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ECOMONT
ECOLOGICAL EFFECTS OF LAND USE CHANGES ON EUROPEAN TERRESTRIAL MOUNTAIN ECOSYSTEMS

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ABSTRACT.- As a contribution to the Terrestrial Ecosystem Research Initiative (TERI) within Framework IV of the EU, ECOMONT aims at investigating ecological effects of land-use changes in European terrestrial mountain ecosystems. ECOMONT is coordinated by Prof. Cernusca (University of Innsbruck) and is carried out by eight European partner teams in the Eastern Alps, the Swiss Alps, the Spanish Pyrennees and the Scottish Highlands. ECOMONT focuses on an analysis of structures and processes in the context of land-use changes, scaling from the leaf to the landscape level. The following research topics are being investigated: Spatial distribution of vegetation and soil in the composite experimental sites; physical and chemical soil properties, SOM status and turnover; canopy structure, primary production, and litter decomposition; water relations of ecosystems and hydrology of catchment areas; microclimate and energy budget of ecosystems; gas exchange of single plants and ecosystems; gas exchange between the composite experimental sites and the atmosphere, population and plant biology of keyspecies, plant-animal interactions, potential risks through land-use changes; GIS; remote sensing - environmental mapping; modelling activities integrating from plant to ecosystem and landscape level. First results of ECOMONT show that land-use changes have strong impacts on vegetation composition, structure and processes, on soil physics and chemistry, and therefore strongly affect exchange processes with the atmosphere and biogeochemical cycles. Abandonment of traditional *agricultural practices (grazing, mowing) causes characteristic changes of the vegetation. In most cases a successional reversion over many decades reaches its climax with the vegetation growing naturally at the sites. Sometimes, however, abandonment can also lead to a degradation of vegetation and soil. In spite of common principles of changes of vegetation, soils and related processes with altered land-use geology, climate, exposition, slope inclination and land-use history may play an important role in determining species composition and specific patterns and processes on a community, ecosystem and landscape level in different European terrestrial mountain ecosystems.*

1. Introduction

Presently, in the mountain regions of Europe land-use changes (intensification, reduction of land-use, and abandonment) in agriculture and forestry are occurring rapidly. Land-use changes are considered to be the major driving forces of change in ecosystem function and dynamics, and in landscape pattern in Europe (cf. EU-Ecosystem Research Report 17). They cause long-lasting changes in the spatial structure of plant canopies, species composition and interactions, soil organic matter (SOM) status and turnover, and biogeochemical cycles, such as of CO_2, H_2O and nutrients. Changes in land-use, by altering the exchange processes between ecosystems and the lower layers of the atmosphere, can also affect the transport of sensible and latent heat (water vapour), CO_2, nutrients (N) and pollutants across the Alps. Thus, feedback effects between changes in land-use and global changes of climate can be expected (cf. Core Projects GCTE and BAHC). In the mountains these changes in ecosystem processes can also cause a considerable increase of potential risks (danger of torrents, snow gliding and avalanches, increased development of patches of bare soil and unstable slopes). Therefore the ALPINE AREA has been identified by European Union as one of the more critical areas for what concerns environmental safeguard.

Within Framework IV for research and technological development of the European Union the research initiative TERI (Terrestrial Ecosystem Research Initiative) was developed on the part of the Head Office number 12. The aim of this research initiative is to investigate the effects of expected global changes (climatic changes, land-use changes) on the level of terrestrial ecosystems and landscapes, and furtheron to work out deciding factors for the policy within the EU. Those regions (the Arctic, coastal areas, the Mediterranean, the Alpine area), classified as more critical areas by the EU, were selected as urgent research field. As a contribution to TERI the EU-research project ECOMONT has been carried out since 1996, headed by the University of Innsbruck (ECOMONT: "Ecological Effects of Land Use Changes on European Terrestrial Mountain Ecosystems", project number ENV-CT95-0179; cf. WWW-homepage HTTP://INFO.UIBK.AC.AT/ECOMONT).

2. Scope of investigations, research sites

The project ECOMONT aims at investigating the ecological changes affected by agricultural and forestal land-use changes in the mountains. Within this project the effects of a reduction of land-use and fallowing, but also an intensification and afforestation of hay meadows and pastures above and below the timber line are to be investigated.

ECOMONT aims at a high degree of integration:

• to investigate which changes in the canopy structure occur due to land-use changes in agricultural and forestal Alpine ecosystems along a South/North research-transect across the Eastern Alps and how these changes affect the exchange processes with the atmosphere;

• to clear up how the changes in canopy structure are connected with species composition and performance, as well as with species competition and interaction;

• to understand the influence of land-use changes on soil organic matter (SOM) status and turnover, on biogeochemical (CO_2, N) and hydrological processes at the ecosystem level, and on the exchange processes between the ecosystems and the lower layers of the atmosphere;

• to extend this understanding to the landscape level by means of multimedia modelling activities;

• to compare the results from the Alps with those of other European Mountains (Spanish Pyrenees, Scottish Highlands);

• to develop functional analysis methods as a basis for the integrated management (sustainable development) of mountain ecosystems.

In order to consider the effect of land-use changes on processes in terrestrial mountain ecosystems at a European scale six composite experimental sites (landscapes in common catchment areas) are investigated in the subalpine belt of the Alps, the Spanish Pyrenees and the Scottish Highland. Three pilot research areas are situated along a South/North-transect across the Eastern Alps (from the Italian to the Austrian Alps, geologically dominated by limestone or silicate), and a fourth site is the catchment Rotenbach brook in the Swiss Alps, geologically dominated by 'FLYSCH'. In order to consider adequately the different background conditions of mountain ecosystems in Europe (exposure, geology, climate, socioeconomy) and thus to be able to draw conclusions for other parts of Europe analyses in the Spanish Pyrenees and the Scottish Highlands are also included.

The three pilot research areas "Monte Bondone", "Passeier Valley" and "Stubai Valley" in the Italian and Austrian Alps give the unique possibility of investigating the connections between land-use changes and the transport of sensible heat, latent heat (water vapour), CO_2 and pollutants (combing

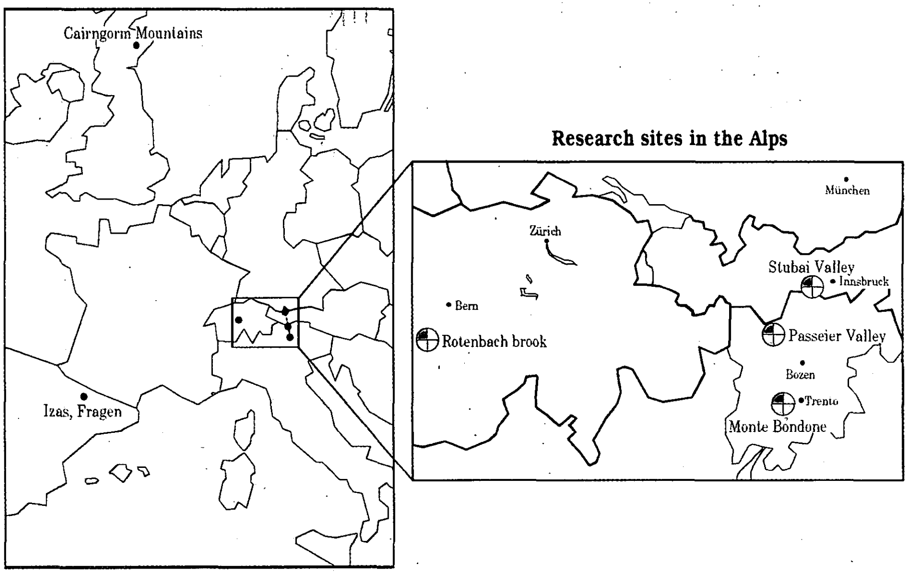

Figure 1. Research sites of ECOMONT in the Alps, Pyrenees and Scottish Highlands.
Areas experimentales de ECOMONT en los Alpes, los Pirineos y los Highlands de Escocia.

effects of different canopy structures) across the Alps. As the research area on Monte Bondone was investigated in detail within EC-STEP project INTEGRALP (CERNUSCA *et al.* 1992, TAPPEINER & CERNUSCA 1993, 1995), results of INTEGRALP can serve as an important baseline for ECOMONT. The results of ECOMONT will be used for elaborating a concept of sustainable development for Monte Bondone, as being an important recreation area of the city of Trento. The two pilot research areas "Passeier Valley" and "Stubai Valley" offer also an important advantage for the application of the research results, because they are situated in Objective-5b-Regions of the EU. In these regions assistance for regional projects for the improvement of the rural infrastructure will be carried out within the EU-programme INTERREG II in the next five Years (CERNUSCA & TAPPEINER 1997). The catchment proposed for the ECOMONT study in the Swiss Alps is of major interest for analysing potential risks through land-use changes.

