

## 8.1. History of Sierra Nevada forest management: implications for adaptation to global change

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### Abstract

The implementation of adaptive management plans for forest resources requires, among other things, the evaluation of forest-management effectiveness. This is even more vital in a context of global change, since the uncertainty concerning the response of ecosystems to the actions is greater. In this sense, a spatial catalogue has been designed for forestry actions undertaken in Sierra Nevada from 1935 to the present. This information enables the evaluation of the time course of variables such as the reforested surface area per year, the density of the reforested stands, or the broadleaf:conifer ratio in the reforested populations. The reforested surface area per year has continued to follow a clear decreasing trend from the 1970s to the present. Also, an increasing trend has been detected in the broadleaf:conifer ratio in reforested stands. Finally, an overall index of forest management has been designed for Sierra Nevada. This index takes into account the type of action, its intensity, and also the timespan between its application and the date of calculating the index. This index shows in a synthetic way the intensity of forest management in Sierra Nevada, which has been decreasing since the 1960s.

### > Aims and methodology

The aim of this work is to analyse the forestry actions conducted in Sierra Nevada, considering the temporal component (data series from 1935 to 2014), the spatial one (spatial representation of the stands acted upon) and the types of actions (reforestation, thinning, post-fire restoration). This shows different spatio-temporal patterns of the forestry actions, providing an assessment of their relation to the prevailing

forestry policies at each stage [1], as well as deepening in knowledge concerning land-use changes [2]. A two-phase methodology was applied: a) Gathering information on forestry actions and including them in a data base, considering that this information has different formats and appears in different sections of public administrations in charge of this forestry material. Since 1990, there has been a registry on paper of the

forestry actions taken. This registry contains information on the different stands treated (reforested, thinned, cleared, pruned, etc.), as well as their characteristics (intensity of the action, species planted, etc.). b) Analysing and interpreting the existing information.

### > Results

The following variables were analysed in relation to the management of Sierra Nevada forests over recent decades (Figure 1):

#### **Reforested stands:**

- Progress of the reforested surface area per year. This variable indicates how the reforesting effort by the environmental administration changes through time. A maximum was reached between the 1960s and 1970s. In this period, about 3,000 ha per year were planted. At present the reforestation rate

is far lower, in no case reaching 500 ha per year.

- Development of the ratio reforested broadleaf:conifer surface area. The results clearly indicate a rise in the amount of surface reforested using broadleaf species.
- Development of planting density. The data available also reflect a clear trend towards a lower density of the reforested populations. This gives an idea of the types of projects performed, which are steadily

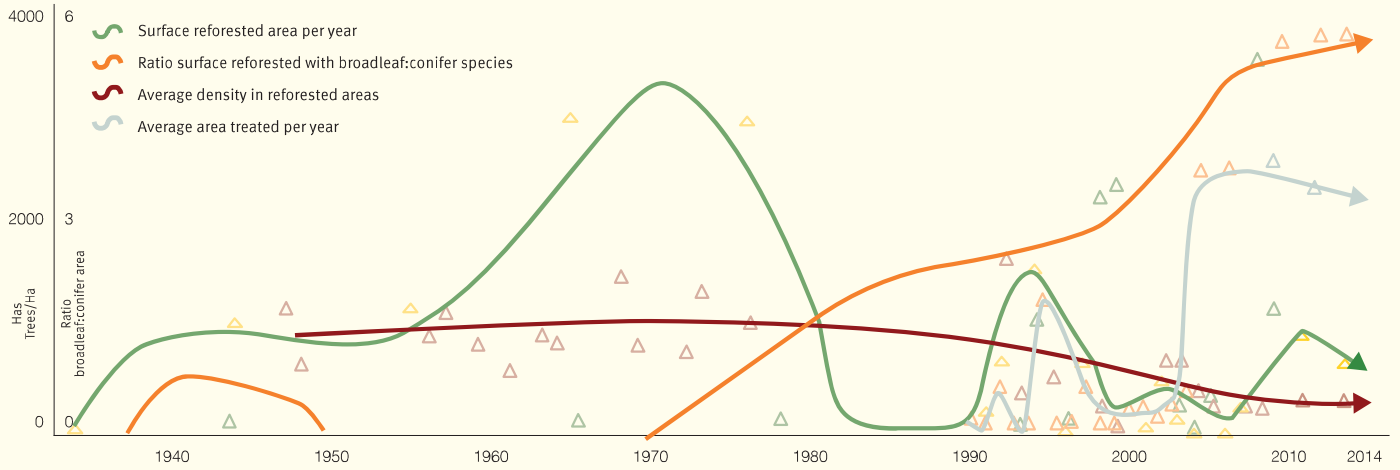
more specific and adapted to needs of each territory.

#### **Forest treatments:**

- The time course of the surface area treated by thinning/clearing and pruning has been analysed from 1990 to the present. This variable greatly fluctuates. No clear trend was discernible.



