Abstract

The landscapes of the French Mediterranean hinterland have undergone profound changes over the course of the last two centuries. The modalities and speeds of such an evolution cannot be understood without joint consideration of ecological and social factors.

The authors here propose to analyse processes of these types at the limits of the supra-forestry zone, under the conditions prevailing in the semi-mountainous Mediterranean area. They insist equally on the necessity of a systemic approach to the areas on a variety of scales, on the interest of a cartography of dynamics which will enable the spatial representation of the phenomena and on the importance of temporal variables, as much for human activities, as for ecological and notably climatic parameters. It is thus possible to establish a typology of landscape dynamics which distinguishes, as a function of the principal factors, units of more or less marked evolution. A cartography of these dynamics is here proposed for the summit region of the mountain of Lure.

Introduction

The mountainous hinterland of the northern shore of the Mediterranean has undergone considerable landscape change over the course of the last two centuries; this evolution has particularly affected the lower sections of slopes that were formerly cultivated and the summits, which had long been given over to pastural uses. Corresponding to the dynamic of landscape change, the consequence of economic and social transformations, is a transformation of ecological processes, which is all the more significant, since, in this case, the area is a threshold one between Mediterranean, Alpine and Temperate Oceanic regions.
The authors propose, after analysing the factors and processes involved in these changes, to establish a dynamic and ecological cartography of landscape units centred on the supra-forestry ecotone. In fact ‘the majority of works\(^2\) on the supra-forestry limits take into account neither its spatial or multi-scale nature, nor the determining role of the geomorphological form’ (Dider & Brun, 1998). Moreover, the authors aim is to combine spatial and geomorphological data with climatic data, and to include in the analysis the different kind of variations in ecological phenomena, indispensable for the comprehension of such a fluctuating ecotone.

**SPATIO-TEMPORAL VARIATIONS OF THE HISTORICAL AND ECOLOGICAL CONTEXTS**

Situated in the Southern Alps, in the western extension of Mont Ventoux, the mountain of Lure (1,824 m) offers a perfect example of these landscape dynamics at the supra-forestry limit. In contrast to the intra-Alpine mountain massifs lying further west, where this limit can rise above 2,000 m, here it scarcely exceeds 1,600 m. The biogeographical altitudinal succession is a clear indication of the Lure’s location at an ecological threshold. At the base of the south facing slope, formations of marked Mediterranean affinities give way to those qualified as supra-Mediterranean (Ozenda, 1994), composed of forests and moors populated with successional sequences of young oaks. The higher half of the slope corresponds to formations characteristic of mountain zones (groves of beech and mixed beech and fir) whose higher limit forms the transition into lower supra-forestry formations, often qualified as supra-Alpine (Archiloque, Borel, Lavagne, 1971). The northern slope of the mountain can be classified, for the main part, as being different types of mountain beech (Rameau J.C., 1992). The lower part of the slope is populated with pines dating from the reforestation at the beginning of the century, and can thus be categorised as supra-Mediterranean formations. This situation, as an ecological threshold area, clearly appears in the analysis of a 30-year climatic data, from which can be distinguished two principal modes: years that are hotter and drier than normal, in general more ‘Mediterranean’, and years that are cooler and wetter, more ‘Oceanic’.

In this situation as an ecological threshold, landscape changes have significant ecological repercussions. In addition, the mountain of Lure has undergone a genuine revolution over the last 150 years (Pech, Simon, Tabeaud, 1997a). This revolution has been threefold:

- Until the middle of the last century, the mountain of Lure functioned under the aegis of an essentially autarkical economic system, which used the whole of the communal territory. The landscapes at this stage were largely open and only a few forests subsist in the mountain zone. This agro-sylvo-pastoral

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\(^2\)The rare examples of works integrating spatial and geomorphologic dimensions are those of Baudičre and Soutadé in the Western Pyrenees, Dider and Brun in the French Alps, and Zimmerman and Eggenberg in the Northern Alps.
system allows (and requires) high population densities. This system collapsed under the combined effects of an ecological crisis (a re-emergence of torrential phenomena), economic maladjustment (weak economic productivity) and heightened competition from lowlands due to the opening of transport links.