The sites proposed for the Spanish ECOMONT study are located in the Izas grazing zone and the Fragen meadowland. The Izas experimental catchment of the Instituto Pirenaico de Ecología had its origin in the need for intensive research of the dynamics of the snow cover, erosive and biogeo-

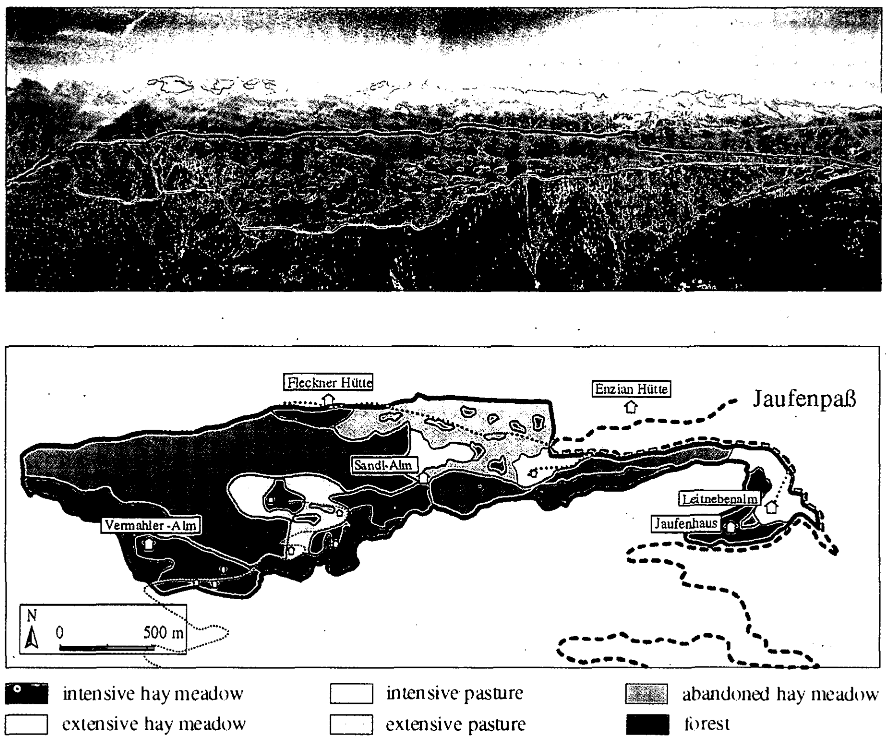

Figure 2. Composite research area „Passeier Valley", South Tyrol, Italy
Area de investigación combinada, "Passeierthal", Tirol Meridional, Italia

chemical processes, and the organization of plant ecology on the belt above the timberline in the Central Pyrenees, which are considered as representative of the environment of mediterranean high mountains. In a transect of the European mountains, the Spanish Pyrenees show less intensive land-use and are therfore useful to interpret the results of further land-use changes in the Alps. The farmers collaboration in the Fragen and Izas studies facilitate a continuous exchange of information between researchers and farmers organizations (Asociación de Ganaderos del Valle de Broto). Further, the proximity of Ordesa National Park permits a strong connection with the Park's staff, and offers the possibility of an effective application of the results of ECOMONT in the planning and development of Ordesa National Park.

The catchment proposed for the Scottish ECOMONT study is located in the western Cairngorm mountains. This site has been well documented in previous studies, particularly in relation to acid rain deposition, and catchment hydrology. The site has been part of the SWAP (Surface Water Acidification Programme) and is currently a proposed ECN (Environmental Change Network) site. Until recently the catchment was heavily grazed by red deer, but now there has been a substantial reduction in grazing levels. Colonization of some of the grazings by trees has begun, and the changes in vegetation structure and composition are likely to have far reaching effects on soil and plant water relations, gas exchange and the interception of pollutants. Now that changes in vegetation cover and structure are taking place it makes an ideal location to examine the ecological effects of these changes. The Scottish part of the ECOMONT project focuses on examining the ecological consequences of reductions in grazing levels on vegetation and soil structure composition and function in the Highlands of Scotland. The results of this part of the ECOMONT project will help assess the implications of land-use change that could be relevant to large areas of the Scottish Highlands, and comparison with similar changes in Alpine Areas will provide an international context and also strengthen the modelling and extrapolation of results from the study site.

3. Work packages and contributing partner teams

In each site of ECOMONT comparative and complementary multidisciplinary integrated ecosystem studies are conducted on differently managed ecosystems (meadows, pastures, abandoned areas, dwarf shrub communities, and forests). Figure 3 shows the 12 research topics (work packages) of ECOMONT and the contributing partner teams.

ECOMONT aims at two different basic approaches: a landscape ecological approach, in selected successional stages (ecosystems under different land-use) detailed analyses of the physical and chemical soil properties (work package n° 2), of the canopy structure (work package n° 3), of the hydrological balance (work package n° 4) and of the energy budget of the ecosystems (workpackage n° 5) are conducted.

The *integrated ecosystem approach* aims to examine in detail how changes in canopy structure are connected with species composition and performance, and to understand the influence of land-use changes on soil organic matter (SOM) status and turnover, on biogeochemical (CO_2, N) and hydrological processes at the ecosystem level, and on the exchange processes between the ecosystems and the lower layers of the atmosphere, additional work packages are intended. These work packages are concentrated at the three pilot areas "Monte Bondone", "Passeier Valley" and "Stubai Valley", but some also operate at the other sites. Following a bottom up approach the gas

Work packages of ECOMONT

1. Spatial distribution of vegetation and soil in the composite experimental sites
2. Physical and chemical soil properties, SOM status and turnover
3. Canopy structure, primary production
4. Water relations of ecosystems and catchment areas
5. Microclimate, energy budget of ecosystems
6. Gas exchange of single plants and ecosystems
7. Gas exchange between the composite experimental sites and the atmosphere
8. Population and plant biological studies
9. Potential risks through land-use changes
10. Geographical Information System (GIS)
11. Remote sensing
12. Modelling activities integrating from the plant level to the ecosystem and landscape level.

Contributing Partner Teams

- Institut für Botanik, Universität Innsbruck (A) (coordinator)
- Institute of Terrestrial Ecology (ITE), Banchory, Kincardineshire, Scotland (GB)
- Institut für Terrestrische Ökosystemforschung (BITÖK), Universität Bayreuth (D)
- Europäische Akademie Bozen (EAB), Bozen (I)
- Centro di Ecologia, Monte Bondone (CEA), Trento (I)
- Instituto Pirenaico de Ecologia (IPE), Jaca (E)
- Paul-Scherrer-Institut (PSI), Villigen-PSI (CH)
- Forschungsanstalt für Agrarökologie und Landbau (IUL), Bern-Liebefeld (CH)

Figure 3. Research topics (work packages) of ECOMONT and the contributing partner teams.
Temas de investigación (grupos de tareas) de ECOMONT, y equipos participantes.

exchange (CO_2, H_2O, and related trace gases) of single plants, functional groups and ecosystems (work package nº 6) are analysed by complementary contributions of the partner teams nº 1, nº 4 and nº 7. Partner nº 1 (University of Innsbruck, A) and nº 4 (EAB-Bozen, I) analyse the gas exchange of the grassland and dwarf shrub ecosystems and partner nº 7 (Paul-Scherrer-Institut, Zürich, CH) of forests. Partner nº 7 takes over the determination of the 13C isotope ratio in order to characterize the longterm carbon water relationship.