**Figure 1**



Temporal evolution of the reforested surface by year (green), the broadleaf:conifer ratio (orange), the average density of the reforestation (red) and the thinning/cleaning surface per year (gray) in Sierra Nevada from 1930s to present.

**Forest-management index for Sierra Nevada:**

- An index was proposed to summarize the intensity of forest management in Sierra Nevada. This indicator represents the degree of management to which the Sierra Nevada forest ecosystems are subjected by the Environmental Administration. The indicator is an useful tool to visualize the intensity of the territorial management.

This index is calculated by assuming that the degree of management is greater the more intense the action at the time of execution (reforestation > tree thinning/clearing > shrubland thinning > branch thinning > pruning > waste removal). This effect is attenuated linearly over time. That is, the longer the passage of time, the lower the intensity of management in a given period.

Figure 2 shows the spatial distribution of the forest-management index in 2014. The red sites are those that have either undergone more intensive or more recent actions. Most of the zones that underwent action have a low degree of management (green tones). These correspond to the large reforestation areas established in the 1960s and 1970s.

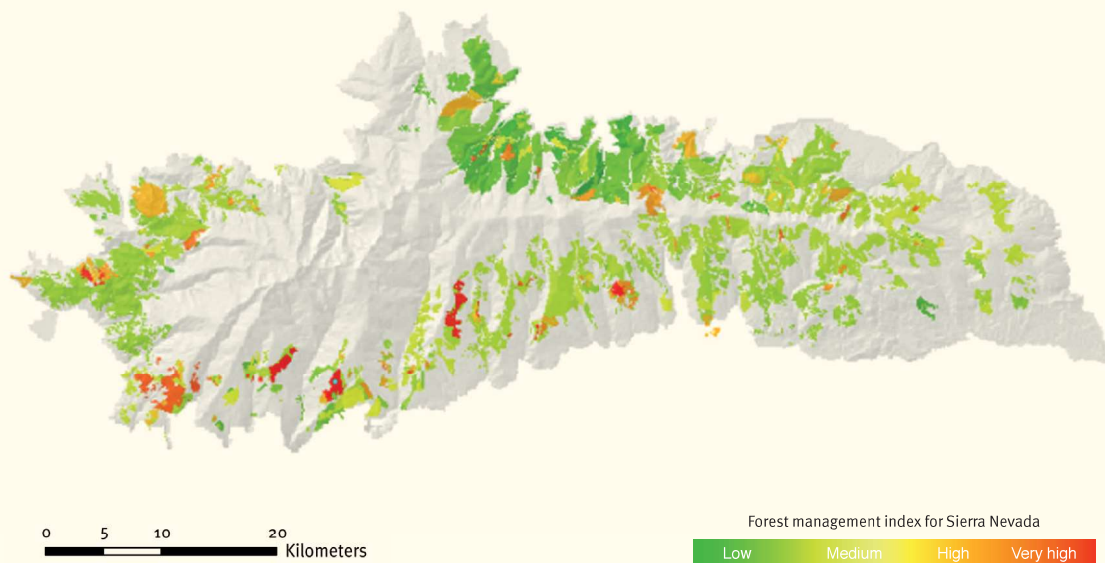


View of the reforested pines of Marquesado del Zenete.



Distribution of plants with pack animals in Laujar de Andarax, April 2009.

Figure 2



Map showing the index of Sierra Nevada forest management in 2014. Green color indicates a low degree of management, while red indicates a high degree of management.

## ► Discussion and conclusions

Figure 1 indicates that the first reforested efforts began in the 1930s and 1940s [3]. From 1954 on, with the creation of the Forest Hydrological Service, there were two decades of very intense reforestation, which reached some 2000 ha per year. More recently, the only noteworthy reforestation peaks correspond to fire restoration, as occurred in 1995, when 1,300 ha were reforested out of the 2,000 ha that burnt in 1994 in the South part of the mountain or after the blaze of more than 3,000 ha in the Southwest in September 2005. From the end of 1970 to the present, there has been a change in reforestation policy. Previously, vast reforestation projects were implemented with the specific aim of reducing soil loss in the territory at the same time as promoting rural employment [4]. Currently, reforestation is considered as a response to impacts on the plant cover, such as fires or other catastrophic events, but also as a way to diversify and reinforce the forest cover. On the other hand, it is also evident (Figure 1) that the reforested broadleaf:conifer ratio has risen. Except for sporadic planting of acorns in the 1940s [5], the rest of the reforestation until the 1990s used conifers as the main species, a

situation which has been reversed at present, with broadleaf species predominating over conifers. The greater availability of resources for reforestation, less reforested surface area per year, and advances in the scientific knowledge and techniques regarding the ecology of the Mediterranean forest could explain for the increased use of broadleaf species and the consequent diversification of the reforested stands. Also, a clear trend can be observed towards reducing the planting density, shifting from a density of greater than 2000 trees/ha in the 1960s and 1970s to 500-600 trees/ha at present.