- This multiple crisis led to a significant rural exodus in the second half of the century. The lands thus liberated, were to make possible a policy of reforestation on the northern slope of the mountain, while the southern slope continued to be a source of livelihood, notably in its higher section, which was still being used as pasture land for the numerous flocks of local or regional origins (significant transhumance until the middle of the last century).
- The last fifty years have constituted another rupture, marked by the decline in traditional landscape uses on the southern slope (decline of ovine farming and of traditional cultivation). It is this context of a rural exodus that has, over the recent years, made possible the self-generated reestablishment of vegetation, which is affecting the lower slopes as much as the higher limits of the forest, while during the same period new aspirations have been emerging.

The progression of the forest runs the risk of leading both to a closing of the landscapes and to their banalisation. The grasslands and moors of the supra-forestry level are, in fact, rich in rare heliophilous species which would be threatened by a forest covering. Above and beyond the effects on specific biodiversity, these changes also have potential consequences on the level of landscape biodiversity, of the geochronodiversity (Arnould, Hotyat, Simon., 1999). On account of its aesthetic and cultural value, that of the landscapes of Giono (Pech P., Simon L., Tabeaud, 1997b) the mountain of Lure is a symbol of this mountainous Haute Provence area of diverse and open landscapes which a continual forestry covering would threaten to denature. The motivation for analysing recent dynamics at the upper limit of the forest, thus, goes beyond purely scientific interest, to a concern for good land management and conservation.

**Speeds and processes of forestry reestablishment**

**Quantitative Data**

By means of photo-interpretation, archive documents and terrain reports, a preliminary cartography of the dynamics of vegetation change on the Lure ridge was carried out (see Fig. 1), enabling a quantitative estimation of principal unities. The major physiognomic categories observed, classify different types of forestry formations, low-level formations, bare soil, and mixed herbaceous and tree formations.

A certain number of conclusions can be reached about the dynamics of spatial change on the Lure ridge over a forty year period. From a strictly quantitative perspective (see Fig. 2), the dynamic is characterised by a marked increase in the surface area of closed forestry (from 18% of the surface area in 1956 to + 38% in 1993, and + 40% including the conifer populations), by a regression in the amount of grasslands and moors (from 37% to 21%) which is partly compensated by the appearance of mixed grassland/conifer units (from 0 to 11%). The total surface area
covered by bare earth covered with gelifracts has sharply diminished (from 11% to 4%), again compensated by the progression of conifers on bare earth (from 0 to 4%).

Going beyond a strictly quantitative resume, maps permit the spatial representation of such evolutions. The increase in closed forestry areas has occurred, above all, through a densification of the open formations existing in 1956 and, secondly, by the installation of conifer populations on grasslands. The advances of forest borders are, on the other hand, limited to a few sites in the shelter of the valley floor and in the east part of the ridge at altitudes below 1,400 m. The regression of grasslands and moors is not homogenous: at altitudes below 1,600 m grasslands progressively cede ground to tree populations, which are still far from being closed (coverage of tree strata of less than 20%). At more than 1,600 m, in the proximity of the summit, stability has the upper hand, and here the dynamic seems largely blocked. The same altitudinal divide, visible on both sides from Pas de la Graille, equally characterises bare earth covered with gelifracts. Their disappearance is particularly noticeable at altitudes lower than 1,600 m, in favour of moors and grasslands and the dispersal of conifers. This initial spatial representation permits a better understanding of the processes of the dynamic of vegetation change underway at the supra-forestry level.

**The processes: analysis of some transects**

Fig. 2. A comparison of the surface areas occupied by different vegetation formations at the upper limit of the forest between 1956 and 1993.
The modalities of the reconquest of this area by vegetation have been analysed on the basis of twenty representative transects. They enable the definition of four dominant processes.

- **Borders in slow progression.** This type of process affects notably the higher limit of the beech area situated here towards 1,650 m below the summit of Lure. The supra-forestry zone reaches its maximum extension (+ 800 m distance between the ridge and the higher limit of the forest on the southern slope). The transition takes place rapidly between closed and high (+10 m) beech areas, extended by a rim only a few metres wide, composed of young beeches 1 or 2 m high. Ahead of this border, the supra-forestry zone is grassland dotted with dwarf junipers (*Juniperus nana* L.) These junipers participate in the reestablishment of forestry by playing a protective role (attenuation of the constraints linked to the wind) which favours the installation of several pioneer species ahead of the forestry limit. *Sorbus aria, Acer opalus, Pinus silvestris* manage to make progress in the shelter of the dwarf junipers. However, this progression is very slow (of the order of a few metres between 1956 and 1993) and fragile (there is a significant mortality rate among the pioneer species). The role of altitude here is the determining factor. To the east of Pas de la Gaille, at a height of about 1,400 m, the progression of the beech areas is far more significant, 30 and 50 m between these two dates.

