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Dynamics of forest landscapes associated with bours crops in Morocco's High Atlantic Atlas (case of the lower Oued Tamri valley)

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INTRODUCTION

The forest landscape of the lower wadi Tamri is shaped by a complex interplay between the natural environment and human activities, influenced by both ecological and human factors. The present study is concerned with the analysis of the dynamics presented by Argania spinosa (Argan) and Tetraclinis articulata (Thuya) in the lower Oued Tamri valley, Morocco. The aim is to understand the climatic, geomorphological, ecological and anthropogenic processes that control the dynamic trajectory of this forest ecosystem and to assess their implications for forest conservation and development policies. In addition, this research will provide a characterization of the forest landscape of the mountainous lower wadi Tamri valley and apply a landscape approach to examine the dynamics of its argan forest. The main objectives are twofold: first, to understand the prevailing physical conditions and second, to assess the influence of human and natural factors on biodiversity, regeneration processes and the dynamics of landscape structures. Ultimately, this will enable the development of more effective strategies to promote natural regeneration and improve the resilience of these forest ecosystems

This study therefore seeks to examine the relationship between rainfall variations and their effects on land use and forest structure. The main objectives are to assess the potential for natural regeneration of Argania spinosa and Tetraclinis articulata in the region and to identify the key factors in this regeneration. A comprehensive methodology was used to achieve these objectives, based primarily on field surveys, vegetation measurements and spatial analyses using geographic information systems (GIS) and remote sensing.

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METHODOLOGY

Using a landscape approach, this study examines the evolution of a landscape unit of argan and cedar trees associated with livestock production in the Ait Khmiss forest in the lower valley of the wadi Tamri. After describing the structures and geographical features of this unit, the spatio-temporal dynamics were assessed using Landsat 5, 7 and 8 satellite images (taken in 1984, 2000 and 2022) and ArcGIS software. Field data were used to validate the results of digital processing and land cover sampling. Floristic studies carried out on circular plots completed the study by assessing the natural regeneration of argan and cedar trees. The spatial evolution of the forest landscape was estimated using Landsat images of October 1984, June 2000 and August 2022, with a resolution of 30 m. Based on this landscape approach, we were able to delineate three homogeneous landscape units within the forest in question.

These units are the result of a combination of different landscape elements. These features, which can be visually identified in the field and on satellite images, have been arranged into classes using visual interpretation of the images in ArcGIS software. For the diachronic analysis, the same classes were used in the digital processing of the three satellite images, by applying a controlled classification using the 'maximum likelihood' algorithm. On the basis of the sampling (learning zones), the classification proved to be the most effective in identifying the different thematic classes: cedar and argan forest cover, argan cover associated with livestock farming and marl outcrops with low forest cover. These classes, together with four forest landscape density classes, were used to assess the dynamics of land use and forest density. Fieldwork was also used to define training zones and provide spectral signatures.

The aim of these surveys was to provide a comprehensive analysis of the dynamics of the various landscape components within the unit under consideration. This approach aimed to confirm specific physical conditions and provide an overview of the study area. GIS assisted in the integration of spatial information, such as land use, density structures, regenerated seedlings, exposure, cover tree density and slope aspect, with vegetation data to identify landscape patterns and relationships. Ultimately, the combination of field surveys, vegetation measurements and GIS-based spatial analysis enabled a comprehensive overview of the natural regeneration processes of Argania spinosa and Tetraclinis articulata) in the study area.

RESULTS

The main results of the study reveal the diversity of parameters influencing the dynamics of the forest landscape and the natural regeneration of Argania spinosa and Tetraclinis articulata. From an ecological point of view, the forest landscapes of this unit have functioned and evolved in a Mediterranean climate, which explains the characteristic floristic, phytogeographic and anthropic diversity of these areas. Organized into heterogeneous structures based on a model of agro-sylvo-pastoral use, these landscapes are functioning correctly, but their proper performance is compromised by recurrent and prolonged drought, as evidenced by the low rates of natural regeneration, the decline in floral biodiversity and the increase in decline of these stands. The ecological, biophysical and anthropogenic conditions generally make it possible to distinguish multiple functional and dynamic landscape structures. The plant inventories revealed a total of 23 species in this forest unit, divided into 21 genera and 12 orders in 16 botanical families. There are 16 families and their associated species in the study area. The most represented families in this landscape unit are Fabaceae and Lamiaceae (13%), followed by Solanaceae, Asparagaceae and Anacardiaceae (9%). The remaining 11 families are represented by a single species (4%).