Finally, the forest-management index (Figure 2) accurately synthesises the management trends above mentioned. The intensive reforestation of the 1960s and 1970s increases the management index, which from this point begins to descend not only in terms of actions undertaken over a smaller surface area, but also less intense measures implemented (lower reforestation density, lower rate of reforested individuals as opposed to other types of lower-intensity forestry action, etc.). However, with respect to recent

actions, it bears emphasizing the efforts made to thin extensive areas of pine forests in Sierra Nevada between 2005 and 2014, funded mainly by the Council of the Environment and Land Management with co-financing from the European Union. However, the index does not include the linear preventive treatments against fires (manual or mechanized, primarily in firebreaks), which are undertaken regularly and throughout the mountains.

## Evolution of the main actions of forest management in Sierra Nevada

A summary of the most significant qualitative differences between past and present forest management of Sierra Nevada is shown below. This results from the analysis of the database of forestry

actions and information collected from interviews to officials from the Environmental Agency, managers and those responsible for the main actions.

1950-2000	2000-2010
<b>REFORESTATION</b>	
<ul style="list-style-type: none"> <li>Greater reforested surface area. Aim: hydrological-forest restoration at basin level, accompanied by engineering management of the river courses.</li> <li>First phase: Manual planting. Second phase: mechanized preparation of the land (terracing).</li> <li>Greater planting density (&gt;2,000 trees/ha).</li> <li>Regular planting distribution (square or staggered pattern, frequently in terraces).</li> <li>Predominance of conifers as opposed to broadleaf species, mainly <i>Pinus halepensis</i> and <i>P. pinaster</i> in the low areas and <i>P. nigra</i> (sunny exposures) and <i>P. sylvestris</i> (shady exposures) in the higher areas. Almost exclusive use of tree species.</li> <li>Often combined planting (1-2 years) with seed in the same hole.</li> <li>Predominance of plants from allochthonous seed.</li> <li>Plants from nurseries located on the same mountain, with rudimentary production systems. Previous acclimation to local conditions.</li> <li>Directly performed by the Forest Administration.</li> </ul>	<ul style="list-style-type: none"> <li>Smaller reforested surface area. Aim: mainly post-fire restoration of forests and dispersal centres for stand diversification.</li> <li>Manual or mechanized planting according to demands of the terrain, without terracing.</li> <li>Lower planting densities.</li> <li>Irregular planting distribution, often in copses.</li> <li>Greater proportion of woody broadleaf species (trees and shrubs) belonging to the floristic group accompanying the natural plant association of the area.</li> <li>Predominance of planting vs. sowing.</li> <li>Plants from a traced origin, with local varieties given priority.</li> <li>Plants from centralized nurseries with more advanced production systems. Plants without previous acclimation to local conditions.</li> <li>Executed by public or private enterprises.</li> </ul>
<b>FORESTRY TREATMENTS OF PINE FORESTS</b>	
<ul style="list-style-type: none"> <li>Minor thinning during the first reforestation stage: elimination of double trunks and pruning with hatchet, especially near roads.</li> <li>Scattered thinning for commercial purposes in the 1980s and 1990s.</li> </ul>	<ul style="list-style-type: none"> <li>From the 1990s on, thinning over a greater surface area, with predominance for conservation (control of competition and diversification of the stand) and preventive aims.</li> <li>Gradually the pattern becomes more irregular, seeking to break the uniformity of the stand. Systematic felling gradually gives way to the combination of cutting of different intensities, predominantly 30-50% of the trees removed.</li> </ul>
<b>BRANCH THINNING AND PRUNING OF BROADLEAF SPECIES (HOLM AND PYRENEAN OAKS)</b>	
<ul style="list-style-type: none"> <li>Done by the local population to obtain firewood.</li> </ul>	<ul style="list-style-type: none"> <li>Done mainly by the administration for conservation and prevention. Secondary use as fuel.</li> </ul>
<b>INFRASTRUCTURES TO SUPPORT THE MANAGEMENT OF FOREST (NOT INCLUDED IN THE FOREST-MANAGEMENT INDEX)</b>	
<ul style="list-style-type: none"> <li>Construction of pens above the reforestation line to support livestock use of the peaks.</li> <li>Opening of practically the entire network of roads and service routes to support forestry activity.</li> <li>Acquisition of terrain, mainly abandoned agricultural land, for property of the state administration and for reforestation. Consortium with the city halls that give rise to the public mountain areas of the city halls.</li> </ul>	<ul style="list-style-type: none"> <li>Scattered construction of pens. Maintenance, improvement, and adaptation of the existing ones to the landscape.</li> <li>Maintenance and improvement of the existing network of roads and service routes.</li> <li>Purchase of parcels with special interest for conservation with the creation of the Sierra Nevada Protected Area (total 6,184 ha)</li> </ul>