- **Densification of existing populations.** This type of process affects the open beech areas already present in 1956. Two modalities can be distinguished here. Firstly, a progression of the beeches aided by the presence of seed bearers and a reasonably dense strata of bushes, which facilitate the development of forest areas. This is most manifestly the case in the proximity of Pas de la Graille, where the densification of the beech area is taking place at the expense of a strata of bushes made up of *Genista radiata* and *Sorbus aria*. Second modality concerns areas that were formerly grassland inside beech areas, and which have been partly overtaken by the installation of conifers (principally *Pinus silvestris*), and have thus created favourable conditions for the installation of beech and pine (presence of young individuals under the conifers). This densification of the beech areas illustrates the different sylvigenetic phases of the beech-pine forest.

- **Dispersal at a distance**: the expansionist role of conifers. At several points on the line of the ridge, notably to the east of Pas de la Graille, conifers have become installed both on the grassland and the juniper moors, and even on areas of bare soil with gelifractions covering. These populations are very heterogenous both in terms of their size and density, comprising black pine (*Pinus nigra*) Scots pine and larches (*Larix decidua*). This reestablishment of forestry seem to develop favourably thanks to the thalwegs that traverse the southern slope.

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3 The representative nature of these transects was established from a passage matrix produced from diachronic photo-interpretation, enabling the definition of characteristic evolution types between the two dates.
The altitudes here are up to 1,500 m, and the slopes are generally less steep than at the summit, in the order of 10 to 15%. In these conditions, there is also a significant increase in beech as undergrowth.

- **Transfers of vegetation from the north slope to the southern slope.** These transfers often occur due to a dip in the ridge line. When the beech-pine areas of the north slope are situated near the ridge, passes permit the development of stunted beeches which then progress onto the southern slope. This process only occurs at altitudes below 1,600 m. In the same way, the largest section of conifers (larches and black pine) present on the ridge line in its western section seem to have come from the major reforestations situated below on the north slope. These processes can in large part be explained by the frequency and the strength of the north winds, most notably the Mistral.

The dynamic of forestry change at the limit of the supra-forestry zone is caused by differential processes revealing different modes of spatial progression. The modalities of reestablishment indicate the multiplicity of ecological factors playing a role in the locations and speeds of evolution: topographical and geomorphological factors, and bioclimatic conditions. It is the combination of these different factors, and their spatial distribution which permit an understanding of the complexity of the upper limit of the forest.

**The ecological factors affecting the forestry dynamic and their variations**

As a mountainous area on the fringe of the Mediterranean region, the Lure ridge suffers from the combined effects of winter cold and summer heat. Two meteorological measuring stations *in situ*, one in a forestry clearing at an altitude of about 1,500 m, other in the supra-forestry zone at about 1,660 m made possible an analysis of climatic parameters and study of their principal gradients by comparing the data recorded at altitude with those provided by Météo-France at Saint-Auban at the foot of the southern slope of Lure (alt.: 450 m). The principal conclusions to be drawn from this information are those of an accentuation of the thermal pressures at the higher limit of the forest. If the average thermal gradient between Saint-Auban and the grassland is in line with the theoretical gradient which has been proposed on many occasions (Douguedroit & de Saintignon, 1980), it appears that this gradient is well below average between the base of the slope and the station situated at 1,500 m (3.4°C/1000 m), and that it increases considerably between the latter station and the grassland (3.1°C for 150 m); the moderating role of the forest can provide a partial explanation only. This increase causes, in addition to a significant reduction in the period of vegetation, an increase in the number of days of frost, and especially of late frosts with serious consequences, as much from a biogeographical perspective, as from a geomorphological one. To these pressures caused by the cold, must be added obstacles created by summer dryness, notably during more ‘Mediterranean’ years, when, in the surface soils with...
minimal hydrous reserves, hydrous stress is possible from March to October, without overlooking, finally, the pressures created by the winds (mechanical and physiological pressures), or, in addition, by the snow covering.

