Observatorio
Cambio Global
Sierra Nevada

Sierra Nevada Global-Change Observatory
Monitoring Methodologies

January 2014

JUNTA DE ANDALUCIA
CONSEJERÍA DE MEDIO AMBIENTE Y ORDENACIÓN DEL TERRITORIO

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SIERRA NEVADA GLOBAL-CHANGE OBSERVATORY
MONITORING METHODOLOGIES

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Introduction

Sierra Nevada Global-Change Observatory: Monitoring Programme

Overview of the programme to monitor the effects of global change in the Sierra Nevada

The Sierra Nevada Global-Change Observatory is intended to put together useful and relevant information regarding the ecological systems and the socioeconomics of Sierra Nevada. The project has four fundamental parts to fulfil its overall objectives: 1) a **monitoring programme** to collect socioeconomic data; 2) an **information system** for appropriate data management; 3) a series of mechanisms that enable the effective transfer of the results on **adaptive management**; and 4) a **outreach and reporting** system. Dissemination is indeed one of the hallmarks of the project, since the design of management systems is considered vital for fortifying the resistance and resilience of the natural systems confronted with the new hypothetical scenarios.

This document contains detailed descriptions of all protocols that have been implemented in the Sierra Nevada monitoring programme. The descriptions offer basic information on the structure and dynamics of key processes that may reflect the impact of global changes in our study area.

The design of the Global-Change Monitoring Programme in the Sierra Nevada is based on the conceptual and thematic frameworks proposed by the GLOCHAMORE strategy (GLObal CHAnge in MOuntain REgions http://mri.scnatweb.ch/projects/glochamore), sponsored by UNESCO, in which hundreds of noted experts (scientists, managers, technicians) have participated. Thus our monitoring programme in the Sierra Nevada can be considered an implementation of the GLOCHAMORE conceptual framework. The local implementation of the global initiative first required the exhaustive compilation of monitoring protocols that were previously used in the Sierra Nevada. Thus, many of the monitoring protocols for wild fauna (Spanish ibex and wild boar) and flora (threatened species endemic to the high peaks) have been incorporated into the current programme. The result provides 48 methodologies related to data collection on various aspects of the composition, structure, and function of the Sierra Nevada ecological system. This set of protocols is the result of including existing methodologies (after a review process) and the specifically designed philosophy of the GLOCHAMORE project. These protocols were designed under the supervision of scientific experts in each field.

For each of the **thematic areas** proposed by GLOCHAMORE, monitoring methodologies are defined in order to assess both the status of key ecological functions, such as the structure of the main Sierra Nevada ecosystem as well as possible global-change impact on Sierra Nevada. It also defines monitoring methods to characterize human activity in Sierra Nevada. The scheme allows us to cover many of the aspects considered to be crucial by the scientific community in evaluating the effects of global change in mountain regions. Therefore, the characterization of GLOCHAMORE thematic areas and the methodology design associated with each of them is based on scientific hypotheses to be addressed by the monitoring programme. In addition, each monitoring procedure is included into a consistent conceptual model based on the ecosystem, our tracking programme can be considered to be “monitoring based on questions”. Each protocol provides information on a number of environmental variables related to the thematic sphere covered. The data is gathered from a total of 130 different variables.

In addition, our programme is designed to take into account the great **spatial** heterogeneity and ecological diversity of the massif. Consequently, the programme follows a hierarchy of **spatial scales of the data gathering**. Thus, the scale or spatial resolution of the data compiled for all methodologies covers a large part of the spatial heterogeneity of the Sierra Nevada. As a result, we have procedures that gather data on a finer scale (points and transects), on a somewhat coarser scale but covering the entire space (pixels of satellite images or polygons of a vegetation map, for example), and finally on an administrative-boundary scale (public mountain, municipal area, or catchment basin). In addition, many of the sampling points that take more detail (points and transects) are spatially aggregated in places with high density and have a multi-parameter weather station. These sites are known as **Intensive Monitoring Stations**. Each of these protocols not only collects data on a spatial scale but may also apply them in other different spatial fields. For example, data from a weather station (collection-point scale) can be extrapolated using various techniques in all territories (the entire area). This interpolation process cannot be applied to other ecological sampling such as the monitoring of raptors. Thus, each procedure can also be characterized by the extent of the application of data captured therein. Some protocols have an extension point, while others may extrapolate their values to municipal scales or to the entire protected area.

Finally, our monitoring programme incorporates the **temporal** dimension from two different perspectives. On the one hand, we consider it essential to gather historical information on the structure and dynamics of the Sierra Nevada ecosystems. The purpose of this historical reconstruction is to ascertain the past in order to understand the present and thereby try to predict future scenarios. In this regard, it is important to consider the length of the series available for each subject monitored. Highlights include the vegetation and climatic data for those with a longer series. On the other hand, it is vital to consider the frequency of the data collection in each protocol. In this sense, we use the methodologies which take information

at periodicities of less than a day (weather stations) to others by which inventories are conducted annually or every several years (e.g. reptile monitoring).

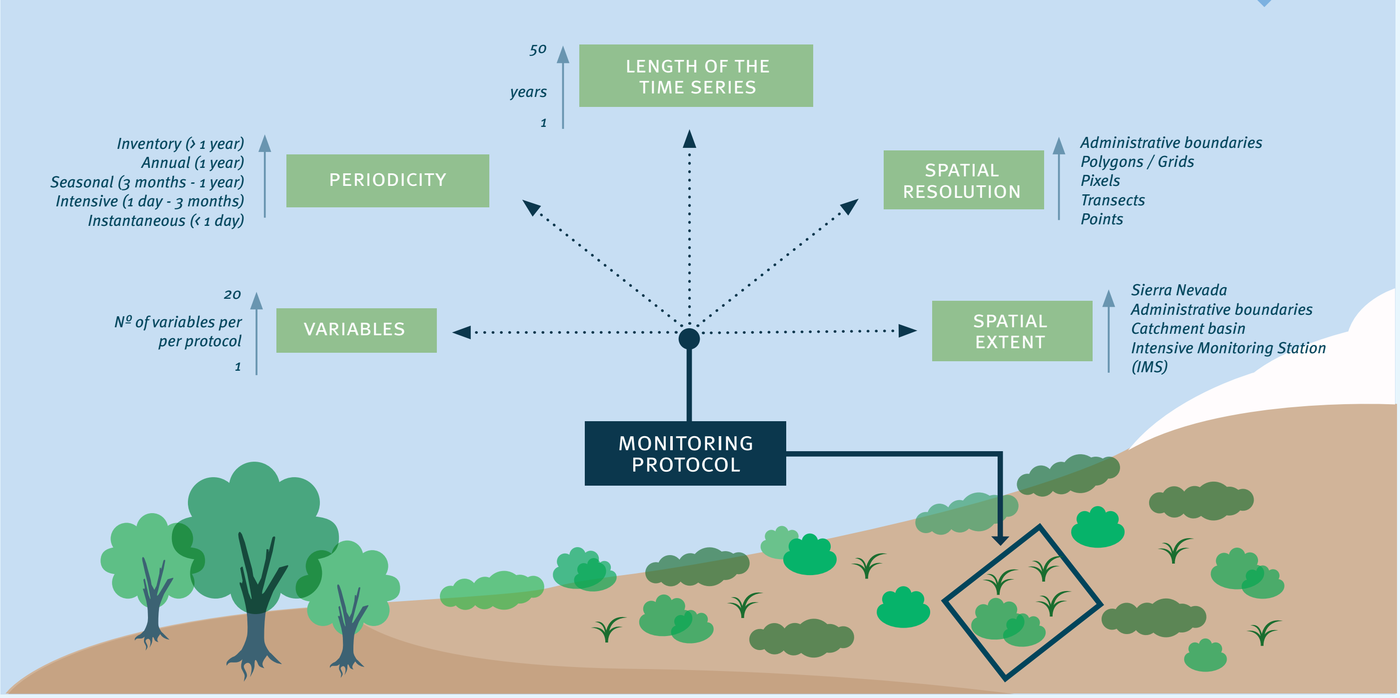
In short, the monitoring programme to assess the effects of global change in Sierra Nevada is comprised of a multitude of protocols that can be described based on a number of attributes, thematic (according to GLOCHAMORE approach), spatial (data-collection scale and the extent of data application), and temporal (length of time series and data-collection periodicity).

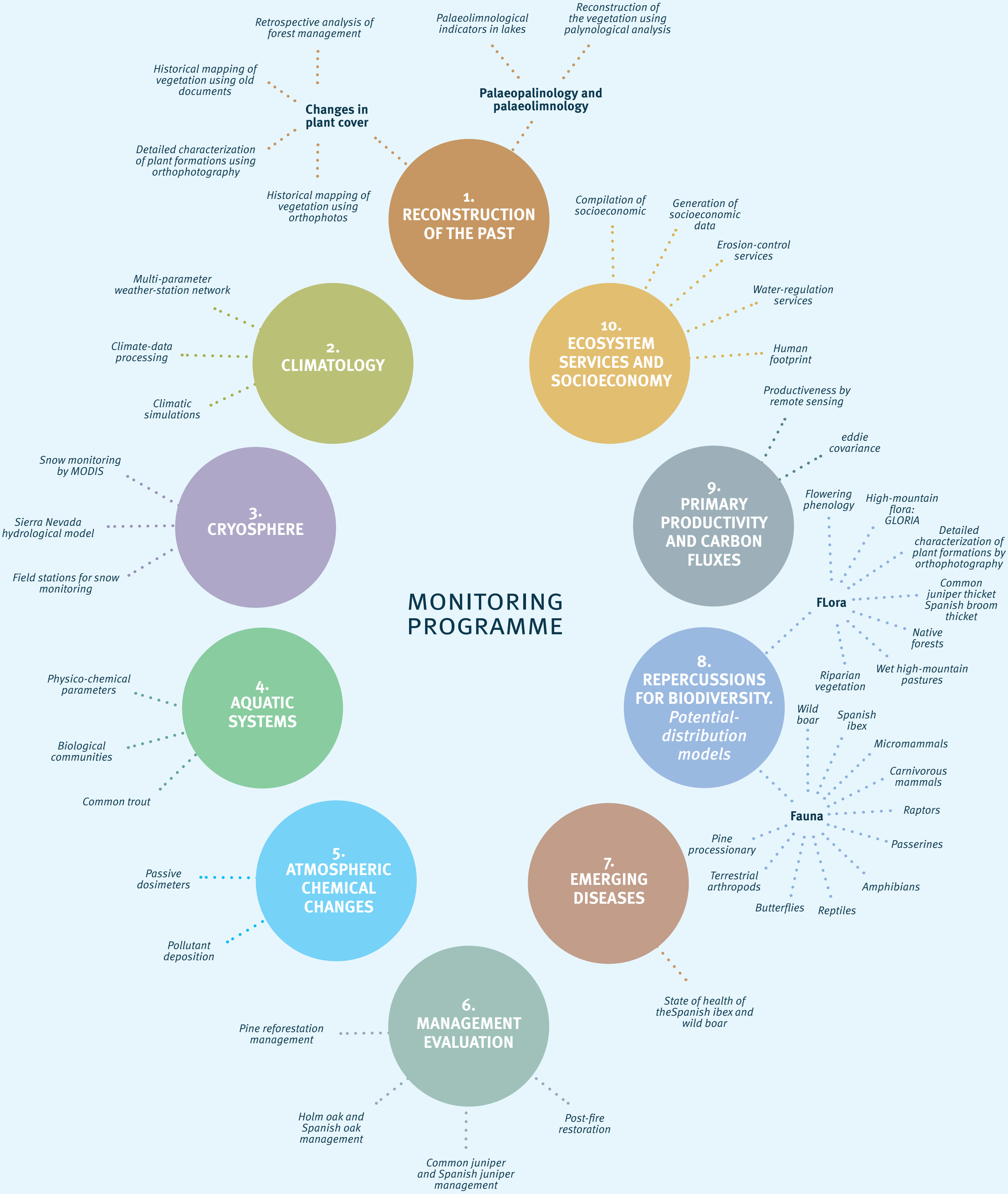
This synthetic diagram presents five of the main attributes that characterize each of the 48 monitoring protocols.

Establishment of relationships with other networks and projects to monitor global change

The Sierra Nevada Observatory emerged as a result of the convergence of two interests: first, managers and scientists who work in the Sierra Nevada and who have demonstrated their interest in the monitoring programme that we have made reality; and second, other initiatives arising from international and national institutions that facilitated the commissioning of this project. The result of these two trends (bottom-up and top-down) is the creation of a project which operates within a specific territorial area, but puts internationally compatible methodologies into practice, showing eager collaboration with other similar initiatives. This collaboration is evident with the Sierra Nevada Observatory in the design and implementation of other projects that are similar both regionally and nationally. This highlights our contribution to the creation and consolidation of the Network of Global-Change Observatories in Andalusia. At the national level, the Sierra Nevada Observatory is part of LTER-Spain (Long-Term Ecological Research) and is also involved in the Global-Change Monitoring Programme sponsored by the Autonomous Agency of National parks (through the Biodiversity Foundation). Internationally, we are also involved in the LTER Europe network, LifeWatch (ESRFI) and EU BON (FP7).

Schematic representation of the five main attributes used to characterize the 48 protocols comprising the Sierra Nevada Global-Change Monitoring Programme. Each attribute is defined using either continuous ranges of values (number of variables or series length) or discrete lists (period of data collection, resolution, and spatial extension).




MONITORING PROGRAMME
1. RECONSTRUCTION OF THE PAST
Changes in plant cover
Retrospective analysis of forest management
Historical mapping of vegetation using old documents
Detailed characterization of plant formations using orthophotography
Historical mapping of vegetation using orthophotos
Palaeopalinology and palaeolimnology
Palaeolimnological indicators in lakes
Reconstruction of the vegetation using palynological analysis
2. CLIMATOLOGY
Multi-parameter weather-station network
Climate-data processing
Climatic simulations
3. CRYOSPHERE
Snow monitoring by MODIS
Sierra Nevada hydrological model
Field stations for snow monitoring
4. AQUATIC SYSTEMS
Physico-chemical parameters
Biological communities
Common trout
5. ATMOSPHERIC CHEMICAL CHANGES
Passive dosimeters
Pollutant deposition
6. MANAGEMENT EVALUATION
Pine reforestation management
Holm oak and Spanish oak management
Common juniper and Spanish juniper management
Post-fire restoration
7. EMERGING DISEASES
State of health of theSpanish ibex and wild boar
8. REPERCUSSIONS FOR BIODIVERSITY. Potential-distribution models
FLora
Flowering phenology
High-mountain flora: GLORIA
Detailed characterization of plant formations by orthophotography
Common juniper thicket Spanish broom thicket
Native forests
Wet high-mountain pastures
Riparian vegetation
Fauna
Wild boar
Spanish ibex
Micromammals
Carnivorous mammals
Raptors
Passerines
Amphibians
Reptiles
Butterflies
Terrestrial arthropods
Pine processionary
9. PRIMARY PRODUCTIVITY AND CARBON FLUXES
Productiveness by remote sensing
eddie covariance
10. ECOSYSTEM SERVICES AND SOCIOECONOMY
Compilation of socioeconomic
Generation of socioeconomic data
Erosion-control services
Water-regulation services
Human footprint

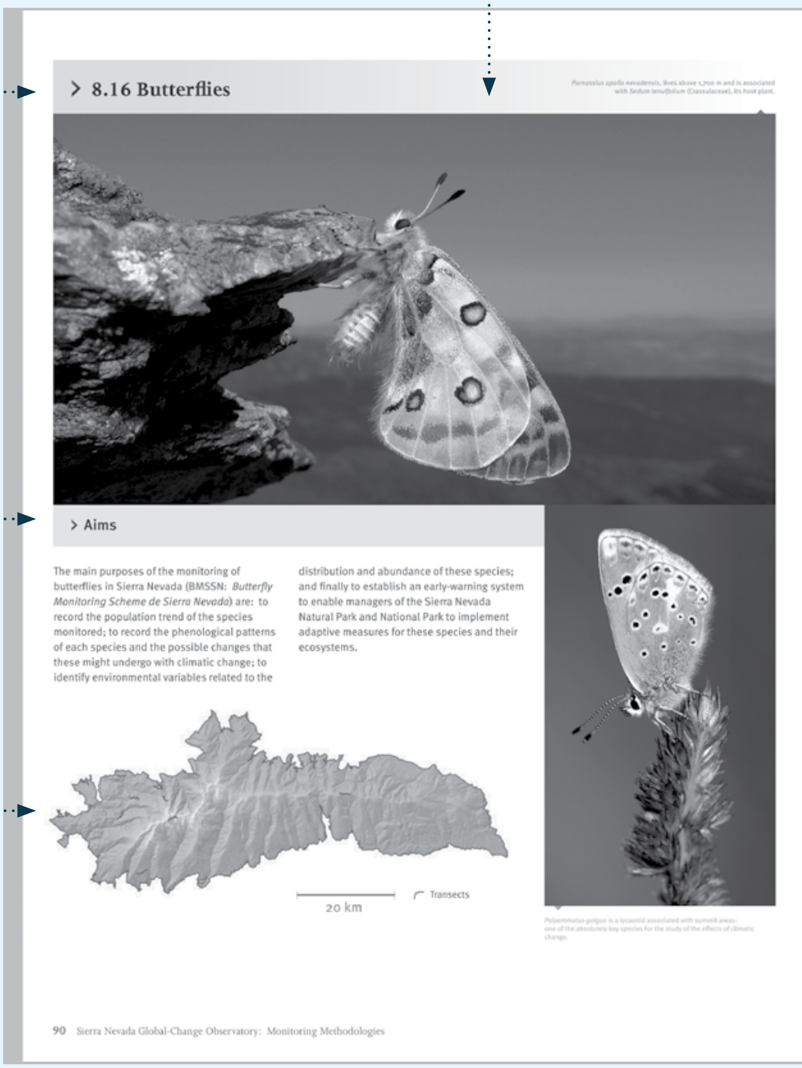
Key to interpret the description section of each methodology*

Photographs: Photographic material is meant to be a visual complement to the information presented on the sheet. This includes a main photograph and other secondary ones, according to the editorial space available.

Title: The chapter covering each methodology is indicated, as is the corresponding section and subsection within each thematic block.

1. Aims: The main aims of the starting hypothesis to be tested have been established through this monitoring.

Location map: In some cases, a map of the study area has been included to illustrate the areas being monitored.



8.16 Butterflies

Parnassius apollo nevadensis, lives above 1,700 m and is associated with *Sedum tenuifolium* (Crassulaceae), its host plant.

Aims

The main purposes of the monitoring of butterflies in Sierra Nevada (BMSSN: *Butterfly Monitoring Scheme de Sierra Nevada*) are: to record the population trend of the species monitored; to record the phenological patterns of each species and the possible changes that these might undergo with climatic change; to identify environmental variables related to the distribution and abundance of these species; and finally to establish an early-warning system to enable managers of the Sierra Nevada Natural Park and National Park to implement adaptive measures for these species and their ecosystems.

Polyommatus golgus is a lycaenid associated with summit areas: one of the absolutely key species for the study of the effects of climatic change.

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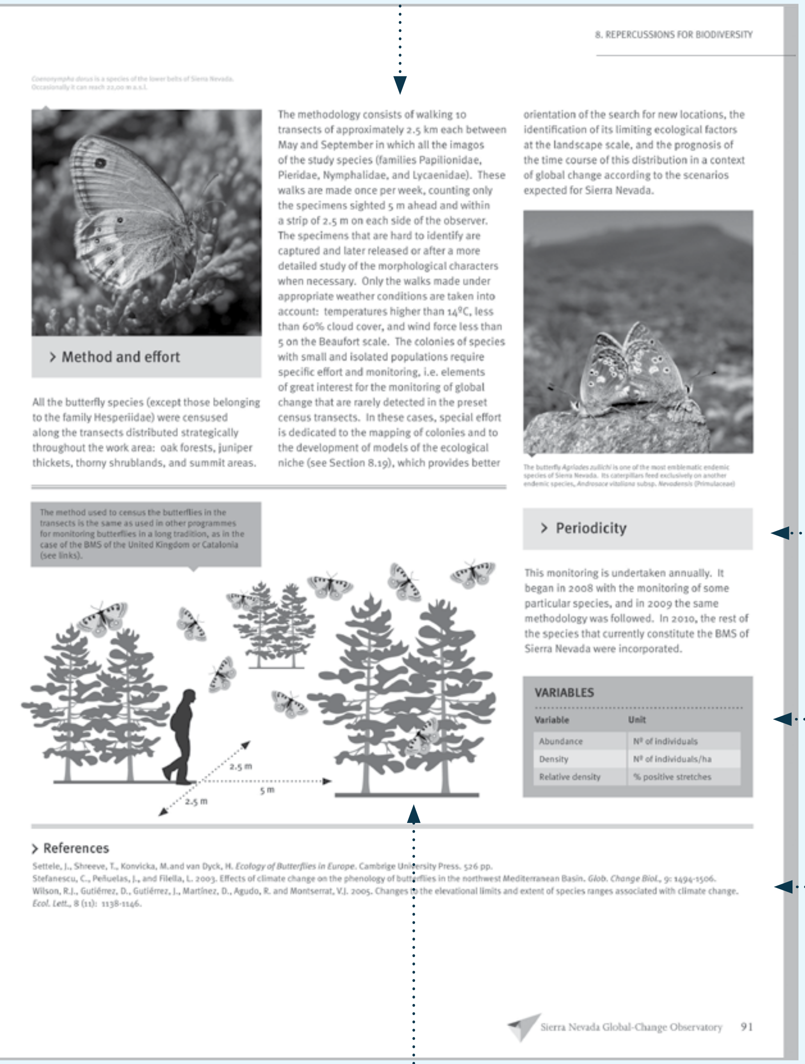
2. Method and effort: A concise explanation is given for the method or methods applied to achieve the aims and test the starting hypothesis.

* For questions purely of space, some sheets are structured on one page and others on two.



8. REPERCUSSIONS FOR BIODIVERSITY

Coenonympha dorus is a species of the lower belts of Sierra Nevada. Occasionally it can reach 22,00 m a.s.l.

> Method and effort

All the butterfly species (except those belonging to the family Hesperiidae) were censused along the transects distributed strategically throughout the work area: oak forests, juniper thickets, thorny shrublands, and summit areas.

The methodology consists of walking 10 transects of approximately 2.5 km each between May and September in which all the imagos of the study species (families Papilionidae, Pieridae, Nymphalidae, and Lycaenidae). These walks are made once per week, counting only the specimens sighted 5 m ahead and within a strip of 2.5 m on each side of the observer. The specimens that are hard to identify are captured and later released or after a more detailed study of the morphological characters when necessary. Only the walks made under appropriate weather conditions are taken into account: temperatures higher than 14ºC, less than 60% cloud cover, and wind force less than 5 on the Beaufort scale. The colonies of species with small and isolated populations require specific effort and monitoring, i.e. elements of great interest for the monitoring of global change that are rarely detected in the preset census transects. In these cases, special effort is dedicated to the mapping of colonies and to the development of models of the ecological niche (see Section 8.19), which provides better orientation of the search for new locations, the identification of its limiting ecological factors at the landscape scale, and the prognosis of the time course of this distribution in a context of global change according to the scenarios expected for Sierra Nevada.

The butterfly *Agriades zullichi* is one of the most emblematic endemic species of Sierra Nevada. Its caterpillars feed exclusively on another endemic species, *Androsace vitaliana* subsp. *Nevadensis* (Primulaceae)

The method used to census the butterflies in the transects is the same as used in other programmes for monitoring butterflies in a long tradition, as in the case of the BMS of the United Kingdom or Catalonia (see links).

> Periodicity

This monitoring is undertaken annually. It began in 2008 with the monitoring of some particular species, and in 2009 the same methodology was followed. In 2010, the rest of the species that currently constitute the BMS of Sierra Nevada were incorporated.

VARIABLES

Variable	Unit
Abundance	Nº of individuals
Density	Nº of individuals/ha
Relative density	% positive stretches

> References

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Stefanescu, C., Peñuelas, J., and Filella, L. 2003. Effects of climate change on the phenology of butterflies in the northwest Mediterranean Basin. *Glob. Change Biol.*, 9: 1494-1506.
Wilson, R.J., Gutiérrez, D., Gutiérrez, J., Martínez, D., Agudo, R. and Montserrat, V.J. 2005. Changes to the elevational limits and extent of species ranges associated with climate change. *Ecol. Lett.*, 8 (11): 1138-1146.

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3. Periodicity: Data is provided on the type of the frequency with which each monitoring session is repeated and in some cases the age of the data series.

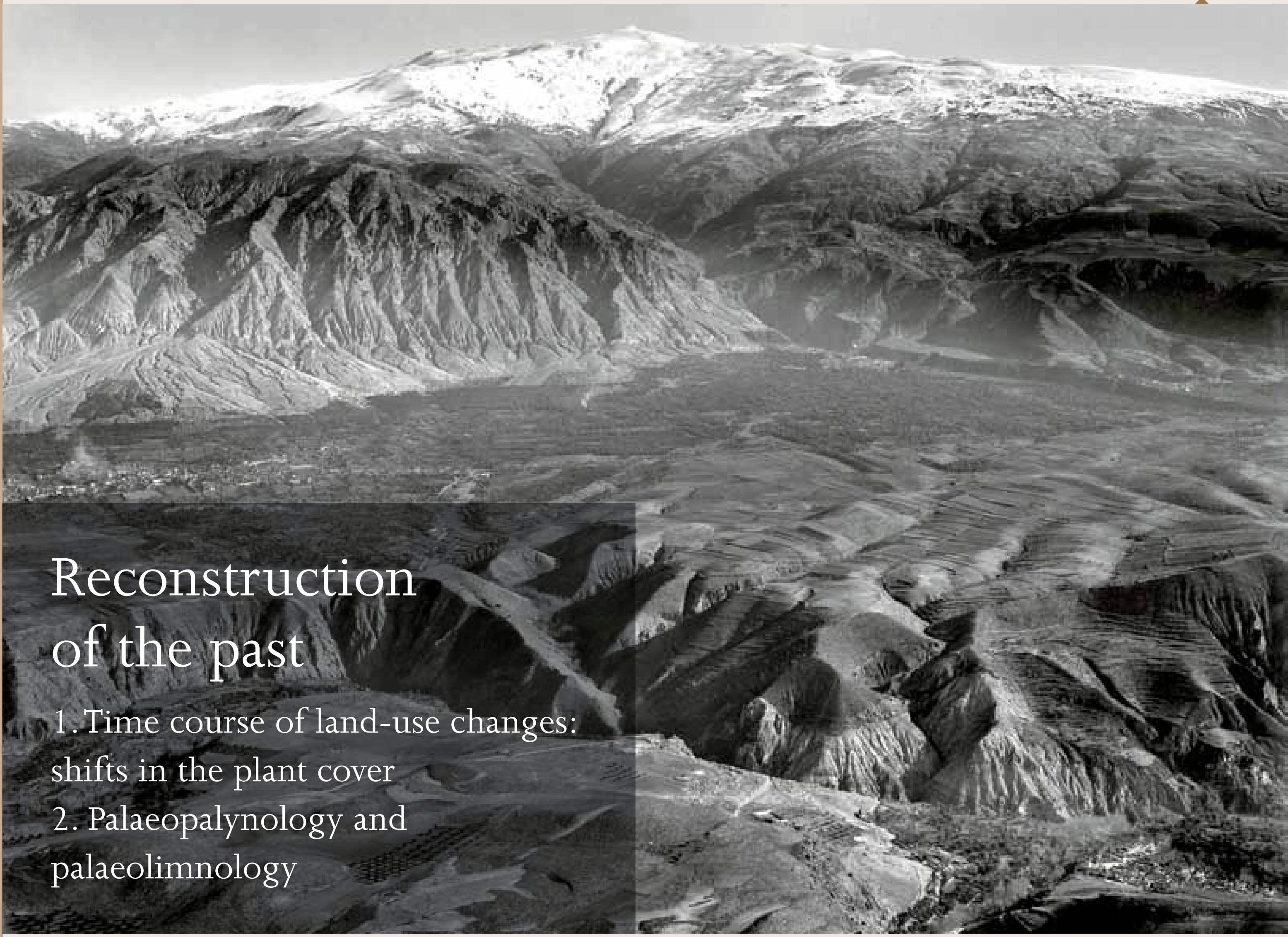
Table of variables: This presents some of the main variables used in each methodology. Also, it includes the units in which these variables were measured. The units are expressed in I.S.

References: general bibliographical references are provided, mainly reviews.

Schematics: in some cases diagrammatical representations are included as support or visual complements to the explanation in the text.

Chapter 1

View of Durcal and Valle de Lecrin, 1964
Source: Paisajes españoles



Reconstruction of the past

1. Time course of land-use changes: shifts in the plant cover
2. Palaeopalynology and palaeolimnology

Land-use changes (deforestation for crops and pastures, reforestation, fire-wood removal, etc.) constitutes one of the primary drivers of global change, since human activity to a greater or lesser degree is altering the plant cover of the planet. In fact, it is estimated that land-use change is the second cause of biodiversity loss at the global scale, and the first in the Mediterranean Basin. Climate change and the shifts in land use are combined, enabling us to explain the distribution and structure of plant formations in the present. Therefore, it is important to ascertain in detail the effects of both motors of change in the plant cover: land use and past climate. For this, it is necessary to design methodologies to **reconstruct the longest possible time series showing land-use changes**, and the effects of climatic change on plant formations. In this chapter, we show the methodologies that have been designed and implemented in the monitoring programme of Sierra Nevada in relation to changes in the plant cover. In general terms, we can group these according to time scales: **characterization of the vegetation at a scale of the last 2-3 centuries and the composition of plant formations at scales of thousands of years.**

To characterize the effect of the land-use changes in the last 2-3 centuries, documentary sources in the form of texts, photographs, or drawings are fundamental. In the Sierra Nevada monitoring programme, diverse methodologies are applied depending on the type of information available.

The use **of aerial photographs to characterize changes in the vegetation** is a widely used method in the national and international context. The key to this technique is not only to describe the vegetation at different points in time, but also to make comparisons at different dates to detect possible changes. The American flight of 1956 provides a reference base for analysing these changes. These photographs make it possible **to create vegetation and land-use maps by photointerpretation**. This first methodology provides a general view at a scale of 1:10,000 of the spatial distribution of plant formations. However, many situations require more detailed information on certain formations of special interest (relict, at their distribution limit, poor reproductive success, etc.). In these cases, other methodologies are applied, also based on aerial photographs and consisting of **delimiting these formations at a detailed scale and characterizing their internal structure** using transects and censusing individuals. In addition, the laying out of elevational transects has made it possible to detect displacements over this gradient.

Other notable sources of information to characterize the state of vegetation in the past are **old graphic documents** (drawings, sketches, charts, maps, etc.). In this sense, we have information from the middle of the 18th century; the descriptive mapping of the Department of the "Marina de Cádiz" of the provinces of Motril and Almeria (1763) or the sketch by the botanist Rojas Clemente (1805) are some examples. Furthermore, there is another type of old documentation, such as forest-hydrology restoration projects or photographs of rural landscapes that, even dating to later than 1956, provide complementary information for the interpretation of the state of the vegetation in the recent past.

There is a final important factor that should be taken into account in the last few decades if we wish to make a detailed characterization of land-use changes. This involves forest activities in the territory. During the last half of the 20th century, a multitude of forestry measures were implemented in Sierra Nevada (reforestation, forest treatments, shrubland slashing, etc.), with the aim of restoring certain functions of the plant cover (fundamentally to halt erosion). The last methodology that we present is used to **gather information on these forestry activities**, in order to evaluate to what extent they were effective and to monitor them.
On much broader temporal scales, it is not easy to detect the use changes provoked by human activity. But the effects of climate change are visible. To perform a retrospective analysis of the past, we need to resort to very different methodologies. Palaeopalynology and Palaeolimnology are instrumental in characterizing the plant cover in the distant past. Pollen and spore remains trapped in the sediments of lakes and bogs make it possible to reconstruct the approximate composition of the plant communities that lived in the surroundings of these sediments thousands of years ago. Also, we can deduce the dominant climatic conditions from the analysis of the sediments of algae and spores found in the sediments of the lakes of Sierra Nevada.

Reproduction of the plate "*Carretera de Granada a la de Laujar a Órgiva por el pico del Veleta*", c. 1920. Manuel Torres Molina
Source: Archivo y Biblioteca de la Casa de los Tiros

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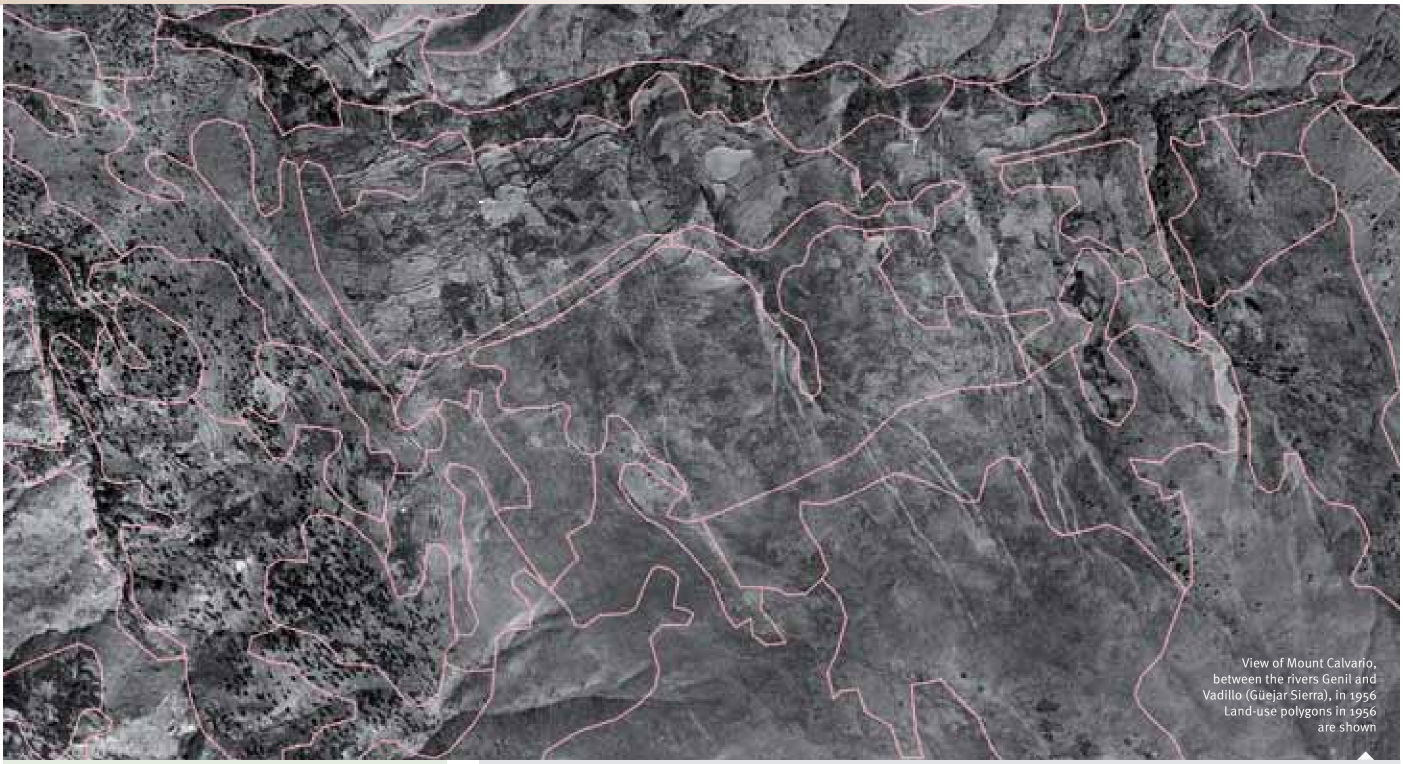
Dale, V.H. 1997. The relationship between land-use change and climate change. *Ecol. Appl.*, 7: 753–769.
Swetnam, T. W., Allen, C. D., and Betancourt, J. L. 1999. Applied historical ecology: using the past to manage for the future. *Ecol. Appl.*, 9(4): 1189-1206.

