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# ALPINE MEADOWS AND PASTURES AFTER ABANDONMENT[1]

## Results of the Austrian MaB-programme and the EC-STEP project INTEGRALP

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*ABSTRACT.- We present the results of a study on the behaviour of alpine ecosystems after the abandon of farming practices. The work has been carried out in Gastein Valley (Austria), the High Tauern National Park (Austria) and the Mt. Bondone (Italy). In the three places different phases of plant succession have been studied, and several ecologic parameters, such as the energy budget, the carbon budget, the canopy structure and many interactions between organisms were measured. Over 20 specialists have worked on the data gathering and analysis. Among the main observed results we can count the relative instability of abandoned plots; the diversity and the specific richness decrease; light becomes there a limiting factor because of the canopy growth; the degradation of litterfall becomes slower than in grazed plots; surface erosion and runoff decrease strongly, and so on. Commonly, the abandoned alpine pastures show a trasition situation between the artificial equilibrium status kept by livestock and the natural equilibrium corresponding to climatic communities.*

*RESUMEN.- Se presentan los resultados de un análisis sobre el comportamiento de los ecosistemas alpinos durante el abandono de las prácticas agrícolas en los mismos. Los trabajos se han llevado a cabo en el valle de Gastein (Austria), en el Parque Nacional del Alto Tauern (Austria) y en el Monte Bondone (Italia). En los tres lugares se han estudiado distintas fases de la sucesión vegetal, midiéndose numerosos parámetros ecológicos, como el balance de carbono, el balance energético, la estructura de la cubierta vegetal y distintas interacciones entre organismos. Más de 20 especialistas han intervenido en la toma y análisis de los datos. Entre los principales resultados observados se cuentan el aumento de diversidad en las áreas abandonadas y su relativa inestabilidad; en ellas la luz se convierte en un factor limitante; la degradación de la hojarasca y la materia muerta se hace más lenta; la escorrentía y la erosión superficial disminuyen apreciablemente. En general,*

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*los pastos alpinos abandonados reflejan una situación de transición entre el estado artificial de equilibrio mantenido por el cultivo y el equilibrio natural existente en las comunidades clímax.*

*RÉSUMÉ.- On présente les résultats d'une étude du comportement des écosystemes alpins après l'abandonnement des pratiques traditionnelles de pâturage. Les observations ont été faites dans la Vallée de Gastein (Autriche), dans le Parc National de l'Haut Tauern (Autriche) et dans le Mt. Bondone (Italie). Dans les trois places on a étudié differents phases de la succession végétale, en mésurant nombreux paramètres écologiques, tel le bilan d'energie, le bilan du carbone, la structure du tapis végétal et diverses interactions entre les organismes. Plus de 20 spécialistes ont travaillé dans la prise et l'analyse des données. Parmi les principaux résultats observés peut-on signaler l'augmentation de la diversité dans les patûrages abandonnés et leur rélative instabilité; la lumière dévient là un facteur limitante, la dégradation de la litière se fait plus lente; l'écoulement et l'érosion de la surface diminuent beaucoup. Généralement les pâturages alpins abandonnées montrent une situation transitionnelle entre l'équilibre artificiel résultant de l'intervention humaine et l'équilibre naturel de la communauté climacique.*

**Key-words:** *Mountains, Alps, alpine pastures, effects of abandon, succession, ecosystem, livestock.*

Alms and meadows are anthropogenically changed environments whose stability has been maintained for centuries by the husbandry of alpine farmers. In the last three decades economic factors have caused considerable structural changes in agriculture in general and in alpine agriculture in particular. This has resulted in neglect and abandonment of certain alpine areas and managed meadows throughout the entire alpine region (SURBER *et al.*, 1978, PENZ, 1978, BÄTZING, 1990). Once the type of cultivation has been altered, typical changes in vegetation often occur (CERNUSCA, 1978b). Plant stands tend to revert to the climax vegetation. Such a development may take decades, running through different successional stages, each associated with typical plant societies (SPATZ *et al.*, 1978). During the course of succession the prevailing plant society is unstable, being subject to continuous changes resulting from competition between plants. Some species are displaced, others invade, spread and are finally replaced by new invaders. This instability of the vegetation necessarily affects the entire ecosystem. Extensivation and abandonment of vast alpine areas lead to a far-reaching reshaping of the landscape and, as a consequence, exert a fundamental influence on ecological stability.