These climatic conditions testify to the diversity and intensity of the morphological processes which affect the limestone ridge where sectors of steep slope (30 to 35 degrees at the summit of the northern slope and on the secondary hogback fronts on the southern slope) alternate with gentle slopes (the structural back slopes of the southern face). The scale and intensity of the liquid precipitations (a high frequency of pluvial episodes of more than 50 mm/24 h) explain the extent of runoff phenomena which result in an eluviation of topsoil and the formation, in certain areas, of a pavement of limestone blocks. On the steeper slopes, this activity can even lead to landslides or erosive runoff streams. Runoff waters are also locally concentrated in torrential channels which can also provide a course for loaded runoff streams (landslides). The water of melting snow actively participates in these runoff processes, particularly on the northern face, where large snow banks accumulate during the winter. Accumulations of snow are also the cause of avalanches localised within the large corridors which mark the northern face. The role of the cold is equally a determining factor in the morphodynamics of the supra-forestry level. Bare slopes are thus submitted to numerous cycles of freeze/thaw which lead to the development of characteristic small forms (periglacial mud circles or pustules lifted by the ice, the initial stages of striated soils on slopes between 25 and 30 degrees). Morphological dynamics is less marked on areas with closed vegetation cover, where only transfers moderated by eluviation as well as limited creep phenomena appear. Thing morphological dynamics have a decisive role in the speed of forestry progression, through the pressures they exert on vegetation (difficulties of rooting, the snapping of branches, the elimination of topsoil and lessening of the useful reserve, etc.)

Under such difficult conditions, absence in the supra-forestry zone of the principal species characteristic of the zone, is of major importance. Spruce and mountain pine are in fact absent from the upper limit of the forest, while larch has only recently been reestablished due to reforestation. This absence of the subalpine level ‘is the most striking and characteristic phenomenon of the meridional Pre-Alps’ (Archiloque et al, 1971). Yet, absence of these species, the best adapted to the rigours of the bioclimatic and morphological conditions encountered at the supra-forestry level, constitutes a major impediment to the forestry reestablishment.

These ecological pressures, discriminatory in themselves, must also be considered in the light of their temporal variations. If the 30 years meteorological data demonstrates the two principal modes outlined above, an analysis of pluviometric data since the beginning of the XIX century, brings to light cycles of variation between dryness or moisture taking place over several decades. These variations, which, it seems, can be brought into correlation with the North Atlantic Oscillation (Tabeaud et al., 1999) result in a variation in the pressures on the ridge, which could in turn lead

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4 It would seem that this absence results from both palaeoecological evolutions (quaternary floral migrations) and from present conditions (an estival dry phase) (Archiloque & alii, 1971).
to more or less rapid advances in the forestry limit, or even by regressions of this limit during successions of particularly dry or cold years. In this optic, current hypotheses on global warming could result in an accentuation of estival pressures on this mountain on the Mediterranean threshold, which could be difficult for a large number of species of the higher mountain zone to bear.

It is, thus, through a systemic perspective that takes duration into account, that the problem of transition in the mountain supra-forestry zone must be approached. The complexity of the parameters to take into consideration, demands work on the scale of biotopes, the largest scale, under which the landscape could here be considered as a mosaic resulting from the heterogeneity of its situations.

**For a geoecological cartography of landscape dynamics**

The map of the synthesis of landscape dynamics is founded on the combined analysis of different ecological parameters and on their effects in evolutionary terms. Three principal types have been drawn up in respect to the rate of change:

The zones of stagnation of the landscape dynamics corresponding to areas of strong geomorphological dynamics, are often situated at more than 1,600 m and are those where the role of the snow-covering is the determining factor. Thus, the following types can be differentiated:

- **Bare soil of the southern slopes near to the summit.** The only evolution, observable with difficulty, concerns the pioneer stages of dwarf junipers, and is marked only very locally by an increase in the density of coverage, but does not exceed a coverage rate exceeding 20%. These slopes remain dependant on alternations between repeated freeze/thaw for 7 months in the year; these alternations are exacerbated by the reshaping of the snow covering on these surfaces which are highly exposed to the north wind. Runoff and gelifraction lead to the mobilisation of the topsoil and to maintenance of rough paving surface.

