lost area during the period from 1984 to 2019 with slight fluctuations, except between 1984 and 1994 when this area declined by more than 38%. In 2019, the area of acacias was estimated at 2,269 ha.

These classification results, as well as the trends in the evolution of the areas for the different species, are confirmed by several studies explaining the extent of these forest formations during the periods of application of the previous development plans [2] [8] [13] [14].

As regards the empty lands and the dayas (Water), they experienced more or less significant changes in their areas during the period 1984-2019. Their areas respectively have increased from 8,122 ha and 780 ha at the beginning of the period to 10,626 ha and 761 ha in 2019, knowing that the area of the dayas is highly dependent on the rainfall of the year and

that of the empties is dependent of the removal of plantations especially by regular wood harvesting carried out by the administration of forests.

Finally, for other covers consisting mainly of roads, buildings, and deposits, ... their area has been generally marked by an upward trend since 1984 to 2019, passing from 2,642 ha in 1984 to more than 2,730 ha in 2019.

3.3 Maps and matrices of cover changes

The analysis of the evolution of the areas of the main forest species from 1984 to 2019 made it possible to distinguish two periods marking the significant changes in their areas: the first is that between 1984 and 1994 and the second is that between 1994 and 2019. Figure 3, Tables 3 and 4 respectively show the maps and matrices of forest cover changes during these two periods.

The analysis of changes, which will concern the conversions of the main forest formations, will only consider the areas estimated at the beginning and at the end of the period, without considering the variations that have occurred during this period.

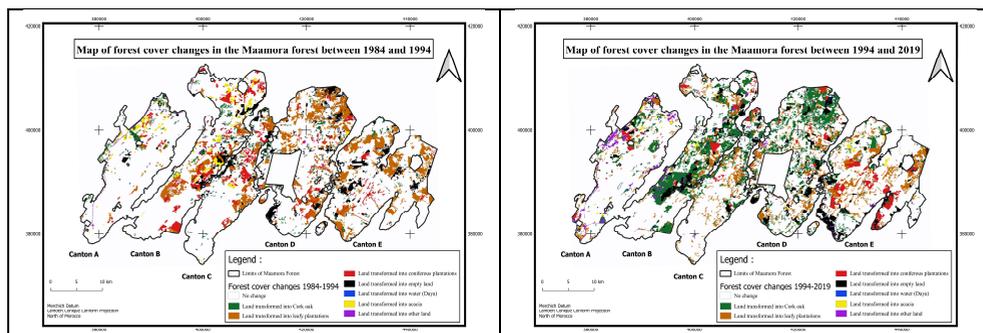


Fig. 3. Maps of forest cover changes during the periods 1984-1994 and 1994-2019

Table 3. Matrix of forest cover changes in % between 1984 and 1994

| Classes | | 1994 | | | | | | Total Area 1984 (ha) | |
|-----------------------------|------------------------|--------------|-------------------|------------------------|--------------|--------------|-------------|----------------------|---------------|
| | | Cork oak | Leafy plantations | Coniferous plantations | Empty land | Water (Daya) | Acacia | | Other |
| 1984 | Cork oak | 86,4 | 28,8 | 32,4 | 45,0 | 19,8 | 54,3 | 20,9 | 76098 |
| | Leafy plantations | 5,0 | 57,1 | 23,3 | 25,0 | 17,3 | 6,9 | 4,7 | 32855 |
| | Coniferous plantations | 1,5 | 3,3 | 28,2 | 2,8 | 1,2 | 7,6 | 5,4 | 5953 |
| | Empty land | 2,4 | 7,8 | 4,2 | 19,1 | 13,1 | 9,2 | 9,5 | 8122 |
| | Water (Daya) | 0,3 | 0,3 | 0,2 | 1,4 | 41,0 | 0,8 | 1,2 | 780 |
| | Acacia | 4,1 | 2,0 | 8,9 | 3,5 | 4,5 | 19,3 | 4,5 | 5471 |
| | Other | 0,3 | 0,7 | 2,8 | 3,2 | 3,1 | 1,9 | 53,8 | 2642 |
| Total % 1994 | | 100 | 100 | 100 | 100 | 100 | 100 | 100 | — |
| Total Area 1994 (ha) | | 61079 | 41929 | 10340 | 11985 | 602 | 3362 | 2624 | 131921 |

The analysis of figure 3 and tables 3 and 4, point out that the forest of Maamora is a very dynamic space that has undergone many changes mainly in the eastern parts of the forest.

During the period 1984-1994, about 14% of the area of the cork oak in 1994 comes from different occupations, especially the eucalyptus; 86% of its area has not changed since 1984, while more than 23,300 ha has been transformed into other occupations.

Leafy plantations have experienced an area gain due mainly to the transformation of cork oak formations and empty lands, which accounted for 29% and 8% respectively of the area of eucalyptus stands when 57% of their area remained unchanged.

As for pine plantations, they have also gained an area of 4,387 ha composed of 72% mainly coming from cork oak and eucalyptus while for the acacia formations, they fell from 5,471 ha to 3,362 ha of which more than 80% of this area comes from the conversion of other species, particularly cork oak (54.3%).