A number of phytosociological studies have been concerned with demonstrating successional changes in the vegetation of abandoned pastures and meadows (SPATZ, 1973, SPATZ *et al.*, 1978, WEIS, 1980). Only rarely, however, have geologists, hydrologists, soil scientists, botanists, zoologists, microbiologists and agronomists cooperated in multidisciplinary investigations on the changes in the ecosystem "abandoned alm" as an entity. So far only a single integrated ecosystem analysis on the ecological consequences of cessation of management of alpine areas has been carried out. This analysis was conducted within the Austrian MaB-programme "Hohe Tauern" in the Gastein Valley in Salzburg (CERNUSCA, 1978a). For the first time, carbon budget, energy budget and water regime as well as soil biology were studied in detail. The results of this study have already had an influence on certain aspects of agricultural practice (CERNUSCA, 1991b). Within the Europe-wide research project INTEGRALP (EC-STEP program), a multinational team of scientists is gathering information on ecological relationships and interactions between grassland and forest ecosystems in alpine regions. In this project the University of Innsbruck has undertaken to carry out ecosystem research on the ecological effects of different types of agricultural management, whereby primary attention is to be given to the ecological effects of reduced agricultural management. Research areas found to be suitable for this purpose are Mt. Bondone near Trento (I), National Park Hohe Tauern (A) and the Stubai Valley near Innsbruck (A) (see Fig. 1). In the following, a comprehensive presentation of the most important results of the ecosystem research on abandoned pastures and meadows in the Austrian Central Alps and in the Southern Alps will be attempted.

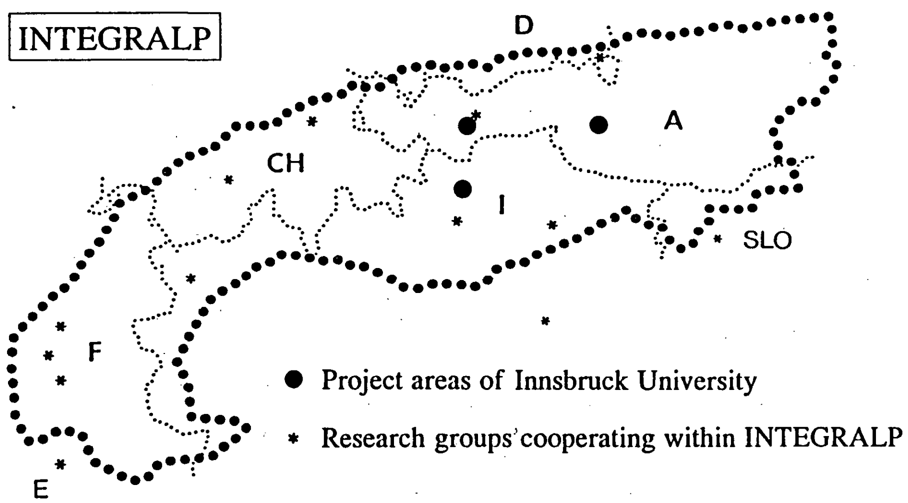



Fig. 1. Geographical location of the experimental sites of the Innsbruck group within the EC-STEP project INTEGRALP (coordination ICALPE, Chamberry, F), from CERNUSCA *et al.*, 1992. *(Localización geográfica de las parcelas experimentales del grupo de Innsbruck, dentro del proyecto EC-STEP INTEGRALP (Coordinación ICALPE, Chamberry, F), de CERNUSCA et al., 1992).*

## 1. Research areas

### 1.1. *Gastein Valley*

In 1978, investigations in the Gastein Valley (Austrian Central Alps) were carried out within the framework of the Austrian MaB-programme. The valley is situated in the northern part of the mountain range Hohe Tauern. Geologically, it belongs to the penninic slate cover of the "Tauernfenster" (EXNER, 1957). With respect to macroclimate, the experimental site lies in the transitional zone between atlantic and continental climates, although it is also subject to mediterranean influence (WEISS, 1978). The investigations concentrated on a managed alm and several abandoned alms on Stubnerkogel near the timberline in the vicinity of Badgastein. Additional investigations were conducted on variously managed alms in the Gastein Valley.