4. Methods

Work package n°1: Spatial distribution of vegetation and soils in the experimental sites

The large-scale mapping of vegetation and soils is the basis for scaling up the results of the detailed ecosystem analyses to the landscape level. Furthermore the maps serve for calibrating and verifying the remote sensing data (see work package n° 11).

- For phytosociological investigations the relevé method is used. The syntaxonomical classification is made with the classification programme Twinspan and the ordination programme Decorana. A further ecological characterization is made on the basis of the ecological indicator values and an estimation of total vegetation cover.
- For the mapping and characterization of soils the following parameters are recorded in the field:
  - Soil type
  - Profile description: geology, soil water regime, soil horizon depths, soil moisture, soil colour, consistency, soil texture, amount and type of humus, pH, soil structure, maculation, concretation, rooting density.
- Mapping with the aid of a satellite navigation system (GPS): The mapping of vegetation and soil is done with the aid of the satellite navigation system Garmin GPS (Garmin International, Inc., Lenexa, KS 66215, USA), which permits the precise recording of coordinates of the mapped area. In addition, altitude, inclination, exposure and topography are recorded for each of the coordinates in a GIS-compatible way (see work package n° 10).

Work package n°2: Physical and chemical soil properties

- *Determination of soil physical parameters* (pore size distribution, bulk density, contents of clay and organic carbon). These parameters are used for modelling of the soil water balance.
- *Measurements of SOM status and turnover, and of plant available nutrients in the soil.*

Work package n°3: Canopy structure, primary production, decomposition

- *Canopy structure* is analysed by indirect methods (hemispherical lens measurements, cf. WELLES & COHEN 1996) and by direct methods (stratified clipping and hand inclinometer, cf. TAPPEINER & CERNUSCA 1996). In the forest stands leaf area index, leaf distribution and mean foliage inclination angle are measured with the CI-100 Plant Canopy Analyser, equipped with a digital camera with a "fish-eye" lens providing a detailed scan of the plant canopy. In the grassland communities canopy structure is analysed by the stratified clipping method, which consists of harvesting layer-wise the above-ground vegetation of a representative plot, and measuring separately the dry mass of stems, leaves, inflorescences or fruits and dead plant material for each species in each layer. Leaf and total plant area index are calculated from measurements of the area of the leaves and the other plant parts of each species per layer using a leaf area meter (LI-3100, LI-COR Corp., Lincoln USA). Field measurements of leaf and stem inclination of the dominant species in each layer are made with a hand inclinometer (for details see TAPPEINER & CERNUSCA 1991, 1996).

• *Primary production* is analysed using the harvesting method. This involves measurements of biomass, necromass and litter throughout the year (for details see CERNUSCA 1991).

• *Litter decomposition* is investigated by the litter bag technique. Samples of canopy litter is exposed in litter bags (mesh size 0.1 mm) on the soil surface. The absolute and relative litter decomposition rate is calculated from the decrease of dry matter over a certain period of time (CERNUSCA 1991).

Work package n°4: Water relations and hydrological balance of ecosystems

• *Precipitation* amount and intensity are measured using a tipping bucket raingauge,

• *Soil water content* is determined by Time Domain Reflectometry (TDR) and soil water potential by tensiometers which also quantifies the pore water pressure. The simultaneous determination of profiles of soil water content and potential allows an in-situ description of the characteristic water content - potential curve; this curve is also determined by laboratory methods on soil cores. These data together with the measured saturated hydraulic conductivity of the soil, are parameters needed by other models applied within ECOMONT, in particular TOPMODEL, used to model the water balance of entire catchments (OSTENDORF *et al.* 1995).

• *Evapotranspiration* of grassland and dwarf shrub ecosystems is monitored by lysimeters, as well as by the energy-balance-Bowen-ratio-method (see also work package n°5 and n°6). The total transpiration of six single trees per forest site is recorded continuously by xylem sap flux measurements, providing the data for establishing the water balance of forest stands (KÖSTNER *et al.* 1992).

• *Run-off* from defined experimental plots is monitored by means of a seesaw system.

• *Discharge of the catchment* is monitored by means of a triangular shaped measuring weir (DIEZ *et al.* 1995).

• *Work package n°5: Microclimate, energy budget of ecosystems*

Portable battery-powered data acquisition systems are installed during the main growth period at each investigation site (CERNUSCA 1987). Profiles of soil, air and leaf temperature, of photosynthetic photon flux density (PPFD), air humidity, wind speed and CO_2 concentration, within and above the canopies, as well as incoming global radiation and net radiation are measured. Measurements are made at intervals ranging from 1 min for rapidly changing variables such as radiation and temperature to 6 min for soil temperature and are averaged over 60-min periods. Soil heat flux is estimated by a combination of the temperature integral method for the upper 20 cm of the soil and the temperature gradient method for the lower layers of the soil. In the grassland canopies water vapour flux and sensible heat flux are calculated by the energy-balance-Bowen-ratio-method (for details see TAPPEINER & CERNUSCA 1994, 1996), in the forest stands by means of the Eddy Correlation method (see work package n°6).

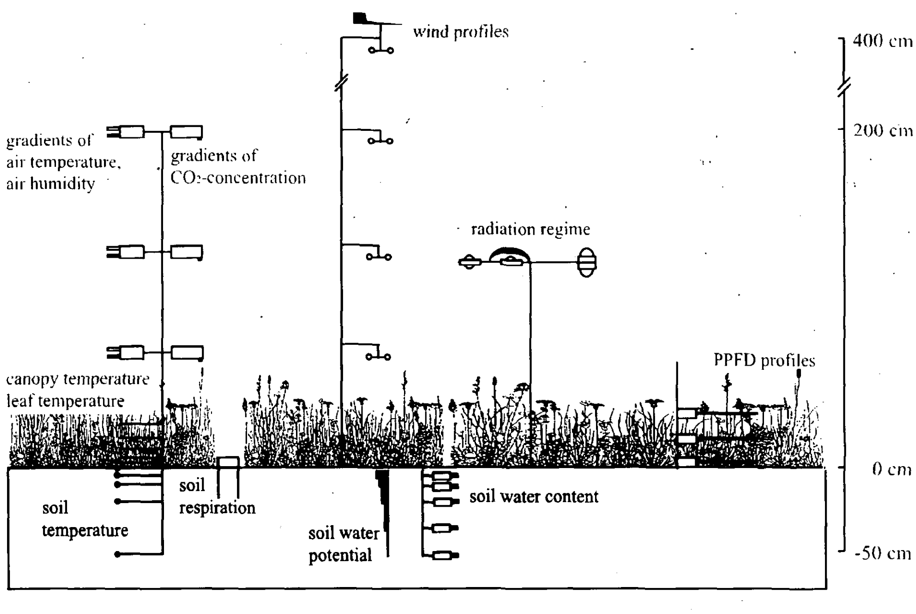

Figure 4. Experimental set-up used for analyzing microclimate, CO_2 and H_2O exchange and the energy balance of grassland ecosystems by means of the Bowen-ratio-method.
Dispositivo experimental utilizado para analizar el microclima, el intercambio de CO_2 y H_2O y el balance energético de los ecosistemas de pasto mediante el método de Bowen.