1.1.1 Historical mapping of the vegetation using orthophotographs



View of Mount Calvario, between the rivers Genil and Vadillo (Güejar Sierra), in 1956 Land-use polygons in 1956 are shown

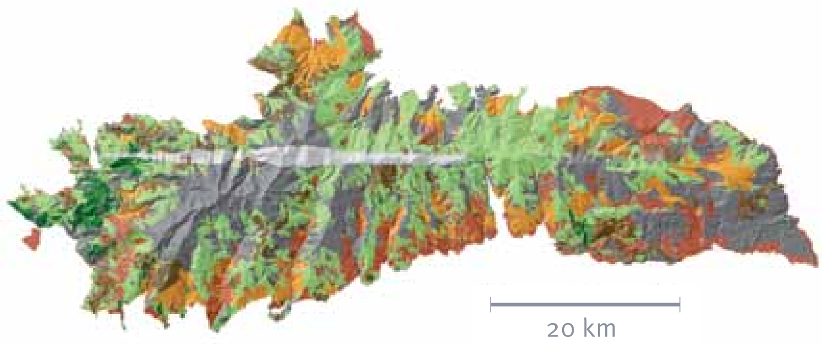
Aims

Information is being compiled on the past vegetation of Sierra Nevada through old aerial photographs (1956) at a level of detail comparable to that of current vegetation maps (1:10,000). This enables studies of land-use-change patterns of plant covers. In addition, the process of generating the map helps us to identify singular areas with ecological processes of special interest in the global-change study.

Method and effort

This consists of reinterpreting the most current version of the vegetation map at 1:10,000 over the orthophotography of 1956[1]. Geometric reviews are made together with reviews of the attributes, assigning to each polygon the variables that were photointerpreted in 1956. The scale of the work is 1:10,000. With the use of the appropriate GIS edition tools, more than 35,000 polygons are reviewed. Also, some of the polygons of the current vegetation map, where errors are detected, are updated. All the information generated is combined into a normalized geographic database to be made compatible with the data models of the Spanish Land-Occupation Information System (Sistema de Información de Ocupación del Suelo de España; SIOSE) and the Andalusian Environmental Information System (Red de Información Ambiental de Andalucía; REDIAM).

The vegetation map of Sierra Nevada from 1956 at a detailed scale makes it possible: to perform diachronic analyses of the plant cover and land uses, as well as to detect ecological processes such as elevational migrations, colonization of degraded habitats, etc..



Vegetation map of 1956 at a scale of 1:25,000. With this methodology, this version of the map can be updated to a working scale of 1:10,000.

- Conifers
- Crops
- Dense thickets
- Open thickets
- Oaks
- Zones with thin vegetation (pastures, scree)

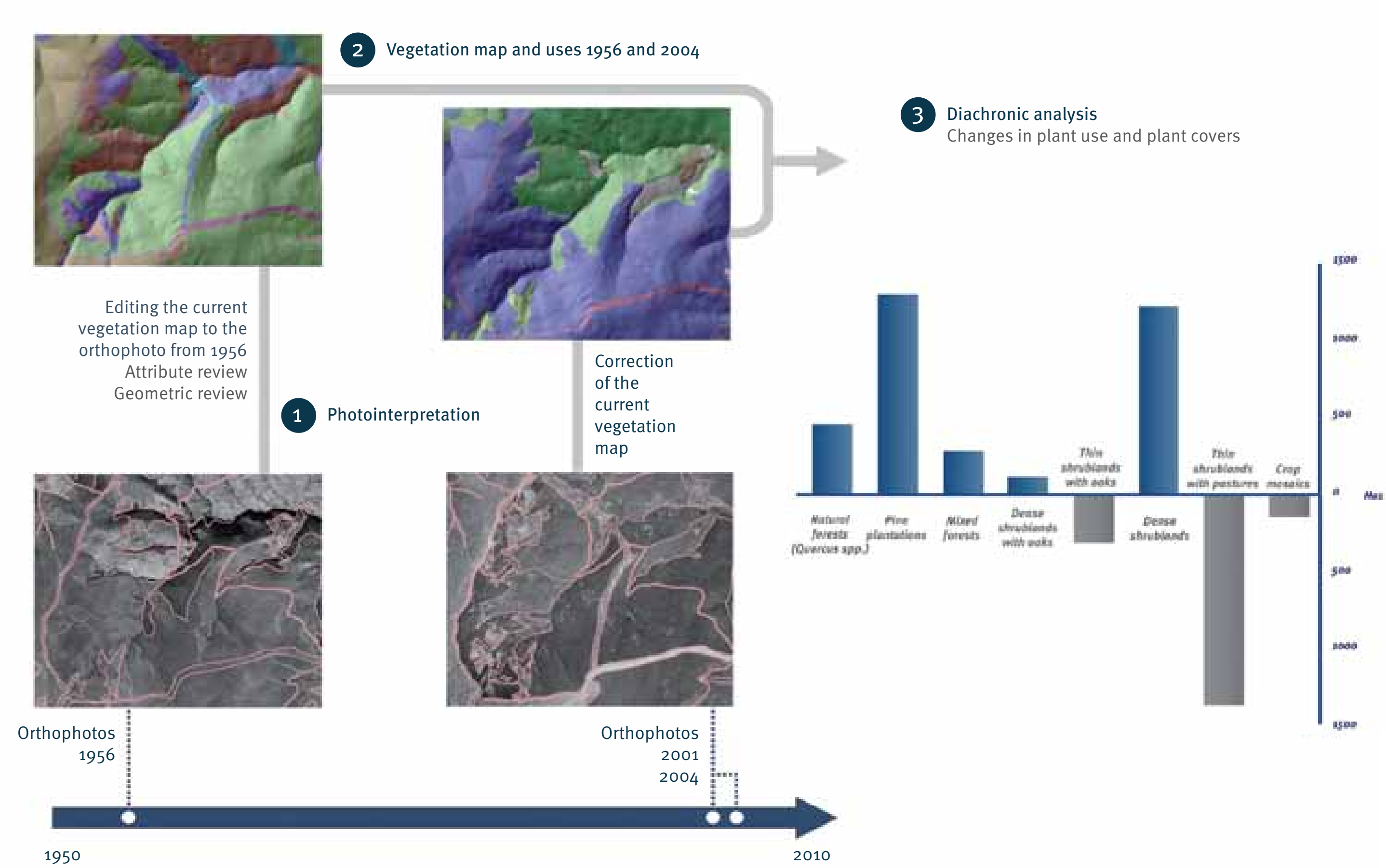
Periodicity

The frequency with which this type of information can be generated depends on the starting material available. At present, there are photos of Sierra Nevada of sufficient quality for the dates: 1956, 1977, 1984, 1998, 2001, 2004, 2007, and 2009.

VARIABLES

Variable	Unit
Plant/Land cover use	SIOSE clases
Tree Forest Canopy Cover (FCC)	% cover
Shrub Canopy Cover	% cover
Herbaceous Canopy Cover	% cover
Bare soil cover	% cover
Main Tree species	Species

Methodological diagram of the analysis of the changes in vegetation by orthophotos



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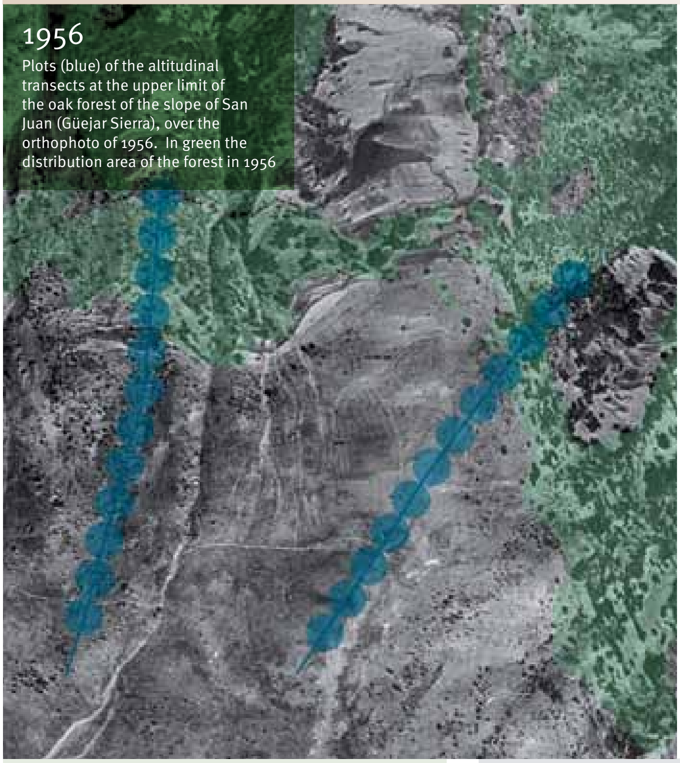
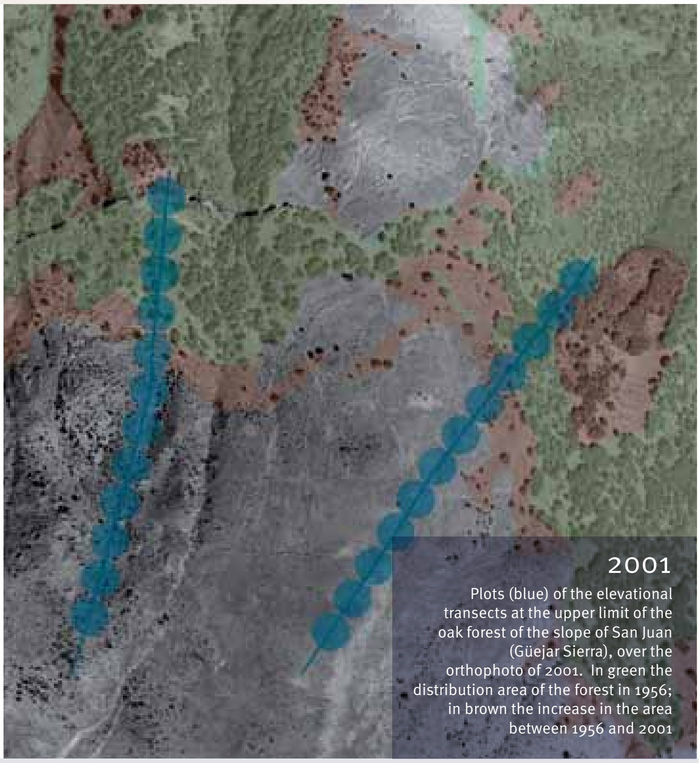
1 Historical digital orthophotography of Andalusia 1956

1.1.2 Detailed characterization of plant formations by orthophotography



1956

Plots (blue) of the altitudinal transects at the upper limit of the oak forest of the slope of San Juan (Güejar Sierra), over the orthophoto of 1956. In green the distribution area of the forest in 1956



2001

Plots (blue) of the elevational transects at the upper limit of the oak forest of the slope of San Juan (Güejar Sierra), over the orthophoto of 2001. In green the distribution area of the forest in 1956; in brown the increase in the area between 1956 and 2001

Aims

The aim of this methodology is to provide a detailed characterization of the changes in the main plant formations of Sierra Nevada. Specifically, the intent is to quantify the temporal variations in density and degree of coverage of the main species in relation to elevation.

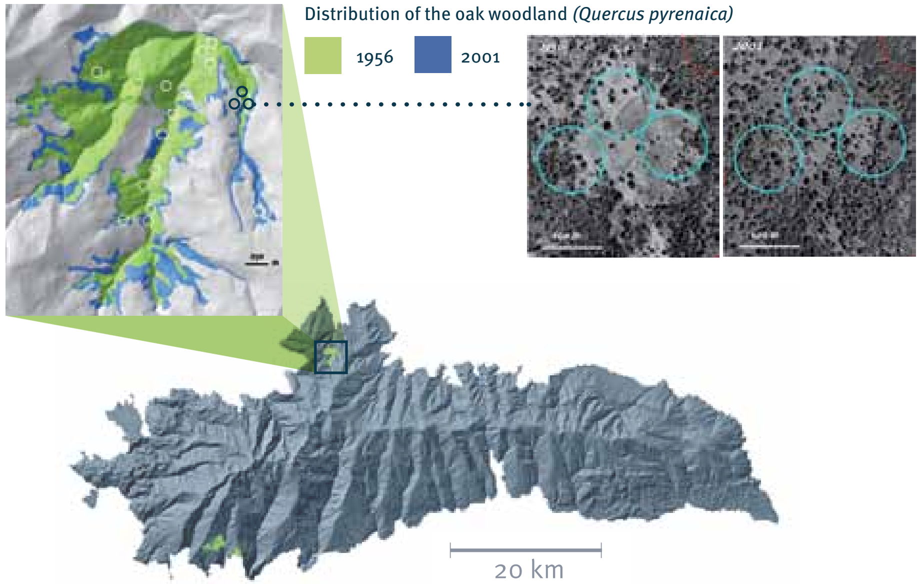
Periodicity

The periodicity with which this type of information can be generated depends on the starting sources available. Currently, there are orthophotos of Sierra Nevada of sufficient quality available for the dates: 1956, 1977, 1984, 1998, 2001, 2004, 2007, and 2009.

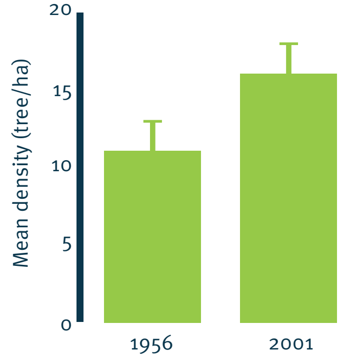
Method and effort

The detailed delineation of plant formations is superimposed over aerial orthorectified photographs of different dates. For this, the orthophotos are integrated into an information system together with other layers of information such as the current vegetation map of Sierra Nevada and the map from 1956, which are used as a reference for the delineation. The working scale varies between 1:5,000 and 1:8,000, depending on the formation. The "limit" of the formation is considered to be the contour of the coverage of a species or main species greater than or equal to 5%, so long as there is spatial continuity.

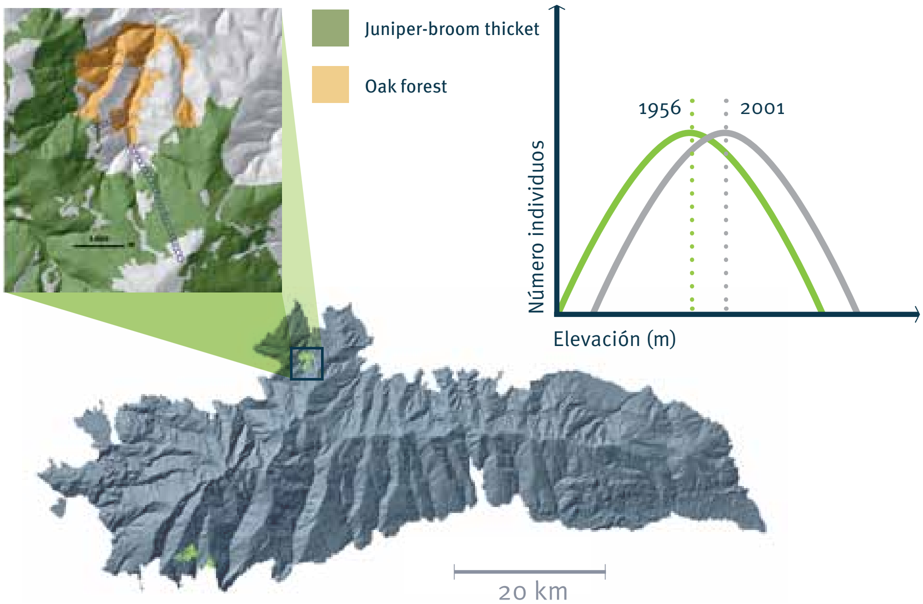
Afterwards, certain zones within the distribution area of the formation are selected to make comparisons between dates. For this, both the availability of data as well as their quality for photointerpretation are considered. In these preselected areas, a series of 1-ha circular plots are randomly distributed. The individuals of the main species are counted and the coverage of this species estimated for the different dates. In addition, a series of transects are laid out by photointerpretation according to an altitudinal gradient. Over each transect, tangential circles are drawn covering the distribution range of the oak forests and juniper thickets (1100 m to 2700 m). The relief and distribution of the formations in each specific subbasin determine the trajectory and size of the transects. The size of the plots is c. 30 m in radius, this being considered a suitable size for the photointerpretation of species over the photo of 1956 (reference base), taking into account the type of vegetation as well as the quality of the photo. In these plots, the photointerpretation is made recording the variables of interest for each date. The working scale varies between 1:3,000 and 1:5,000, depending on the formation and the quality of the photo in this area. The average elevation of each plot is assigned from the digital model of elevations.



Change in the distribution and mean density of the oak woodland of Camarate (Lugros) between 1956 and 2001. Location of the random plots for the censuses



Location of altitudinal transects in the oak woodland and juniper thicket of Camarate (Lugros). Changes expected in the number of individuals with respect to elevation, between 1956 and 2001.



VARIABLES

Variable	Unit
Distribution area of Pyrenean oak forest	ha
Distribution area of juniper-broom thicket	ha
Distribution area of Scots pine	ha
Average density of Pyrenean oak trees	tree/ha
Average density of common juniper	tree/ha
Average density of Scots pine trees	tree/ha
Average cover of Pyrenean oak trees	%
Mean coverage common juniper	%
Mean coverage Scots pine	%
Pyrenean oak tree density by altitude	tree/ha
Common juniper density by altitude	tree/ha
Pyrenean oak tree coverage by altitude	%
Common juniper coverage by altitude	%

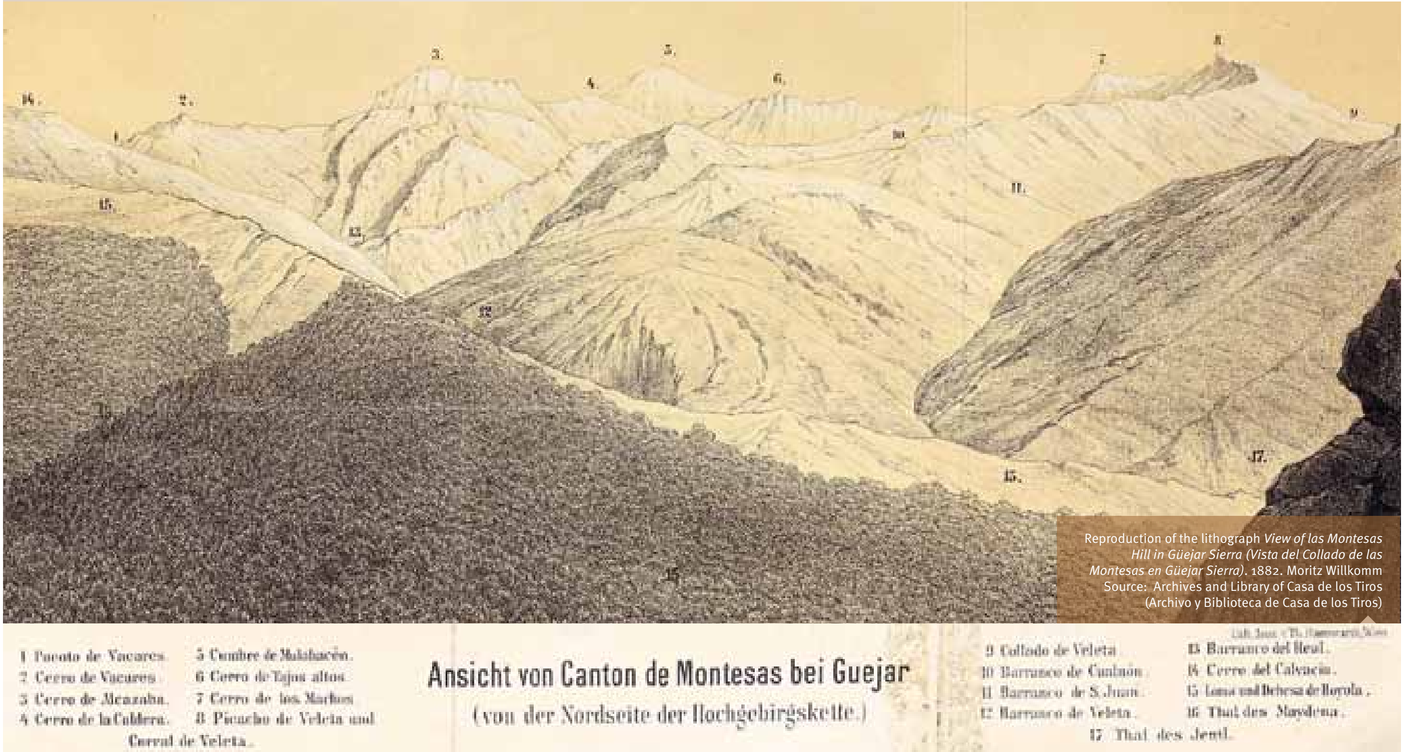
References

Allen, C.D. and Breshears, D.D. 1998. Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. *PNAS*, 95 (25): 14839–14842

Navarro González, I. and Bonet García, F.J. 2010. Vegetation cover changes in Sierra Nevada mountains (Spain) during the past 50 years and relation to land use and climate change. p. 53. En: *2ª International GMBA-DIVERSITAS Conference "Functional significance of mountain biodiversity"*. Chandolin, Switzerland. 27 - 30 Jul. Conference abstracts.

Sanz-Elorza, M., Dana, E., González, A. and Sobrino, E. 2003. Changes in the high-mountain vegetation of the central Iberian Peninsula as a probable sign of global warming. *Ann. Bot.*, 92: 273–280.

Retrospective analysis of forest management



Reproduction of the lithograph *View of las Montesas Hill in Güejar Sierra (Vista del Collado de las Montesas en Güejar Sierra)*. 1882. Moritz Willkomm
Source: Archives and Library of Casa de los Tiros (Archivo y Biblioteca de Casa de los Tiros)

Aims

The goal is to gather spatial information of the state of vegetation on Sierra Nevada in the past, broadening the time series as much as possible according to the existing historical archives.

Periodicity

The periodicity of information gathering depends on the availability of sources that can be georeferenced. Some dates for which documents exist prior to 1956 are: 1753, 1763, 1805, 1932, and 1944.

VARIABLES

Variable	Unit
Plant/Land cover use	SIOSE clases
Area covered by vegetation	ha

Methods and effort

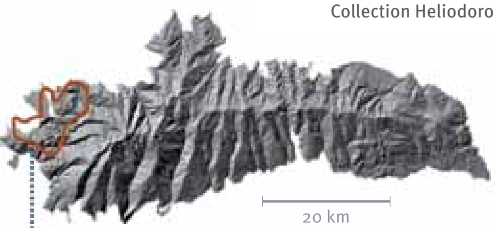
The working method consists of the search for and compilation of old documents of different characteristics and dates offering information on the state of the vegetation in a specific area of Sierra Nevada in the past. There are graphic documents of different types such as descriptive maps, sketches, photographs, pictures, maps of forest-restoration projects, etc..[1] Once the appropriate documents are selected with relevant information that can be georeferenced, they are positioned and interpreted over the corresponding orthomap according to the date. In the case of dates prior to the existence of aerial photographs, the orthphotos of 1956 and 2001 are used as reference bases for digitalization. Three-dimensional panoramas are prepared and photo-interpretation tools are used in 3D to facilitate the process of interpretation, given the paucity of visual references. The polygons of the interpreted plant formations are delineated and the attributes necessary for their characterization are assigned. Although the information is partial, it is important to georeference it and store it in a database. This allows the diachronic analysis of these areas with the mapping of land use and vegetation of the present as well as of intermediate dates, providing information of interest on shifting land use and vegetation from the earliest documentation available.

Reproduction of the *"Croquis de Durcal. Catastro de Ensenada"*, 1753-1758
Source: Historical Archives of Granada Province (Archivo Historico Provincial de Granada)

Methodological outline

1905 Sierra Nevada. Isidoro MarÍn
Collection Heliodoro Fernandez-Nieto

1 Compiling of historical documents



2 Location of the area of the historical document

Digitalization of the areas interpreted without vegetation in the historical document

Land use comparison between 1956 and present

3 3D photointerpretation

References

Badia Miró, M. and Rodríguez Valle, F. 2005. Una nueva metodología para la reconstrucción de la evolución histórica del paisaje agrario. *GeoFocus*, 5: 69–78.
Fernández del Castillo, T., Delgado García, J., Cardenal Escarcena, F. J., Jiménez Peralvarez, J., Fernández Oliveras, P. and Irigaray Fernández, C. 2006. Generación de una base de datos de movimiento de ladera mediante técnicas de fotogrametría digital en la Sierra de la Contraviesa (Granada). Pp. 799-814 En: *Actas del XII Congreso Nacional de Tecnologías de la Información Geográfica. El acceso a la información espacial y las nuevas tecnologías geográficas*. Granada, Sep. 2006.
Gómez Ortiz, A., Milheiro Santos, B. and Serrano Giné, D. 2008. Nieves, hielos y aguas en los paisajes de Sierra Nevada. El interés de la información gráfica de los libros de época. *Cuadernos de investigación geográfica*, 34: 101–118.

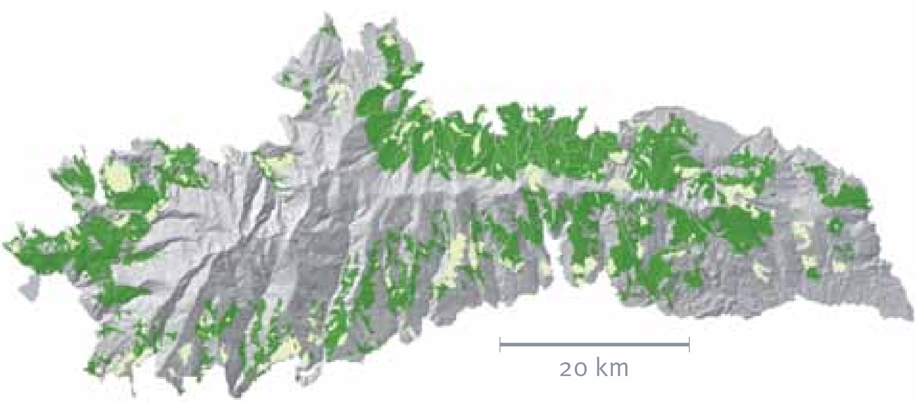
[1] Exposición Luces de Sulayr. Cinco siglos en la imagen de Sierra Nevada. Consejería de Cultura. Junta de Andalucía.

1.1.4 Retrospective analysis of forest management

Aspecto del robledal de San Jerónimo
a principios del invierno, Granada.

Aims

The main aim is to review some of the most representative forest-management actions conducted in Sierra Nevada in the last decade, seeding to identify the effects of these actions on the state of the ecosystems before and after the works were executed. In short, the idea is to compile an "account of forest management" in Sierra Nevada.



Areas of forestry action 1990-2008
Surface area of reforestation in 1999

Method and effort

To put this methodology into practice involves the following steps:

1. Compiling and locating the area of all the actions to be undertaken on the forest stands of the Sierra Nevada National and Natural Parks from 1999. All these actions are digitalized and included in a geographic database that also includes an execution date, the project that funds them, and a brief description of them.

For this, an existing compilation will be taken as the base, updated with the projects conducted after this compilation date. By consultation with The Directors of Works and Agents of the Environment involved, possible modifications will be made in the execution phase of the work due to the unforeseen arising after the date of project approval.

2. Compiling of information that enables the description of the state of the forest stands at different points in time during the study. Among other data, the following will be taken into account:

- National Forest Inventory.
- Network of plots in the pan-European System for the Intensive and Ongoing Monitoring of Forest Ecosystems (Level II CE Network).
- Characterization inventory for the naturalization of tree masses of the Sierra Nevada National Park.
- Inventories of the natural state of the different plans made in different districts of the Sierra Nevada (Marquesado, Alpujarra Oriental, and Alpujarra Occidental).
- Other possible existing forest inventories.

3. Selection of pilot areas for the retrospective analysis of the time course of the stand monitored under the management applied. These stands are selected, on the one hand, according to the availability of reliable, quality information referring both to the actions taken as well as the situation of the stands before and after management; on the other hand, they are selected for their representativeness with respect to the group of tree masses of Sierra Nevada. In these, a complete forest inventory (dasometric, epidometric and floristic) is made to evaluate the development of the stand over the time period monitored. A study is made not only of structure (e.g. variations in vertical and horizontal structure, in floristic and faunistic diversity) but also function (recovery of biodiversity, production capacity, and capacity to capture the carbon of the stand).

Pine reforestation in the district of Marquesado, Sierra Nevada.

Clearing in a reforested Scots pine stand.

Periodicity

Both the compiling of the information as well as the data gathering in the field are undertaken only once per area.

VARIABLES

Variable	Unit
Tree growth	mm/year
Tree density	tree/ha
Tree Forest Canopy Cover (FCC)	%
Shrub Canopy Cover	%
Base height by species	m^2/ha
Average crown diameter	m
Species Richness	number of species
Species abundance	nº ind / taxa
Tree-species regeneration	number of seedlings or sprouts

Century-old Holm oak tree within the reforested maritime pine stand, Abrucena, Almeria.

References

Arias Abellán, J. 1981. La repoblación forestal en la vertiente norte de Sierra Nevada. *Cuadernos Geográficos de la Universidad de Granada*, 11: 283-306.

Bonet García, F. J., Villegas Sánchez, I., Navarro, J. and Zamora Rodríguez, R. 2009. Breve historia de la gestión de los pinares de repoblación en Sierra Nevada. Una aproximación desde la ecología de la regeneración. En: *S.E.C.F.-Junta de Castilla-León (eds.), Actas 5º Congreso Forestal Español. CD-Rom. Sociedad Española de Ciencias Forestales*. Ávila.

Cano, L., Castillo A., De La Hoz, F. and Cabrera M. 1998. Ordenación de nueve montes de la zona del Marquesado en el Parque Natural de Sierra Nevada, Granada. *Cuad. Soc. Esp. Cienc. For.*, 6: 215-236.

1.2.1 Analysis of palaeolimnological indicators in Sierra Nevada lakes

Toma de testigo de sedimento en una laguna de Sierra Nevada

Aims

The analysis of the fossil record of aquatic organisms in the lakes of Sierra Nevada enable us to evaluate the changes undergone in these ecosystems over a broad time interval. The groups analysed are diatoms, cladocerans, and chironomids, at a time scale of roughly 200 years. The sediment indicates changes in the lake but also throughout its catchment basin, so that the palaeolimnological analysis of several aquatic systems in a region can provide evidence of environmental changes that occurred there.

Method and effort

Cores samples are taken from the sediment in the zone of maximum depth of several lakes. The length of the cores must span the last two centuries and they are selected in intervals of 0.25 cm in the first 7 cm, and 0.5 cm in the following ones. The sediments are dated radiometrically by gamma spectrometry (determination of ^{210}Pb, ^{226}Ra, and ^{137}Cs) and alpha spectrometry (more precise 210Pb determination in the deepest layers). In each interval of sediment, the fossils of different species of diatoms, cladocerans, and chironomids are identified and specific abundance is determined. These organisms function as palaeoindicators, so that, knowing their ecological niche, we can infer the environmental conditions under which they existed. Thus, for example, diatoms are excellent bioindicators to infer changes in temperature, pH, alkalinity, trophic degree, or changes in water level. Chironomids are especially sensitive to changes in temperature and trophic degree, while cladocerans indicate variations in the water level and nutrient concentrations.

Sectioning the core sample into sediment intervals.

Periodicity

These samples are taken only once.

VARIABLES

Variable	Unit
Species richness	number of species
Specific abundance	number of individuals

References

Smol, J.P. (Series Editor). 2001. *Developments in Paleoenvironmental Research (DPER Series): Tracking Environmental Change Using Lake Sediments*, vols 1 a 5. Springer-Verlag.

1.2.2 Reconstruction of the vegetation from palynological analysis


Sediment sampling using a Livingstone corer in Laguna de Rio Seco.

Aims

The main aim of this methodology is to describe the changes in vegetation and in the frequency of fires in order to decipher possible fluctuations in the climate as well as in human influence in the Alpine ecosystems of Sierra Nevada.

Periodicity

The sampling campaigns are made at certain points, taking the entire sedimentary record only once.