### 1.2. *National Park Hohe Tauern*

In 1991 the University of Innsbruck carried out ecosystem analysis in the central zone of the National Park Hohe Tauern within the INTEGRALP project. Investigations concentrated on the Ferleiten Valley, at sites between 1500 and 3000 m a.s.l. The underlying rock consists mainly of greywacke, a rock of intermediary character. Hence, both silicate and carbonate flora can be found. Weather conditions are similar to those of Gastein Valley (see CERNUSCA, 1991a).

### 1.3. *Monte Bondone*

The second research area investigated in 1991 was Mt. Bondone near Trento (I). The region of Mt. Bondone consists of different kinds of limestones. Deeper layers of the plateau are overlain by silicates of moraine material. The soils are typical brown soils which, under the influence of water, have in places become podsolized. Mt. Bondone is situated on the southern slopes of the Alps and its climate is mainly alpine continental with some mediterranean influence.

The vegetation of Mt. Bondone has been strongly influenced by man. The region was originally covered by forests, which were cleared to a considerable extent in the 17th century. Alpine meadows and pastures came into being, but today only some of them are managed. Natural woods, meadows and abandoned areas are the predominant features of the landscape (CETTO, 1963). A description of the vegetation of Mt. Bondone has been provided by PEDROTTI (1981). Within the INTEGRALP project four areas with different types of management, all at 1550 m a.s.l. are being investigated.

These sites are: a meadow which is mown once a year, an area with isolated shrubs and young trees which has been abandoned for 30 years and a natural mixed wood with beech and larch.

## 2. Methods

The present paper aims at gaining further insights into the ecological impacts of changes in the agricultural management of alpine pastures and meadows by two different basic approaches: a landscape-ecological approach, including investigations of vegetation dynamics, soil properties and agricultural ecology on transects along different successional stages from intensively managed to abandoned areas; secondly, a comprehensive ecosystem analysis of selected successional stages.

Important ecological parameters, such as canopy structure, carbon budget and energy budget, competition for limiting factors, as well as interactions between plants, animals and microorganism were studied in detail. Due to the complexity of the ecosystems, research could only be carried out satisfactorily with the interdisciplinary collaboration of meteorologists, soil scientists, geologists, hydrologists, botanists, zoologists, microbiologists, as well as agriculturalists and specialists in forestry. The project involved the collaboration of 15 to 20 specialists as well as graduate and doctoral students of the University of Innsbruck. The ecological parameters investigated in such an integrated ecosystem analysis are shown in Table 1.

TABLE 1

Ecological parameters investigated.

| | | |
|---|---|---|
| **1. Meteorology**<br>Macrometeorology<br>Micrometeorology<br>Energy budget | **2. Hydrology**<br>Water budget<br>Surface run-off<br>Geomorphology | **3. Soil parameters**<br>Soil erosion<br>Soil respiration<br>Soil microbiology |
| **4. Botany**<br>Phytosociology<br>Canopy structure<br>Primary production<br>$H_2O/CO_2$ Gas exchange<br>Plant competition | **5. Interactions**<br>Interaction between plants and animals<br>Epigaeic arthropods as bioindicators<br>Stress ecology | **6. Data acquisition and modelling**<br>Ecological data bank<br>Mathematical models<br>Development of methods for ecosystem research |

*Meteorology:* Besides the application of standard climatic methods in studying the macroclimate, detailed measurements of the microclimate were made. A portable battery-powered data acquisition system (Mikromet,