Fabaceae are represented by species such as *Ononis natrix, Genista tricuspidata*, and *Chamaecytisus albidus*. The Lamiaceae include *Lavandula multifida, Lavandula dentata*, and *Thymus satureioides*. The Solanaceae are represented by *Lycium intrecatum* and *Withania frutescens*. In this unit, Argan and Thuya are mainly associated with common species such as *Genista tricuspidata, Olea europea, Pistacia lentiscus, Chamaecytisus albidus*, and *Globularia alypum*, forming plant groupings like the Argan and Thuya grouping with *Globularia alypum* (2477.89 ha), followed by the Argan-Thuya group with *Olea europea* (1380.29 ha), and the Argan-Thuya group

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with *Genista tricuspidata* (1154.57 ha). The grouping of Argan and Thuya with *Pistacia lentiscus* (182.08 ha) represents the smallest area, at 3% of the total.

This forest unit presents fragile landscapes and low resilience that reflect spatial degradation resulting from the combined action of biophysical and anthropogenic factors. As a result, dense and medium-dense forest formations have become preferred grazing areas. Similarly, the area of pure forest landscapes has decreased considerably since 1984, showing a regression of 37% between 1984 and 2000 (falling from 21% to 16% of the forest unit). This decline continued between 2000 and 2022, with a further reduction of 181.25 hectares. The class of marl outcrops with low forest cover increased from 45% to 49% over the same period. The area of forest cover associated with bours crops initially increased by 35% between 1984 and 2000, then decreased by 18% between 2000 and 2022. Conversely, the area of marl outcrops with low forest cover decreased by 16% between 1984 and 2000, then increased by 30% in the following period. The decrease in the area of forested landscapes between 2000 and 2022, in favor of marl outcrops with low forest cover, indicates a transformation of forested areas into landscapes with less dense vegetation.

CONCLUSION

The results of the diachronic analysis confirm this "matorral formation" of forest landscapes, which is linked to persistent drought and the expansion of agricultural land, especially in the northeast of the landscape unit. Between 1984 and 2022, the forest area decreased by 307.56 ha (-5%), while the cultivated land with low forest cover increased by 605.79 ha. The class of bare or very low forest cover lost 295.86 ha (-5%) of its total area over these 38 years. The medium forest cover increased by 32% between 1984 and 2000. Meanwhile, the area of low-density forest cover increased steadily over the whole period, from 23% in 1984 to 33% in 2022. This steady increase is probably due to the medium forest cover class and the bare ground or very low forest cover class, which show an evolution rate of 42% between 1984 and 2022. The regressive dynamics of the bare ground or very low forest cover class is reflected in some plant reclamation, with the appearance of shrubs such as Genista tricuspidata, Launea arborescens or Lycium intrecatum on these slopes, or as a result of land conversion to farmland. The study suggests that a variety of factors impact the regeneration of Argania spinosa and Tetraclinis articulata. These factors include tree cover density, altitude, slope exposure and anthropogenic activities such as grazing and agricultural practices. The main results of the study indicate that different factors influence the regeneration of the two forest species, Argania spinosa and Tetraclinis articulata. These factors depend on the density of the vegetation cover, the topography and human activities such as grazing and agricultural practices. The analysis reveals different levels of natural regeneration potential in different landscape units, with some areas having higher seedling densities than others.

During this period, the study area experienced increasingly frequent and intense droughts. Despite their adaptation to arid and semi-arid environments, the resilience of argan and thuya trees has been compromised by these prolonged or extreme episodes. This affects their growth, reproduction and natural regeneration. This water stress is a threat to the sustainability of these ecosystems and results in a significant weakening of young plants. Furthermore, despite the current low level of deforestation, the regeneration of the argan tree, which is subject to strong anthropogenic pressure, in particular from the significant livestock farming in the lower Oued Tamri valley, is severely compromised by intensive grazing, especially by goats. The combined effects of climate change-induced droughts and persistent human pressure result in limited resilience of Argan and Thuya stands. This is manifested in a reduced ability to resist and recover, a significant decrease in forest density leading to an opening up of the landscape and a challenge for regeneration, especially for the argan tree. The decline in landscape dynamics is mainly due to human impact. This has resulted in the opening up of the forest landscape. Simultaneously, frequent droughts have exacerbated the decreasing forest density.

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