VARIABLES

Variable	Unit
Relative pollen abundance	%
Carbons	gr C / gr(cm3) sediment

Method and effort

Pollen and carbon from sediments of lakes and wet grasslands during the Holocene (the last 12,000 years) are studied at high resolution. The sediments from lakes and pastures are taken by core sampling of the sediment in the zones of greatest depth in these basins by a gravity corer and a Livingstone corer. The cores are 1.5 to 2.5 m long and samples are taken at intervals of 0.5 cm. The sediments are dated primarily by carbon-14 dating. The pollen is separated from the rest of the sediments by chemical attack with chlorhydric acid (HCl), fluorhydric acid (HF) and acetolysis, which destroys the mineral particles and the cellulose matter. The final residue, rich in pollen grains, is mounted in slides together with glycerine and analysed under the light microscope. With respect to the study of the carbons, a volume of 1 cm^3 is taken every 0.5 cm over the length of the sediment cores. The samples are processed following carbon high-resolution particle analysis described by Millspaugh and Whitlock (1995). A solution of 10% sodium metaphosphate $Na(PO_3)$ is added to the samples until the sediment completely disaggregates. Later, the samples are sieved (screen size 125-µm and 250-µm) and the remaining sediment is transferred to Petri dishes, in which the carbons in the different sediment fractions are counted under a binocular microscope (x10-20).

References

Anderson, R. S., Jiménez-Moreno, G., Carrión, J.S. and Pérez-Martínez, C. 2011. Holocene vegetation history from Laguna de Río Seco, Sierra Nevada, southern Spain. *Quaternary Sci. Rev.*, 30: 1615-1629.

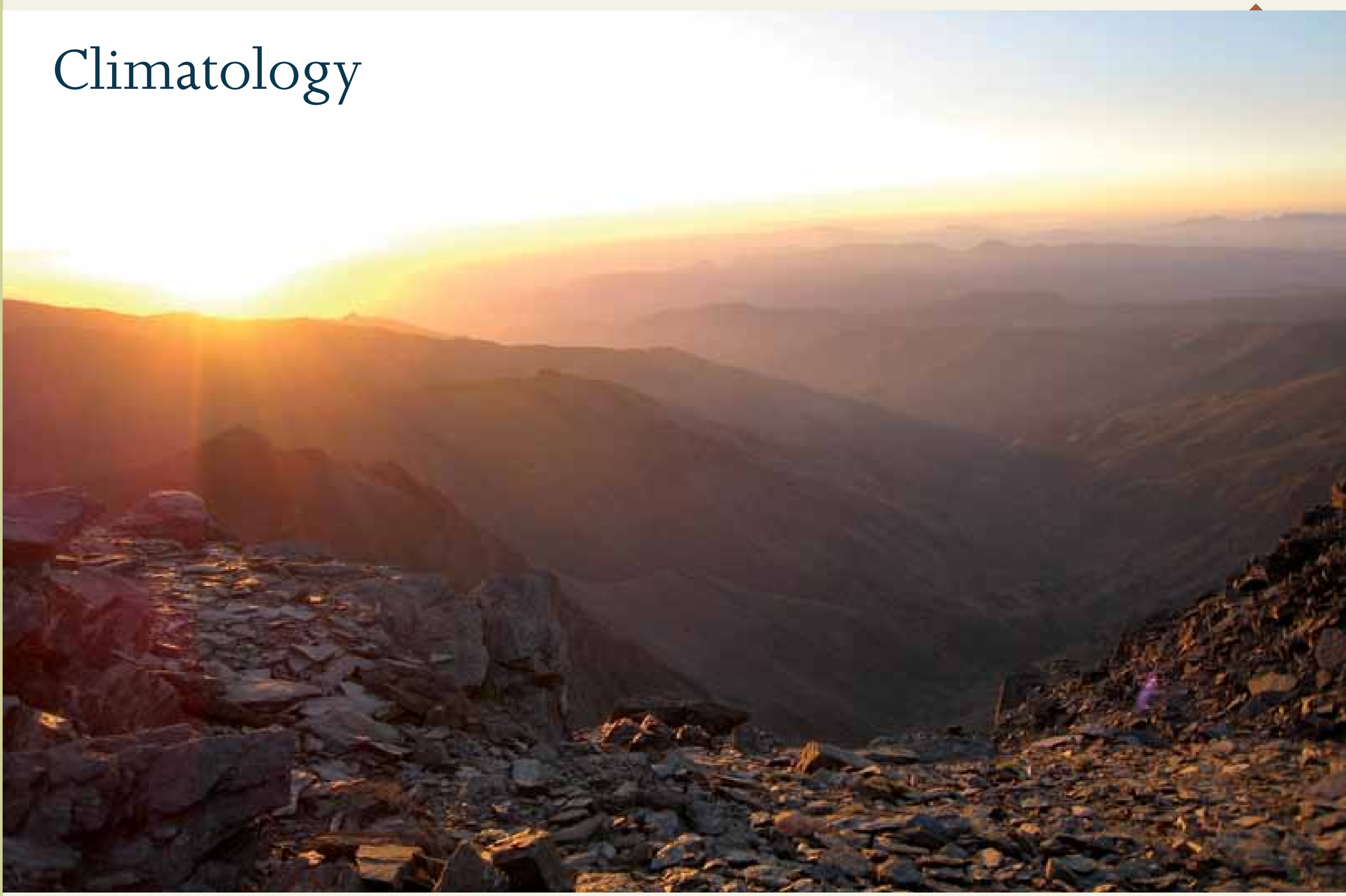
Jiménez-Moreno, G. and Anderson, R.S. 2012. Holocene vegetation and climate change recorded in alpine bog sediments from the Borreguiles de la Virgen, Sierra Nevada, southern Spain. *Quaternary Res.*, 77: 44-53

Millspaugh, S.H. and Whitlock. C. 1995. A 750-yr fire history based on lake sediment records in central Yellowstone Nacional Park. *The Holocene*, 5: 283-292.

Chapter 2

Climate change exerts great influence on the peaks of Sierra Nevada, which are less altered than the lower zones.

Climatology



The climate of Sierra Nevada is dominated by two geographical gradients. In the altitudinal gradient, temperatures predominantly decline with elevation, while longitudinally, precipitation descends from west to east. Both factors determine the characteristics of the snow cover, which functions as a reservoir, providing water during the thaw to different rivers on the mountain and the millennium-old irrigation channels designed to recharge the aquifers and to carry irrigation water to fields.

These climatic patterns have their own spatio-temporal dynamics. However, in recent years, as a consequence of climatic change, marked changes are occurring, such as rising temperatures and greater irregularity in precipitation. In the year 2007, the 4th report of the IPCC indicated that the climate will continue to change significantly as a consequence of

The snow remaining on the high peaks of Sierra Nevada over a large part of the year has far-reaching implications for the local hydrological cycle.

human activity, and therefore these changes are expected to continue to affect Sierra Nevada during the coming decades.

For a determination of the possible impact of climatic change in the Sierra Nevada ecosystems and in the ecosystem services that the massif provides to the local inhabitants, it proves fundamental to understand the past, present, and future climatic dynamics on Sierra Nevada.

The first milestone in this sense was to design and install a network of **12 multiparametric automatic meteorological stations** distributed along the entire altitudinal gradient on the massif and located in the most representative ecosystems. This has enabled us to cover a major gap in climatic data in remote high-mountain areas.

With the addition of this to the new records from other networks of national and regional stations, **an automated system was designed to collect, store, and analyse all the information in a single data base**, accessible from the interface of the Information System (http://linaria.obsnev.es).

These records have been used together with spatial-modelling techniques to generate in a GIS format a group of **digital climatic maps of the recent past** for Sierra Nevada (period 1961-2011). Also, using as the regionalized entry climate data simulated according to different climatic-change scenarios, opened to public access by AEMET, we have drawn **simulated climate maps of the future**. As a final result, a series of high-resolution spatial maps (100 m) and temporal maps (1 year) have been drawn using variables of precipitation together with minimum and maximum average temperatures for the period 1961-2100, which are highly useful to model ecological processes that are sensitive to the climate in Sierra Nevada.

The flora of the high peaks is extremely vulnerable to climatic change, as its possibilities to colonize higher elevations in response to rising temperatures are severely limited.

References

IPCC, 2001. *IPCC Third Special Report. Climate Change 2001: The Scientific basis 2001*. Cambridge University Press, Cambridge.

IPCC, 2007. *IPCC Fourth Assessment Report- Climate Change 2007: the Physical Science Basis*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

2.1 Multiparametric meteorological station network

The weather station situated in the foothills of Veleta peak.

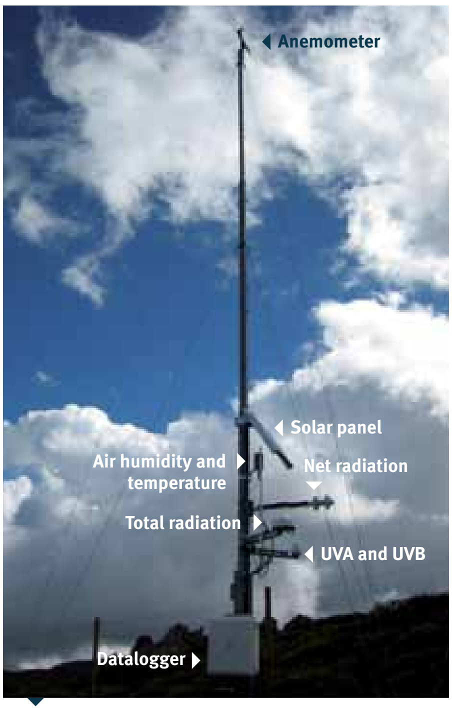
Aims

With the network of multiparametric weather stations, time series of climatic data are continually recorded and stored to be consulted by managers and researchers. This information, fundamental for the interpretation of the results of the rest of the methodologies of the Sierra Nevada Global-Change Observatory, is rarely available in mountainous regions for the difficulties involved in the maintenance of the stations under such extreme conditions.

Periodicity

All the data are continuously recorded. The mean, maximum, and minimum values are stored with accumulations of each of the parameters measured with at 10-min intervals. The data can be consulted through Internet (see links). The data are downloaded daily, when there is telephone coverage, or monthly if not.

Method and effort



Example of a multiparametric meteo station

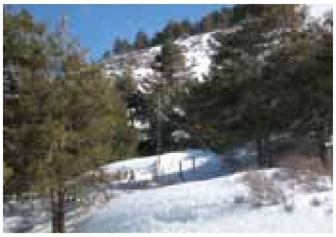
A network of mountain weather stations that fulfil certain requirements set by the Global Climate-Observing Systems (GCOS) has been installed. Two of these were installed by the National Park of Sierra Nevada (Cortijuela and Lanjarón), while the other eight belong to the Autonomous Agency of National Parks.

These provide a continuous record of the different conventional meteorological parameters as well as other specific ones to evaluate environmental processes. The measurement instruments respond to physical changes in electrical properties. The sensors are connected to dataloggers that are downloaded onsite or by a GSM/GPRS cell-phone system.

The equipment is situated in representative locations of the main ecosystems of Sierra Nevada, distributed between 600 and 3100 m a.s.l.. All of these, except the one located in the foothills of Veleta Peak, are autonomous and are supplied with energy by solar panels.

VARIABLES

Variable	Unit
Precipitation and snow depth	mm and cm
Air and soil temperature	ºC
Air humidity and soil moisture	%
Radiation: Total, UVA, UVB, and IR	W/m^2
Photosynthetically active radiation (PAR)	µE/sm2
Soil Heat Flux Density	W/m^2
Wind speed and Wind direction	m/s and º
Atmospheric pressure	mb



1. Cortijuela. In a pure limestone core, it records the climate data concerning native Scots pine and oromediterranean Spanish juniper woodlands at 1700 m.

2. Lanjarón. In a landscape dominated by communities in the initial phase of post-fire regeneration, on the southern slope at more than 2,400 m.

3. El Encinar. Inside a Holm oak woodland at almost 1,700 m. This community is widespread throughout the north-eastern sector of Sierra Nevada.

4. Aljibe de Montenegro. In a hot, dry reforested pine forest, at 975 m, in the transition zone between the *Anthyllis cytisoides* thicket (downslope) and the retama thicket (upslope).

5. Rambla de Guadix. In a landscape of extensive *Anthyllis cytisoides* thickets and deep washes (*ramblas*) strongly influenced by the nearby subdesertic area of the Levante of the Iberian Peninsula, at 600 m.

6. Camarate I- Embarcadero. Surrounded by great extensions of Holm oak woods and Spanish oak forests that have endured with a low level of alteration, at 1550 m.

7. Camarate II- Piedra de los Soldados. In the middle of the domain of the oromediterranean juniper and broom thickets, situated at 600 m in elevation above the previous one.

8. Veleta. At 3,100 m, the alpine grasslands present in the stablest zone alternate with great vertical walls, scree, rocky areas, and grasslands.

9. Robledal de Cáñar. Located on one of the most southern *Q. pyrenaica forests* of Europe, strongly threatened by the current climatic trend and conditioned by the precipitation from the Mediterranean, at 1700 m.

10. Laguna Seca. Located at the dividing line between the northern and southern slopes. Expanse of broom thickets and grasslands, just at the tree line, at 2,300 m.

★ Carbon flux. In Lanjarón (2) and Laguna Seca (10) two meteorological stations have been installed to monitor carbon fluxes, the first in a burnt pine plantation and the second in a juniper-broom ecosystem. Section 9.1 describes this measuring technique.

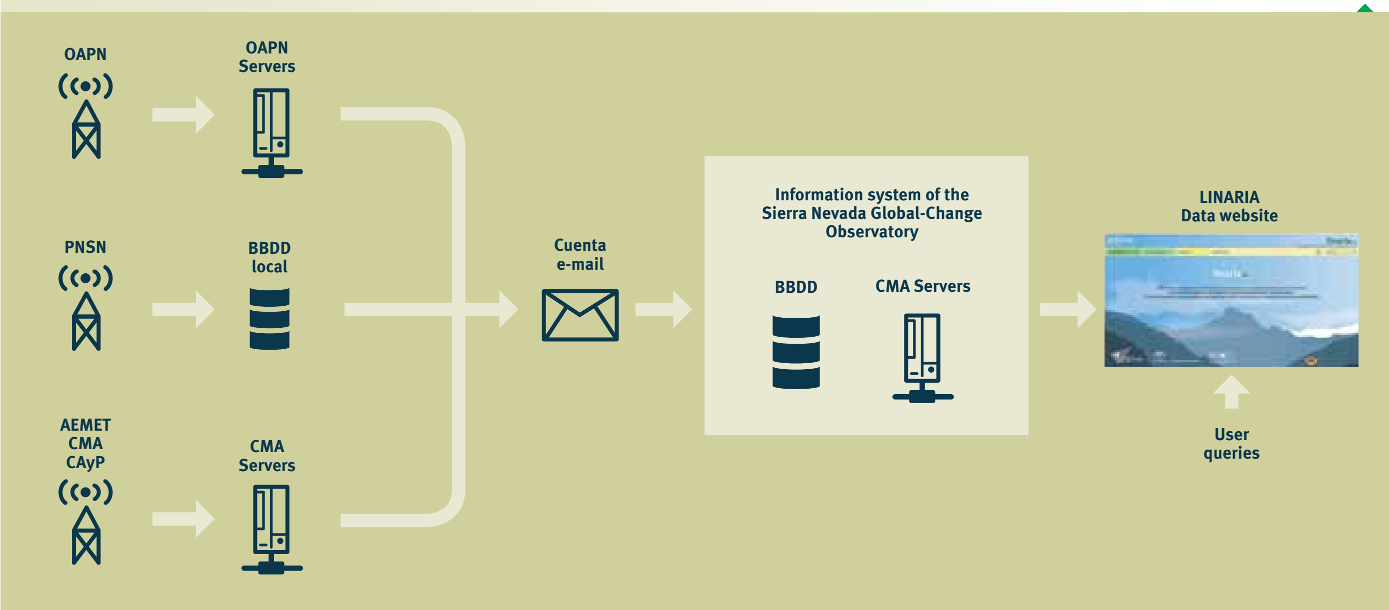
References

WMO, 2008a. Future climate change research and observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report. *GCOS-117, WCRP-127, IGBP Report No. 58 (WMO/TD No. 1418)*. January 2008.

WMO, 2008b. Guide to meteorological instruments and methods of observation. *WMO-No.8*. Seventh edition. World Meteorological Organization, Publications Board.

2.2 Supply and processing of climate data

Steps followed in the system to process climatic data.



Aims

The aim is to systematically store the data gathered by all the meteorological stations into a central database so that they can be queried by managers and researchers.

It is necessary to gather the raw data from the meteo-stations in order to simulate climatic behaviour spatially or to develop certain works of ecological analysis on a specific area of an ecosystem.

VARIABLES

Variable	Unit
Quality level of the data	adimensional

Method and effort

The integration of the raw data provided by the different meteorological stations and agencies involved the following phases:

1. Definition of the structure of the stored database adjusted to the REDIAM format in such a way that the information is easily interchanged.

2. Setting up the data-transfer system as attached documents to be sent by email (by data managers: REDIAM and OAPN) to an email address (clima@iecolab.es).

3. Programming of the workflow that automatically processes the raw data: store all the information in a database. In addition, this workkflow validates the data, filtering them according to the ranges of values and classifying them according to their quality.

4. Development of a querying procedure via web interface.

The entire process is documented in the repository of models and is executed periodically, processing and integrating the climatic data of different meteorological stations.

Periodicity

The raw climatic data are supplied with a minimum periodicity of one day in the case of the multiparametric stations of the OAPN[1] and a maximum of one month in the case of the stations of the subsystem CLIMA[2] of REDIAM[3].

The data are processed automatically every day, incorporating the data in the information system of the Global-Change Observatory (http://linaria.obsnev.es).

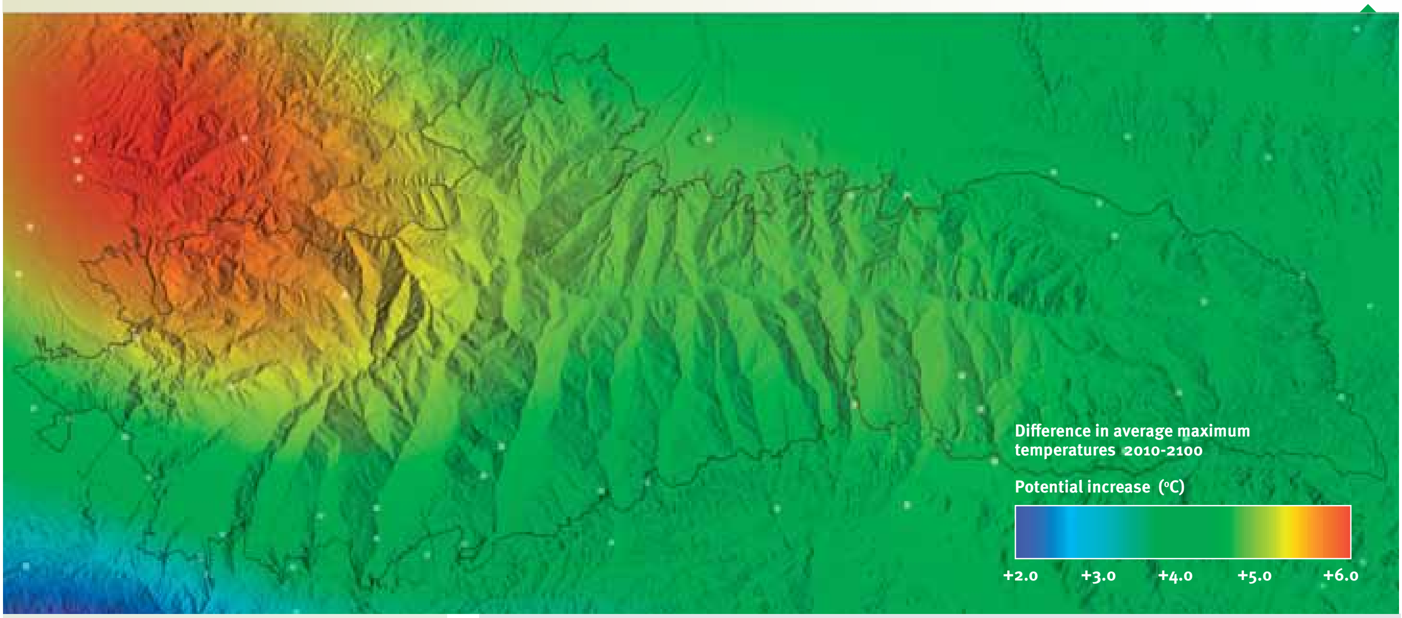
[1] Organismo Autónomo Parques Nacionales, Ministerio de Agricultura, Alimentación y Medio Ambiente.
[2] Subsistema de Información de Climatología Ambiental, Consejería de Medio Ambiente, Junta de Andalucía.
[3] Red de Información Ambiental, Consejería de Medio Ambiente, Junta de Andalucía.

References

Meek d.W. and Hatfield J.L. 1993. Data quality checking for single station meteorological databases. *Agr. Forest Meteorol.*, 69: 85–109.

2.3 Climate simulations

Temperature increase forecasted for the period 2010-2100 for the Sierra Nevada massif.



Aims

The aim is to generate digital climate maps of high resolution, both spatially (100 m) and temporally (1 year) for the average annual precipitation variables, average temperature maximus and minimus throughout the entire Sierra Nevada.

The maps represent the climate observed in the period 1961-2011, and the simulated climate according to the scenarios of climate change (A2 and B2) in the period 2011-2100.

Periodicity

The methodology is completely automated and it will be repeated as new climatic data improve those already available.

VARIABLES

Variable	Unit
Average accumulated rainfall	mm
Average maximum temperatures	ºC x 10
Average minimum temperatures	ºC x 10

Method and effort

The procedure for preparing climate maps of the past and future is the same, changing the starting data: data observed for the past and data simulated for the future.

As an initial step, a multiple-regression model was formulated taking the entry the data observed for the period 1990-2010 and predictive variables with a known influence on climate. The resulting equation is introduced in a GIS to generate a regression map, which is added to a map of spatially interpolated residuals, resulting in a reference map.

To calculate a climate map for the past or future of a variable and for any single year, the following steps are necessary:

- Selection of meteorological stations that have simulated data for this period.
- Calculation of the annual averages of the climatic variables for each station.
- Subtract from the annual averages and the reference map to find the anomaly values for each meteorological station.
- Spatial interpolation of the anomalies by regression tension splines.
- Adding together the reference map of the variable and the anomaly map of the period in question to create the final map.

This methodology ensures spatio-temporal consistency of the results, giving uniform time series that are very useful for establishing relations between the climatic dynamics and the changes in different ecological variables, facilitating the formulation of explicative models and the development of predictive models.

The maps are available from the Information System of the Global-Change Observatory in a vectorial format compatible with any GIS software.

References

Ninyerola, M., Pons, M. and Roure, J.M. 2007. Monthly precipitation mapping of the Iberian Peninsula using spatial interpolation tools implemented in a Geographic Information System. *2007 Theor. Appl. Climatol.*: 89. 195-209.

Chapter 3

Snow on the north face of Sierra Nevada, with Mulhacén and Alcazaba in the background.

Analysis of temporal changes in the cryosphere

The snow cover determines and explains a good part of the hydrological cycle of Sierra Nevada. The snow is an important reservoir of water for the forest systems and for the rivers of the massif. Also, it plays a major role as a thermal buffer in the areas where snow is present. For example, the temperature under the snow cover is higher and more constant than in places without snow situated in similar exposures and elevations. Also, it exerts a notable physical effect on the vegetation, largely determining the spatial distribution of forest, shrub, and grass formations. In short, it can be stated that the snow is co-responsible for the landscape above the tree line on Sierra Nevada. However, the snow cover is also key for other processes that are not strictly ecological. Specifically, Sierra Nevada is also economically valuable. The ski station Pradollano and the recreational station of Puerto de la Ragua constitute an undeniable source of income for the local human populations. In addition, cross-country skiing is becoming steadily more popular, not strictly linked to fixed sports facilities. The importance of the snow on Sierra Nevada is increasing because it is the southernmost mountain in Europe where water frequently freezes. Finally, the snow cover is found between the meteorological phenomena that will most likely be affected by climatic change. The combination of susceptibility to climatic change, plus the importance of this meteorological event in Sierra Nevada makes its tracking fundamental for the monitoring that we describe in this document.

The monitoring strategy of the snow cover is based on three methodological approaches at different scales. First, we undertook an **automatic monitoring of the snow cover by images** supplied by the sensor **MODIS** of

During a routine check of the multiparametric meteorological station EN1 located near Collado de las Buitreras (Sierra Nevada).

NASA. The satellites Terra and Aqua (carrying the aforementioned sensor) provide access to the daily information on the extent of snow cover, the albedo of this cover, and also on the percentage of snow in each pixel. In short, we gather weekly information on the maximum extent of the snow cover. This sensor provides a time series dating from the year 2000, with a resolution of 500 m, showing key aspects of the snow-cover dynamics in Sierra Nevada. This methodology describes the snow cover in an extensive way, but it has a major limitation in spatial resolution (500 m is too coarse to characterize certain processes) as well as temporal resolution. To solve this problem, a hydrological model was designed for the entire massif, which, by the calculation of balances of matter and energy, enable us to simulate (with 30 m of resolution) fundamental variables on the snow cover. This model shows the daily extent of the snow cover, the quantity of water contained in the snow, the thickness of the cover, and the flow that the melting snow provides, for example. Furthermore, because it is a model, we can parametrize it, incorporating entry data from past climatic conditions or future predictions. This enables us to know the state of the snow at other points in time. The last scale used in characterizing the snow is fundamental to calibrate the above hydrological model. This is a methodology based on three **meteorological stations located at sites frequently occupied by snow**. These devices measure typical climate variables and at the same time evaluate the thickness of the snow. Also, periodical visits are made to the meteorological stations to maintain the equipment and to test the snow cover. These tests tell us the thickness and quantity of water accumulated in the snow.

Depth sounding in the upper basin of the Trevélez river (Sierra Nevada).

References

Kelly, R.E.J. and Hall, D.K. 2008. Remote sensing of terrestrial snow and ice for global change studies. Pp. 189-219. En: Chuvieco, E. (ed.) *Earth Observation of Global Change*. Springer-Verlag Press.

Bonet-García, F.J. 2009. *Caracterización de la cubierta de nieve de Sierra Nevada y tendencias temporales mediante el uso de imágenes MODIS (2000-2008)*. Informe Inédito. Available.

3.1 Monitoring snow cover extent

Viewer of the Information System in which the state of the snow is shown, according to MOD10A1, for the date 24 January 2012.

Aims

The main aim of this monitoring is to characterize the snow cover in space and time, with basic information on parameters such as duration, extension, beginning and ending dates of the snow season, melt cycles, etc.. All this is gained by downloading, processing, and analysing the images of the MODIS sensor of NASA, lodged in the satellite Terra.

Periodicity

Taking into account the periodicity of the products of the MODIS sensor, 1 day for the MOD10A1 product, and 8 days for the MOD10A2 product.

VARIABLES

Variable	Unit
Percentage of the pixel occupied by snow per day	%
Albedo	adimensional
Information-quality index	range 1-5
Maximum extent of the snow cover in 8 days	ha
Extent of cloud cover per day	ha

Method and effort

Among the images taken by the MODIS sensor, two of its products were used: MOD10A1 and MOD10A2. The product MOD10A1 has a daily periodicity and provides values for the snow-cover extent (% of surface area occupied by snow per pixel), the albedo, and the quality of observation. The product MOD10A2 has a periodicity of 8 days, and it is an aggregated product that indicates the maximum of snow cover in these 8 days, improving the sensitivity of the one-day model with respect to the presence of clouds. It provides values for: maximum cover and cover over 8 days. We have created an automatic workflow that takes care of processing the satellite images and incorporating the raw data into a relational database. Afterwards, with the raw data, indicators are generated for the snowing profile, duration, and commencement dates and ending dates of the snow, the melting cycles for the different spatial entities existing in the Information System.

The workflow can be summarized as follows:

1. Download of MODIS images from NASA.
2. Extraction of values for a given zone.
3. Sending of the images taken from the Information System by web services.
4. Processing of the metadata associated with the image and sending it to the Information System by web services.
5. Automatic notification of the end of the image processing.

When the raw data for each image are transferred to the Information System, different products are created:

- Web Services of snow-cover maps (WMS, WFS, SHP, KML).
- Raw data in format CSV.
- Indicators aggregated in a graphic form and CSV.

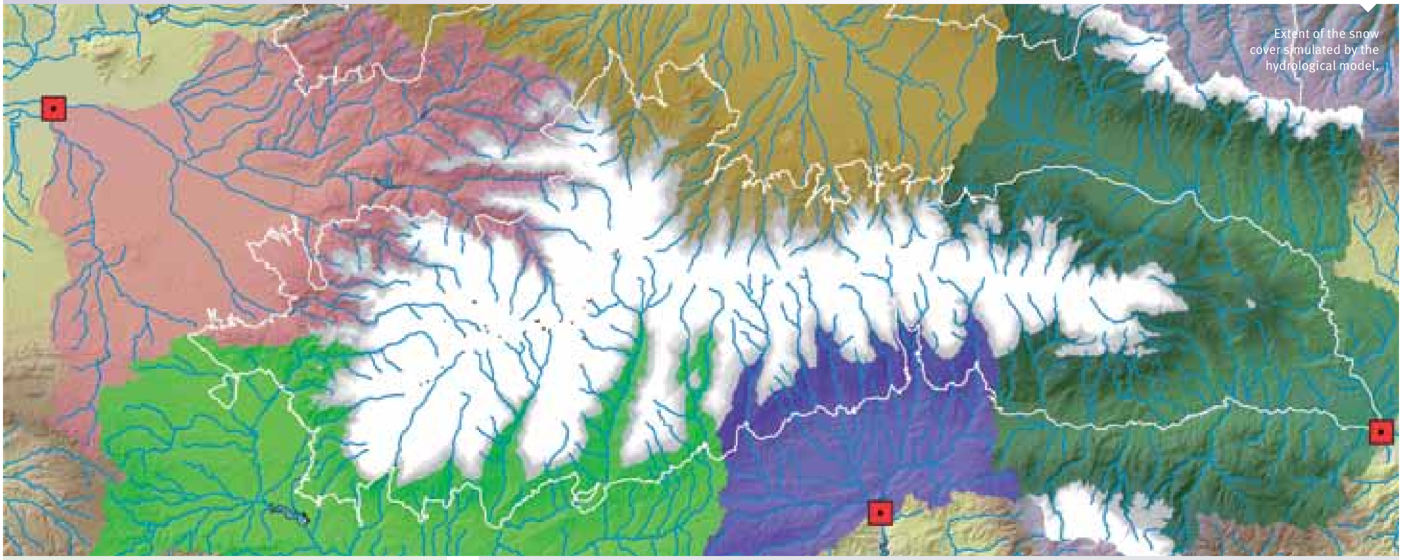
References

Pérez-Pérez, R., Benito, B.M. and Bonet, F.J. 2012. ModeleR: an environmental model repository as knowledge base for experts. *Expert Syst. Appl*. http://dx.doi.org/10.1016/j.eswa.2012.01.180

Bonet-García, F.J. 2010. Coupling of snow cover and vegetation structure in Sierra Nevada (Spain). En: *2ª International GMBA-DIVERSITAS Conference "Functional significance of mountain biodiversity"*. Chandolin, Switzerland. 27 - 30 Julio. Conference abstracts, pp. 39–40

Hall, D.K., Riggs, G.A., Salomonson, V.V., DiGirolamo, N.E. and Bayr, K.J. 2002. MODIS snow-cover products. *Remote Sens. Environ*., 83 (1-2): 181–194.

3.2 Creation of a hydrological model for Sierra Nevada: snow and water flows



Aims

The aim is to create a hydrological model in the Sierra Nevada to be able to translate the predictions of climate change to forecasts of change in the snowpack and in the flow of different watercourses of Sierra Nevada.

Periodicity

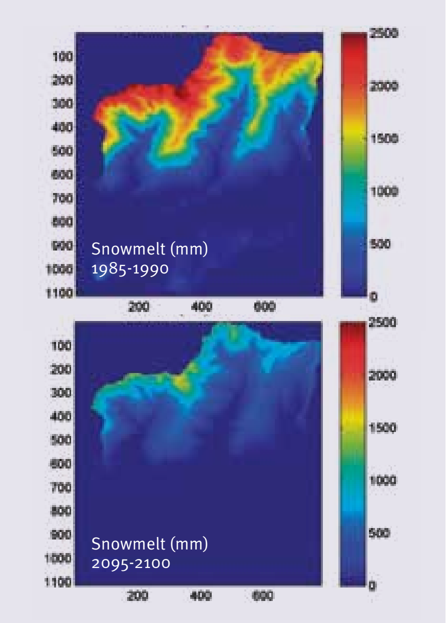
The works were executed in a continuous manner, as they involve simulation.

VARIABLES

Variable	Unit
Snow water equivalent	mm
Snow thickness	cm
Snow density	kg/l
Temperature	ºC
Rainfall	mm
Precipitation in form of snow	mm
Solar radiation	W/m²
Radiation of incident wavelength	W/m²
Snowmelt	mm
Evaporation from the snow	mm

Method and effort

WiMMed, a physical hydrological model distributed and prepared by the Universities of Granada and Córdoba (Spain) was selected for the Environmental Council of the Regional Government of Andalusia. The formulation of the model required meteorological data, physical and hydrological properties of the soil, data on vegetation, and satellite images to be compiled and translated into the appropriate format. WiMMed uses a great quantity of information to represent reality with the greatest precision possible. From the measurements of snow and water flows available at certain points, the model was calibrated and validated. As new data become available, the model will be updated to refine the simulation. Simulations have been made to draw historical snow maps (from the past) and to estimate the reduction in the snow layer and of its melting from some of the climate scenarios considered at present by the IPCC.



Changes in average annual snowmelt in the Poqueira and Trevélez valleys according to theclimate change predicted for the scenario a2 of the CGM2 model (2007) for the periods 1985-1990 and 2095-2100

References

Herrero J., Millares, A., Aguilar, C., Díaz, A., Polo, M.J. and Losada, M.A. 2011. *WiMMed. Base teórica*. Grupo de Dinámica de Flujos Ambientales. Universidad de Granada. Grupo de Dinámica Fluvial e Hidrología. Universidad de Córdoba. 41 pp.

Piña, V., Carpintero M., Millares, A., Aguilar, C., Herrero, J. and Polo, M.J. 2011. Diferencias en la relación almacenamiento descarga en las vertientes norte y sur de Sierra Nevada. *Estudios en la Zona No Saturada del Suelo*, 10: 347-352.

3.3 *In situ* snow-monitoring stations

During one monthly check
of the station EN2 (2,300 a.s.l.).