A. Cernusca, Innsbruck, Austria, cf. CERNUSCA, 1987) provided profiles of soil, air and leaf temperature, profiles of air humidity, wind speed and $CO_2$ concentration within and above the canopy throughout the vegetation period. Incoming global radiation and net radiation as well as soil heat flux were recorded continuously. Micrometeorological measurements were made at intervals ranging from 1 minute for rapidly changing variables like radiation, wind, water vapour pressure and $CO_2$ concentration, to 12 minutes for soil temperature. The following sensors were used: Star pyranometer and net radiometer (SCHENK, Vienna, Austria), small thermocouples for soil, leaf and air temperature (home made: copper/constantan, 0.08 mm diameter), thermocouple psychrometers (home made), heat flux plates (Keithly Instruments, S.A.), cup anemometer (Type AM, Rimco Inc., Australia) and infrared gas analyser (LCA-2, ADC, Hoddesdon, England) for measuring $CO_2$ concentration. Measurements of photosynthetic photon flux density (PFD) were made using DECAGON, Sunfleck Ceptometer (Modell SF-80, Delta-T Devices, Ltd., Cambridge, England).

*Water balance, evapotranspiration, surface runoff:* An important area of the ecosystem studies was devoted to the water balance of individual plants and the ecosystems as a whole. These investigations were carried out using diffusion porometers to measure stomatal opening (AP4 porometer, Delta-T Devices Ltd., Cambridge, England), the Scholander pressure chamber to record the water potential of plants, and automatic, electrically-recording lysimeters (CERNUSCA, 1991c) for the continuous recording of evapotranspiration throughout the day and over the course of the year. Measurements of infiltration rate were made by means of double-ring infiltrometry (NEUWINGER, 1982). An important contribution was made by the Bavarian Water Authority (Bayerisches Landesamt für Wasserwirtschaft): surface runoff and erosion experiments carried out using a mobile rain machine (KARL & TOLDRIAN 1973), proved to be an invaluable supplement to the stationary surface runoff measurements. These experiments provided the basis for an exact analysis of soil erosion caused by catastrophic rain under a wide range of local conditions.

*Phytosociological investigations:* For the phytosociological investigations in the field the relevé method of BRAUN-BLANQUET (1964) and REICHELT & WILMANNS (1973) was used. The syntaxonomical classification of the areas studied was carried out by means of a computer-supported numerical analysis of the vegetation, using the classification programme TWINSPAN (HILL, 1979a) and the ordination programme DECORANA (HILL, 1979b), and in principle adhered to the vegetation classification of OBERDORFER (1978, 1983) and PEDROTTI (1981). The ecological characteristics were determined by the ecological values of LANDOLT (1977), life forms according to RAUNKIAER.

*Primary production, vertical structure of vegetation:* An important section of the project was concerned with analyses of primary production, such as measurements of biomass and necromass over the course of the year, as well as measurements of canopy structure (leaf area index, leaf inclination) employing the stratified clipping method (MONSI & SAEKI, 1953). In the woodland sites, canopy structure was analysed using a portable canopy analyser (LAI-2000, LI-COR Instr. Co., Lincoln, Nebraska, USA).

*$CO_2$ gas exchange:* For the analysis of the carbon regime of the individual ecosystems, *in situ* measurements of photosynthesis and respiration of single leaves were carried out. All measurements were made in the field under the currently prevailing conditions of temperature, humidity and light. Response curves were determined using the portable ADC-system (LCA-2, ADC Co., Hoddesdon, England) and the adjustable WALZ-system (compact porometer, Fa. WALZ, Effeltrich, Germany).

In addition to the measurements of $CO_2$ gas exchange of single leaves, detailed measurements of the $CO_2$ gas exchange of the whole canopy were made using a micrometeorological approach, i.e. the Bowen-ratio energy-balance method (cf. NORMAN and HESKETH, 1980, CERNUSCA, 1982). Release of $CO_2$ from the soil was measured in situ by IRGA techniques (LCA-2, ADC, Hoddesdon, England) using the cuvette method in the "open test gas system" (CERNUSCA & DECKER, 1984). The sum of the $CO_2$ output of the soil and the $CO_2$ flux in the atmosphere made up the $CO_2$ exchange of the entire plant stand.