Work package n°6: Gas exchange (CO_2, H_2O, and related trace gases) of single plants, and ecosystems:

- Gas exchange of single leaves and branches is measured by means of fully climatized portable gas exchange cuvettes (Waltz, Germany)
- The crown conductance, a prerequisite to calculate fluxes of trace gases from the atmosphere into selected trees, is determined by means of the xylem sap flux measurements (see work package n°4) in combination with micrometeorological data.
- Gas exchange of grassland and dwarf shrub ecosystems is monitored by means of energy-balance-Bowen-ratio-method (see work package n° 5). In forest stands a mobile tower of 30 m height is used to carry the sonic anemometers and the fast responding water vapour and temperature sensors to measure the CO_2 and H_2O fluxes by means of the eddy correlation method.
- The determination of the $\delta^{13}C$ isotope ratio is used to characterize the long-term carbon water relationship. In combination with C3-Photosynthesis models reliable estimates of the carbon relation for various vegetation types can be simulated. The temporal and spatial integrative property of this approach is described in Lloyd and Farquhar (1994).
- Carbon isotope discrimination has been shown to be a valuable tool for the long-term estimation of water use efficiency, because this parameter is influenced by the CO_2 gas exchange. The $^{13}C/^{12}C$ ratio is in part determined by the ratio of intercellular to ambient CO_2 concentration, which again is related to the water use efficiency. Since carbon incorporated in leaves is assimilated over a considerable length of time and under a variable range of environmental conditions, the $^{13}C/^{12}C$ ratio is a long term average estimate of the water use efficiency and thus a long term indicator of plant metabolism (Ehleringer et al. 1992). Since it is assumed, that a change in land-use in Alpine ecosystems influences the carbon water relationship, it is suggested that this is reflected in the isotopic composition of the studied vegetation, and therefore the analysis of the $^{13}C/^{12}C$ isotope ratio is the method of choice.
- *Soil respiration:* In order to calculate the apparent canopy photosynthesis, besides the CO_2-flux also soil respiration needs to be known. Release of CO_2 from the soil is measured in situ by IRGA techniques (CERNUSCA 1991, TAPPEINER & CERNUSCA 1996). For this, opaque cuvettes (diameter 19 cm, depth 16 cm) are installed at the soil surface, and continuously flushed with air from 2 m height at a constant rate. At constant intervals air samples are drawn into the gas analyser and rate of soil respiration is calculated from the difference between the CO_2 concentrations entering and leaving the cuvette.

Work package n°7: Gas exchange (CO_2, H_2O, and related trace gases) between the experimental sites and the adjacent atmosphere

Over each of the three composite experimental sites along the South/North-transect across the Eastern Alps a box volume is defined which covers the ecosystem complexes of the catchment (see Fig. 5). The upper boundary is given by the flight height of the aircraft, which is chosen approximately at the constant flux layer top (ca. 200 m above ground). The horizontal fluxes from and to the box are determined by means of a combination of scintillation anemometry and open path absorption spectroscopy. A setup of four to five optical beams is planned to surround the box. The vertical fluxes are measured by means of the Eddy Correlation method, xylem sap flux measurements for the determination of water flux from single trees to the atmosphere, continuous bulk sampling for the measurement of deposition fluxes and the aircraft measurements flying on a constant height. The long-term spatial and temporal carbon water relation of the vegetation under consideration is characterized by means of the $\delta^{13}C$ isotope ratio (see work package n° 6).

The following equipments are used to determine the various fluxes between the landscape and the atmosphere:

- The direct measurement of fluxes through the valley is based on two parallel light beams, one for a DOAS system (differential optical absorption spectroscopy) and one for a scintillation anemometer system (SCIDAR, scintillation detection and ranging). The DOAS system reveals trace gas concentrations, which are integral values over the light path. The SCIDAR is able to measure the total air mass flux through a plane defined by two detectors and the light source. By pointing the beams perpendicular to the valley axis, it is possible to experimentally determine the fluxes of the trace gases from and to the valley under consideration (see GRABER & FURGER, 1993).
- An instrumented motorglider (Stemme, MetAir) is equipped with instruments for measuring NO_2 with a resolution of 0.2 sec, O_3 with a time resolution of 2 s, temperature, humidity and pressure with a resolution of 1 s, a video camera, wind speed and direction measurements with 1 s time resolution, up to 20 VOC species with an on-board GC and a time resolution of 10 minutes. In addition to this on-board GC, up to 12 electropolished steel-bottles can be filled and analysed after the flight in the laboratory. The collaboration of the Paul-Scherrer-Institut (Villigen) with the Flinders University, Australia, permits the use of a fast responding CO_2 and H_2O device, which is able to resolve changes of these gases due to large eddies and therefore is suitable for the determination of corresponding vertical fluxes.
- Bulk samplers for the determination of the deposition of nitrogen compounds and ground stations for continuous measurements of water and NO_2 are used to specify the atmospheric environment of the sites.

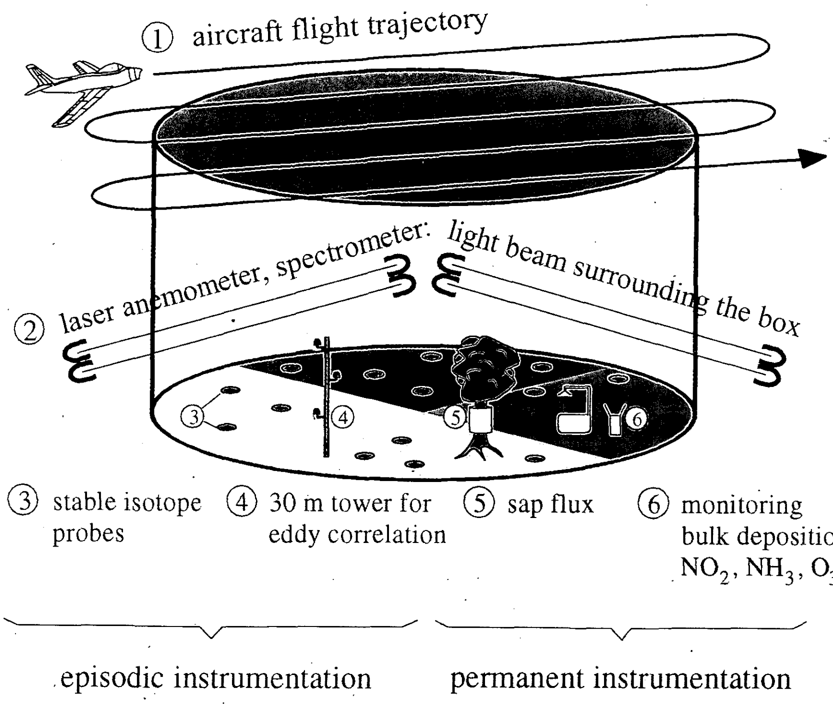

Figure 5. Air mass box over the composite study area consisting of four different landscape elements (hay meadow, pasture, forest, abandonned area). Experimental setup in order to analyse the various fluxes between the landscape and the atmosphere.
Recinto de masa de aire sobre el área de estudio combinado, consistente en cuatro elementos de paisaje (prado de siega, pastizal, bosque, terreno abandonado). Dispositivo experimental para analizar los distintos flujos entre el paisaje y la atmósfera

Work package nº8: Population and plant biological studies

The population and plant biological studies aim at assessing the effects of changes in resource availability (light, nutrients, CO_2, water) and mechanical impacts (grazing, mowing) on the form and functioning of plant species and their populations. Thus, these investigations are intended to provide background informations for causal analyses of changes in plant species composition (work package nº 1) and canopy structure (work package nº 3) following changes in land-use. Furthermore, a link is provided for interpreting the results of gas exchange studies (work package nº 6) in the context of whole plant carbon, nutrient and water relations.