Aims

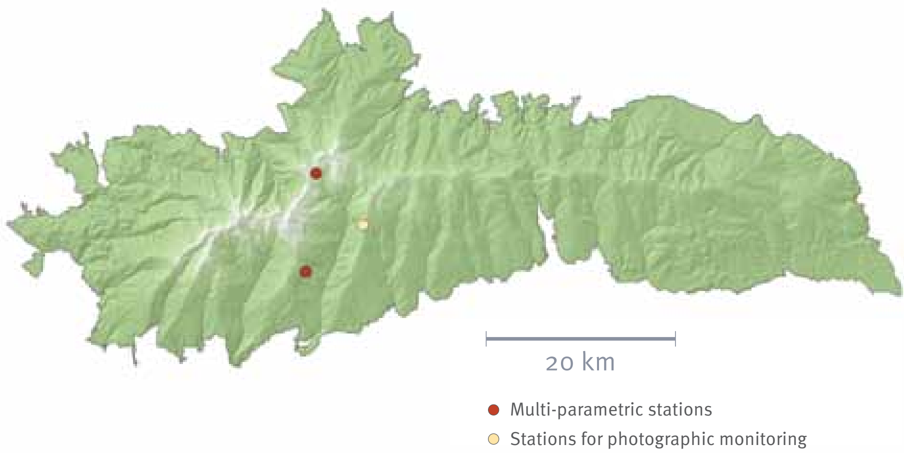
The aim of this monitoring protocol is to gather detailed information on the structure of the snow cover in specific plots. Different methodologies are applied in the same basin to compile detailed information to be used to calibrate and validate the hydrological model WiMMed (sheet 3.2).

Method and effort

Three specific meteorological stations were installed to monitor the snow in a pilot basin in Sierra Nevada. Two of these, located at 2,900 and 2,300 m a.s.l., respectively are multiparametric stations with the particularity of measuring the thickness of the snow layer, its temperature, and the solar radiation. Furthermore, they gather also typical meteorological data (temperature, wind velocity, precipitation, etc.). All of this enables us to calculate a balance of snow energy. A third station, situated at 2,600 m a.s.l. with a view of the entire upper part of the study basin, allows automatic photographs to be taken of the snow distribution. Six photos were taken daily to ensure that at least one would be valid, since variable cloudiness, adverse weather, fog, etc. determine the quality of the photo.

Periodicity

The multiparametric stations collect data daily and, due to their remote location, are checked monthly. During the winter period, at least 4 days of samples are taken monthly for snow depth and density, in addition to digging one snow well.



Monthly visits are made to check the equipment and download the data. In a parallel way, over the transects, depth probes are made, density samples are taken, and the snow wells are examined. The paths are variable in length (500-4,000 m), depending on the location, climatology, topography, and type of snow. The distance between sampling points is 200 m; each sampling point includes 5 replicates in a cross pattern, one m apart, to homogenize the values. The snow-density samples were made at fixed points, searching for significant changes in the type of snow in the trajectory of the path. In the snow wells made in each probe, information is collected to characterize: density, thickness, hardness, temperatures, microstructure (crystals), macrostructure (layers identifiable to the naked eye) and depth. All the data gathered were georeferenced, in an effort to cover all the variability in the basin. With this methodology, the automatic information gathering is combined through the snow stations, with the detailed characterization of the snow cover provided by the data taken along the transects.

VARIABLES

Variable	Unit
Snow depth	cm
Snow density	gr/cm³
Relative hardness of the snow layer	own scale
Snow temperature	ºC
Type of snow grain	own scale
Snow grain size	mm
Snow water equivalent	mm

Preparing a snow well for its analysis.

Probing snow depth.

References

Corripio, J. G., Durand, Y., Guyomarch, G., Mérindol, L., Lecorps, D. and Pugliése, P. 2004, Land-based remote sensing of snow for the validation of a snow transport model. *Cold Regi. Sci. Tech.*, 39 (2-3): 93–104.

Corripio, J. G. 2004. Snow surface albedo estimation using terrestrial photography. *Int. J. Remote Sens.*, 25(24): 5705–5729.

Durand, Y., Guyomarch, G., Mérindol, L. and Corripio, J. G. 2005. Improvement of a numerical snow drift model and field validation. *Cold Regi. Sci. Tech.*, 43 (1-2): 93–103.

Fierz, C., Armstrong, R.L., Durand, Y., Etchevers, P., Greene, E., McClung, D.M., Nishimura, K., Satyawali, P.K. and Sokratov, S.A. 2009. *The International Classification form Seasonal Snow on the Ground*. IHP-VII Technical Documents in Hydrology Nº 83 IASC Contribution Nº1, UNESCO-IHP, Paris, 80 p.

Chapter 4

In the high mountain, the study of glacial lakes provides clues to record the past and present effects of climatic change and thereby help us to understand the evolution foreseen. In the photo, Laguna Hondera (2,850 m).

Aquatic Systems

Fluvial ecosystems receive many types of pressure and impact and therefore constitute one of the most vulnerable environments against possible adverse effects of global change. Therefore, both the increase in environmental temperature as well as significant changes in the water cycles can have immediate repercussion on continental aquatic ecosystems. Temperature substantially determines **physico-chemical and biological processes** and thus marked changes in temperature can affect the metabolism, growth, reproduction, emergence, and distribution of a multitude of organisms. With rising water temperatures, the respiration rate (decomposition of organic matter and nutrient recycling) would boost the consumption of dissolved oxygen, with heavy repercussions on the organisms that have high oxygen requirements. On the other hand, a decline in the duration of the snow cover, as possible alterations in the thaw cycles could accentuate the **temporal dynamics of some flows and lakes**, causing changes in the structure and functioning of these systems. This justifies the monitoring of the physico-chemical parameters in the aquatic systems of Sierra Nevada. In addition, protocols have been implemented to monitor the biotic part of the aquatic ecosystems. In this sense, the monitoring programme of Sierra Nevada centres on **aquatic macroinvertebrates** and **particularly the common trout** (*Salmo trutta*). Aquatic macroinvertebrates should be considered the true bioindicators, due to their sensitivity to temperature changes. The predictions indicate that rising water temperatures will provoke phenological changes and thus alter the distribution of the biodiversity of macroinvertebrates, possibly leading to the

Trevelez river, situated on the southern slope of Sierra Nevada, is one of the best-studied water courses in the Sierra Nevada monitoring programme.

extinction of some of these species. Similarly, species considered invasive could colonize new areas, with consequences still unknown for local biodiversity. The common trout constitutes one of the fundamental species of the aquatic ecosystems of Sierra Nevada, occupying the cusp of the trophic chain and therefore contributing notably to shape the associated communities. The aforementioned environmental changes could affect this salmonid, altering its reproductive phenology, its distribution ranges, conversion rates, reproductive success, and its susceptibility to pathologies.

Los arroyos de alta montaña canalizan el agua procedente del deshielo.

References

Catalán J., Pla S., Rieradevall M., Felip M., Ventura M., Buchaca T., Camarero L., Brancelj A., Appleby P.G., Lami A., Grytnes J.A., Agustí-Panareda A. and Thompson R. 2002. Lake Redó ecosystem response to an increasing warming in the Pyrennees during the twentieth century. *J. Paleolimnol.*, 28: 129-145.

Durance, I. y Ormerod, S. J. 2007. Climate change effects on upland stream macroinvertebrates over a 25-year period. *Glob. Change Biol.*, 13(5): 1365-2486.

Monitoring of physico-chemical and flow parameters

Aguas Verdes Lake.

Aims

The main objectives in the monitoring of the physico-chemical parameters of the water both in the rivers as well as in the lakes are: to detect significant medium- to long-term variations in the average water temperature, as well as the influence of these variations on the rest of the parameters (pH, dissolved oxygen, and electrical conductivity) and physico-chemical processes. In the case of the flow, the intent is to detect significant variations in the natural water cycle, whether major irregularities occur in the flow, as well as a possible reduction of the quantity of water in the high-mountain rivers and streams.

Method and effort

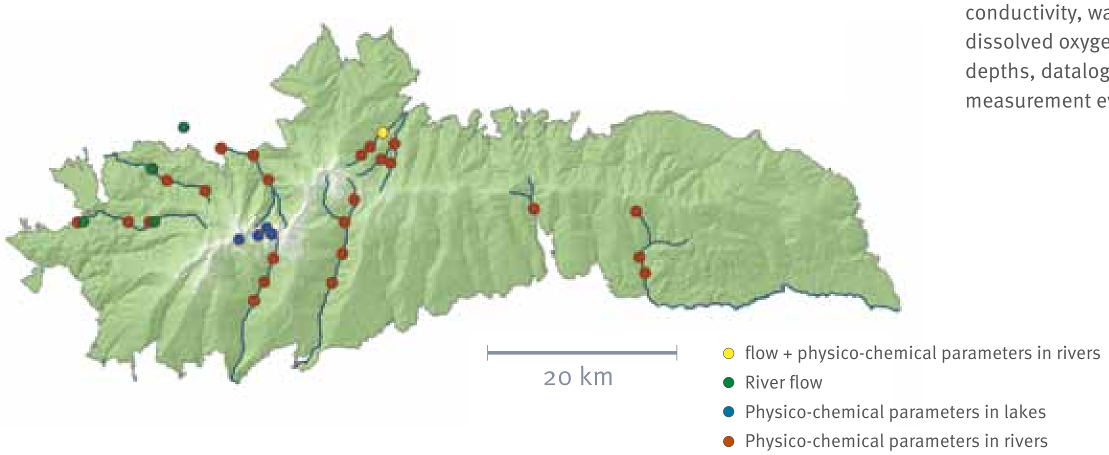
Rivers:

For the monitoring of the physico-chemical parameters and the flow in the rivers of Sierra Nevada, 23 sampling localities have been established, where data are taken *in situ* with multiparametric probes: temperature, dissolved oxygen, electrical conductivity, and pH. At the same time, water samples are collected and analysed in the laboratory using a multifunction photometer that measures: ammonium, nitrates, nitrites, total chloride, and phosphates. At some of these localities, dataloggers have been installed that measure the temperature in order to detect thermal oscillations, hourly, seasonally, and according to elevation.

The calculation of the flow in one stretch of the river representative of the season is recorded according to the scheme in the figure on the following page.

Lakes:

In the case of monitoring the physico-chemical parameters in high-mountain lakes, the sampling is made by the collection of an integrated water sample to analyse the different parameters (nitrates, ammonium, orthophosphates, silicates, electrical conductivity, water temperature, pH, and dissolved oxygen). For temperature and depths, dataloggers are placed for continuous measurement every three hours.



Periodicity

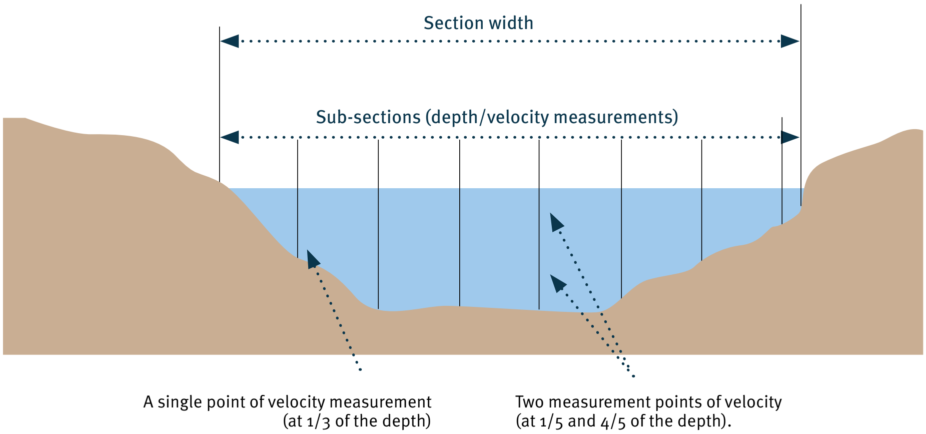
Rivers are monitored by sampling each location under study in spring, summer, and autumn, while high-mountain lakes are sampled monthly.

Laguna de Rio Seco.

Dataloggers installed in Laguna Larga.

VARIABLES

Variable	Unit
Water temperature (lakes)	ºC
Dissolved oxygen (lakes)	mg/l and % of saturation
Conductivity (lakes)	µS/cm
pH (lakes)	pH units
Water temperature (rivers)	ºC
Dissolved oxygen (rivers)	% of saturation
Dissolved oxygen (rivers)	mg/l
pH (rivers)	pH units
Conductivity (rivers)	µS/cm
Ammonium (rivers)	mg/l
Nitrates (rivers)	mg/l
Nitrites (rivers)	mg/l
Phosphates (rivers)	mg/l
Total chloride (rivers)	mg/l
River flow	l/s



For the calculation of the flow in rivers, the total width of the section is measured, establishing an initial subsection of 20 cm of the right bank of the flow, while the distance between consecutive subsections corresponds to 20% of the total width of the section, and the velocity of each of these subsections is calculated. If the depth in the subsection is less than 0.5 m, only one measurement is taken of the velocity at 1/3 of the distance between the bottom and the surface; on the contrary, if the depth is greater than 0.5 m, two measurements are taken of the velocity, one at 1/5 and the other at 4/5 from the bottom. Afterwards, the average of the two measurements is calculated.

Vi=V1/3 (h<0.5 m) or (V1/5 + V4/5) /2
Flow in each subsection: Qi=Vi -Ai
Total real flow: QR=Σ Qi
Ai=h subsection width

References

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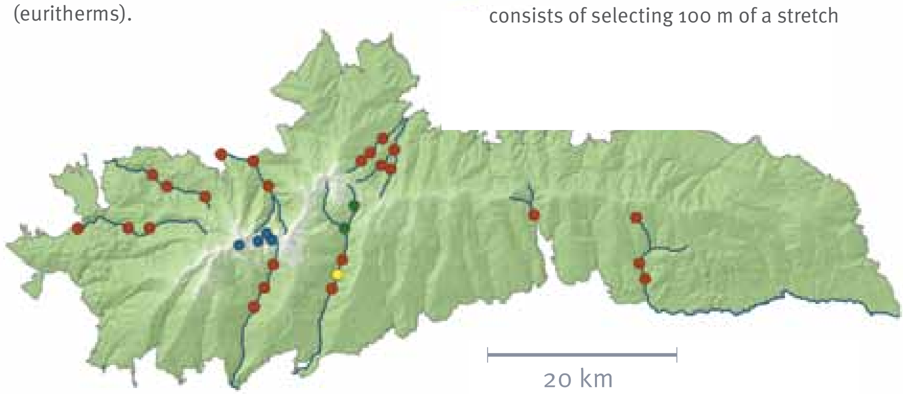
4.2 Monitoring of Biological Communities

Sampling (*kicks*).

Aims

The aims of this monitoring methodology are: to detect possible changes in the distribution and abundance of the benthonic communities, modifications in the phenology, and the distribution in elevation of the species considered stenothermal of cold water (Plecoptera), and the possible colonization by more tolerant species at high temperatures (euritherms).



Method and effort

Rivers:
A methodology compatible with the Water Framework Directive is implemented. The samplings are made in 23 localities distributed in 8 rivers of Sierra Nevada (Alhori, Andarax, Bayarcal, Dilar, Genil, Monachil, Poqueira, and Trevelez), where aquatic macroinvertebrates are sampled by an evaluation protocol. This method consists of selecting 100 m of a stretch of river where the most frequent habitats are represented (hard substrates, plant detritus, banks with vegetation, submerged macrophytes, fine sediments). The covering (%) of the habitat types determines the number of samples (20) that correspond to each habitat. At each sampling point, the samples are taken with a hand net square in section (0.25 m x0.5 m), using the hands and feet to stir the substrate situated at 0.5 m from the mouth of the net. Once the samples are collected, the contents are fixed in 96% alcohol. These samples are determined with a minimum of up to the family level in order to apply the biological-quality index IBMWP *"Iberian Biomonitoring Working Party"*. In the case of monitoring of the phenology of Plecoptera, qualitative and quantitative samples are taken of nymphs as well as adults in the Trevélez river at three different elevations (1500, 2000, and 2500 m). For the nymphs, a Surber net (40 x 40 cm) is used in 6 sweeps, while for adults, a transect (50 m long by 5 m wide) is sampled on both banks, where the riparian vegetation is beaten with an entomological rod while looking for adults hidden among the rocks. These adults are

placed in 10-ml vials containing 70% alcohol to be separated and identified to the species level.

Other quality indices used are: the Riverbank-quality Index (QBR) and Fluvial Habitat Index (IHF; see Section 8.7).

Lakes:
In the case of high-mountain lakes (Laguna Larga, Aguas Verdes, Laguna de la Caldera, and Rio Seco), macroinvertebrate samples are collected by semi-quantitative sampling. The kicking method is used with hand nets of 300 µm grid size, and all the organisms within the zones accessible to the water mass are captured.

In these enclaves, the phytoplankton community was also sampled by filtering the nets and collecting known volumes of water at different heights in the water column. The composition and abundance are studied by sampling in various positions of the water column and by qualitative sampling. The qualitative samplings are taken by dragging a conical net of 60 µm grid size on the surface (1 m deep) and at the lower limit of the photic layer. For the quantitative analysis of phytoplankton and chlorophyll, a water volume is taken from a sample with the use of a Van Dorn bottle. The sampling of diatoms enables the relative population density of each species to be established in reference to the surface sampling by the detailed count. The population density and relative abundance are determined for the different species by removing rocks from the lake bed or from the upper part of the mud. For the clorophyll, a volume of water is taken from the sample integrated with the help of a Van Dorn bottle. From each lake, three replicates are collected.


The Tricoptera are among the most demanding insects with respect to water quality.

Periodicity

Samples were taken at each study site in spring, summer, and autumn, while Plecoptera phenology was sampled monthly at each station of Trevélez river.

Adult *Perla marginata* (female).

Adult *Cordulegaster boltoni*, one of the most characteristic dragonflies of the brooks and upper reaches of Sierra Nevada.

VARIABLES

Variable	Unit
Species Richness	species number
Family Richness	family numbers
ETP Richness	Nº families of the orders Ephemeroptera, Plecoptera, and Trichoptera
Absolute abundance of phytoplankton (lakes)	cells/ml
Diatoms abundance (lakes)	number of individuals
Diatoms richness (lakes)	species number
Relative abundance of diatoms (lakes)	%
Phytoplankton abundance (lakes)	number of individuals

References

Clarke, A., Mac Nally. R., Bond, N. and Lake, P.S. 2008. Macroinvertebrate diversity in headwater streams: a review. *Freshwater Biol.*, 53: 1707–1721.

Bonada, N., Rieradevall, M. and Prat, N. 2007. Macroinvertebrate community structure and biological traits related to flow permanence in a Mediterranean river network. *Hydrobiologia*, 589: 91-106.

Alba-Tercedor, J. 1979. Larvas de plecópteros de las estribaciones de Sierra Nevada (Granada). Factores que intervienen en su distribución. Boln. Asoc. Esp. Entom., 3: 193-198.

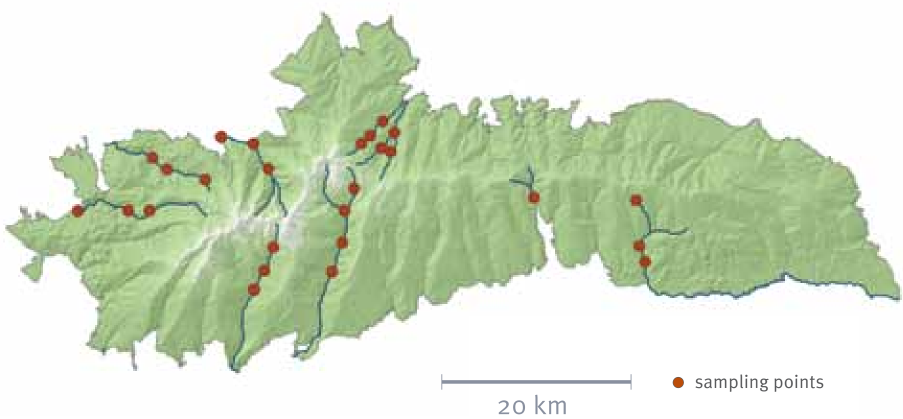
Tierno de Figueroa, J. M., Sánchez-Ortega, A., Membiela Iglesias, P. and Luzón-Ortega, J.M. 2003. *Plecoptera*. Fauna Ibérica (vol. 22) . Ramos, M.A. et al. (Eds.). Museo Nacional de Ciencias Naturales. CSIC. Madrid. 404 pp.

4.3 Monitoring of the common trout populations

Capture of a common trout by electric fishing.

Aims

The aim of the monitoring of common trout (*Salmo trutta*) populations is to determine the influence of the environmental changes on the population structure, biomass-conversion efficiency, reproductive phenology, population limits, and disease prevalence in this salmonid. These variables are correlated with other ecosystem variables in order to infer effects attributable to climatic change.



Method and effort

For the study of the structure and biomass of the common trout, 7 rivers are studied (Genil, Alcázar, Monachil, Dílar, Trevélez, Poqueira, and Andarax) using the method of successive captures with extraction by electric fishing on homogeneous surfaces. For the delineation of the populations, we firstly identify the known points with the presence of the species. Form these points, we proceed to verify by electric fishing the presence of the species upstream in the case of the upper stretch and downstream in the lower one. For this, the river is sampled in 500-m stretches previously marked with nets, making a single pass in the entire stretch with the only goal of verifying the presence/absence of the species.

The reproductive phenology is monitored by abdominal massage of specimens captured in different periods of the year, noting the formation of eggs or sperm for each individual without making a significant extraction of reproductive material. For the determination of biomass-conversion efficiency, the age was determined by scales, to test the population structures proposed by mathematical models, thus gathering morphometric information on an annual basis. Finally, periodic controls were made for pathologies to detect the incidence of emerging diseases that may be related to environmental changes.

All these biotic variables are associated with the abiotic variables taken at the same sampling points (see Sections 4.1 and 8.7).

Removal of scales of common trout to determine age.

Abdominal massage of a common trout specimen to monitor the reproductive phenology.

Periodicity

The common trout populations are monitored annually.

VARIABLES

Variable	Unit
Water temperature (rivers)	ºC
Dissolved oxygen (rivers)	mg/l
Dissolved oxygen (rivers)	% saturation
Conductivity (rivers)	µ S/cm
pH (rivers)	pH units
Water turbidity (rivers)	own scale
Flow	m/s
Granulometry of the riverbed	%
Composition of the plant cover on the banks	%
Length of the sampling area	m
Width of the sampling area	m
Furcal length of the fish species captured	cm
Weight of the fish species captured	gr
Sex and reproductive state of the fish species captured	

References

García de Jalón, D., Mayo, M., Hervella, G., Barceló, E. and Fernández, T. 1993. *Principios y técnicas de gestión de la pesca en aguas continentales*. Ediciones Mundi-Prensa. Madrid, 247 pp.
Petersen, C.G.J. 1896. The yearly inmigration of young plaice into Linsfjord from the German sea. *Rep. Dan. Biol. Stn.*, 6: 1-48.
Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Bd. Can.*, 191: 383.

Chapter 5

Alayos ridge, Sierra Nevada.

Changes in atmospheric chemistry, contaminant deposition, and aerosols

The atmosphere is an enveloping fluid that connects ecosystems on a grand scale. Its dynamic character is evident given the atmospheric processes relevant for biogeochemical cycles, as the atmosphere is highly sensitive to biogeochemical processes of the biosphere and especially to anthropogenic disturbances.

Atmospheric transport of material is highly efficient, so that hemispheric mixing occurs in hardly two weeks, implying that regional emissions can be transported over long distances to remote regions of the planet. This explains the important role of the atmosphere in the processes of global change, transmitting the impact of local or regional activities to the global scale and vice versa. This effect applies both to primary emissions (directly from human activity) as well as for secondary emissions (environmental or diffuse emissions but induced by anthropogenic disturbances or by the very dynamics of biogeochemical cycles).

In view of the potential negative incidence of certain contaminants in natural ecosystems and their transport towards remote areas, a protocol of **air-quality monitoring** has been put into practice in Sierra Nevada, described in the first section. For this, it should be taken into account that this is an important extension, where remote areas without electricity abound, hampering the installation of sophisticated equipment to measure contaminant gases. In addition, the territory is heterogeneous and the topography is complex, so that the concentrations of the contaminants at a single point are not usually adequately representative of the entire territory.

Therefore, passive dosimeters have been used. Their interest resides in the possibility of estimating the concentrations of some gaseous contaminants at remote sites or their use in extensive spatial networks. For this, four gases recognized as the contaminants exerting the greatest impact on plant species were selected.

View of the upper part of the Monachil river basin with Trevenque peak in the background.

View of the peaks of Alcazaba, 3,371 m. (centre) and Mulhacen, 3,481 (right).

Two of these are primary contaminants (SO_2 and NH_3) while the other two are secondary (O_3 and NO_2).

On the other hand, it has recently been discovered that certain elements of the earth's crust, without a gas phase, are transported intercontinentally in the form of aerosols, constituting the main supply to continental ecosystems and oceanic deficits in these elements. Thus, the interest arises to ascertain the atmospheric flows of aerosols, especially in areas of Sierra Nevada with nutrient-poor ecosystems and near the Sahara Desert, the arid zone that produces the greatest quantity of aerosols in the world.

To monitor this process, a protocol has been designed to allow the measurement of atmospheric deposition, dry and wet, of elements and substances of relevance for biogeochemical flows of the Sierra Nevada ecosystems. In this monitoring, we will also investigate the variability of the dry deposition in relation to the seasonal and annual atmospheric conditions at a synoptic level. This, as opposed to the rain, is a meteorological variable that has been scarcely studied, despite that in Sierra Nevada the dry deposition is more important than the wet one.

Blanket of clouds in the oak woodland of Canar.

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5.1 Monitoring of the atmospheric pollution by passive dosimeters

A general view of the support for two passive collectors, Cortijuela

Aims

The aim is to monitor the air quality on Sierra Nevada by the measuring of atmospheric contaminants without the need to install a permanent infrastructure or one that requires electric energy to operate.

View, from below, of the support for passive dosimeters. A casing holds the collectors of nitrogen dioxide (NO_2), ammonia (NH_3), and sulphur dioxide (SO_2), and the other casing collects ozone (O_3).

Method and effort

The devices installed are based on the physical principles of absorption and adsorption. They enable us to generate a time series of the concentrations of four of the gases known to be the contaminants with the greatest impact on plant species. Two of these gases are considered primary contaminants (SO_2 and NH_3) and the other two secondary ones (O_3 and NO_2). These may have been transported over long distances or may have been produced in situ.

In each location, two replicates are installed to collect each contaminant. The collectors of SO_2, NO_2, and NH_3 are mounted on one PVC frame and those of O_3 on another. Both frames are fixed to a post of 2.5 m high.
The ensembles are located in three localities:

Puerto de La Ragua
Landscape dominated by extensive reforestation within the oromediterranean juniper and broom domain, with snow cover several months of the year.

Cortijuela
Located on the north-western slope of Sierra Nevada, at the head of Barranco de Huenes, in a very heterogeneous landscape dominated by Holm oak and native or reforested pine stands. The point closest to the urban centre of Granada.

Puente Palo
This is found on the southern slope of Sierra Nevada in a forest setting where oak and pine forests predominate.

Periodicity

The collectors are replaced every two weeks.

VARIABLES

Variable	Unit
SO_2 concentration	ppb
NO_2 concetration	ppb
NH_3 concentration	ppb
O_3 concentration	ppb

References

Matyssek, R., Bytnerowicz, A., Karlsson, P.E., Paoletti, E., Sanz, M., Schaub, M. and Wieser, G. 2007. Promoting the O3 flux concept for European forest trees. *Environ. Pollution* 146. 587-607.

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5.2 Deposition of atmospheric aerosols

Saharan dust storm over the southern Iberian Peninsula.

Aims

The aim of this monitoring protocol is to measure the atmospheric deposition, dry and wet, of elements and substances of relevance for the biogeochemical flows of ecosystems. Furthermore, we seek to study the variability of the dry deposition in relation to the seasonal and annual atmospheric conditions at the synoptic scale.

Passive particle collector for wet deposition (left) and dry (right) partially buried in the snow. Multiparametric station of Veleta, Sierra Nevada

Method and effort

Dry and wet deposition are measured with a passive sampler equipped with a rain sensor that automatically opens or closes the containers used to collect the dry or wet precipitation. The sampler collects continuously while the samples are removed periodically and taken to the laboratory for analysis. This technique, although not exempt of certain limitations, is adequate to monitor the atmospheric flow of soluble and particulate substances that reach Sierra Nevada. The measurements of the deposition are complemented with high-volume collectors that filter large volumes of air during preset time periods to retain the aerosols in the filters, permitting the calculation of the atmospheric concentrations. In addition, we have the means necessary to relate the measurements made with the movements of air masses at a scale greater than 1000 km.

Periodicity

The passive collection of aerosols is continuous, with sampling periodically (ideally weekly) the result of the collection. Active collection (several hours) is made according to the assumption of events affecting the presence of aerosols. The collectors are reviewed each visit.

VARIABLES

Variable	Unit
Total nitrogen	μmol/l
Total phosphorus	μmol/l
Dissolved organic carbon (DOC)	μmol/l
Main ions (nitrates, sulphates, chlorides, silicates)	μmol/l
Main cations (calcium, sodium)	μmol/l
Alkalinity	mEq/l

References

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Okin, G. S., Mahowald, N., Chadwick, O. A. and Artaxo, P. 2004. Impact of desert dust on the biogeochemistry of phosphorus in terrestrial ecosystems. *Glob. Biogeochem. Cycles*, 18: Art. No. GB2005.

Chapter 6

Mixed vegetation at the head of the Alhama river in autumn.

Evaluation of the management for the conservation and recovery of biodiversity and ecological functioning

In a scenario such as the present one, in which human impact is evident (overexploitation of resources, climate change, biodiversity loss, land-use changes, pollution, etc.), responsible resource management should necessarily incorporate the concept of adaptation both in its theoretic underpinnings as well as in specific actions.

Therefore, from the Protected Area of Sierra Nevada, the choice has been adaptive management, combining scientific knowledge on ecosystems with the experience acquired in the field. Thus, the management itself that the government implements regarding natural resources becomes the object of monitoring and analysis within the Sierra Nevada Global-Change Observatory.

The aim is to show the methodologies that allow us to assess degree to which the main actions put into practice in forest ecosystems achieve the effects pursued. With these methods, we assume that no unequivocal knowledge exists concerning the manner in which ecosystems function and we recognize the uncertainty that dominates our interaction with those systems. This implies that the preparing of questions, the experimental design, data gathering, data analysis, and interpretation of the results are iterative steps, though this does not undermine the integrity of large data series and basic measurements.

These management-assessment protocols have been followed in plant formations key to Sierra Nevada: forest plantations, Holm oak

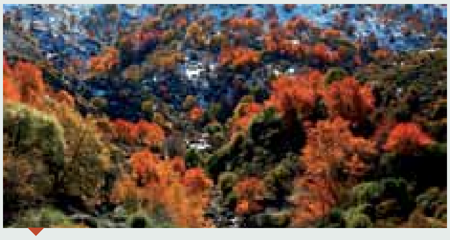
Masa mixta de encinas y vegetación riparia, Alpujarra Occidental, Granada.

woodlands, Pyrenean oak forests, and common juniper and Spanish juniper high-mountain populations:

Reforested pine stands currently face serious ecological problems. The excess density and lack of forest actions during the first stages of the trees have caused coetaneous monospecific masses of similar size. Excessive competition for water, light, and nutrients has prevented the development of an adequate understory or colonization by other forest species under the forest canopy. All this translates as great vulnerability to possible disturbances as well as a more limited offer in terms of ecosystem services than might be expected from a natural forest. Therefore, in the last few decades, the forest administration has sought both to improve the conditions against possible fires as well as to foster structural and floristic naturalization and diversification. Also, it has invested great effort in restoring burnt areas.

In recent decades, the **pyrenean oak forests** of Sierra Nevada have been submitted to shifting pressures. A drop has been noted in the number of individuals, in vegetative vigour, and in the reproductive capacity of certain populations. One hypothesis is the ascent in elevation as adaptation to global change. **Holm oak woodlands** have frequently been eliminated or degraded by human activity, in addition to felling to make charcoal and frequent blazes. In the face of this situation, management actions are directed at favouring the state of these stands in places where they are considered to develop satisfactorily according to climatic forecasts, as well as plantations and sowing in areas conducive to their colonization.

The **common juniper and Spanish juniper formations** of Sierra Nevada, of great diversity and landscape value, are in clear recession due to clearing and the burning of pastures as well as to the limitations of recruitment under current climatic conditions. To reverse this situation and bolster the capacity of adaptation of these ecosystems, a set of actions has been undertaken with the goal of creating centres of dispersal with the main components of this community. This chapter describes the monitoring methodologies employed to assess the effectiveness of the main actions taken in the aforementioned forest formations. Also, a summary is provided concerning the experimental design followed in order to evaluate the different techniques used in the forest restoration after the fire that burnt some 3,000 ha, mostly pines, in the year 2005.



View of a mixed stand in Dehesa del Camarate after the first snows.

Dense pyrenean oak stand on Sierra Nevada after intense charcoal burning in the past; now the trees have a low reproductive capacity.

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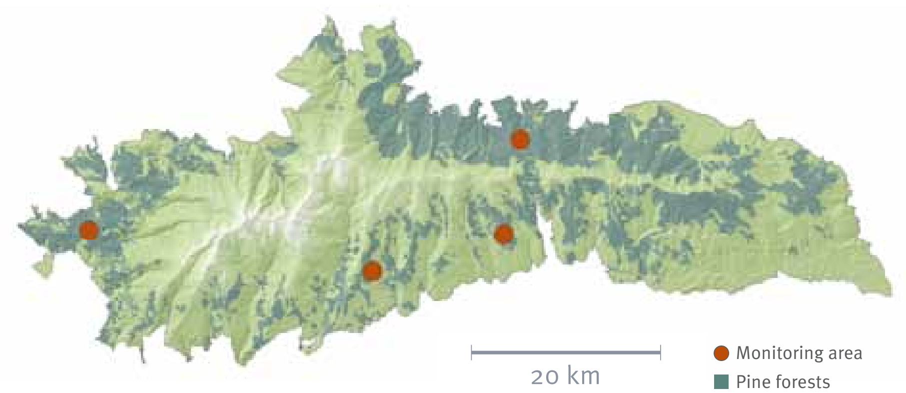
6.1 Assessment of forest management in pine plantations

Typical aspect of reforested Scots pines in Sierra Nevada, reflecting the excessive density and the artificial straight lines coinciding with the outer limits of the stand.