  Similar processes affect the hogback fronts situated on the southern slope and oriented towards the north. There, the snow-covering lasts for limited durations under the cumulative effects of the slope and exposure to the winds of the northern sector, as well. Active runoff keeps small channels open while, locally, striated soil forms appear. These hogback fronts are virtually without any vegetation.

- **The ravines of the northern slope are the site of an irregular, but on occasions intense morphological dynamic.** Situated underneath snowbanks which accumulate under the ridge exposed to the north, they are liable to being traversed by avalanches and loaded runoff. Vegetation bears witness to this instability with the presence of groupings of pioneer willows, maples and withe beam which rarely achieve the stage of a maple grove, representing the state of
normal equilibrium, lower on the slope.

- Grasslands situated in the snow coombs near the summit (alt. 1,700 m) also demonstrate a great stability. An accumulation of topsoil, thickness and duration of the snow-covering permit the development of a thick grass covering which, at this altitude, hinders the possible progression of tree species, despite the reduced morphological dynamics. In addition, these grasslands are regularly used as pasture for the rare flocks still present, a factor which contributes to maintaining the asylvan environment.

The principal characteristics of the forest ecotones is that of a slow landscape change. This can either be observed through an external dynamics marked by slow forest progression or an internal rate of density of vegetation cover increase.

- The upper limit of the beeches on the southern slope at about 1,600 m altitude is an example of this type of dynamics. A slow progression can be observed on the grasslands dotted with junipers, which favour the installation of pioneer species. This slow progression is demonstrated by the presence of failing junipers on the threshold of the beech woods, in areas which have recently been reconquered by forestry.

- On the north face, the conifer/beech area has only succeeded in populating the ridge at altitudes below 1,600 m, generally in the shelter of a pass. The progression is a slow one because of a morphological dynamics which is still active (runoff, landslides). The old trees, notably firs, present in the upper section of the beech conifer area play an important role for the young individuals in protecting them from the north wind.

- The internal dynamics of beech wood, which is marked by an increase in the density of the tree cover, is a slow process, as the presence of a succession of different sylvo-genetic stages proves. It corresponds to a deceleration of the morphologic dynamics in favour of pedological developments, notably on the gentler slopes, which limits the effects of the estival hydrous pressures.

At an altitude of less than 1,500 m, the morphological and climatic pressures become blurred. The duration and thickness of the snow covering diminish, and the freeze/thaw cycles still present, are less frequent. Under these conditions, forest progression appears much more clearly. These rapid evolutions characterise particularly the grasslands and partially uncovered soils to the east of Pas de la Graille. The processes that cause this have already been discussed: the dispersal of conifers and the progression of beeches along the thalwegs that cross the slope.

**Conclusion**

This approach to the landscape dynamics of the forest/supraforestry ecotone suggests a series of conclusions:

- The understanding of evolution rates requires a **systemic approach** to the areas,
since ecological factors seem so tightly involved in a highly rigorous context of this type. To the determining role of reliefs, an influence of climatic factors, in particular of snow must be added.

• In this perspective, a multiscale and spatial approach is indispensable. Regional situation here, explains the cumulative effect of the pressures of both the cold and the dry seasons, which account for the reduction of the higher limit of the forest, in comparison with other Alpine massifs. These pressures, due to a position as an ecological threshold, find a variety of expression as a function of the multiplicity of biotopes present in the vicinity of the ridge line, and demand a large scale cartography of the landscapes and processes.

• The temporal and historical approach, although often overlooked, cannot be so here. Anthropic interventions, but also variations in climatic parameters, can result in a significant modification to the dynamics, as was the case in the last century (Pech, Simon & Tabeaud, 1997a).

A geoecological approach of this type to the landscapes study underlines the complexity of the problems faced by a manager of these regions, marked by a strong dynamics of landscape change, by an imbrication of ecological and social factors and by marked temporal variations. The stakes, in terms of landscape, biodiversity and getting the maximum from available resources, are high.

References


Fig. 1. Dynamic of vegetation formations on Lure mountain, 1956-1993.
Fig. 3. Examples of the dynamic of forestry change at the limit of the supra-forestry zone.
Fig. 4. Geoecological units at the upper forestry limit (The mountain of Lure, Southern Alps).