The methods to be applied are from the field of ecophysiology and population biology. Both morphological and phenological aspects are considered. The following parameters are investigated for dominant species as well as species that are found to play a central role in the dynamics of canopies after changes in land-use:

• *Horizontal structure of populations* of keystone species with different morphological and phenological strategies, population densities and abundance.

• *Dynamics of plant architecture and leaf gas exchange* in connection with light availability in the relevant canopy layers.

• *Biomass and nutrient allocation* to fine roots and roots, stems, leaves and reproductive organs.

• *Carbon and nitrogen isotope analyses* in the context of whole plant water and nutrient relations. The use of the stable isotope ^{15}N provides the possibility to distinguish the nitrogen sources of the several plant species, to which degree plants profit from nitrogen fixing plants (e.g. leguminous species) and to which degree plants are dependent on other external nitrogen sources, provided by agricultural fertilization or profit from it. Since nitrogen fixing plants do not discriminate the heavier nitrogen isotope, these plants leave an "isotopic fingerprint" both in the soil and in the associated plant material. This represents a very valuable tool in population dynamics, as it provides strong criteria for grouping plants rather according to their processional functions (work package n° 6).

• *Phenological observations* of vegetative and generative plant development.

Work package n° 9: Potential risks through land-use changes

• *Key parameters of soil stability:* At the beginning of the investigations soil-mechanical parameters of the sloped sites are analysed (Φ, angle of internal friction and c, cohesion). Together with water content and pore water pressure, these parameters give an estimate of soil stability.

• *Measurements of soil stability and soil movement* are determined by inclinometers and traction sensors.

• *Determination of rooting density and rooting intensity on slopes,* as these parameters strongly influence the shearing strength of the soil. Determinations are carried out at different times during the vegetation period, especially during late summer when events of heavy rain and storm are most likely to occur.

• *Development of patches of bare soil and unstable slopes.*

• *Development of snow gliding avalanches.*

Work package n° 10: Geographic Information System (GIS)

The registration of data in a Geographic Information System makes possible a functional superimposition of the maps and the other spatially relevant data. The data of all investigation areas are digitalized with Arc-Info, read in, edited and processed. The data are visualized, analyzed and organized with the data Publishing-Programme Arc-View. This form of data recording and processing guarantees the possibility of using and transferring the data between the individual partner teams of ECOMONT. The following mapping topics is recorded in a GIS-compatible way:

• *Topography* of the investigated areas from maps and aerial photographs. The topographic information serves as an essential basis for modelling (work package n° 12).

• *Large-scale vegetation maps* from aerial photographs, remote-sensing and phytosociological investigations (see work packages n° 1, n° 11). This combination allows a calibration and verification of aerial photographs based on the actual field investigations.

• *Soil maps.*

• *Maps of potential risks* based on the investigations in work package n° 9 and the combination (superimposition) of the information obtained there with informations of vegetation, soil and topographic maps on a landscape ecological level.

Work package n° 11: Remote Sensing - environmental mapping

Remote sensing is carried out at up to four sites using an aircraft-mounted multi-spectral imaging system with a 4 metre pixel size, and covers an area of about 140 square kilometres (FULLER *et al.* 1994). These data are used to input into a GIS system and in conjunction with ground observations, are used as an aid to interpreting and predicting the effects of land-use change. Ground measurements and some ground mapping are also undertaken as a ground truthing exercise and to provide greater definition where this is required.

Work package n° 12: Integrative modelling activities

A hierarchy of models scaling up from the individual leaf or branch to the stand and the landscape (catchment) are used to quantify controls on CO_2 and water fluxes within the Alpine ecosystems and landscapes (Fig. 6). A hierarchy of models is required in order to bring together information on species-specific response to climate conditions, large differences in vegetation canopy structure due to natural variation in vegetation distribution and to

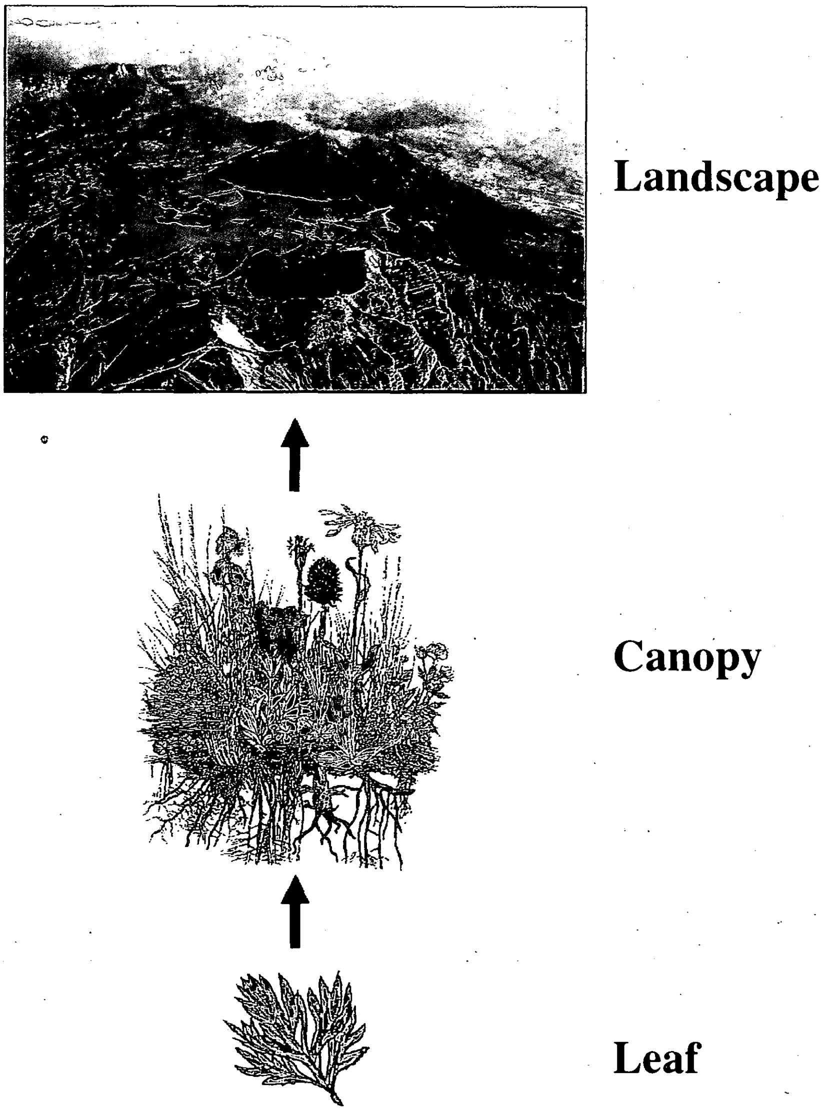

Figure 6: Hierarchical structure of measurements and modelling activities scaling up from the individual leaf or branch to the stand and the landscape shown for the composite research area Monte Bondone.
Estructura jerárquica de las actividades de medida y modelización, abarcando desde la hoja o rama individual hasta la parcela o el paisaje, en el área de investigación combinada de Monte Bondone.

anthropogenic influences (land-use changes), and elevation and slope effects on climate (radiation, surface and soil temperature, soil drying) which affect phenology and vegetation composition.