Aims

The objective is to evaluate the response of the forest pines to actions taken to foment floristic as well as structural diversity of the ecosystem, its resilience, and its capacity to provide environmental services.

More concretely, we seek to evaluate the incidence of:
- The intensity of the treatments applied for growth and regeneration of the main species, recruitment of other species, and the increase in floristic diversity, the increase in spatial diversity (vertical structure), survival after the treatments, and possible effects on the control of diseases.
- The effect of elevation, exposure, and the main species for the same treatment in relation to the above-mentioned variables.
- The type of machinery used to eliminate the wastes produced in the regeneration of tree species, the recruitment of other species, and the growth/survival of the accompanying undergrowth.



Method and effort

The methodology consists of laying out permanent plots for monitoring, where several experimental treatments are applied. Different treatment zones are selected based on exposure, elevation, soil type, and main species of the formation. Each area has three replicates per treatment, classified according to intensity of the clearing: 0% (control), 30, 50, and 70%.

The main parameters studied are: height, spread of the crown of the tree, growth of the last few years (before and after treatment), and regeneration of the main species and of other accompanying tree species, coverage-abundance index, and height of woody and shrubland species with importance in ecological succession, leaf-area index (LAI), Nº of dead individuals, felled or fallen, possible disappearances or alterations in the shrubland after the actions taken, and possible affects of pests. In addition, the forest plots studied are compared with their appearance in the orthophoto from the year 1956.

Hemispherical photograph taken from the interior of a reforested Scots pine stand, showing the intertwining of the crowns.

View of interior of a reforested stand of Scots pine.

Supramediterranean pine forest in Alpujarra Occidental, Granada.

Periodicity

The dasometry and epidometry of tree species are studied immediately after the forest actions taken and are repeated every 3-5 years, depending on the results found. The growth and regeneration of woody species within the framework of ecological success are studied immediately after the action taken, repeating the study one year later and thereafter every 1-3 years, depending on the results found.

VARIABLES

Variable	Unit
Tree density	tree/ha
Nº individuals/diametric category	number
Average tree height	m
Average crown diameter	m
Growth	mm/year
Fraction of live crown	relative %
Tree-species regeneration	number of seedlings or sprouts
Species richness	number of species
Species abundance	nº ind / taxa
Origin of leafy-species regeneration	% saplings/total and % or root sprouts/total
Mean coverage per taxon	%

References

Carreras , C. 2006. Diversificación estructural de masas forestales artificiales. Resultados de ensayos en Andalucía Oriental. *Invest. Agrar.: Sist. Recur. For*. (Fuera de serie): 103-110.
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Noss, R. F. 1999. Assessing and monitoring forest biodiversity: A suggested framework and indicators. *Forest Ecol. Manag.*, 115: 135-146.

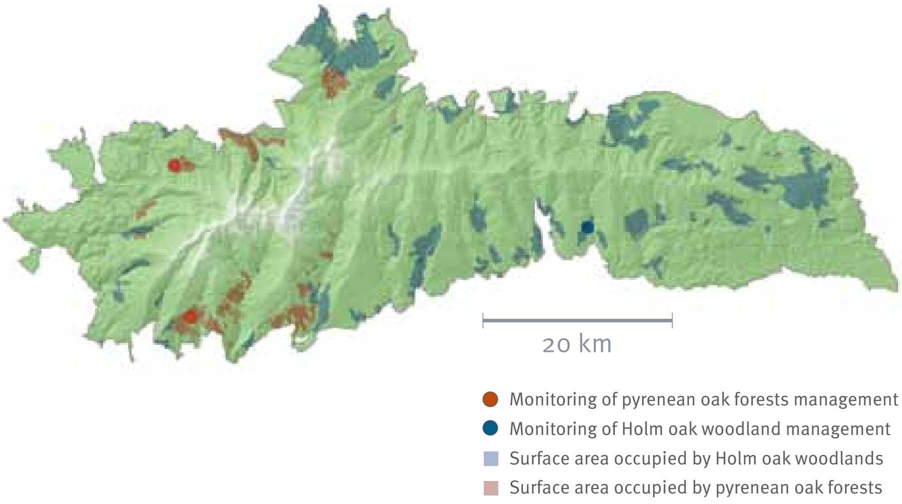
6.2 Assessment of management of Holm oak woodlands and Pyrenean oak forests

View of oak woodland of San Jeronimo in winter.

Aims

The goal is monitor the main management actions in Holm oak woodlands and pyrenean oak forests in Sierra Nevada, evaluating to what degree these improve the state of the stand, favouring its diversification both floristically as well as structurally —in short, bolstering its resilience. The actions include thinning and clearing, selective cutting, and deadwood removal, as well planting and sowing to encourage diversity, enrichment, and colonization of potential areas. The specific objectives are:

- To determine the effects of the actions to improve the physiological state of the stand, evaluated through its vegetative vigour in relation to its capacity to resist possible disturbances that might be aggravated by global-change phenomena.
- To help elucidate the relation of the density of the Holm oak and Spanish oak with respect to its regeneration, seeking the optimal density at which the flowering, pollination, and fruiting processes are most successful (maximum productivity) as well as actions that favour the capacity of seed regeneration (seedlings).
- To determine the most appropriate recovery actions of the stand at each site (according to elevation, exposure, precipitation, soil type, etc.) and type of stand.
- To appraise the success of sowing and planting to foment diversity, seeking to promote the formation of mixed stands rich in tree and shrub species.



Oak seedling.

Method and effort

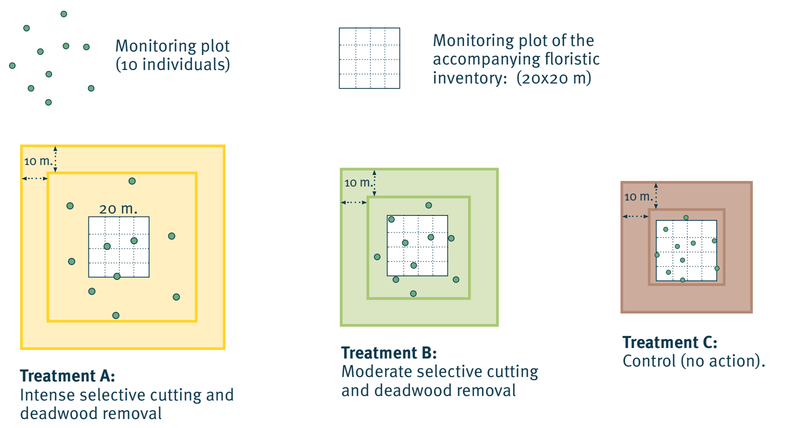
The experimental design involves the study of two oak woodlands, one on the northern slope (San Jeronimo) and the other on the southern slope of the Sierra Nevada (Canar). In each of these, three zones were delineated: oak forest, transition oak-pine forest, and pine forest.

a) Prior studies:
- Study of the time course of the area under treatment: comparisons of the information available on the past situation (flight of 1956 and 1:10,000 vegetation map of 1956) with the current situation (recent orthophotos, current vegetation maps, and the next LIDAR inventory).
- Comparative structural study by systematic photographs (pre-treatment, immediately following treatment, and 3 years afterwards)

b) Monitoring of the actions on the forest mass:
- Three treatments of different intensity of pruning and deadwood removal (oak) or clearing (pine): control, moderate intensity and strong intensity. Monitoring of 3 replicates/treatment, including each of them:
- Monitoring of the plot within the stand. Marking and monitoring of 10 individuals per plot (3 branches/individual), included in a plot with uniform treatment. Measurement of conventional dasometric variables, disease incidence, vegetative growth, productivity, and flowering.
- Monitoring plot of the accompanying floristic inventory: identical characteristics as in the monitoring plots of plant communities in the oak forests and Holm oak woodlands in order to compare data (see Section 8.5). Certain groups of species are studied, previously identified in monitoring plots of plant communities as possible indicators of structural and functional changes in oak forests and Holm oak woodlands, with special attention to changes in density and changes in cover.

c) Monitoring of sowing or planting for diversification and enrichment:
- Study of survival of plantings (monitoring of 30 seedling transplants per wooded area in a total of 3 representative wooded areas) and sowing (30 squares in pine/oak forested zones; 30 squares in a zone of medium degradation without tree cover).

Experimental design for the monitoring of oak-woodland management. The monitoring plot of the accompanying floristic inventory, 20 x 20 m per side, is identical to that used in the monitoring of plant communities (see Section 8.5).
The monitoring plot of the tree stand includes 10 individuals, which are included in a plot of homogeneous treatment with spaced a minimum of 10 m from any edge.



Periodicity

The treatments will be monitored after one year, and subsequent monitoring will be every 2-3 years, according to the results found.

VARIABLES

Variable	Unit
Tree density	tree
Basimetric area	m²/ha
Average tree height	m
Average crown diameter	m
Coverage	%
Species richness	number of species
Tree growth	cm/año
Fruit production	fruit number and average fruit size
Damage pest	%

References

Alvarez, L., Alejano, R., Madrigal, A. and Martínez, E. 1997. Influencia de los tratamientos selvícolas destinados a optimizar el desarrollo de *Quercus ilex* ssp. *ballota* bajo la cubierta de pinares de repoblación. En: *Actas del II Congreso Forestal Español. Sociedad Española de Ciencias Forestales.*

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6.3 Assessment of the forest management of common juniper (*Juniperus communis*) and Spanish juniper (*Juniperus haemispherica*)

Spanish juniper domain.

Aims

The main aim of this monitoring protocol is to gather information for future action to improve the common juniper and Spanish juniper populations based on the calculation of germination and survival rates at four different sites.

VARIABLES

Variable	Unit
Survival rate	%

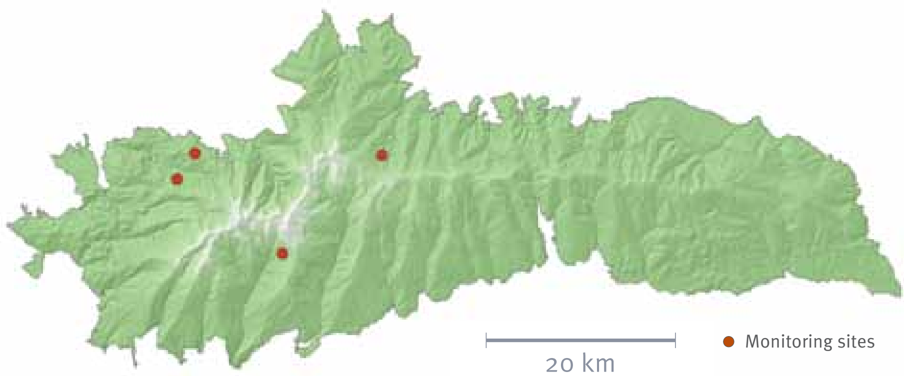
Method and effort

For sowing and planting in woodlands, we exclude livestock by fencing and, for new individual plantings, we install individual protectors. For sowing, plots of 40 x 40 cm are used with 25 seeds per sowing unit. The different species, their relative proportion, and planting density vary in each zone according to the degree of development of the action units.

For the monitoring of the planting, in each core of each dispersion, a sample of 20 specimens per species and per exclusion technique are selected. Periodically the surviving individuals are recorded.

In the areas of Poqueira, Jerez del Marquesado, and San Jerónimo, 40 sown units without protection are monitored together with another 40 protected ones.

For the planted individuals, the survival of 20 specimens of *Juniperus communis* subsp.



nana, *Thymus serpylloides*, and *Cerastium gribraltaricum*, excluded from herbivores with individual protection and perimeter fences, are monitored. For comparison, another 20 specimens of each species have been planted without exclusion structures. At the planting site of the Spanish juniper, in Collado de Las Sabinas, the survival of 20 unprotected individuals is monitored together with a number of others provided individual protection for the species *Juniperus sabina*, *Rosa sicula*, *Vella spinosa*, *Berberis hispanica*, and *Hormathophylla spinosa*. Two habitats have been differentiated, the first being a thicket of *Astragalus granatensis* and the second in clearings of reforested *Pinus sylvestris*.

Periodicity

The survival of each sample was monitored twice yearly, once in spring and again in autumn.

Specimen of Spanish juniper planted using broom as the nurse plant.

Also, other species belonging to this community are being used.

The development of grasses indicates a high degree of livestock exclusion.

References

García, D., Zamora, R., Hódar, J. A. and Gómez, J. M. 1999. Age structure of *Juniperus communis* L. in the Iberian Peninsula: Conservation of remnant populations in Mediterranean mountains. *Biol. Conserv.*, 87: 215-220.
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Harris, J. A., Hobbs, R. J., Higgs, E. y Aronson, J. 2006.Ecological restoration and Global Climate Change. *Restor. Ecol.*, 14(2): 170-176.

6.4 Monitoring of post-fire restoration

General view of the monitoring area.

Aims

The general goal is to evaluate the effectiveness of a forest-restoration plan after a fire that burned some 3000 ha in the year 2005 and that affected mainly reforested pines within the jurisdiction of the towns Lanjarón, Nigüelas, Lecrín, Dúrcal, and Cañar. The specific objectives are:

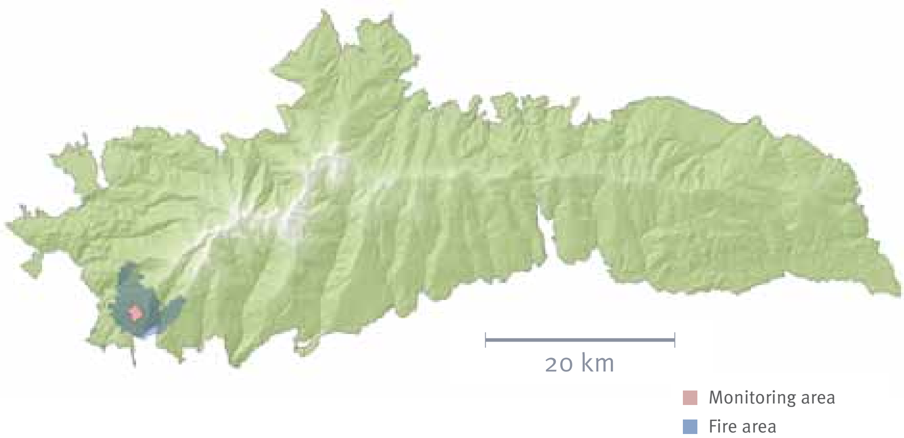
- To evaluate the effects of different techniques of restoring the forest area.
- To analyse the survival and differential growth of a diverse number of tree and shrub species used in restoration.
- To analyse the influence of pioneer shrublands and the height over the seedlings in the dispersion cores, taking into account survival, growth, and herbivory.
- To analyse the effect of elevation and exposure on the survival and growth of the young plants in the traditional reforested stands.

Method and effort

The experimental approach consists of monitoring the restoration through the dispersion cores and traditional reforested stands.

Dispersion cores: measure 30 x 30 m and 10x10 m. In these, individuals of *Crataegus monogyna*, *Rosa canina, Berberis hispanica, Prunus ramburii,* and *Quercus ilex* subsp. *ballota*, were planted 25, 50, and 100 m apart. Each of these nuclei are surrounded by pines, using *Pinus sylvestris* at the highest elevations and *P. pinaster* at the lowest.

The six introduced species are monitored in two scenarios at the low elevations (with and without



the presence of de *Ulex* spp.) and another two at high elevations (with and without *Adenocarpus* sp.). A total of 55-100 individuals of each of the 6 species were marked among the 550-560 individuals in each of the four scenarios. In addition, the presence or absence of pioneer shrubland (*Adenocarpus* sp. and *Ulex* spp.), and the influence of other factors, such as elevation and size of the nucleus, are also evaluated.

Traditional reforestation stands: in these, the same species are grouped in wooded areas of variable dimensions. The development of the population is evaluated in two areas: one on the southern slope at 1,540 m and another on the western slope at 2,140 m. In each area, 30 individual plants of the 6 species chosen were tagged individually for monitoring.

Periodicity

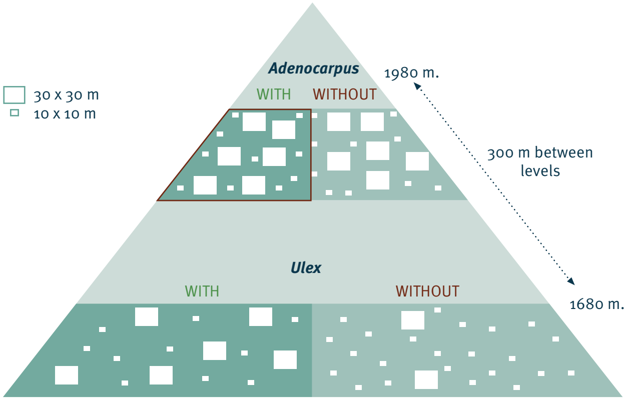
Individualized monitoring is undertaken twice yearly, once in spring and once in autumn, to evaluate winter and summer mortality, respectively.

VARIABLES

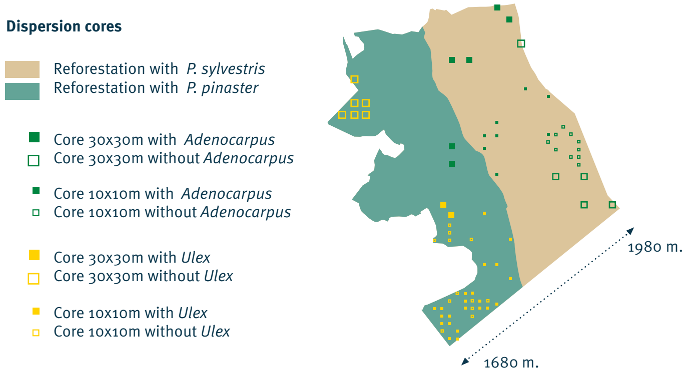
Variable	Unit
Survival rate	%
Plant growth	cm
Herbivory	% (number of shoots browsed/total shoots)
Soil moisture	%
Status of the plant	own scale

Measurement of the size and estimation of the state of herbivory.

Methodological design: in each scenario (outlined in red), 6 different species are measured and 55 to 100 individuals/species are monitored In total, 550 and 560 individuals per scenario are monitored.



Distribution of the dispersion cores over the altitudinal gradient that goes from 1680 to 1980 m inside the reforested *Pinus silvestris* and *Pinus sylvestris*.



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Castro, J., Allen, C. D., Molina-Morales, M., Marañon-Jiménez, S., Sánchez-Miranda, A. and Zamora, R. 2011. Salvage logging versus the use of burnt wood as a nurse object to promote post-fire tree seedling establishment. *Restor. Ecol.*, 19(4): 537-544.

Chapter 7

Young Spanish ibex sunning itself on a slab of slate in the summits of Sierra Nevada.

Monitoring of emerging diseases in native fauna

The reports of the Intergovernmental Group on Climatic Change and the World Health Organization warn about **changes in the distribution patterns of potentially serious diseases**. Certain diseases are sensitive to climate, which influences infection frequency and distribution as well as the transmission vectors, and can exert an impact not only on human health but also on that of livestock as well as wildlife, particularly on threatened species, which can be pushed to extinction by stochastic events.

The interaction of these variables at a certain time and place can result in epidemics triggered by the emergence and re-emergence of vectorial and zoonotic **infectious diseases**. An emerging infectious disease is defined as one that has undergone increased incidence in recent years or that threatens to increase in the coming years. In general, two groups can be differentiated: those caused by currently unknown agents such as the avian influenza (H5N1), and those caused by known infectious agents but that are on the rise (re-emerging diseases), such as tuberculosis. Wildlife is considered the reservoir of more than 70% of all **emerging diseases.**

These risks need to be better known and require new mechanisms of supervision and prevention. For this, **the populations of Spanish ibex and wild boar in Sierra Nevada are being intensively monitored**, not only at the population level but also with respect to the diseases that affect them, combining epidemiological surveillance with ecological, demographic, and reproductive aspects.

Instruments used for the sampling in wild fauna.

Stretched hide of a Spanish ibex seriously affected by scabies.

Samples being taken from a wild boar.

Male adult Spanish ibex not affected by scabies.

References

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7.1 Health state of Spanish ibex and wild boar populations

Spanish ibex affected by the parasitosis.

Aims

The aims of this monitoring protocol are: 1) to monitor and control scabies as well as other infectious/contagious diseases in Spanish ibex (*Capra pyrenaica*) populations; 2) to supervise the state of health of the wild boar (*Sus scrofa*) population as a reservoir of epizootics and emerging diseases.

Handling specimens of Spanish ibex.

Method and effort

Spanish ibex

Since 1992, the Spanish ibex population has suffered an epizootic of scabies with 4% prevalence. The prevention of scabies includes measures to avoid or prevent the disease in uninfected groups. The main tool for the management of scabies consists of reducing the density of the hosts. This would diminish the probability of contact and therefore the transmission of the disease.

1. Capture of live specimens, by physical methods (box-trap captures) as well as chemical ones (anaesthesia) followed by sampling (biometric and biological).
2. Thinning of the animals, from which a series of biometric and biological data are taken.
3. Biological studies of the population. The samples provide information concerning the state of health of the population (studies of parasites and other infectious/contagious diseases), biological studies (reproduction, indices of fat deposits on organs, etc.).
4. Studies of parasites and other infectious/contagious diseases.
5. Collaring and monitoring animals.
6. Epidemiological analysis of scabies in the Spanish ibex population in Sierra Nevada. Resistant individuals are characterized and transmission of the parasitosis among individuals of the same group or between groups is studied.
7. Thermography calibration as a diagnostic tool for scabies and as a gauge for characterizing the intensity of the parasitism.
8. Estimation of the density of mites in the hides of animals affected by scabies, by real-time PCR.
9. Characterization of oxidative stress of the hosts affected by scabies.
10. Pathologies associated with different levels of infestation of *Sarcoptes scabiei*.

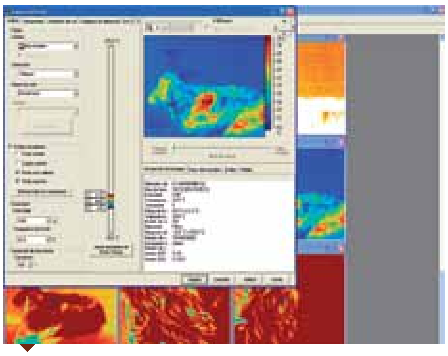
Wild boar

For the wild boar population on Sierra Nevada, the methodology has been designed to ascertain the presence and frequency of the vectors capable of provoking mass deaths or states of debility. This methodology is based on characterizing the following:

1. Taking samples from animals killed in thinning the local population.
2. Calculation of epidemiological values of different infectious agents that can provoke mass death or states of debility. Several infectious agents (parasites, bacteria, and viruses) are being monitored, given their epizootic and zoonotic nature.
3. Diagnosis of tuberculosis in the specimens handled.

Specimen wearing a GPS-GSM collar affected by the disease.

Capture of wild boar with corral traps.



Application of thermographic techniques to determine the lesions caused by scabies.

Wild boar captured for marking and subsequent monitoring.

VARIABLES

Variable	Unit
Scabies prevalence in Spanish ibex	%
Tuberculosis prevalence in wild boar	%
Serum prevalence of Aujesky disease (HVP), *Salmonella* spp., Chlamydia, and circovirus	%
Trichinosis (*Trichinella* sp.) prevalence	%

Periodicity

The works are undertaken daily, except for the hunting season (October-February).

Monitoring of a Spanish ibex specimen.

Blood extraction from a Spanish ibex captured with an anaesthetic rifle.

Necropsy of a wild boar. Submandibular ganglia with lesions compatible with tuberculosis.

References

Granados, J.E., Soriguer, R.C., Pérez, J.M., Fandos, P. and Serrano, E. 2007. La cabra montés. Bases para la implementación de un Plan de gestión de la cabra montés en Andalucía. Pp.: 677-698. En:. Barea, J.M., Ballesteros, E., Luzón, J.M., Moleón, M., Tierno, J.M. and Travesí, R. (eds.). *Biodiversidad y Conservación de fauna y flora en ambientes mediterráneos*. Granada.
Granados, J.E., Castillo, A., Cano-Manuel, J., Serrano, E., Pérez, J.M., Soriguer, R.C. and Fandos, P. 2009. Gestión de la cabra montés. Manejo de sus poblaciones. Pp.: 452-485. En: Saez de Buruaga, M. and Carranza, J. (eds.) *Gestión cinegética en los ecosistemas mediterráneos*. Consejería de Medio Ambiente. Junta de Andalucía. Sevilla.
Ruiz-Fons, F., Segalés, J., and Gortázar, G. 2008. A review of viral diseases of the European wild boar: effects of population dynamics and reservoir role. *Vet. J.*, 176: 158-169.

Chapter 8

The phenology of the arrival and departure of migratorybirds such as European bee eaters, is a good indicator of environmental change.

Repercussions for biodiversity: phenology, population trends, and changes in the abundance and distribution of species and communities

Global change constitutes an emerging problem that threatens the viability of ecosystems worldwide. One aspect demonstrated to be undergoing the heaviest impact of this phenomenon is biodiversity. In Sierra Nevada, the foreseen impact on biodiversity is similar to that expected for other mountainous regions, with the particularity that this is an isolated massif that reaches very high elevations and that is situated in Southern Europe, near a zone connecting contiguous biogeographical regions. *A priori*, we could consider that the main impact of climatic change on biodiversity could affect the following functional and structural aspects of ecosystems:

a. Changes in phenology: in different places on the planet, plants have been found to flower and fruit earlier and the phenological phases of invertebrate animals, amphibians, or birds have been found to occur earlier. The forecasts are for these shifts to provoke severe ecological problems. The alteration of the ecological relations and the competitive capacity among species in the new scenarios due to climatic change will have major ramifications for the functioning of ecosystems.

b. Changes in altitudinal distribution and abundance of species: mountain slopes and valleys constitute exceptional laboratories to study global change. It is predicted that the species in low and middle zones will progressively colonize higher elevations while organisms exclusive to the higher levels may go extinct locally or even globally, as would occur in the case of exclusive endemic species.

c. Changes in latitudinal distribution and abundance of species: the scientific literature provides a great quantity of examples of how species shift their distribution areas according to climate change. The most common pattern is one in which, under climate warming, these limits expand northwards and contract in the south, although examples are described in different directions and with highly variable magnitudes. Sierra Nevada constitutes the southernmost limit of the distribution of a considerable number of organisms and therefore many of these species may disappear with the contraction of their southern distribution limit. Meanwhile, other species from warmer latitudes will become present. This pattern has been clearly discerned in the southern Iberian Peninsula in general and in Sierra Nevada in particular.

d. Changes in ecological interactions: changes in phenology and in species distribution lead

Bonelli's eagle is one of the great predators of Mediterranean ecosystems.
Its position at the top of the ecological pyramid make this and other predators sensitive elements to alterations in the community of prey species.

to changes in community composition, including the rupture of certain interactions and the creation of new ones. Within our work area, one of the clearest examples in this sense is the expansion, thanks to rising temperatures at certain elevations, of defoliating insects such as the pine processionary in native forest areas and relict stands of Scots pine.

Amphibians, like reptiles, are ectothermic vertebrates, making them especially dependent on the environmental characteristics of their surroundings.

Butterflies constitute one of the groups of organisms in which the effects of climatic change have been studied in the greatest depth.

References

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.*, 37: 637-669.

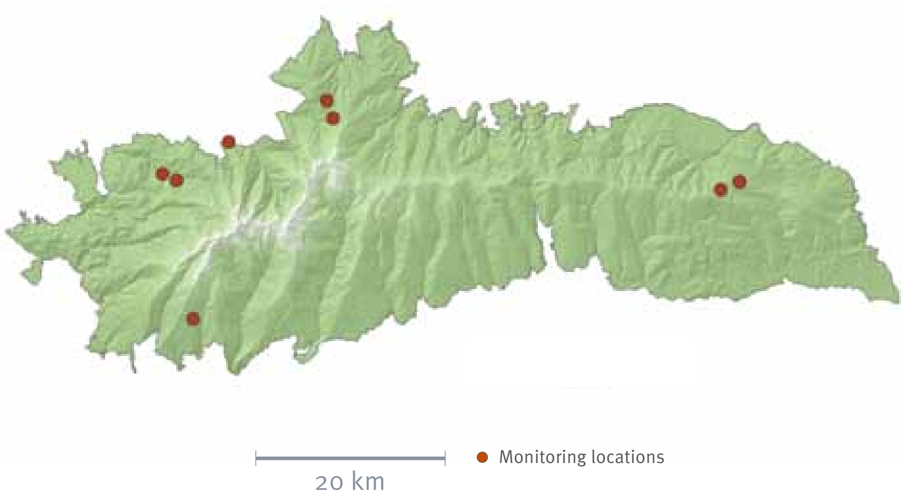
Moreno, J.M. (coord.). 2005. *Evaluación preliminar de los impactos en España por efecto del cambio climático.* Ministerio de Medio Ambiente, Madrid. 822 pp.

8.1 Flowering phenology

Shrub legumes such as Adenocarpus decorticans develop massive flowering, which helps in the identification of the different phases in the monitoring process.

Aims

The objective is to monitor phenological changes in a group of plant species along an altitudinal gradient.



Method and effort

The time course of flowering is being monitored in *Anthyllis cytisoides, Retama sphaerocarpa, Prunus dulcis, P. avium, Crataegus monogyna, Adenocarpus decorticans, Genista versicolor,* and *Cytisus galianoi*. A site is selected where each species is frequent in the landscape and is present over an altitudinal gradient enough (more than 100 m is recommended) to permit detectable differences with the methodology applied. Two different points per elevation are identified and, at each point, 20 reproductive specimens are selected. In each monitoring event, the phenological phase of the plant is registered according to the following scale:

Phase 0: flower structures are developing but anthesis has not yet begun.

Phase 1: between 1 and 5 flowers are open in the specimen.

Phase 2: more than 5 flowers are open but without having reached peak flowering.

Phase 3: peak flowering is reached.

Phase 4: fruits appear.

Phase 5: only fruit and dry flowers appear.

Flowering of *Cytisus galianoi*.

For the specific case of the Pyrenean oak (*Quercus pyrenaica*), three different locations were selected on the three main slopes of Sierra Nevada (south, north-east, and north). At each site, two pairs of plots were laid out at two different elevations. In each plot, 10 specimens were identified. In each, the development of the male and female reproductive structures were monitored. Special attention was placed on the development of the female flowers and fruits.

Periodicity

This monitoring was undertaken annually during the flowering period of each species.

VARIABLES

Variable	Unit
Flowering phase	own scale

Early-flowering species, such as wild cherry (*Prunus avium*) stand out from the rest of the tree species that form the oak forest.

Specimen of the Ibero-Magrebi endemic species *Adenocarpus decorticans* at the end of its flowering and beginning fruiting.

The appearance of incipient capitula indicate the onset of the reproductive phase of *Genista umbellata*.

During the spring, in the high peaks, great masses of broom begin to flower. The species endemic to Sierra Nevada, *Genista* versicolor is the most widespread broom on the massif.

Massive flowering of the hawthorn (*Crataegus monogyna*). A very characteristic shrub on the fringes of the Mediterranean forest.

Even within the same specimen, flowering is a progressive process according to the orientation of each branch, as reflected in this specimen of *C. galianoi*.

References

Menzel, A., Sparks, T.H., Estrella, N., Koch, E., Aasa, A., Ahas, R., Alm-Kübler, K., Bissolli, P., Braslavská, O., Briede, A., Chmielewski, F.M., Crepinsek, Z., Curnel, Y., Åslög, D., Defila, C., Donnelly, A., Filella, Y., Jatczak, K., Måge., F., Mestre, A., Nordli, Ø., Peñuelas, J., Pirinen, P., Remišová, V., Scheifinger, H., Striz, M., Susnik, A., Van Vliet, A.J.H., Wielgolaski, F.E., Zach, S. and Zust, A. 2006. European phenological response to climate change matches the warming pattern. *Glob. Change Biol*., 12: 1969-1976.

Springer, C.J. and Ward, J.K. 2007. Flowering time and elevated atmospheric CO_2. *New Phytol*., 12: 1969-1976.

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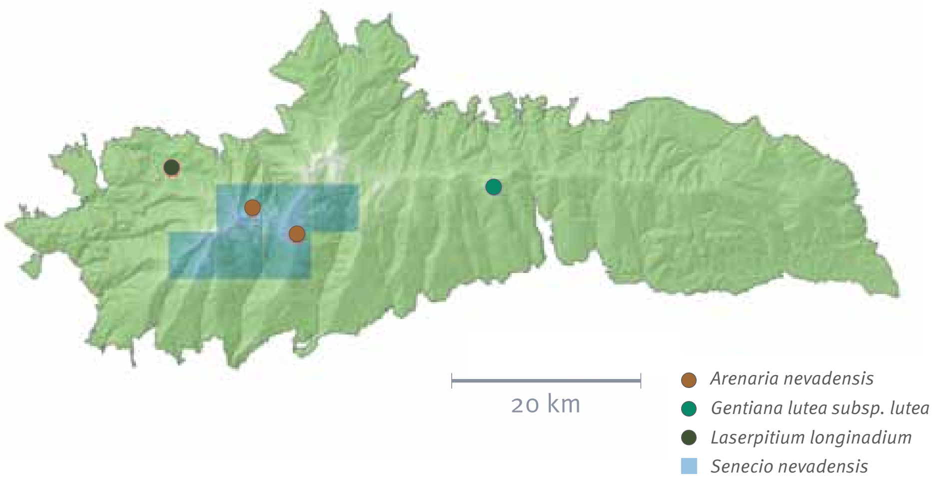
8.2 Plant-population trends

Gentiana lutea subsp. lutea

Aims

The goal of this monitoring protocol is to detect variations in the vital parameters and demographic structure of certain plant populations sensitive to environmental changes. Also, the possible contractions or expansions of the area occupied by the core populations were evaluated.