Table 4. Matrix of forest cover changes in % between 1994 and 2019

| | | 2019 | | | | | | | Total Area 1994 (ha) |
|-----------------------------|------------------------|-------------------|------------------------|--------------|--------------|-------------|-------------|---------------|-------------------------|
| Classes | Cork oak | Leafy plantations | Coniferous plantations | Empty land | Water (Daya) | Acacia | Other | | |
| 1994 | Cork oak | 69,1 | 21,4 | 18,3 | 27,1 | 29,2 | 41,1 | 11,2 | 61079 |
| | Leafy plantations | 14,6 | 58,4 | 34,0 | 42,3 | 20,0 | 27,4 | 13,3 | 41929 |
| | Coniferous plantations | 5,0 | 8,4 | 32,2 | 9,1 | 6,6 | 9,5 | 3,8 | 10340 |
| | Empty land | 7,7 | 9,7 | 11,0 | 14,1 | 20,1 | 7,6 | 8,5 | 11985 |
| | Water (Daya) | 0,4 | 0,3 | 0,2 | 0,3 | 19,1 | 0,6 | 0,4 | 602 |
| | Acacia | 2,6 | 1,1 | 2,6 | 5,2 | 1,6 | 11,8 | 5,0 | 3362 |
| | Other | 0,6 | 0,7 | 1,7 | 1,9 | 3,4 | 2,0 | 57,8 | 2624 |
| Total % 2019 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | – |
| Total Area 2019 (ha) | 67563 | 41427 | 6544 | 10626 | 761 | 2269 | 2731 | 131921 | |

For the period 1994-2019, the unchanged area of cork oak is around 70% and the rest of the estimated area in 2019 comes from other forest cover, allowing an area gain of around 6,484 ha between the beginning and the end of the period.

Regarding the leafy reforestation based on eucalyptus, they have practically maintained their areas of more than 41,000 ha although the area unchanged between 1994 and 2019 does not exceed 58.4%.

The coniferous pine formations recorded a decrease of about 3,800 ha, of which only one-third remained unchanged.

As for the acacia stands, only 12% of their area in 2019 which remained unchanged while all the rest, i.e. 88%, comes from the transformation of other cover, particularly cork oak (41.1%) and eucalyptus (27.5%).

4 Discussions

The analysis of the general evolution of the area of cork oak shows a regression between 1984 and 1994, while since 1994, a reversal of this trend towards an increase in his area has been observed. On the other hand, in general for the introduced forest species, in particular eucalyptus and pines, it is an inverse evolution of that of the cork oak which was observed.

The increase in their area was noted during the period 1984-1994 after which it decreased. As for the areas of acacias, they continued to decrease from 1984 to 2019.

Trends in the area changes of the different forest species during the two periods confirm the results obtained by different sources [8] [14]. They are mainly due to the forest policies adopted combined with other factors such as climatic conditions and anthropozoogenic pressures. The impact of these factors was manifested mainly, between 1984 and 2019, in the reduction in area and density and the degradation of the state of development of cork oak stands. These impacts were accentuated by the absence of natural regeneration of this species and by the choice of species to plant.

In terms of forest management methods, during the period before 1994, the main objectives of the forest administration were to maintain cork oak where it was economically profitable; and its conversion into introduced species with rapid growth, where the density of the cork oak is low and where edapho-climatic conditions are difficult for its maintenance [8]. This policy has been guided specifically by economic choices aimed at satisfying the local wood market, in particular eucalyptus wood, for the needs of the Moroccan cellulose industrial unit.

Since 1994, following the various evaluations carried out, especially in terms of reduction of area of the cork oak associated with the reduction of the density of this native species, the orientation has thus changed and aimed to densification and reconstitution of the cork oak stands by assisted regeneration. The area of cork oak regenerated only since 1994 until 2010 are estimated at over 14,600 ha [15] and 12,300ha [16]. These actions carried out have essentially made it possible, on the one hand, to extend the surface area of cork oak to the detriment of the surface area of exogenous species, and on the other hand to densify existing low-density stands while ensuring the production of wood by planting introduced species which are eucalyptus and pine.

5 Conclusion

Maamora Forest is a rich and diverse natural ecosystem that occupies an important place among national forest ecosystems. It is a very dynamic space subject to a multitude of factors that impact its state and its future: climatic conditions, anthropozoogenic pressures, management methods, etc.

The present study provides information on the evolution of the areas of the different forest cover of this ecosystem and consequently the analysis of forest dynamics.

The results of this work have made it possible, using spatial remote sensing, to draw up maps of forest composition and maps of changes from 1984 to 2019, to quantify the evolutions and changes that have occurred as well as to analyse this dynamic.

The analysis of the results obtained allowed to highlight two periods oriented essentially by the management methods adopted and the environmental conditions. The first period before 1994, was characterized by a decrease in the area of cork oak in favour of the area of introduced species such as eucalyptus, pines and acacia. The second period is that from 1994 when there was a reversal of the trend of regression of the area of cork oak compared to exogenous species, mainly following the artificial regeneration work carried out.

Finally, the results obtained from this work will make it possible to propose the need to continue the dynamic of rejuvenation and extension of the area of the cork oak, the indigenous species of the Maamora forest due to its better qualities of adaptation to environmental conditions [2].

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