- *Leaf and Branch Gas Exchange:* Dependent on the determined light climate, temperature, relative humidity, carbon dioxide concentration, and wind speed at a particular point in the canopy, the momentary steady-state gas exchange response of needles (leaves) on branches is calculated. The needle or leaf model is that of HARLEY and TENHUNEN (1991) based on the enzyme kinetics of Rubisco, electron transport, and an empirical formulation for leaf conductance which remains proportional to net photosynthesis. At the level of individual branches and leaves, species-specific stomatal control and "responsiveness" of the vegetation to changes in radiation, temperature, vapor pressure deficit, and water stress are included in the models.
- *Canopy Gas Exchange:* The model STANDFLUX provides a framework for integrating three-dimensional aspects of forest stand structure and light interception, one-dimensional aspects (with depth) of stand microclimate, and the gas exchange behaviour of plant organs (needles, branches with needles, and potentially respiring branches) distributed throughout the stand. GASFLUX is an alternative model that may be applied to vegetation of relatively homogeneous structure, such as that in meadows and grasslands at high elevation (see also TAPPEINER & CERNUSCA 1991).
- *Landscape Gas Exchange:* To model the partitioning of water flux between transpiration and discharge at the landscape scale, initial conditions are defined within a GIS based on remote sensing, maps, or field studies. From this GIS, homogeneous "source areas" with similar vegetation, soils, and topography may be recognized that exhibit essentially the same potential response. From the coded "source area" information alone it is possible to derive spatial "correlative models", e.g., to predict characteristics of soil development and depth, or weighting factors for climate variables (model SISKLIM). These "correlative models" provide boundary conditions affecting the simulation of vegetation or soil processes. Simultaneously, techniques may be developed to derive parameter values for spatial hydrological models, such as the "topographic index" of TOPMODEL which expresses hydrologic similarity of source areas dependent on their upslope contributing area and local topographic gradient. Spatially explicit landscape assessments of the effects of vegetation change on water balance, watershed discharge, carbon dioxide exchange, and dry deposition are achieved by coupling 1) the spatial climate models, 2) the semi-distributed hydrological TOPMODEL and 3) the ecosystem BIG-LEAF stand process simulator.

Relationship of Models to Field Studies

Similar data are collected at all field sites. The field data provide essential input information as well as verification potential for modelling. The relationship of these field activities to the modelling framework described is indicated in Fig. 7. While the modelling achieves the linkages and integration shown below, two additional areas of extremely relevant research must be mentioned. Spatial models that are constructed together with remote sensing activities offer considerable potential for extrapolation of the results, i.e., the remotely sensed data should aid application of the models at additional sites. The stepwise development of this research at multiple sites permits us jointly to investigate extrapolation potentials. Additionally, the spatial models are examined with respect to prediction of ecological risks. Risks due to soil movement and avalanches (work package n°9) are related to topography, soil properties, and vegetation. Spatial simulations of the dynamics of ecosystem water balance are studied with respect to these potential risks. The causes of risk are complex and best examined with multi-dimensional modelling techniques.

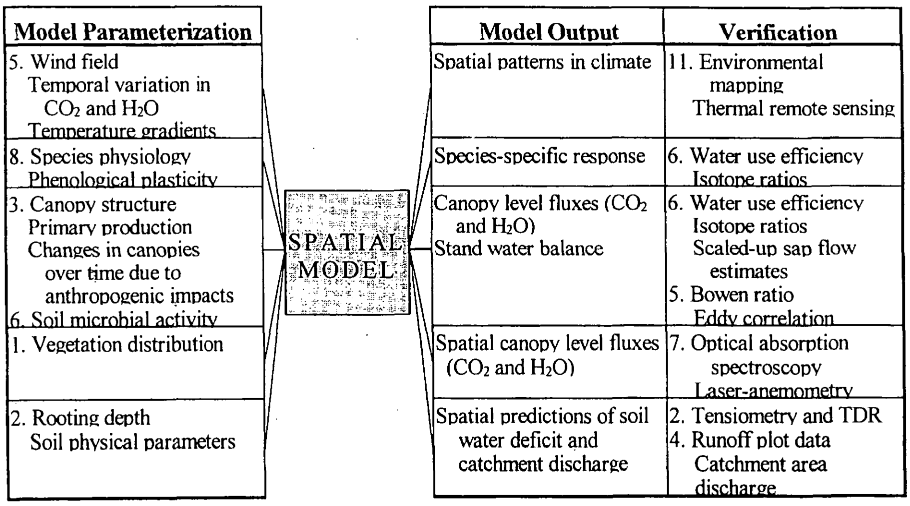

Figure 7. Relationship of Models to the Field Studies (numbers indicate the work packages).
Relaciones entre modelos y estudios de campo (los números indican grupos de tareas).

5. First results of ecomont

Vegetation and land-use change

In the ECOMONT research areas in the Eastern Alps, the Pyrenees and the Scottish Highlands characteristic patterns of vegetation change following changes in land-use can be observed. While there is the general trend in the Eastern Alps, the Pyrenees and the Scottish Highlands that upon abandonment of management open grassland changes to dwarf shrub communities and to woods, regional differences in specific patterns of vegetation change can be observed, which are related to land-use history, geology, altitude, exposure and geology.

Fig. 8 (left) shows a typical example for the change of vegetation communities following land-use change in the **Eastern Alps** on silicate (composite experimental site at Passeier Valley, 1600 - 2000 m a.s.l.). Up to the mid-seventies the research area in the Passeier Valley was characterized by hay meadows with a low degree of management. Since the construction of a forest road 20 years ago some meadows have been used more intensively, while others have been abandoned (50%) or transformed into pastures (15% of the area). Increased fertilization and irrigation have transformed smaller parts of the hay meadows to *Trisetetum flavescentis*. When the intensity of management decreases the vegetation community of the hay meadows changes from *Festuca-Agrostietum* to *Hypochoero-Nardetum* and *Caricetum sempervirentis*. Where meadows or pastures have been abandoned for more than five years dwarf shrubs start dominating the communities (*Junipero-Arctostaphyletum, Empetro-Vaccinietum*). The climax vegetation of this successional sequence is a spruce forest (*Homogyno-Piceetum*).

A typical example of the change of vegetation communities following land use change in the Eastern Alps on limestone is shown in Fig. 8 (right) (composite experimental site at Stubai Valley, 1600-2000 m a.s.l.). In the research area in the Stubai Valley more intensively used meadows (*Geranio sylvatici-Trisetetum*) are cut once a year, fertilized and grazed later in summer. In meadows mowed only every two years *Nardus stricta* and dwarf shrubs get established (*Sieversio-Nardetum strictae*). Pastures on limestone belong to the association of *Seslerio-Caricetum sempervirentis*. Where trampling impact due to higher grazing pressure from cattle increases an *Alchemillo-Poetum* develops. Resting places for animals are dominated by *Rumex alpinus* (*Rumicetum alpini*). When abandoned meadows and pastures change to dwarf shrub communities (*Vaccinio-Callunetum*). The climax vegetation on limestone is sometimes a *Mugetum*, in most cases however a subalpine spruce forest (*Homogyno-Piceetum*).

At the composite experimental site Monte Bondone, the southernmost research area in the Eastern Alpine transect (geology: limestone), a major part of the grassland belongs to the association *Nardetum alpigenum*, which is observed on pastures and hay meadows with a low degree of management. Where land-use is intensified pastures develop to *Crepido-Cynosuretum*, hay meadows change to communities belonging to the *Geranio sylvatici-Trisetetum* and the *Arrhenateretum elatioris*. When pastures and hay meadows are abandoned dwarf shrubs and young trees invade. The climax vegetation on Monte Bondone is a beech forest (*Dentario-Fagetum*), which in a smaller area has been transformed by forestry measures into a larch wood.

In the **Spanish Pyrenees** (Fig. 9) main land-use changes in the meadowland are the intensification in the meadows close to the villages and an initial abandonment in the distant ones (CHOCARRO et al 1987). When intenisified meadows are fertilized and irrigated, and according to the possibilities of irrigation meadows are cut once or twice a year.The low accessibility of distant meadows to machines has often led to a shift in land-use from mowing to grazing or abandonment. The heterogeneity of relief and vegetation in the summer rangelands produces different intensities of the pastoral utilization -according to the spatial accessibility, plant cover palatability, etc.- which in turn produce changes in the structure and dynamics of plant communities (Fig. 9) (ALDEZABAL *et al.* 1992). A time lag in plant phenological development with increasing altitude permits the altitudinal transhumance of livestock (GÓMEZ and REMÓN 1990).