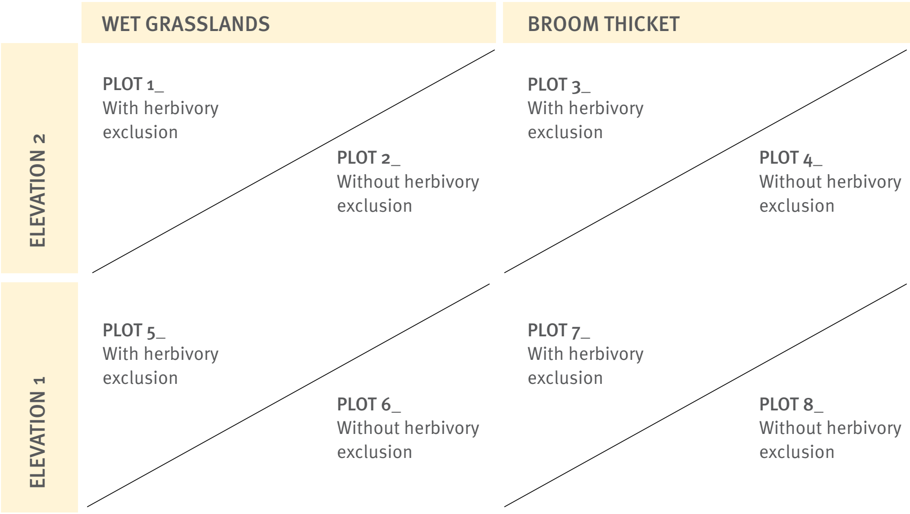
Method and effort

The species under study with this methodology are: *Arenaria nevadensis, Laserpitium longiradium, Gentiana lutea subsp. Lutea,* and Senecio *nevadensis*.

Two study levels were distinguished with two different methodologies: For S*enecio nevadensis*, a simple presence/absence model was used to compare changes in the distribution of the taxon in space and time. The monitoring was made in a series of plots selected according to the altitudinal range of the taxon. Thus, three types of plots were established: outside the altitudinal range (to detect absence and future colonization), within the range (to find individuals), and at the altitudinal limit (to detect variations). On the other hand, *Arenaria nevadensis*, *Laserpitium longiradium*, and *Gentiana lutea* subsp. *Lutea* require a more in-depth sampling, as the aim was to evaluate population trends. For this, fixed plots were laid out; for the hemicryptophytes *Gentiana lutea* and *Laserpitium longiradium*, approximately 750 individuals were included.

In the case of the therophyte *Arenaria nevadensis*, fixed sampling lines were established throughout each core population.

In each sampling, demographic parameters were determined, such as the rates of germination, recruitment, growth, survival, mortality, and fecundity. For this, variables were measured in reference to the structure into age classes and the transition of individuals among them, the percentage and cause of damage, the number of flowers and how many of them produced fruit, the number seed per fruit, the number of seeds that germinated, and the morphometric data.



Monitoring plots and map of individuals of *Gentiana lutea* subsp. *lutea*

Plántula de *Laserpitium longiradium*.

References

Iriondo, J.M., Albert, M.J., Giménez Benavides, L., Domínguez Lozano, F. and Escudero, A. (eds.) 2009. *Poblaciones en Peligro: Viabilidad Demográfica de la Flora Vascular Amenazada de España*. Dirección General de Medio Natural y Política Forestal (Ministerio de Medio Ambiente, y Medio Rural y Marino). Madrid, 242 pp.

Morris, W.F., Doak, D.F., Groom, M., Kareiva, P., Fieberg, J., Gerber, L., Murphy, P. and Thomson, D. 1999. *A Practical Handbook for Population Viability Analysis*. The Nature Conservancy. New York. 80 pp.

Periodicidad

This monitoring method is undertaken annualy.

VARIABLES

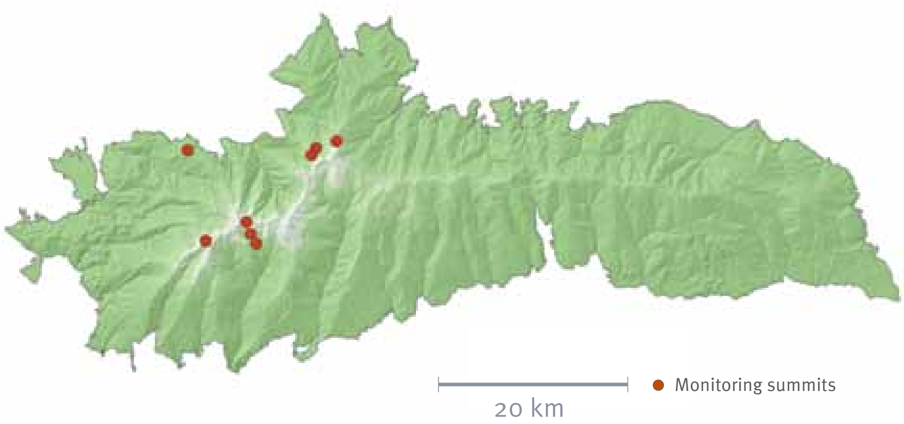
Variable	Unit
Abundance	number of individuals
Population structure by classes	Nº of individuals/ class
Population structure reproductive/vegetative	Nº reproductive individuals/ Nº vegetative individuals
Size of individuals (surface area)	cm^2
Size: heigth	cm
Growth: surface area	surface area year t+1/surface area year t
Growth: height	height year t+1/ height year t
Damage estimation: % browsing	% browsed/total
Damage estimation: trampling	% trampled/total
Damage estimation: invertebrate predation	% depredated/total
Damage estimation: drought	% died/total
Seed abundance	Nº seeds/fruit
Fruit abundance	Nº fruits/individual
Germination rate	% of seeds that germinate in one sowing
Occupation area	ha
Variation in occupation area	ha year t+1/ha year t
Distance	cm
Density	Nº individuals/m^2
Presence/absence	yes/no

8.3 High-mountain plant communities: Project GLORIA

Sampling summit:
Peak 2,968 metros.

Aims

The basic goal of this protocol is to evaluate the possible losses in biodiversity as well as the vulnerability of high-mountain ecosystems under climatic change. This approach is based on the project GLORIA-EUROPE (*Global Observation Research Initiative in Alpine Environments*), begun in 2001. This is the first European monitoring network for the effects of climatic change on biodiversity. With this purpose, in situ observations are made to detect shifts in the specific composition and in the plant cover, estimating the coverage and frequency of each taxon as well as the different types of surfaces (rock, rocky soil, bare soil, etc.). In parallel, a continuous record is kept of the temperature to enable the thermal regimes and snowfall to be compared between the summits according elevation.

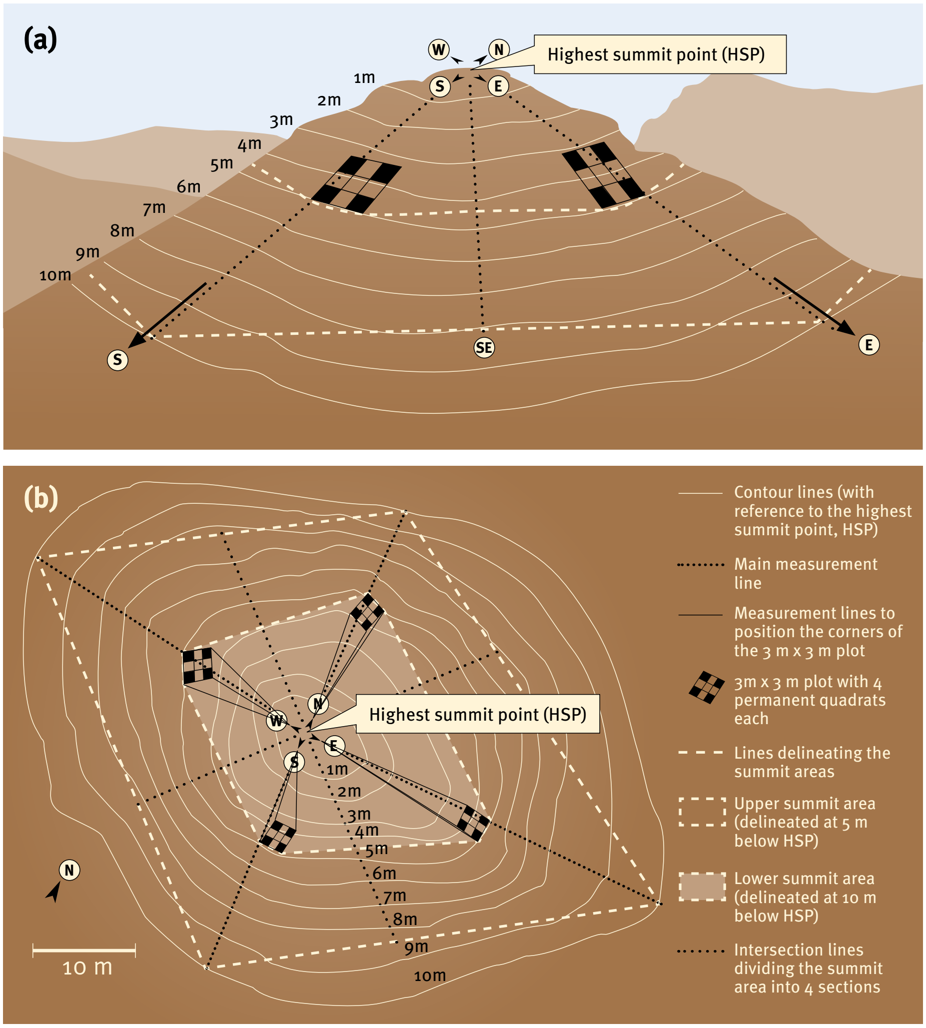


Method and effort

Four summits were selected on an altitudinal gradient of 2,700 to 3,300 m a.s.l.. At each summit the sampling of vegetation was structured in two parts:

1. Detailed sampling in 4 plots of 3 x 3 m, each divided into quadrats of 1 x 1 m; the 4 plots, corresponding to the four cardinal directions, were set into the corners a rhombus drawn with one side some 5 m from the peak of the summit; this rhombus was inscribed within a lower rhombus some 10 m from the peak also oriented to the four cardinal points. In each quadrat, a record was made on the one hand of the species composition and the cover of each component (plant, bare soil, rock, etc.) expressed as a percentage, and on the other hand the frequency of appearance of each biotic or abiotic component considered.
2. Sampling in 8 sections of the summit area roughly corresponding to contour lines of each m of elevation from the peak. For each section, the composition in taxa and their corresponding cover were estimated on a qualitative abundance scale according to the representativeness (dominant, common, widespread, rare, very rare, or spotty). Also, representativeness was estimated as percentages of the different types of ground surface.

The peaks of Sierra Nevada constitute a suitable environment to register the impacts of climatic change on plant diversity.



Adapted from Pauli et al. (2003)

Periodicity

The periodicity initially established was 7 years. The possibility is being considered of modifying the frequency for future monitoring.

VARIABLES

Variable	Unit
Species richness	number of species
Species frequency	%
Frequency of a substrate type	%
Taxon coverage per plot and summit area	%
Surface-type Coverage per plot and summit area	%
Soil temperature at 10 cm deep each hour	ºC

Schematic design of the sampling of a summit:

(a) Lateral view with schematic contour lines.

(b) Top view. Plots of 3 x 3 m and corners of the summit areas are oriented to the cardinal points.

References

Pauli, H., Gottfried, M., Hohenwallner, D., Reiter K. and Grabherr, G. 2003. *Manual para el trabajo de campo del proyecto GLORIA. Aproximación al estudio de las cimas*. Iniciativa para la Investigación y el Seguimiento Global de los Ambientes Alpinos, como contribución al Sistema Terrestre de Observación Global (GTOS). Versión traducida por Luís Villar. 67 pp.

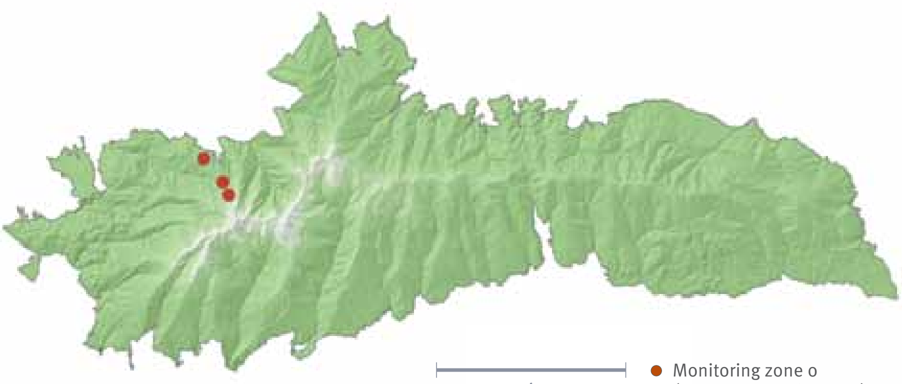
Gottfried, M., Pauli, H., Futschik, A., Akhalkatsi, M., Barancok, P., Benito Alonso, J.L., Coldea, G., Dick, J., Erschbamer, B., Fern·ndez Calzado, M.R., Kazakis, G., Krajci, J., Larsson, P., Mallaun, M., Michelsen, O., Moiseev, D., Moiseev, P., Molau, U., Merzouki, A., Nagy, L., Nakhutsrishvili, G., Pedersen, B., Pelino, G., Puscas, M., Rossi, G., Stanisci, A., Theurillat, J.P., Tomaselli, M., Villar, L., Vittoz, P., Vogiatzakis, I. and Grabherr, G. 2012. Continent-wide response of mountain vegetation to climate change. *Nature Climate Change*. doi: 10.1038/NCLIMATE1329

8.4 Common juniper and Spanish broom thickets along stress gradients

Monitoring at the head of the San Juan river 2.300 m.

Aims

The basic objective of this monitoring protocol is to assess the changes in incidence and abundance of the taxa as well as their role in the positive interactions between plants in maintaining biodiversity and ecosystem functioning in extreme environments and within a framework of global change. The methodology proposed pursues three specific aims: to advance in our knowledge of the structure and the functioning of these ecosystems over stress gradients; to evaluate the role of the positive interactions between vascular plants in this structure and functioning, and finally to apply the knowledge acquired to the management and conservation of the biodiversity in mountain habitats.



Method and effort

The monitoring is planned over an altitudinal gradient, combining two different situations or physiognomies that coexist at this elevation: the psicroxerophilous grasslands and juniper-broom shrublands to their altitudinal distribution limit. The structural difference is based on the different density of dominant shrubland species, particularly of brooms and junipers. All this is undertaken with three interrelated monitoring methods designed as: sampling by line intercepts, sampling of cover diversity, and the study of facilitation.

With these premises, paired plots were installed from 2,300 to 2,700 m with 2 or 3 replicates per elevation. These paired plots are situated adjacently and represent situations with different thicket density, with a minimum of 45% for the shrubland encroachment and 25% for the most open areas. Each one is subdivided into transects every 8 m, on which two monitoring protocols were applied. On the one hand, the line-intercept method examined the different types of patchiness that in an imbricate way intercept the line marked by a measuring tape as well as its dimensions (width and cut-off points with the measuring tape) and associated species (defining patch as an aggregate of thicket or grassy area or else rock or other types of surface).

On the other hand, for detailed knowledge on the cover and diversity, quadrats of 1.5 m square were used to record the abundance (%) of the taxa present as well as the different types of surface (rocks, fixed stones, loose stones, bare soil, plant remains, or excrement). Only perennial species were considered.

With the aim of determining the function of the ecosystem in relation to the nutrients and soil microorganisms, soil samples were extracted in the surroundings of the dominant species for each type of aggregate (*Juniperus communis* subsp. *nana, Genista versicolor, Festuca indigesta*) as well as bare soil.

The specific monitoring to study the phenomenon of facilitation included 20 isolated individuals of *Juniperus communis* and in turn *Genista versicolor* within a well-defined outline. This enabled comparisons of incidence and relative abundance of the species, according to the Braun-Blanquet scale, both for the specimen chosen as well as for the adjacent grassland.

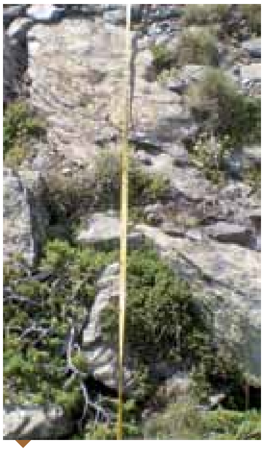
Periodicity

Initially a triennial periodicity was established, to be modified depending on the results in successive replicates.

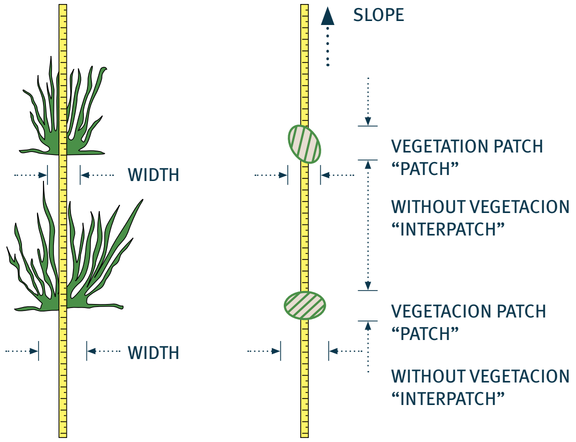
Monitoring of cover-diversity quadrats 1.5 m².

General scheme of the samplings per line intercept, illustrating the measurement of the width and length of the patches along the transect.

Adapted from: Maestre, F. et al.. Sampling protocol for the vegetation and soils. Project InterCamBio (2007-2010). http://www.escet.urjc.es/biodiversos/espa/investigacion/intercambio/protocolos_trabajo.html



The rocks measuring more than 20 cm are also considered.



VARIABLES

Variable	Unit
Species richness	number of species
Coverage by taxon	%
Coverage by type	%
Shrubland Patch intercepted	number of shurbland patches intercepted / linear surface sampled
Grassland Patch intercepted	number of grassland patches intercepted / linear surface sampled
Species richness associate to *Genista versicolor or J. communis nana*	number of species
Abundance of each taxon associated with the specimen	Braun-Blanquet scale
Enzyme activity: soil phosphatase urease and glucosidase	μmols of p-nitrophenol per gr of dry soil
pH	
Soil Conductivity	μS/cm
Soil carbon content	mg/gr
Soil nitrogen content	mg/gr
Soil phosphorus content	mg/gr
Soil potassium content	mg/gr
Average size of the patches by type	m²
Species richness associated to patch-type	number of species

References

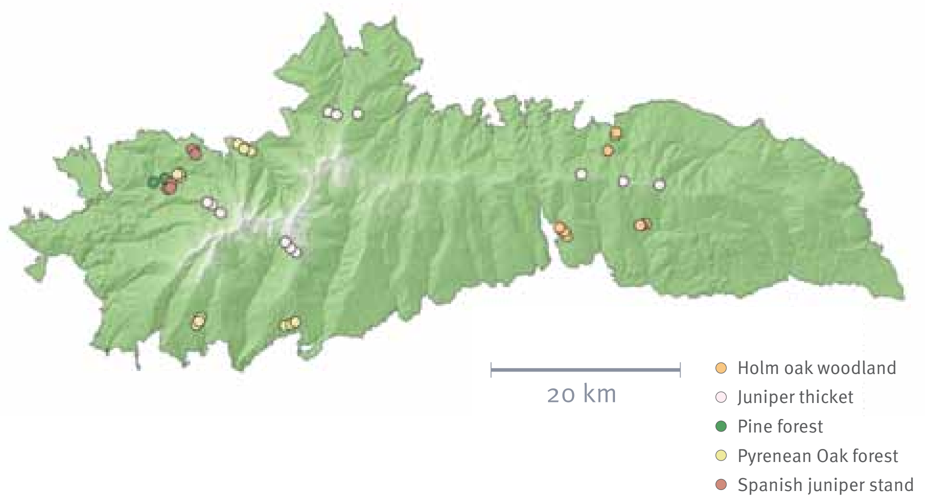
B.L.M. (Eds.) 1996. Sampling vegetation attributes. BLM Technical reference 1734-4. Bureau of Land Management´s National Applied Resource Sciences Center. Denver, USA.
Maestre, F. T., Callaway, R. M., Valladares, F. and Lortie, C. 2009. Refining the stress-gradient hypothesis for competition and facilitation in plant communities. *J. Ecol.*, 97: 199-205.
Maestre, F. T. and Escudero, A. 2009. Is the patch-size distribution of vegetation a suitable indicator of desertification processes? *Ecology*, 90: 1729-1735.

8.5 Native forests and shrublands of middle and high elevations

Dense pyrenean oak forest.

Aims

The basic aim of this protocol is to detect changes in species richness in terms of cover and frequency. The study focuses on native forests (mainly Holm oak woodlands and pyrenean oak forests) and shrublands of the medium and high-mountain of Sierra Nevada massif.



Method and effort

Sampling points were chosen in the different ecosystems studied using the available mapping of the vegetation. The monitoring effort for each community selected is directly proportional to its presence in the natural space and to its singularity. In this way, the selection made of a number of localities was intended to be sufficient to encompass the maximum diversity that Sierra Nevada offers, seeking to maintain a balanced geographical distribution. At each location, 3 replicates were established in an effort to maintain, as far as possible, the same conditions of orientation, elevation, and slope. Each of the replicates consists of a plot 20 m x 20 m which is subdivided into 16 quadrats of 5 m x 5 m each. In each quadrat, a complete inventory of taxa present is prepared and the relative coverage of each taxon is determined in the plot. This general methodology is particularized in the different plant formations selected following these criteria:

Acidophilous Holm oak woodland: This community is widespread throughout the medium mountain of the eastern end of Sierra Nevada. Holm oaks were monitored on the three sides of the massive that they occupy: Fiñana to the north, Laujar of Andarax to the east, and Bayarcal to the south.

Pyrenean oak forest: This community is considered relict in Sierra Nevada and is present in the wettest parts of the basins of the main rivers. These forests are monitored on the northern slope in San Juan and San Jerónimo. On the southern slope, those of Canar and Portugos are monitored.

Native pine forest: Present only in small stands in the limestone core of Sierra Nevada. A plot at the site of La Dehesilla is monitored.

Juniper thicket: This community is potentially abundant around the summits of Sierra Nevada but clearly in recession. Monitoring is conducted in juniper thickets of Loma de Dilar, Dehesa del Camarate, Loma de Mulhacen, and those around the southernmost summits.

Spanish juniper stands: This community is in clear regression. The stands that persist appear to maintain high rates of plant diversity and endemicity.

Dolomitic thyme thickets: These communities have a high level of endemicity on substrates very stressful for plants. Monitoring is performed at the highest elevations of Los Alayos de Dilar.

Semiarid shrublands: These communities are severely deteriorated at low elevations on the eastern slope of Sierra Nevada. In specific, we have focused on the areas of *Anthyllis cytisoides* present in Ragol and Alboloduy.

The juniper thickets have persisted in a few locations or have been relegated to the highest elevations of its potential distribution in Sierra Nevada. Some decades ago, they were periodically cut down and burned to generate pastures.

The main bottleneck limiting the continuity of Sierra Nevada oak forests is considered to be the poor regeneration capacity by seed.

Periodicity

Monitoring is undertaken every three years.

VARIABLES

Variable	Unit
Coverage	%
Species richness	Species richness

At each monitoring point, the aim is to detect changes in biological diversity and in the presence of the different biological types (therophytes, hemicryptophytes, chamaeophytes, and phanerophytes).

The methodology selected allows any type of plant community to be related practically to any environment.

The Holm oak woodlands are the most widespread tree communities in Sierra Nevada, occupying the slopes of the middle mountain over any type of substrate.

References

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8.6 Wet high-mountain pastures: *borreguiles*

Monitoring at the head of the San Juan river at 2,700 m.

Aims

High-mountain edaphohygrophilous communities known as borreguiles, are systems conditioned by the snow dynamics and potentially sensitive to temperature and precipitation changes. The systematic observation of their communities can contribute in a presumably shorter time span than other ecosystems to evidence and calibrate change phenomena related to global change. The importance and relative fragility of these ecosystems, added to the existence of prior data registered during the 1980s with a similar methodology, has led to the selection of this ecosystem as an indicator of the change processes.

The main objectives of the monitoring consist of: evaluating the changes in the composition and abundance of the taxa that make up the wet pastures of the high-mountain, recording phenological shifts, and relating all these changes to the climatic parameters available.

Periodicity

This monitoring is annual.

Method and effort

The monitoring developed in the *borreguiles* focuses on recording the changes in incidence and abundance of the taxa comprising these pastures. For the detection of alterations over a shorter term, the main phenological phases of its taxa are recorded.

The monitoring centres on the most widespread communities that inhabit this riparian setting, forming more or less wet grasslands. By means of fixed plots of 1 m^2, the existing taxa are recorded and their abundance estimated as a percentage of coverage, as is the number of specimens of each main phenological phase (preflowering, flowering, fruiting).

A small number of taxa are counted by individuals once yearly (e.g. *Pinguicula nevadensis*). The phenological aspect is monitored every fortnight, while the abundance of taxa is estimated twice per monitoring cycle, between the months of May and October. Also, 43 plots are laid out between 2,200 and 2,700 m. These include fences to exclude livestock as reference information with respect to the effect of pasturing in the area.

VARIABLES

Variable	Unidad
Species richness	species number
Abundance per phenological phase	number of individuals^2
Livestock load	number of individuals / ha
Browsing damage	%/plot
Taxon coverage	%
Abundance of key species	number of individuals

References

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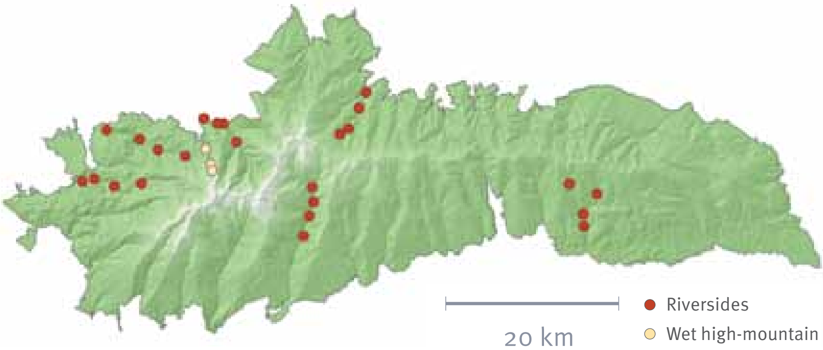
8.7 Riparian vegetation

Fluvial flow flanked by specimens of young alders *Alnus glutinosa*.

Aims

The aim is to detect possible variations in the composition and structure of the riparian plant communities. The data gathered can be related to the monitoring of fluvial systems.



Method and effort

Rivers with permanent flow and minor alteration in the plant cover have been selected. Sampling points have been established in the monitoring of fluvial systems.

Thus, 3 sampling points are established on 6 different riverbanks. In an upper elevation the density of the riparian tree or shrub vegetation diminishes drastically or does not appear, a point to follow the same monitoring process is established as described for the points with riparian vegetation.

After the sampling point is selected, a sequence of 8 squares of 5 m x 5m are laid out in parallel on the riverside. The process is repeated symmetrically to install another 8 squares on the opposite shore. In each square, the total plant coverage is estimated. Afterwards, the species present are enumerated and each level of abundance-coverage is indicated in each square (according to the values r, +, 1, 2, 3, 4, and 5) and number of feet for the species with tree or shrub habit (according to the values 1, 2, 3, 4, or ∞).

Periodicity

It is considered sufficient to repeat the process every three years

VARIABLES

Variable	Unit
Coverage	%
Species richness	number of species

References

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8.8 Monitoring of the wild boar population

Wild boar specimen.

Aims

This species is of great interest from the standpoint of emerging infectious diseases, and therefore it is worthwhile monitoring its health and population status.

Periodicity

The monitoring works are undertaken annually coinciding with the hunting season (October to February).

VARIABLES

Variable	Unit
Relative density of individuals downed	individuals/km²
Relative density of individuals observed	individuals/km²
Population size	number of individulas
Sex ratio	% females/males siempre que aparezca
Reproductive index	offspring/female
Fertility rate	Nº foetuses/female
Age structure	% of age category

Method and effort

Knowledge of population sizes of the large mammals is one of the basic requisites for the rational management of this resource. The utility of the censusing methods varies according to the objectives as well as the characteristics of the habitats that the species occupies. Due to the ecological peculiarities of the wild boar, it is considered that the method of management hunting is adequate to gather information and carry out effective control of the wild boar population of Sierra Nevada. The hunting, in which the animals are tracked with the help of dogs, facilitates the detection of the individuals found in the area; therefore, the data recorded during the hunts, properly treated, provide estimates and indicators of population density and structure.

During the hunting season, some 35 population controls are made in which around 50 people usually participate. The hours range from 8:00 to 15:00 h. Afterwards from the animals captured, biometric data and a series of biological samples are taken (blood for serum and target organs, primarily submandibular ganglia, and lung) in order to determine the prevalence of different infectious/contagious diseases and to test for the presence of tuberculosis.

From the relation between the animals observed and captured in the hunting sessions, we estimate the population size based o the equation N= n/p, where n is the number of animals captured and p is the percentage of the animals collected with respect to those observed.

References

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Tellería, J.L. and Sáez-Royuela, C. 1985. L'evolution démographique du sanglier (Sus scrofa) en Espagne. *Mammalia*, 49(2): 195-202.

Abaigar, T. 1990. *Características biológicas y ecológicas de una población de jabalíes (Sus scrofa, L., 1758) en el SE ibérico.* Tesis doctoral. Universidad de Navarra.

8.9 Monitoring of the Spanish ibex population

Joven macho enfermo de sarcoptidosis, marcado para su seguimiento.

Aims

The aim is to monitor the population parameters of the Spanish ibex. In Sierra Nevada the population of this species reaches densities of some 9 individuals/km², although in certain areas and specific periods the optimal density is estimated at some 4 to 5 individuals/km². This triggers adverse effects on endemic plants and ecosystems of Sierra Nevada that should be appropriately managed. Therefore, the aim of this monitoring is to assess the population trends of the Spanish ibex in Sierra Nevada and to implement management measures intended to conserve the species and maintain its populations within sustainable ranges.

Method and effort

For the objectives set, the following methodologies have been put into practice:

1. Annual population estimates, both in Sierra Nevada as well as in peripheral mountain systems.
2. Matching the population to theoretic parameters (sex ratio, populational pyramid, reproductive index, reproductive potential, etc.).
3. Capture of live specimens, both by physical methods (capture devices) as well as chemical (anaesthesia) and the taking of biometric and biological samples.
4. Hunting of animals, from which a series of biometric and biological data are taken.
5. Studies of the state of health of the population: studies of parasites and other infectious/contagious diseases as well as the genetic characterization of the hosts.
6. Research on the reproduction biology and physiology.

Periodicity

The population estimates are made annually during the month of October. The rest of the works are executed daily.

VARIABLES

Variable	Unit
Density	individuals/km²
Sex-ratio	% females/males
Reproductive index	offspring/female
Age pyramid in males	% of age category

References

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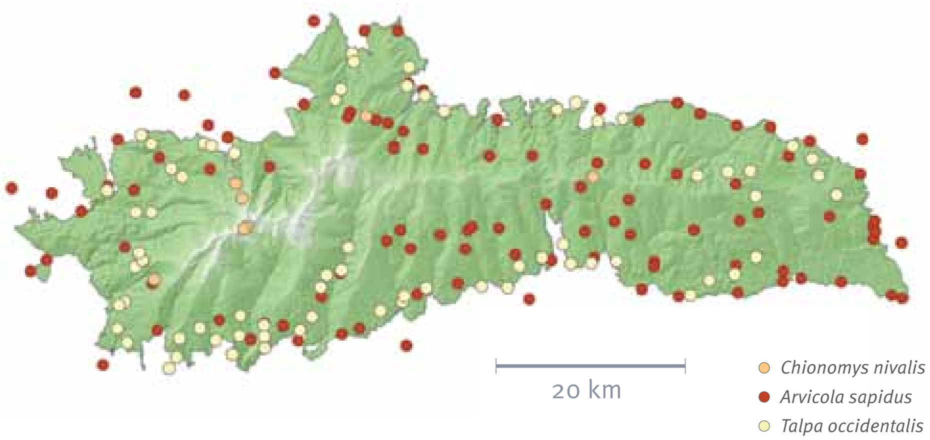
8.10 Micromammals

European snow vole is a rodent adapted to rocky areas.

Aims

The objective of this monitoring is to assess the population trends of certain micromammal species in Sierra Nevada.



Method and effort

The micromammal species included in the monitoring program are the European snow vole (*Chionomys nivalis*), the south-western water vole (*Arvicola sapidus*) and the Spanish mole (*Talpa occidentalis*). The three species have very different ecological requirements and thus the data derived from their monitoring reveal evolutionary aspects of the three well-differentiated types of ecological systems. Below, the three methodologies used are described:

European snow vole (*Chionomys nivalis*): between June and August, the intensive monitoring is made in seven colonies. These colonies are found at different elevations and orientations. The study is made by live trapping with 30 folding Sherman traps © (8 x 9 x 23 cm). Each is baited with fruit and bread impregnated with peanut butter. Also, a piece of cotton is used. The traps remain active for five days and four nights per location and are reviewed daily at sunup and sunset. Each specimen captured is marked with a microchip to recognize its identity in case it is recaptured. The biometry is recorded, parasite load, and sex of each specimen. After handling, each specimen is released at the same places as it was captured.

South-western water vole (*Arvicola sapidus*): half-hour sampling sessions were conducted in each location likely to harbour this species. If the sampling proves positive, it is concluded and the time until locating this first indication is noted. The indirect indices used to validate the presence of this species are: latrines, feeding remains, and galleries. In parallel, some physical characteristics are also recorded at each location to estimate the type of response the south-western water vole makes when faced with changes in the environment. All of the 5-km UTM squares on the side of Sierra Nevada were prospected.

Spanish mole (*Talpa occidentalis*): given that the abundance of mole hills can be considered as an index of activity of this species, both the distribution as well as the abundance are inferred from these indirect indices in the field. A total of 18 transects 7.5 km long have been laid out with a total of four sampling stations per transect, roughly 2.5 m apart. In all, there are 72 stations or plots. Each plot measured 50 m wide and 100 m long, and within them the mole hills are identified simultaneously by two persons. Each observer counts the number of mole hills in a strip approximately 12.5 m wide, and therefore it is necessary to complete the 100 m in two turns in order to adequately cover the 50-m strip of the plot. The plot of 100 m long is divided into five segments of 20 m, where the presence/absence of mole hills is recorded. In this way, the proportion of the positive segments can be interpreted as an index of relative abundance. In each of these subplots of 20 x 50 m, not only the number of mole hills but also a number of variables are recorded to be interpreted later as environmental predictors. These variables are related to the structure of the habitat and to livestock uses at a detailed scale.

Periodicity

The same methodology is implemented once per year in the case of the snow vole (since 2008) and is repeated every two years in the case of the south-western water vole (since 2011) and the Spanish mole (2008 and 2010).

Preparation of Sherman traps© for the study of a European snow vole colony.

Handling of a European snow vole specimen.

Exit of galeries excavated by the Spanish mole.

Gallery by south-western water voles in the vegetation generated.

VARIABLES

Variable	Unit
EUROPEAN SNOW VOLE	
Sex ratio	% females/males
Age structure	% adults, % juveniles
Absolute abundance	number of individuals
idem	Nº of individuals/trap and night
Size and weight (biometry)	mm and gr
SPANISH MOLE	
Relative density	% positive substations
SOUTH-WESTERN WATER VOLE	
Distribution	presence/absence

References

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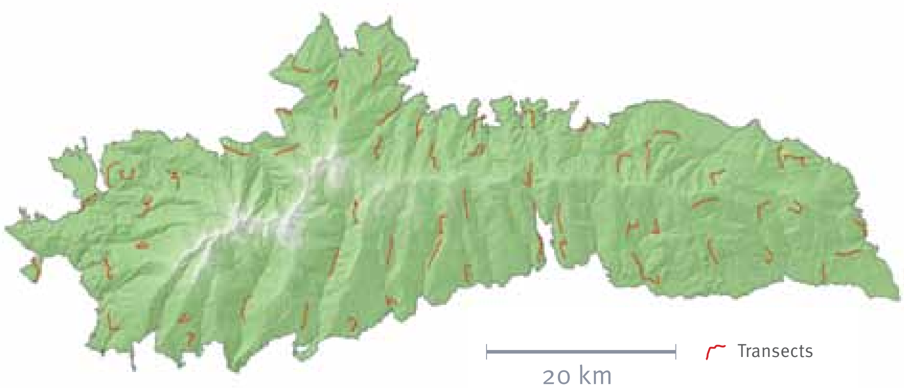
8.11 Carnivorous mammals

The fox is a common carnivorous mammal in Sierra Nevada and has a key role dispersing seeds.

Aims

The objectives of the monitoring of certain carnivorous mammal species within the framework of this monitoring project are to identify the distribution patterns, abundance, and habitat selection of the species monitored.



Method and effort

These species are: fox (*Vulpes vulpes*), beech marten (*Martes foina*), European badger (*Meles meles*), European wildcat (*Felis silvestris*), and common genet (*Genetta genetta*). To map the distribution and abundance of the mesocarnivore community in Sierra Nevada, we used a UTM grid with squares 5 km x 5 km as the study unit. All the complete UTM squares that contained at least 50% of land included in the protected area were studied, except for 6 squares where elevations of higher than 2,500 m predominated. In each square, we walked a fixed segment of 3 km. In total, 198 km were sampled. In this way, over the 3-km length of each transect, the intent was to sample all the units of interest or strata present in the square, maintaining the same proportion within the stretch in which these strata are represented in the environment or at least seeking to stratify sets of stretches on landscape units on a large scale. The design method consisted of dividing each stretch into 12 stations of equal length (250 m each), and searching for indices of the presence of carnivorous mammals over that stretch. The presence of a species in a square was considered if at least one indication assignable to this species was located.

The relative abundance of a species in each stretch and consequently in each square was inferred from the number of 250-m stations where excrement (or depositions of glandular secretions) were found. For the calculation of relative abundance, only excrement and glandular markings were used because the occurrence of tracks depends on the type of substrate sampled, which would bias the abundance study.

In parallel, local studies are made of the carnivorous fauna by camera traps in order to detect species for which indices could be overlooked during the sampling of the transects (e.g. the common genet), species of low density but of high interest for our work (e.g. European wildcat) and in general as a means of recording the absolute density of the species that make up the mesocarnivore community at the local level as a complement to the larger-scale monitoring explained above.

The camera-trap was used primarily in the oak forests, Holm oak woodlands, and reforested pine stands on the north and south slopes of the massif. At each location, 12 cameras are set, covering a surface area of 12 km^2 and spaced at least one km apart, with an effort of nearly 700 photographs/night.

Periodicity

The monitoring was performed four years apart, in 2007 and again in 2011. The camera trap was begun in 2011, after an experimental phase in 2010.

VARIABLES

Variable	Unit
Relative density	positive station/ total stations
Absolute density	individuals/ha (camera traps)
Distribution	presence/absence

European badgers deposit their excrement in latrines. They are also responsible for a large quantity of glandular secretions with social significance.

European badger sett, showing esparto grass used to line the interior of the burrows

European badger tracks.

European wildcat female captured by a camera trap in the Chico river valley.

Tracks of European wildcat.

Process of setting up a camera-trap system.

References

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8.12 Raptors

Golden eagle adult soaring over one of the spectacular glacial valleys on the northern face of Sierra Nevada.

Aims

The main aims of the monitoring of raptors in Sierra Nevada are: to ascertain the trends in their populations over time in terms of number of reproductive pairs, to record variations in the different parameters related to population dynamics, and to establish a relation between distribution and development of the populations as well as their reproductive parameters over time.

Observer recording nesting parameters in a golden eagle territory.

Method and effort

The monitoring focuses on identifying reproductive units. Once the number of pairs is estimated, the reproduction process is monitored. Greater effort is dedicated mainly to rupicolous species (golden eagle, Bonelli's eagle, and peregrine falcon), although this monitoring also centres on forest species (northern goshawk, Eurasian sparrow hawk, booted eagle, short-toed snake eagle, and common buzzard). The only reproductive diurnal raptor in the study area not included in the monitoring described here is the common kestrel. The monitoring in the three rupicolous raptor species consists of making different visits throughout each territory, checking incubation, the number of hatched chicks, and finally the number of chicks that leave the nest. Also, the age of the reproductive pair is recorded. In the case of raptors associated with forest environments, the monitoring is least intensive, recording only the exact location of the nest where the reproduction event occurs and the number of chicks that hatch.

The booted eagle is a migratory raptor that reproduces in substantial numbers in Sierra Nevada.

A short-toed snake eagle is a migratory raptor that can be considered scarce in Sierra Nevada.

Periodicity

The raptors in Sierra Nevada are monitored yearly, coinciding with the different reproduction dates. The monitoring therefore spans the end of winter (beginning of incubation of the golden eagle(until the onset of summer (when the nest is vacated by chicks of some species that have a later reproductive phenology or a longer period of rearing the chicks).

VARIABLES

Variable	Unit
Abundance	Nº of territories
Density	Nº of territories/ha
Occupation rate	% territories with incubation
Breeding success	% of territories with fledged young
Productivity	Nº chicks/territory occupied
Nest-leaving rate	Nº chicks leaving the nest/territory with chicks
Rate of adult pairs	% adult pairs
Rate of adults	% of reproductive adults
Mortality rate	% adults that die

The common buzzard is a forest nester in Sierra Nevada.

Fifteen pairs of Bonelli's eagle nest in Sierra Nevada.

For the control of the nests, binoculars (10x40) and telescopes (20 to 60x) were used. The monitoring of each pair is intensive, and reproduction is not ruled out until completing the necessary number of visits to the territory.

Associated with each reproductive event, the characteristics of the nesting site are recorded together with the possible threats that could affect the normal development of the brood.

The golden eagle, with 21 pairs, can be considered an abundant species in Sierra Nevada.

References

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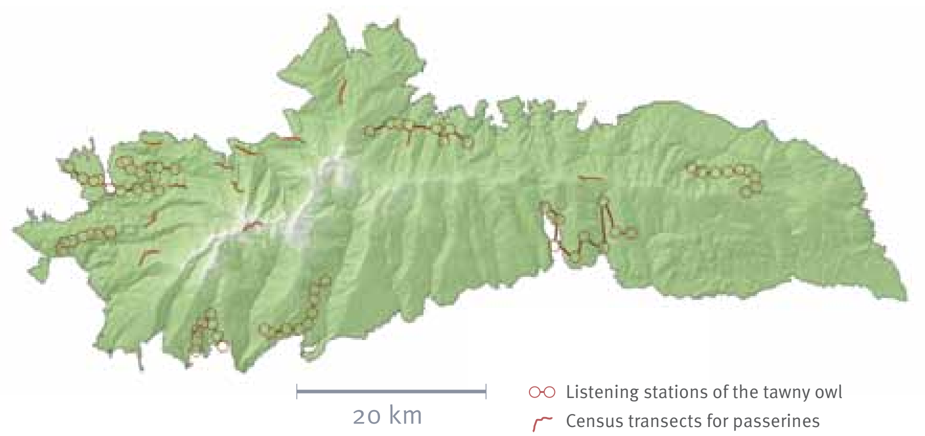
8.13 Passerines and other birds

The Alpine accentor is the clearest example of a high-mountain passeriforme in Sierra Nevada.

Aims

The main aims of the monitoring of birds in Sierra Nevada are: to ascertain the trends of their populations over time, to determine the shifts in community composition, to record possible changes in phenology of arrival and departure of migratory species, and finally to assess the state of the ecosystems inhabited as a means of foreseeing possible problems.



Method and effort

Three different types of methodology were used:

Census transects: used especially for passerines, although also for other orders. A total of 16 transects are completed, each roughly 2.5 km long and along which all sightings are recorded in a strip measuring 50 m on each side of the observer, which in turn is divided into 5 strips 10 m wide.

The observer walks at a constant speed of 2 to 4 km/h for the first stretch of the morning. These census walks are distributed among three specific ecosystems: forest (oak stands), shrub (thorny thickets on the edge of the forest as well as common juniper and Spanish juniper areas) and summit environments. These ecosystems were selected based on criteria of singularity and ecological functionality in the context of Sierra Nevada.

In parallel, the autumn crop of fruits was monitored in the species *Crataegus monogyna, Prunus spinosa, Berberis hispana, Lonicera arborea, Juniperus oxycedrus, Quercus pyrenaica, Rosa* spp., and *Sorbus* spp. with the aim of relating the trend and phenology of frugivorous birds to the state of this crop.

Listening stations: used exclusively for monitoring the tawny owl (*Strix aluco*). Eighty stations distributed every 1,500 m in 10 transects of 12 km long each are monitored. There, for 15 min, a recording of the calls of this species are emitted. At each station, different environmental parameters are recorded, as well as the number of specimens of tawny owl that respond to the calls, and its sex. The time until the call is answered is also recorded.

Direct search: seeking reproductive pairs of common rock thrush (*Monticola saxatilis*) and reproductive pairs, feeding areas, and roosts of the red-billed chough (*Pyrrhocorax pyrrhocorax* subsp. *erythrorhamphus*). In both cases, habitats propitious for both species are walked, sampling with optical devices (binoculars 10x40 and telescopes 20-60x100).

A specimen of rufous tailed rock thrush.

The great tit (Parus major) feeds on little arthropods, contributing to the ecosystem functioning in forest areas.

The European robin eats fruits, becoming an active seed disperser.

Periodicity

The transects are monitored monthly all year except for the stretches of the summit areas, which are completed only during the dry period, which is the time during which the biotopes are accessible for sampling. These transects have been monitored since 2007. The common rock thrush, the red-billed chough, and the tawny owl are monitored annually during the period appropriate for each species.

VARIABLES

Variable	Unit
PASEIFORMES	
Kilometric Abundance Index (KAI)	Nº of individuals/km
Density	Nº of individuals/10 ha
% of ripe fruits	ripe fruits/total fruits
Fruit crop	own scale
Species richness	number of species
TAWNY OWL	
Abundance	Nº of territories
Relative density	% positive stations
COMMON ROCK THRUSH	
Distribution	presence/absence
Abundance	minimum Nº of territories
Density	Nº territories/ha
RED-BILLED CHOUGH	
Abundance of reproductive pairs	minimum Nº of pairs
Distribution	presence/absence
Abundance of Wintering Birds	minimum Nº of individuals

Hay una dua en esta unidad¿?

References

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8.14 Amphibians

The Betic midwife toad is endemic of the south-east Iberian Peninsula; its populations can ascend in Sierra Nevada to 2,500 m, the world altitudinal limit for this species.

Aims

The main objectives of the monitoring of the seven amphibian species in Sierra Nevada have been to compile an inventory of species to date, to analyse their distributions, to forecast the effects of global change on their populations, and to analyse the set of threats against them. Adaptive management has also constituted a priority and conservation actions have been specified to mitigate the impact of global change on their populations.

Periodicity

The amphibians of Sierra Nevada were intensively studied in 2009 and 2010. Efforts will be continued for certain strategic areas, periods and species.

Method and effort

The samplings are based primarily on counting larvae or adults at the reproduction points, and therefore the initial effort was the search for these sites. Regardless of the presence or not of amphibians at the time of sampling, the enclaves with the potential for reproduction of these species were searched for and characterized. After the location of these points, itineraries were drawn and strategically designed nocturnal routes were followed. For the measurement of the sampling effort, the starting and ending hours were recorded. Given that amphibian reproduction dynamics depend on meteorological variables, in spring the samplings were intensified, since the species reproduce after spring rains. However, with autumn rains, and before the onset of the cold and the first snows, conditions are conducive to the reproduction of the common toad (*Bufo bufo*), Spanish painted frog (*Discoglossus jeanneae*), and the Iberian parsley frog (*Pelodytes ibericus*). If this period is short, they do not reproduce but some adults can be found on wet nights. In the summer months, the high zones are sampled, where spring is late. The species with a long larval development, such as the Betic midwife toad (*Alytes dickhilleni*), need permanent sources of water. The potential water sources are characterized by daytime samplings, collecting data on the typology (natural or artificial) of the microhabitats, dimensions, presence of vegetation and of macroinvertebrates, temperature, pH, and electrical conductivity of the water. At night, the sites where amphibian activity is recorded (spawn, larvae in the first phases of development, or the presence of uncommon adults) are sampled. The samplings are programmed to avoid windy or snowy days and times of the day with excessive heat or cold.

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8.15 Reptiles

The populations of the smooth snake in Sierra Nevada appear at 2,100 to 2,700 m and represent one of the southern distribution limits of this species.

Aims

The main aims of the monitoring of reptiles in Sierra Nevada were: 1) to analyse the distributions of the 20 species present; 2) to evaluate preliminarily the effects of global change on their populations; 3) to analyse the set of threats. The adaptive management has also implied a priority and management measures have been proposed to mitigate the impact of the effects of global change on their populations.

Periodicity

The field work was performed in 2009 and 2010. Afterwards, efforts will continue for strategic areas, periods, and species.

VARIABLES ANFIBIOS Y REPTILES

Variable	Unit
Species richness per utm grid	number of species
Density	Nº of individuals/ unit of effort
Distribution	presence/absence

Method and effort

For the field samplings, the species richness and number of individuals were taken into account. The samplings were based on three censuses taken for 45 min by two observers (or for 90 min by one observer) by a UTM grid with squares of 5 km x 5 km. Only squares with less than 50% of the surface area included in the protected area were considered (n=71). For the rest of the squares, one or two samplings were made according to the variety of habitats present (n=27). Thus, 251 samplings were made, distributed throughout the National and Natural Park. The data were used to determine the current chorological distribution of herpetofauna in Sierra Nevada.

The censuses consisted of looking for reptiles in appropriate zones. Refuges were carefully uplifted and afterwards placed in their original position to minimize possible alterations of these microhabitats. This technique proves appropriate for determining the presence and abundance of the different reptile species.

Being ectothermal and thermophilous, reptiles show a marked seasonality in the Mediterranean region, with greater activity under certain environmental conditions. These environmental factors are considered in scheduling samplings, selecting only the periods of the year in which reptiles are most active (spring, summer and early autumn). Surveys were conducted under appropriate weather conditions, avoiding days of fog, rain, excessive wind, etc..

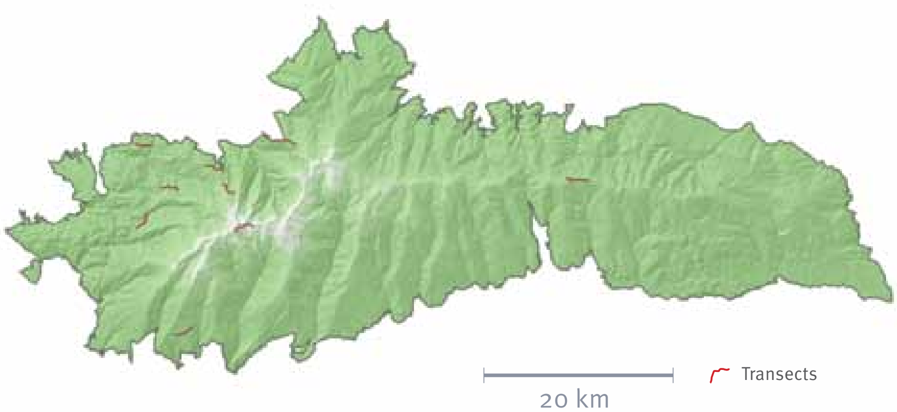
Another aspect taken into consideration was the habitat. Although any biotope of the massif can harbour some species, certain environments are especially suited to finding rare species or those with more restricted distributions. Therefore, prior to field visits, mapping was used to locate certain preferential habitats for sampling. Special attention was placed on biotopes propitious for certain distributions of taxa: wet grasslands (western three-toed skink *Chalcides striatus*), broom thickets near streams and high-mountain grasslands (smooth snake, *Coronella austriaca*), and irrigation channels (grass snake, *Natrix natrix*), scree and rocky areas (Lataste's viper, *Vipera latastei*), etc..

8.16 Butterflies

Parnassius apollo nevadensis, lives above 1,700 m and is associated with *Sedum tenuifolium* (Crassulaceae), its host plant.

Aims

The main purposes of the monitoring of butterflies in Sierra Nevada (BMSSN: *Butterfly Monitoring Scheme de Sierra Nevada*) are: to record the population trend of the species monitored; to record the phenological patterns of each species and the possible changes that these might undergo with climatic change; to identify environmental variables related to the distribution and abundance of these species; and finally to establish an early-warning system to enable managers of the Sierra Nevada Natural Park and National Park to implement adaptive measures for these species and their ecosystems.



Polyommatus golgus is a lycaenid associated with summit areas: one of the absolutely key species for the study of the effects of climatic change.

Coenonympha dorus is a species of the lower belts of Sierra Nevada. Occasionally it can reach 22,00 m a.s.l.

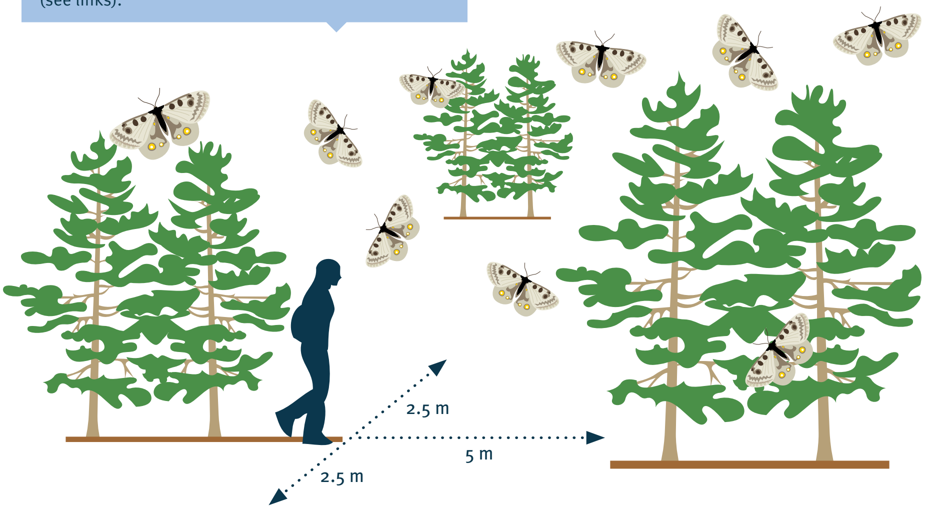
Method and effort

All the butterfly species (except those belonging to the family Hesperiidae) were censused along the transects distributed strategically throughout the work area: oak forests, juniper thickets, thorny shrublands, and summit areas.

The methodology consists of walking 10 transects of approximately 2.5 km each between May and September in which all the imagos of the study species (families Papilionidae, Pieridae, Nymphalidae, and Lycaenidae). These walks are made once per week, counting only the specimens sighted 5 m ahead and within a strip of 2.5 m on each side of the observer. The specimens that are hard to identify are captured and later released or after a more detailed study of the morphological characters when necessary. Only the walks made under appropriate weather conditions are taken into account: temperatures higher than 14ºC, less than 60% cloud cover, and wind force less than 5 on the Beaufort scale. The colonies of species with small and isolated populations require specific effort and monitoring, i.e. elements of great interest for the monitoring of global change that are rarely detected in the preset census transects. In these cases, special effort is dedicated to the mapping of colonies and to the development of models of the ecological niche (see Section 8.19), which provides better orientation of the search for new locations, the identification of its limiting ecological factors at the landscape scale, and the prognosis of the time course of this distribution in a context of global change according to the scenarios expected for Sierra Nevada.

The butterfly *Agriades zullichi* is one of the most emblematic endemic species of Sierra Nevada. Its caterpillars feed exclusively on another endemic species, *Androsace vitaliana* subsp. *Nevadensis* (Primulaceae)

The method used to census the butterflies in the transects is the same as used in other programmes for monitoring butterflies in a long tradition, as in the case of the BMS of the United Kingdom or Catalonia (see links).



Periodicity

This monitoring is undertaken annually. It began in 2008 with the monitoring of some particular species, and in 2009 the same methodology was followed. In 2010, the rest of the species that currently constitute the BMS of Sierra Nevada were incorporated.

VARIABLES

Variable	Unit
Abundance	Nº of individuals
Density	Nº of individuals/ha
Relative density	% positive stretches

References

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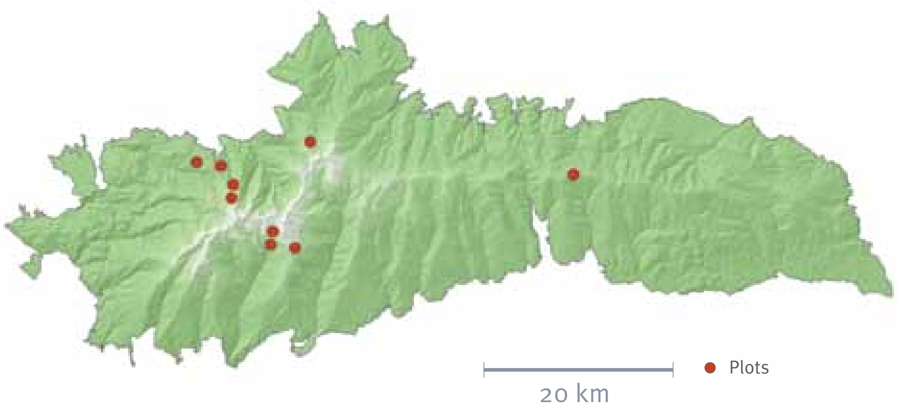
8.17 High-mountain terrestrial arthropods

Baetica ustulata ustulata is one of the most singular elements of the Sierra Nevada summits. The photograph is of a female.

Aims

The main aim of the monitoring of arthropods in Sierra Nevada is to identify variations in relative abundance of the populations of certain species in oromediterranean and cryomediterranean environments above 2,200 m.



Method and effort

The species selected for this monitoring are:

Roeweritta carpentieri:
Arachnida, Palpatores, Phalangiidae.
Baetica ustulata:
Insecta, Orthoptera, Tettigonidae.
Pygnogaster inermis:
Insecta, Orthoptera, Tettigonidae.
Eumigus rubioi:
Insecta, Orthoptera, Pamphagidae.
Eumigus monticola:
Insecta, Orthoptera, Pamphagidae.
Timarcha marginicollis:
Insecta, Coleoptera, Chrysomelidae.
Timarcha insparsa:
Insecta, Coleoptera, Chrysomelidae.
Timarcha lugens:
Insecta, Coleoptera, Chrysomelidae.
Iberodorcadion lorquini:
Insecta, Coleoptera, Cerambycidae.
Dinodes (Iberodinodes) baeticus:
Insecta, Coleoptera, Carabidae.
Eulithinus analis:
Insecta, Dermaptera, Forficulidae.

This selection was based on the orophilous or stenothermic character of these species, which enables us to predict that climate change may carry appreciable consequences for these species in their environments.

For the monitoring of terrestrial arthropods, census plots were established where the presence/absence and abundance of arthropod taxa being monitored were recorded. Specifically, the 18 plots were distributed throughout different enclaves of the summit area of the massif. The plots were strategically located in terms of altitudinal distribution and orientation (northern and southern exposure). Each plot is visited twice from the second fortnight in July until the end of August. In these plots, abundance in absolute terms is estimated by direct counts, including scrutiny of the vegetation and the search for specimens hidden under rocks. The dimensions of the plots are variable, usually between 3 and 6 m wide and 50 to 100 m long, depending on the characteristics of the location and on species composition and abundance of the arthropod community included on the list of study species.

Harvestman *Roeweritta carpentieri* is endemic to Sierra Nevada.

Pycnogaster inermis appears in the Sierras de Baza, Filabres and in Sierra Nevada.

Periodicity

This monitoring of high-mountain arthropods is conducted annually

VARIABLES

Variable	Unit
Density	Nº individuals/ha
Distribution	presence/absence

Female *Eumigus monticola*.

In the summits of Sierra Nevada appear three Coleoptera species of the genus Timarcha: *lugens*, *insparsa* y *marginicollis*.

Dinodes (Iberodinodes) baeticus, a carabid exclusive to the summits of Sierra Nevada.

Iberodorcadion lorquini a longhorn beetle (Fam. Cerambycidae) frequent at certain points of Sierra Nevada.

Male *Eulithinus analis*.

Egg mass of *Eulithinus analis*.

References

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8.18 Pine processionary moth

Cluster of caterpillars of the pine processionary in an affected pine stand.

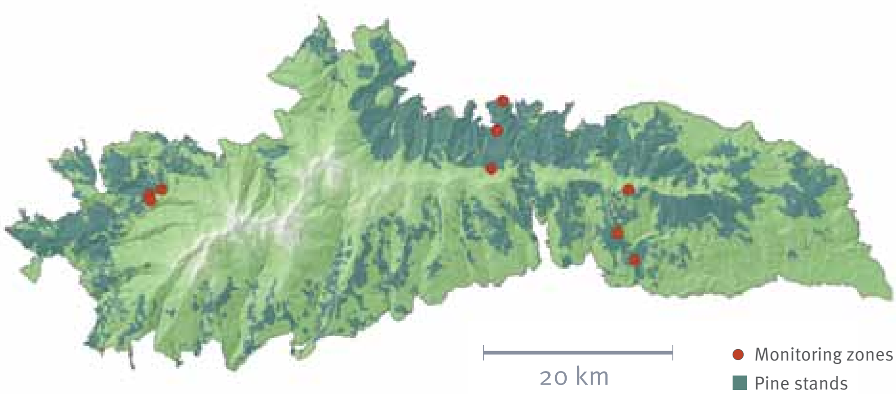
Aims

The main aim of the monitoring of the pine processionary moth (*Thaumetopoea pityocampa*) is to observe possible variations in it biological cycle, specifically in relation to its phenology and its population dynamics. This lepidopteran is considered the main defoliator in the Mediterranean forest and has very particular microclimatic demands for its development.

Method and effort

A monitoring system has been established to coincide with the key times of the life cycle of the pine processionary, such as hatching of the caterpillars, the procession and burrowing into the soil, and emergence as adults, all processes linked to specific conditions of temperature and moisture and thus sensitive to climatic variations.

The forest structure is determinant in the population dynamics of this social insect. Thus, three sampling regions were chosen within the Park that are representative in terms of sensitivity of the processionary: orientation, elevation, and dominant forest species. In each region, three sampling zones were established, seeking to cover the entire altitudinal range in which the pine forest is distributed and establishing a minimum difference of 200 m between elevations. The summer monitoring spans from the appearance of the adult until the hatching of the egg masses (July to September) and consists of setting one pheromone trap per elevation and monitoring 30 egg masses in the needles of each of the study zones.



Egg masses of pine processionary on pine needles tagged for summer monitoring.

In each sampling, data are taken on the number of imagos found in each trap and at the same time the hatching date of each egg mass is specified as accurately as possible (3- to 4-day intervals). The winter monitoring encompasses the leaving of the nest by the caterpillars (November to December) until they bury themselves in the soil (March to April) and consists of setting a trap at the foot of 30 trees per zone and collecting the number of individuals found in each sampling. In addition, transects are laid out 1 km long and of variable widths, one in each sampling zone. In these, the number of burials found in each visit is recorded. The final monitoring is when no procession is detected for more than two weeks.

Periodicity

The monitoring is annual, being divided into winter (November/January to March/April, depending on the year) and summer (July to September). In both periods the sampling frequency is 2-3 times per week.

Forest stand affected by the pine processionary, with a high degree of defoliation.

VARIABLES

Variable	Unit
Hatching period	Beginning day-ending day
Burial period	Beginning day-ending day
Trapping period	Beginning day-ending day
Pest incidence/ altitudinal range	relative % of individuals sampled/altitudinal range
Pest intensity: trapping	Nº of individuals captured/plot
Pest intensity: burials	Nº of burials/km

Formation of a procession of fifth-instar caterpillars.

Trap used to count caterpillars in the winter monitoring.

References

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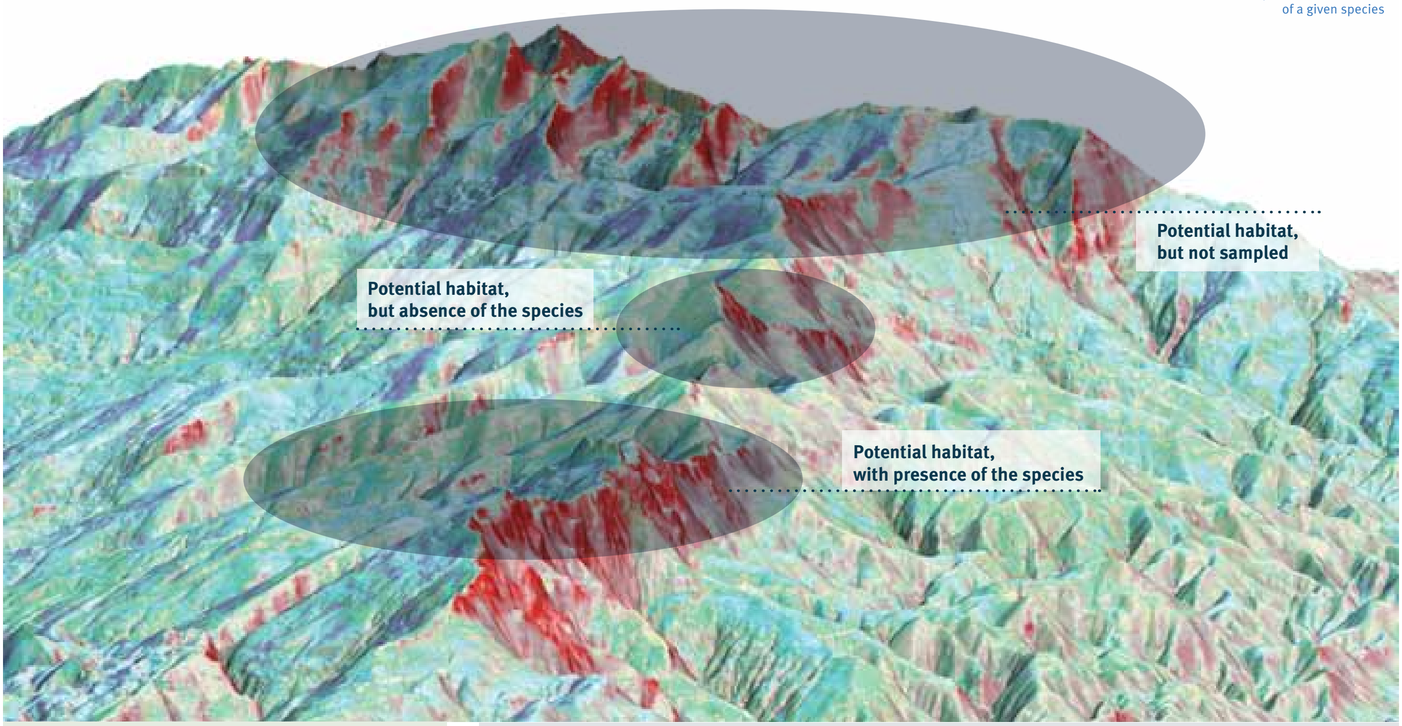
Sánchez Peña, E., González Rosa, E. and Martínez de Saavedra, J. 2006. La procesionaria del pino: Análisis de su posible uso como bioindicador del cambio climático. Puesta en marcha de un mecanismo de seguimiento de las expansiones en la distribución geográfica de este lepidóptero defoliador. Pp.: 79-92.. En: *VII Jornadas sobre Recerca al Parc Nacional d'Aigüestortes i Estany de Sant Maurici Boí (Alta Ribagorda).*

8.19 Spatial distribution models and future and future projections



Simulation of the potential distribution of a given species

Aims

The aim of this methodology is to simulate changes in the geographic distribution of species of flora and fauna in Sierra Nevada according to different scenarios of climatic change in order to compile data to be used for improving adaptive management plans for the natural protected space.

Periodicity

This methodology does not require a specific periodicity. It can be repeated semi-automatically when confronted with any updating of the technical means or availability of new information on species distribution.

VARIABLES

Variable	Unit
Potential species richness	Nº of species for which a cell presents suitable conditions
Probability of presence	probability
Distribution	presence/absence

Method and effort

With climate change, the distribution limits of mountain species will move in elevation, ascending or descending with temperature. This process has already been detected in high-mountains. For the low- and medium-elevation species this situation implies the opportunity to colonize new habitats, while the species of the high summits may be condemned to disappearance.

Climate-change simulations combined with modelling techniques for species distributions enables the changes in spatial distribution of species to be simulated according to different climate-change scenarios. The results of these simulations facilitate the design of strategies for management and conservation of biodiversity.

The working methodology requires:

1. Records of species presence acquired by the different data-gathering protocols included in the monitoring programme and other conservation plans.