In the former domain of the subalpine forest, up to 2000-2200 m, mesophilous pastures of *Mesobromion erecti* and *Nardion strictae* become dominant (Fig. 9). These two kinds of pastures are the most important basis of livestock utilization, and their structure and dynamics are closely related to human management. When herbivore utilization increases, nitrophilous plant communities such as *Polygonion avicularis* and *Rumicion alpini* can be found in salt points and resting areas. When pastures are abandoned *Brachypodium pinnatum* colonizes quickly and later *Juniperus communis* and *Pinus uncinata* from the climax stages of the vegetation succession in the subalpine belt.

In **Scotland**, vegetation within the natural forest zone is largely man made, directly or indirectly. The principal management influences are grazing, which is almost ubiquitous, and burning, which is less widespread, but still extensively employed. These practices maintain most of the upland and mountain parts of the country as non-woodland vegetation for use by grazing animals (mainly sheep and red deer) and for cover for game birds (mainly red grouse). On granitic soils fertility is low and there is little arable agriculture, although some enclosed pastures may be cut for hay. Unenclosed

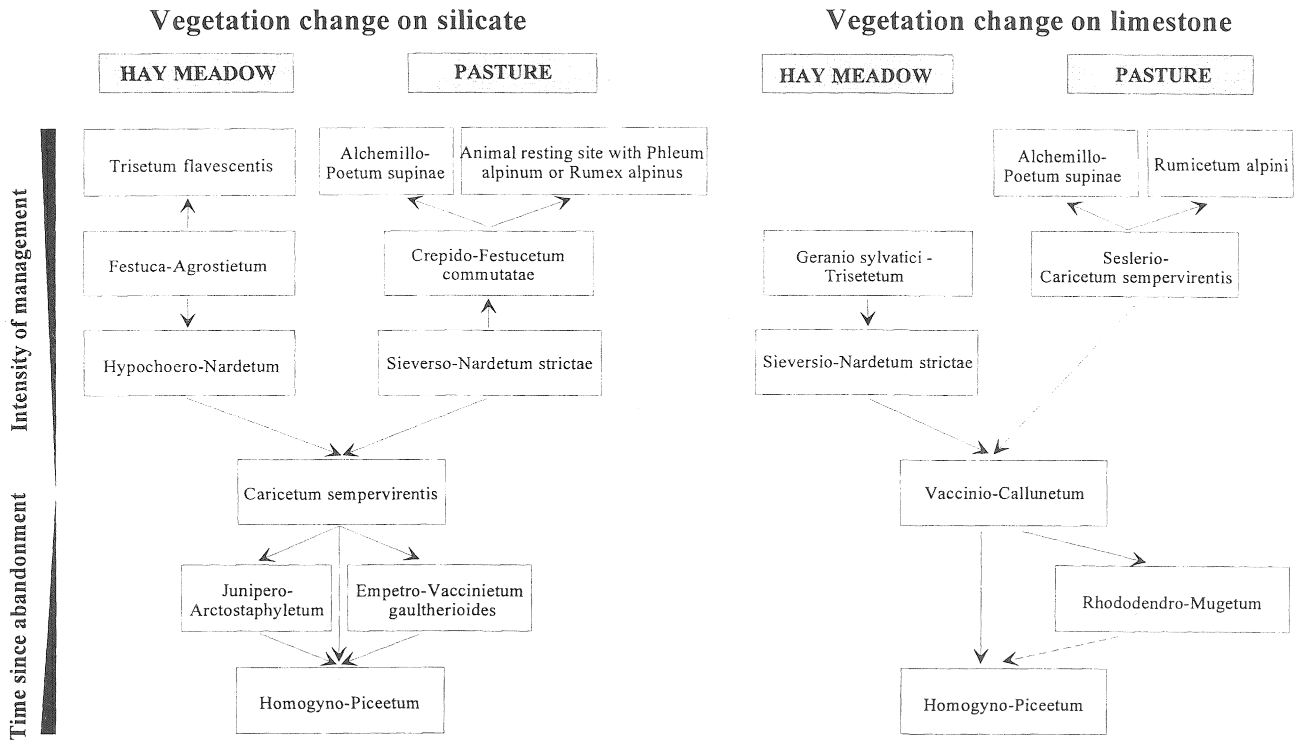

Figure 8. Effects of land-use change on the vegetation composition in the Eastern Alps (left: on silicate composite experimental site at Passeier Valley, 1600 - 2000 m a.s.l.; right: composite experimental site at Stubai Valley, 1600-2000 m a.s.l.).
Efectos del cambio de uso de la tierra en la composición de la vegetación en los Alpes Orientales (a la izquierda: en el área de investigación combinada, sobre sustrato silíceo en el valle de Passeier, 1600-2000 m; a la derecha: en el área de investigación combinada en el valle de Stubai, 1600-2000 m)

mountain and moorland vegetation subject to grazing may compromise predominantly acid grassland communities or predominantly dwarf shrub communities, depending on the level of grazing (MILES 1988, WELCH 1995). Burning is widely used to maintain the cover of dwarf shrub heaths (mainly *Calluna vulgaris* heaths). Burning destroys the existing *Calluna* cover, but regeneration takes place from basal shoot growth and from seedlings to replace a closed canopy of *Calluna* in about 5 years. Initially though there is usually a phase of transient *Deschampsia flexuosa* grassland, gradually replaced by the new *Calluna* growth (Fig. 10).

Where management is by grazing, increasing grazing intensity leads first to a mosaic of acid *Agrostis – Festuca ovina* grassland and *Calluna* heath with loss of the heath species at very high levels of grazing. When the cover of grasses is complete reversion to heathland may be very protracted, even if grazing levels drop substantially.The elimination or substantial reduction of grazing of dwarf shrub heaths results in invasion by scrub and trees, mainly of *Pinus sylvestris*, but sometimes also of *Betula* species. *Betula* woodland or *Betula-Pinus* woodland normally leads to dominance by *Pinus sylvestris*, which is probably the climax species (Fig. 10).

Soils and land-use change

The soil reacts considerably slowlier than the vegetation concerning land-use changes. Mostly it takes many decades until the various stages of the soil development line have been shaped or reshaped again (KUBIENA 1986). Investigations in the Eastern Alps have shown that reduced land-use causes an accumulation of surface litter. This surface litter consists of increasing portions of dwarf shrub and needle litter which are difficult to decompose, because of higher contents of lignins, cellulose, and hemicellulose (GREEN *et al*. 1993). As a consequence trinomial O-horizons develop (moder-like mull to raw humus), which are typical for dwarf shrub stands (Fig. 11). From these O-horizons humic acids penetrate to the mineral soil and there they result in a profile differentiation and in a great change of all physical and chemical soil parameters (soil structure, storage capacity of the soil, soil acidity etc.). As a consequence of this permanent acid influence the brown soils on silicate at Kaserstattalm (Stubai Valley, Eastern Alps) show a continuing podzolization process (clay mineral destruction and translocation of substances to the B-horizon). Due to the penetration of strong humic acids into the topsoil it becomes acidified, and the pH values decrease. The continuing acidification of the topsoil causes developmental dynamics with the consequence of an irreversible transformation of the soils. The mineral horizons become impoverished with humus and other important ion nutrients (nitrogen, phospho-

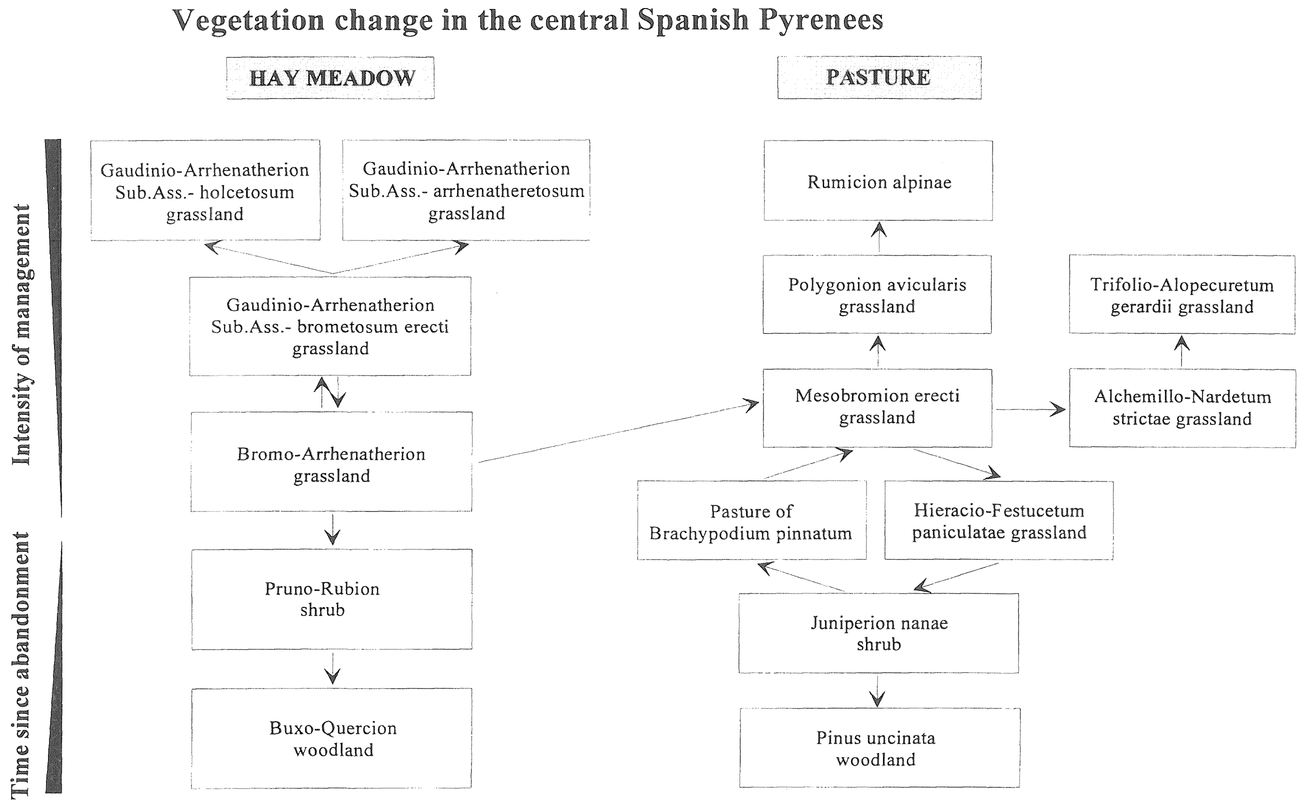

Figure 9. Effects of land-use change on the vegetation composition in the Central Spanish Pyrenees (800 - 2000 m a.s.l.).
Efectos de los cambios de uso de la tierra en la composición de la vegetación en los Pirineos Centrales españoles

rus, potassium, exchangeable alkaline cation etc.). The accumulation of surface litter that is difficult to decompose and the increasing acidification of the topsoil result in a decrease both in the number and the activity of soil organisms, and the C/N ratios increase. The former crumb structure becomes indistinct and begins to decompose to a coherent structure. Changes concerning the soil structure, the pore space and the organic substance content also bring along changes concerning the water storage and the ability of water transport in the soil.

As soon as the woodland has established during the proceeding succession, weakly to strongly shaped podzolized moder to raw humus-like moder brown soils can be found, as well as podzoles (iron- and iron humus podzol) with weak raw humus layers (Fig. 11), which form the climax stages of the soil development line. This process up to the podzol lasts, however, several centuries (KUBIENA 1986). Podzoles below raw humus layers but also podzolized moder brown soils below dwarf shrubs can only be reshaped with greatest effort (soil ploughing, fertilization, etc.) into soils that are suitable for an agricultural land-use.

Applied aspects

The first results of ECOMONT show that land-use changes cause characteristic changes in the vegetation, the soil and related processes, which affect biodiversity and may increase potential risk. A high degree of biodiversity can be achieved when management is adapted to maintain lower levels of plant available nutrients. An increase in management intensity, especially when coupled to higher nutrient inputs into ecosystems, as well as complete abandonment leads to a significant decrease in biodiversity. Abandonment may increase potential risks by increasing the probability of snow gliding avalanches, as well as erosion related to gliding snow. In addition, soil aggregate stability in the upper soil decreases after abandonment, which may result in a decrease of water storage capacity and potential infiltration.

These important aspects, as well as future results to be expected from ECOMONT will allow for a more detailed assessment of ecosystem development, biodiversity, potential risks and interlinkages between plant - ecosystem and landscape level and should provide a scientific basis for application towards developing concepts of sustainable land-use.

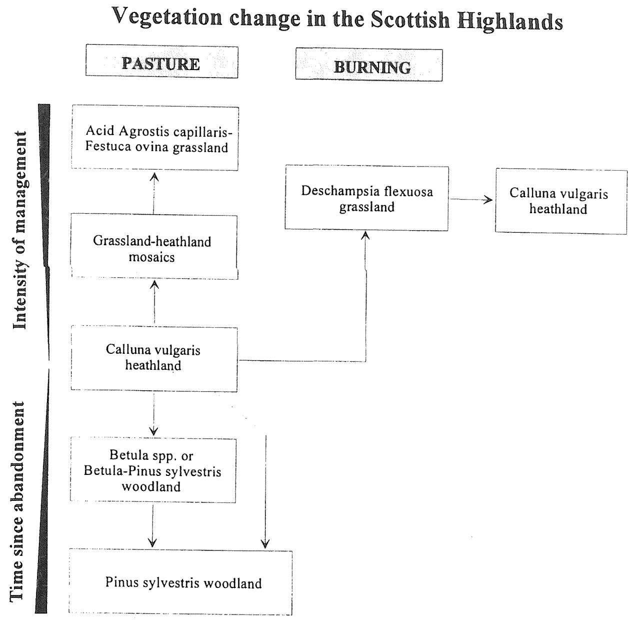

Figure 10. Effects of land-use change on the vegetation composition in the Scottish Highlands. Efectos de los cambios del uso de la tierra en la composición de la vegetación en los Highlands de Escocia.

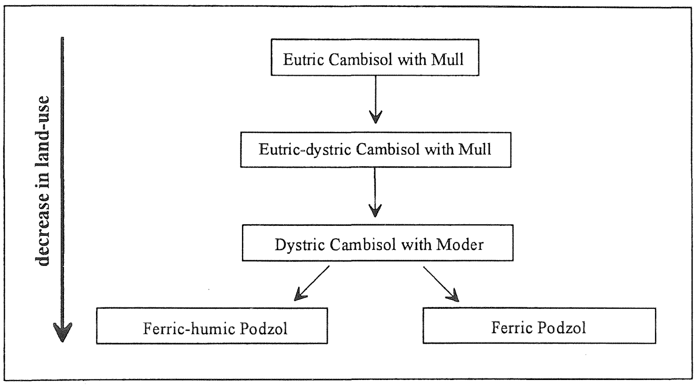

Figure 11. Effects of land-use change on the soil in the Eastern Alps (example of composite experimental site at Stubai Valley, 1600-2000 m a.s.l.).
Efectos de los cambiosdel uso de la tierra en el suelo de los Alpes Orientales (ejemplo de la parcela experimental combinada en el valle de Stubai, 1600-2000 m).

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