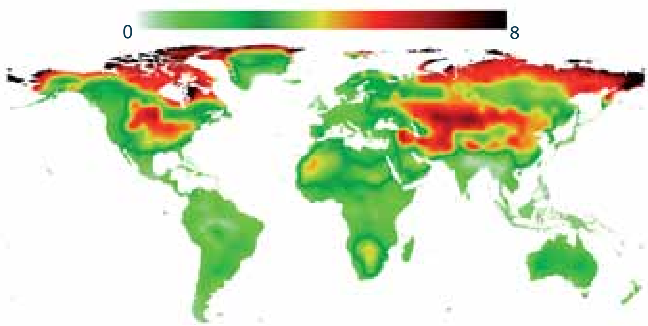
2. Simulated future climate maps according to different climate-change scenarios. Currently, we have maps of 10-m spatial resolution and 10-year temporal resolution according to the IPPCC A2 and B2 scenarios using the CGCM2 global circulation model formulated from the data provided by the State Weather Agency and Foundation for Climate Research.

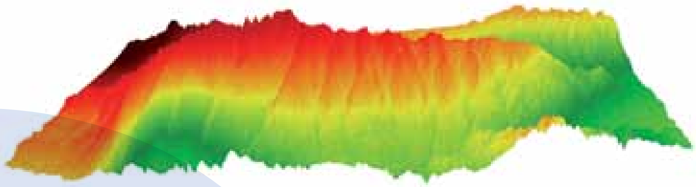
3. An automated workflow called MODPLAN, which coordinates the execution of the different software packages required to generate simulations. MODPLAN, a work flow designed with Kepler software, which uses different programs to execute the models MaxEnt, OpenModeller, GRASS GIS, and R.
The results consist of vectorial files (shapefile) of polygons with the prognosticated shapes of the populations of species under study at 10-year intervals for each climatic scenario considered.

Methodological scheme for simulating changes in species distributions

We start on the one hand with the climate-change forecasts made by the scientific community and on the other hand with the current spatial distribution of the species to be studied. First, the global predictions are regionalized using local climate forecasts. These models show the areas potentially usable by the species in question, taking into account the climate conditions expected.

Regionalization of climate predictions





Sierra Nevada

Creation of potential distribution models taking into account the climate forecasts

Fauna and flora species with current known distributions

References

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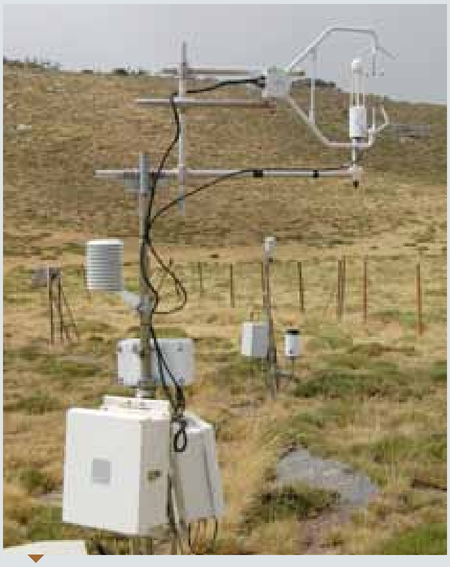
Chapter 9

Broom thicket on Loma de Cáñar.

Primary productivity and carbon fluxes

In recent years, a great number of scientists have worked at characterizing the global carbon cycle. This interest arose with the discovery of an increase in the atmospheric CO_2 concentration caused by the burning of fossil fuels beginning in the Industrial Revolution as well as by the changes in land use and other disturbances. This increase in the atmospheric CO_2 concentration leads to global warming associated with the subsequent increase in the greenhouse effect. On the other hand, the photosynthesis of green plants is one of the key processes that explains the concentration and abundance of CO_2 in the atmosphere. The **detailed characterization of carbon sources and sinks**, as well as the internal dynamics of one of these is crucial in the context of global-change monitoring programmes. The present study presents two monitoring methodologies related to this question. The two are complementary although they involve the carbon cycle at different scales and spatial resolutions.

The first methodology, using remote sensors, permits us to **determine the biological production by photosynthesis**. The downloading and processing of the images of vegetation indices (NDVI and EVI) of the MODIS sensor of NASA provides relevant information on the spatio-temporal distribution of photosynthetic activity. Thanks to this methodology, we can characterize the functioning of the forest ecosystems of Sierra Nevada and we can establish indices of great interest, such as production, the activity period, etc.. In short, this methodology offers useful information on the state of vegetation as a carbon sink and repository.



Eddy covariance tower in Laguna Seca.

Satellite images cover a large spatial area but lack detail. Therefore, we also have a methodology that enables us to **evaluate in a highly detailed way the fluxes of carbon and water vapour** at a given point. This is the eddy covariance micrometeorological system, which is the only one capable of directly measuring, without altering the surroundings, the exchange of CO_2 and water vapour at the ecosystem scale. This technique is used by the international FLUXNET, which numerous researchers have joined worldwide and which currently has more than 500 measurement stations in different ecosystems.

Installation of a monitoring station for carbon fluxes in the areas affected by the fire of Lanjarón.

References

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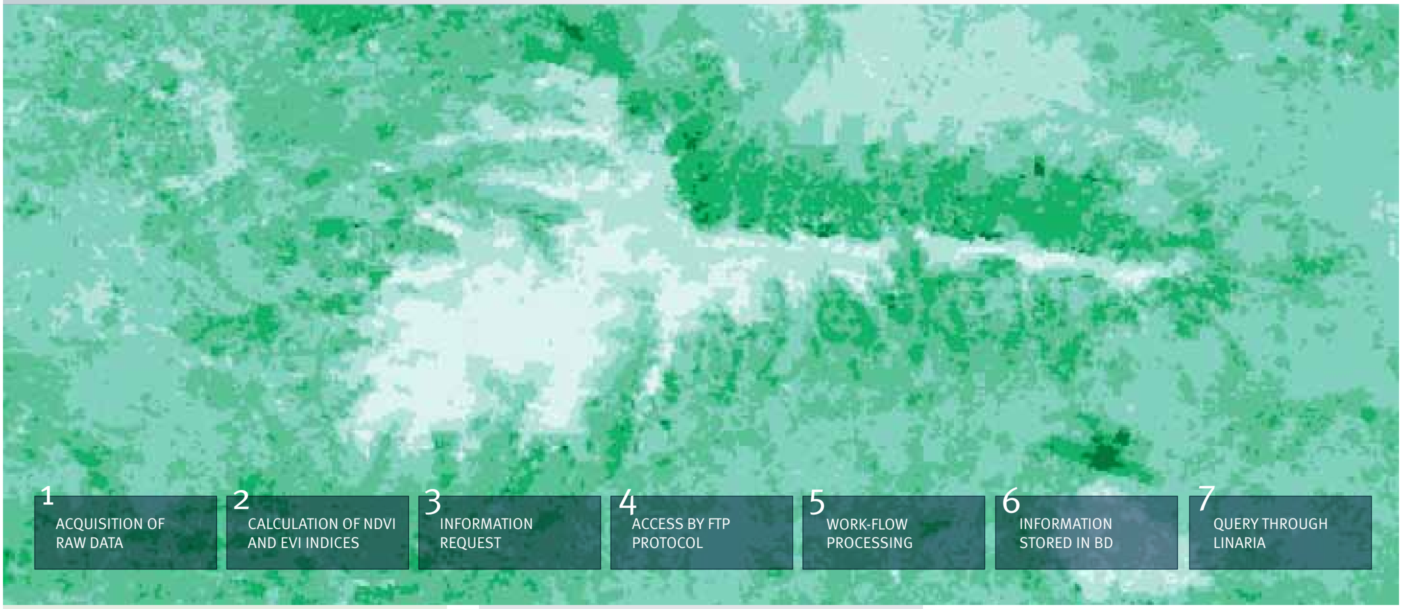
Kawabata, A., Ichii, K. and Yamaguchi, Y. 2001. Global monitoring of interannual changes in vegetation activities using NDVI and its relationships to temperature and precipitation. *Int. J. Remote Sens.*, 22 (7): 1377–1382.

9.1 Assessment of vegetation productivity using remote sensing



Aims

The automatic supply of the NDVI (*Normalized Difference Vegetation Index*) and EVI (*Enhanced Vegetation Index*) images provides information on the plant cover and enables us to monitor the time course of the ecosystems on Sierra Nevada for a time series that begins in the year 2000.

Periodicity

The NDVI and EVI images are created by MODIS sensor every 16 days. The image-processing system permits them to be automatically introduced into the information system periodically each time that a new image is created.

VARIABLES

Variable	Unit
NDVI	adimensional
EVI	adimensional

Method and effort

The NDVI and the EVI are calculated as the quotient between the part of the incident radiation absorbed by the vegetation (in the visible red spectrum) with respect to the quantity of radiation reflected by the surface (in the near-infrared spectrum). The EVI improves the sensitivity with respect to the NDVI to detect the vegetation whether thin or dense. The NDVI and EVI images are generated by the MODIS sensor, lodged in the NASA satellites Terra and Aqua. Both vegetation indices provide an idea of the photosynthetic capacity of green plants. They are, therefore, proxies of the primary production of ecosystems. The methodology that we apply in the monitoring programme to compile this information starts with the tools that NASA has placed at the disposal of the scientific community for downloading and processing its images. The images are downloaded by a data-supply platform of NASA in HDF format. Each file contains different bands of information: NDVI index, EVI index, data quality, observation angle, date, etc., and an xml file of associated metadata. Our compilation methodology begins with a workflow programmed with Kepler, which derives raster information from the vegetation indices for the area of Sierra Nevada, transforms it to vectorial format, and adds it to the database. The information can be visualized successively over the entire time series by a graphic interface in the system Sierra Nevada Global-Change Observatory (http://linaria.obsnev.es), which makes use of a geographic information system for spatial representation.

Scheme showing the steps followed to incorporate the NDVI Images in the Monitoring Programme Information System.

(1) The raw data on radiation is captured through the MODIS sensor (satellites Terra and Aqua). **(2)** The data are transferred to earth, where they are processed to calculate the NDVI and EVI indices. **(3)** This information is distributed publicly through a consultation platform (WIST). **(4)** The data are downloaded by ftp protocol. **(5)** A workflow selects the associated data and metadata for the area of Sierra Nevada, transforms them to vectorial format, and **(6)** saves them in a data base of the information system. **(7)** The information can be consulted by web in the interface of the information system (http://linaria.obsnev.es)

References

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9.2 Monitoring of CO_2 and water-vapour exchanges at the ecosystem scale

View of a eddy tower station in a high-mountain broom shrubland (Laguna Seca)

Aims

The main aim of measuring the CO_2 exchanges in different ecosystems of Sierra Nevada is to quantify the quantity of CO_2 that they assimilate. In addition, complementary measures of the state of the vegetation, soil, and atmosphere enable us to study the main factors controlling whether the ecosystem acts as a CO_2 source or sink. Finally, after quantifying the capacity of the ecosystem to assimilate CO_2 and determine the factors on which this depends, we can act accordingly, strengthening the main sinks.

VARIABLES

Variable	Unidad
CO_2 flux	μ mol m^{-2} s^{-1}
Water-vapour flux	mm
Sensible heat flow	W m^{-2}
Heat flow to the soil	W m^{-2}
Net radiation	W m^{-2}
Air temperature	ºC
Air humidity	%
Soil temperature	ºC
Photosynthetic Photon Flux Density	μ mol m^{-2} s^{-1}
Wind speed	m s^{-1}
Wind direction	º
Atmospheric pressure	hPa

Method and effort

By the micrometeorological system eddy covariance, we continuously measure the CO_2 exchanges between the earth surface and the atmosphere. This system is based on taking measurements from the air without disturbing the ecosystem. This requires instrumentation capable of working with a quick response and at a high sampling frequency (i.e. 10 Hz), providing information on exchanges at scales of hours or even less. Despite the difficulties in continuously taking and storing the measurements, it has been demonstrated that the integration on an annual scale of CO_2 exchange at the scale of the ecosystem is possible, thus making it possible to quantify the CO_2 assimilated by an ecosystem over a long time period (seasons, years, decades, etc.). The eddy covariance system is used by the international network FLUXNET, with research members worldwide.

Within the Sierra Nevada Global-Change Observatory, we have two towers (one in a broom shrubland and another in a burnt pine forest) composed of an sonic anemometer (quick-response wind-velocity measurements), an infrared gas analyser (rapid-response measurements of CO_2 and water-vapour density) and complementary instrumentation to characterize the vegetation, soil, and atmosphere.

Periodicity

The data of CO_2 and water-vapour exchange as well as the complementary information is registered every 30 minutes. The installations are visited monthly to calibrate the instruments, supervise the functioning, and download the stored data.

References

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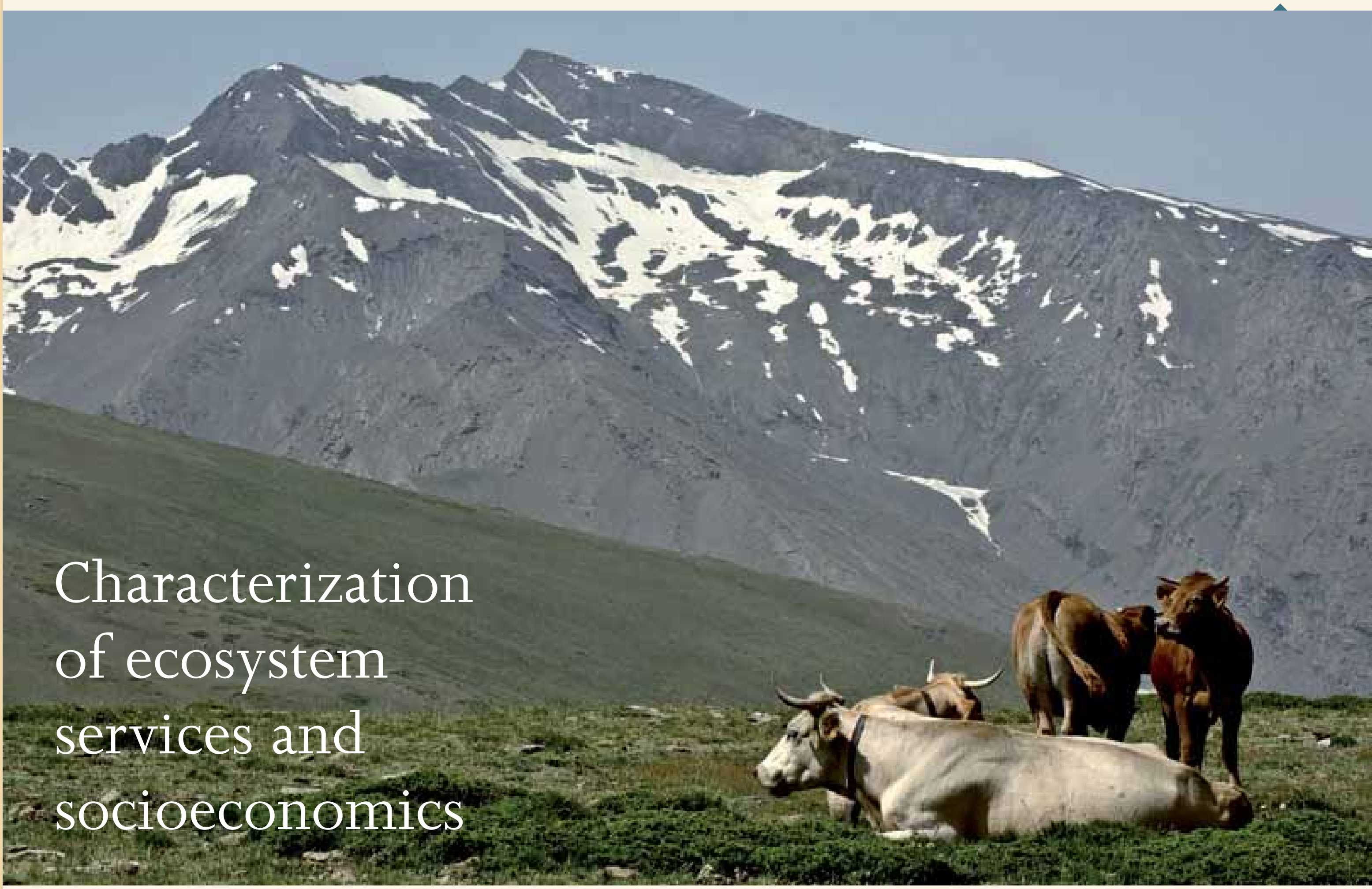
Serrano-Ortiz, P., Marañón-Jiménez, S., Reverter, B.R., Sánchez-Cañete, E.P., Castro, J., Zamora, R. and Kowalski, A.S 2011. Post-fire salvage logging reduces carbon sequestration in Mediterranean coniferous forest. *Forest Ecol. Manag.*, 262: 2287-2296.

Chapter 10

Livestock on the slope of Maitena.



Characterization of ecosystem services and socioeconomics

The main national and international initiatives for monitoring global change (GLOCHAMORE1, GLOCHAMOST$_2$, LTSER$_3$, Millennium Ecosystem Assessment$_4$, SISESCG$_5$) include socioeconomy as a key element. All these projects highlight the importance of having socioeconomic information in order to characterize the possible impact of human activity on natural systems and also to identify the possible effects of global change on society. We have distinguished two **different methodologies to gather this socioeconomic information**. On the one hand, we describe the main sources of information concerning economic aspects, demographics, tourism, etc., which are of interest for the monitoring programme. These sources of information supply the parameters necessary to characterize socioeconomic activity. Other more concrete aspects (perception of certain problems, local economic activity, etc.) must be compiled by surveys.

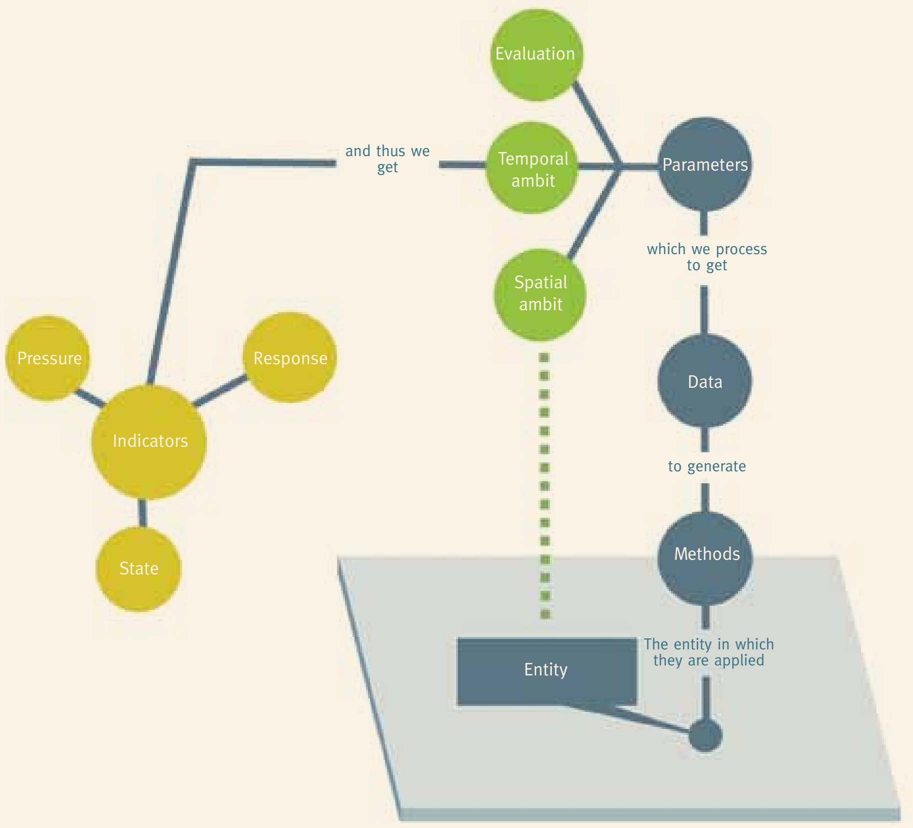
The socioeconomic information allows us to **characterize the needs and demands** of natural resources belonging to different urban centres in Sierra Nevada. In a parallel way, it is necessary to ascertain to what degree natural systems are capable or not of satisfying these needs. This latter point is addressed by the **characterization and quantification of the ecosystem services** that the natural systems can provide. In this study, we present two examples of characterization and quantification of ecosystem services of regulation (water and erosion control). Finally, we describe a methodology that can show synthetically the impact of human activity on ecosystems: **the characterization of the human footprint**.

Irrigation channels are key to water management in Sierra Nevada.

The socioeconomic information gathered through the different monitoring methodologies corresponds to the design of a system of indicators, pressure, and response for Sierra Nevada. To generate an indicator from the raw information, we need to contextualize the original data. First, it is fundamental to define the spatial setting for which the data are valid. In the case of the socioeconomic information, this setting usually corresponds to the municipality. Also, the parameters or variables established by the monitoring methodologies refer to diverse thematic spheres. In the case of the socioeconomic methods, these spheres are related to the different aspects of the production system and social organization. Finally, the parameters must be contextualized temporally, indicating the time range in which the indicator is applicable. In this way, we generate indicators from the raw data.

Mushroom gathering

Logging



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[1] Global Change in Mountain Regions. Mas información en http://mri.scnatweb.ch/glochamore/
[2] Global and Climate Change in Mountain Sites. Mas información en http://sl.ugr.es/unesco_glochamost
[3] Long Term SocioEcological Research. Mas información en http://sl.ugr.es/LTSER_Europe
[4] More information at http://www.maweb.org/en/index.aspx

10.1 Compilation of existing socioeconomic information

Aims

The objective of this methodology is to collect socioeconomic data. Some of these are compiled by web services published by different official agencies and private entities. Others are not routinely accessible and an active search becomes necessary.

Periodicity

The periodicity of the data is variable, depending on the type of index and its age. There are data with a decadal frequency (the oldest) and annual (the newest), with scant data published with less than annual frequency.

Method and effort

Web services
The information according to the source is presented in a time series and different intervals. Although we can gather data from 1900 to the present, the great majority of the data are a decade old. Similarly, the output format is different: from the data that can be downloaded as spreadsheet, to data visualization on computer screens, these cases require manual gathering procedures and transformation in order to transfer them to data bases.

There are data from the socioeconomic sphere published in web services by official agencies as well as private entities.

Active search
There is information that is not directly accessible or usable for different reasons (e.g. it is not of value, unsuitable aggregation level, sensitive information). Therefore, we must make a search and active request for this information at different administrative levels: municipal, district, regional, and national. The previous link offers a list with the desirable socioeconomic attributes and characteristics of scale and aggregation.

VARIABLES

Variable	Unit
Population	inhabitants
Old-age index	(population ≥ 65/total population)*100
Ratio immigrants/ emigrants	%
Employment rate	%
Balance of new businesses	nº
Average expenditure per rural tourist	€/day
Organic farms	nº
Head of cattle	large livestock unit

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10.2 Socioeconomic survey

Cattle in Sierra Nevada.

Aims

The aim of this methodology is to generate socioeconomic data.

Periodicity

The periodicity depends on the type of study, varying between a continuous survey (e.g. public use) annual (e.g. social participation) or occasional without a defined periodicity (e.g. livestock-characterization analysis).

VARIABLES

Variable	Unit
Companies that associate their sales	%
Abandonment of traditional farming practices	ha
Investment made in proposals presented by groups that participate in the management of the natural spaces of Sierra Nevada	€
Appraisal of recreational areas	€
Visitors in the Natural Area	Nº
Quality of services of public use	adimensional scale 1-7

Method and effort

Although a great part of the socioeconomic information is acquired through administrations or private entities, the data are usually very general on demographic or economic matters. For a detailed socioeconomic characterization of the natural space of Sierra Nevada, we need to use specific methodologies, for which, in the socioeconomic sphere, *in situ* studies are made using surveys.

By questionnaires, we will gather information of different types: satisfaction, opinion, characterization, evaluation, contingent, etc.. We will use structured and semi-structured questionnaires with open and closed responses. For closed multiple-choice responses, nominal scales will be used, i.e. interval and Likert.

The general structure of the questionnaire will be:

1. Introduction and justification of the study to the interview.
2. Introduction questions.
3. Key questions with respect to the aims of the research.
4. More complex questions.
5. Delicate questions.
6. Personal data and acknowledgements.

The modality of application, depending on the aim of the poll, will be with personal presence or by telephone. The link shows an analysis of the studies made concerning different socioeconomic spheres.

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10.3 Assessment of the erosion-control service in Sierra Nevada

Erosion in Trevenque.

Aims

The aim of this methodology is to determine the capacity of soil-erosion regulation according to the land-use changes, within the framework of global change. This calculation gains meaning when the values are compared within the same territory for two different temporal references, enabling us to analyse the trends in providing this service.

Periodicity

The periodicity of these studies is subject to the availability of information on soil uses and management practices, given that the rest of the parameters at the working scale are considered invariable.

VARIABLES

Variable	Unit
Potential soil erosion	ton/ha/year

Method and effort

To evaluate the capacity of the ecosystem to regulate soil erosion, we use an indirect indicator. We cannot assess the magnitude of the erosion at the scale of Sierra Nevada but we can estimate the potential erosion of a specific area and compare it with what would occur in different scenarios of land use and agricultural practices. In this way, we can ascertain the quantity of potential erosion that is being avoided or that is being provoked as a surrogate of the regulation capacity.

To calculate the potential erosion, we use the methodology known as R.U.S.L.E., a revised U.S.L.E. (Universal Soil Loss Equation), published in 1962 and widely used in the scientific literature. The equation that defines the potential erosion is:

$$A = R \times K \times L \times S \times C \times P \text{ (t/ha/year)}$$

where:
A= is the soil loss per unit of surface area and time.
R= rainfall erosivity.
K= soil erodibility.
L= slope length.
S= slope gradient.
C= soil use.
P= management practices.

RUSLE is calculated in the same way, although modifications and improvements have been made in the way to calculate the different variables. Thus, for the factor R, new isovalue maps have been calculated; K takes into account the possibility of freezing; L and S are estimated jointly with GIS tools; C includes new classifications; and, for P, new typologies of agricultural practices have been included.

Also, a case study can be consulted within and outside the natural spaces of Sierra Nevada (Moreno Llorca et *al*., 2011).

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10.4 Assessment of the water-regulation service in Sierra Nevada

Snowmelt in the area known as "Lavaderos de la Reina".

Aims

Water regulation is one of the most important services provided to society by mountain ecosystems. Actions in the territory that cause changes in land uses imply variations in the capacity of the territory to regulate the water from precipitation. The aim of this methodology is to evaluate this regulation capacity by Sierra Nevada ecosystems.

Periodicity

The periodicity of this methodology is determined by the strong dynamic component implicit in water regulation by the territory.

VARIABLES

Variable	Unit
Torrential flow	m^3/s

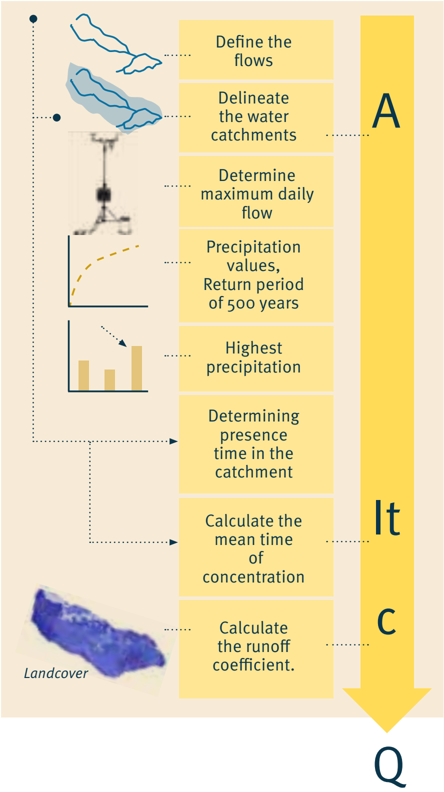
Method and effort

As in the case of potential erosion, it is more difficult to measure the water that Sierra Nevada ecosystems regulate through percolation, aquifers, snowmelt, etc., than to calculate the maximum expected flows as counterpoint indicators. In this way, the higher the flow the lower the regulation capacity of this resource.

To evaluate the way in which this service varies throughout the territory and over time, we use the rational method, which determines the instantaneous maximum discharge flow (Q). This flow depends on three major factors: precipitation intensity (It); the area of the catchment basin (A), and the runoff coefficient (C).

Q = It x A x C

The first ones, in principle, cannot be altered by humans. However, the runoff depends on the land use and plant cover. Thus, we measure the capacity of the different land uses to diminish maximum flows as a proxy of the ecosystem service of water-resource regulation, according to the steps depicted in the figure.



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10.5 Assessment of the human footprint in Sierra Nevada

Mining is one of the main factors of the human footprint.

Aims

The human footprint gives us an integrated assessment of the pressure that the ecosystems are undergoing as a consequence of human activity. This methodology shows quantitatively the impact on the ecosystems.

Periodicity

The map of the human footprint has a strong dynamic component. The human activities are compiled over a temporal gradient to assess the variation of the impact from the past to present, and thus a specific periodicity makes no sense.

VARIABLES

Variable	Unit
Human footprint	(adimensional; scale 0-100)

Method and effort

The methodology followed for the analysis of the human footprint in Sierra Nevada is based on the most relevant studies conducted to date, which are summarized in the following steps:

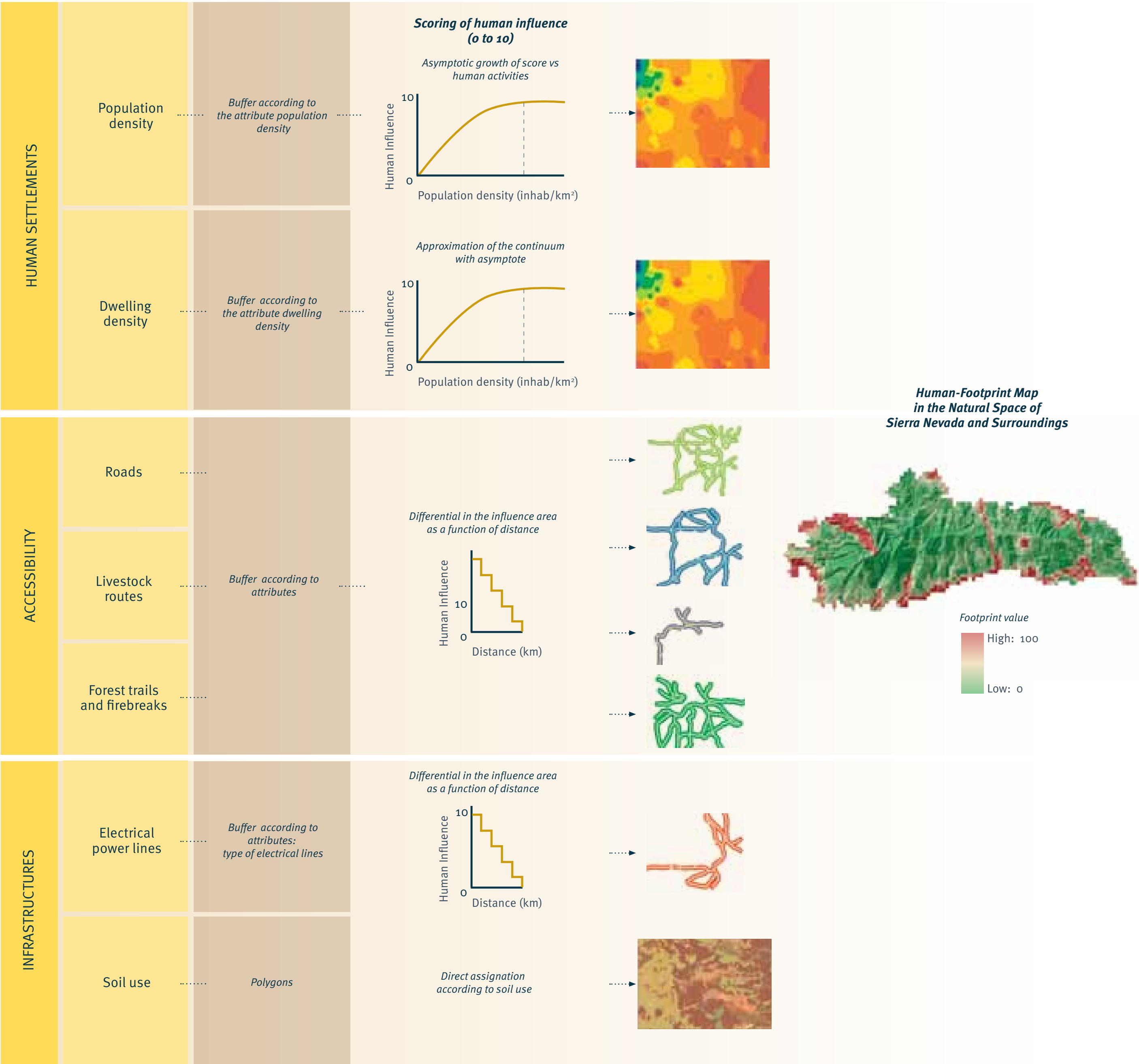
1. The information is compiled on the variables that define human activity in Sierra Nevada and that determine the structure and functioning of the ecosystems with respect to the population (population and dwelling density), accessibility (roads, highways, livestock routes, firebreaks), infrastructures (heliports, reservoirs, canals, quarries, wind parks, and electrical power lines), land use (livestock, fires, forest activity), public use (installations), fragmentation, etc.. This information spans 1950 to the present to be able to conduct a study dynamic in time.
2. The spatial scale of each layer of information is analysed (ecological and of human activity) to decide the appropriate scale of the work.
3. Each variable is assigned an influence value throughout the study territory between 0 and 10 as a function of the information available in the scientific literature. For this, different buffer areas of each factor are established, these presenting a range of descending values of influence as the distance increases away from the alteration.
4. Human-influence values of all the variables are added to find an index value for human influence in each territorial pixel. This gives a range of values in the territory.
5. The information is normalized to transpose the footprint map into a range of values from 0 to 100 by the following formula:

where

$$Hhi = \frac{(IIhi - IIh\mathrm{min}) \times 100}{IIh\mathrm{max} - IIh\mathrm{min}}$$

Hhi= human footprint in the pixel "i"
IIhi= Index of human influence in the pixel "i"
IIhmin= Minimum human influence in the study area
IIhmax= Maximum value of human influence in the study area

METHODOLOGICAL SCHEME TO CALCULATE THE HUMAN FOOTPRINT



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