*Data acquisition and modelling:* Particular importance was attached to the storage of all measurements in an ecological data bank. Additionally, the data bank system contains a number of programmes for evaluation and simulation, that not only make possible exhaustive analyses of the stored data but also permit the design of mathematical ecosystem models based on the entire body of data. Models for soil temperature and soil water content, for the distribution of radiation in a plant canopy, for leaf temperature and canopy photosynthesis are already available (TAPPEINER & CERNUSCA, 1989a, 1991).

## 3. Selected results

In the following, the most important results of ecosystem research in the Gastein Valley (Austrian MaB-programme), in the National Park Hohe Tauern and on Mt. Bondone (EC-STEP project INTEGRALP) are presented.

### 3.1. *Phytosociological investigations on abandoned alms*

Detailed phytosociological investigations in the Gastein Valley disclosed that the characteristic succession on abandoned alms is primarily determined by altitude, exposure, underlying geology and the supplies of nutrients and water (SPATZ *et al.*, 1978). Abandoned culture land tends to revert to the natural type of vegetation determined by the specific habitat. In the mountain range Hohe Tauern, "natural type" near the timberline would be a *Pinus cembra*-larch stand (Larici Pinetum cembrae), or a spruce-larch wood (Piceetum subalpinum) below the timberline. SPATZ *et al.*, (1978) found several different types of succession. Results from the Ferleiten Valley

(National Park Hohe Tauern) corroborated results from the Gastein Valley and provided more information about vegetation on carbonaceous soil. A survey of most important successions are given below:

1. High montane to subalpine zone; humid, nutrient-rich habitats

Initial vegetation: cultivated alpine pastures and alpine mats (Nardetum, Festucetum rubrae, Poa-Prunelletum, Trisetum). Long-grass meadows develop at the beginning, mixed with rapidly growing alder bushes (*Alnus viridis*). Within a few years dense alder stands may then develop. When these stands grow old and become less dense, forest trees are able to develop.

Climax vegetation: *Pinus cembra* with *Larix decidua* (Piceetum subalpinum)

2. High montane to subalpine zone; dry nutrient-poor habitats

Initial vegetation: cultivated alpine pastures and mats (Nardetum alpigenum and Festucetum rubrae)

In the first stage short-grass mats are formed, dwarf shrubs immigrate (*Rhododendron, Vaccinium*). Later, larch, spruce, and *Pinus cembra* seedlings immigrate gradually.

Climax vegetation: subalpine spruce forest with larch trees and *Pinus cembra* (Piceetum subalpinum).

3. Upper subalpine zone; humid, nutrient-rich habitats

Initial vegetation: Cultivated alpine pastures and alpine mats (Poa-Prunelletum, wet meadows). At the beginning of the succession process, long-grass pastures develop, rapidly becoming interspersed with tall herbs.

Climax vegetation: alder stands (*Alnus viridis*)

4. Upper subalpine zone; dry nutrient-poor habitats

Initial vegetation: cultivated, grazed alpine pastures (Nardetum, grazed Curvuletum); on carbonaceous soil also Seslerion. Succession runs through short-grass stands and dwarf shrubs. On carbonate, *Pinus mugo* immigrates und determines climax vegetation.

Climax vegetation: *Pinus cembra* and larch woods (Larici-Pinetum cembrae)

5. Lower subalpine zone

Initial vegetation: cultivated alpine pastures (Nardetum, grazed Curvuletum and Vaccinium-heath); on carbonate also Seslerion.

Climax vegetation: Dwarf shrub heath (Empetro-Vaccinietum) or Seslerion coeruleae.

6. Alpine zone

Initial vegetation: cultivated alpine pastures (Nardetum, grazed Curvuletum and carbonate mats). Abandoned grazing areas develop directly - without intermediate stage - into natural mats.

In general, phytosociological investigations in the mountain range Hohe Tauern show that the course of the successional process becomes simpler and shorter with increasing altitude (see Fig. 2).

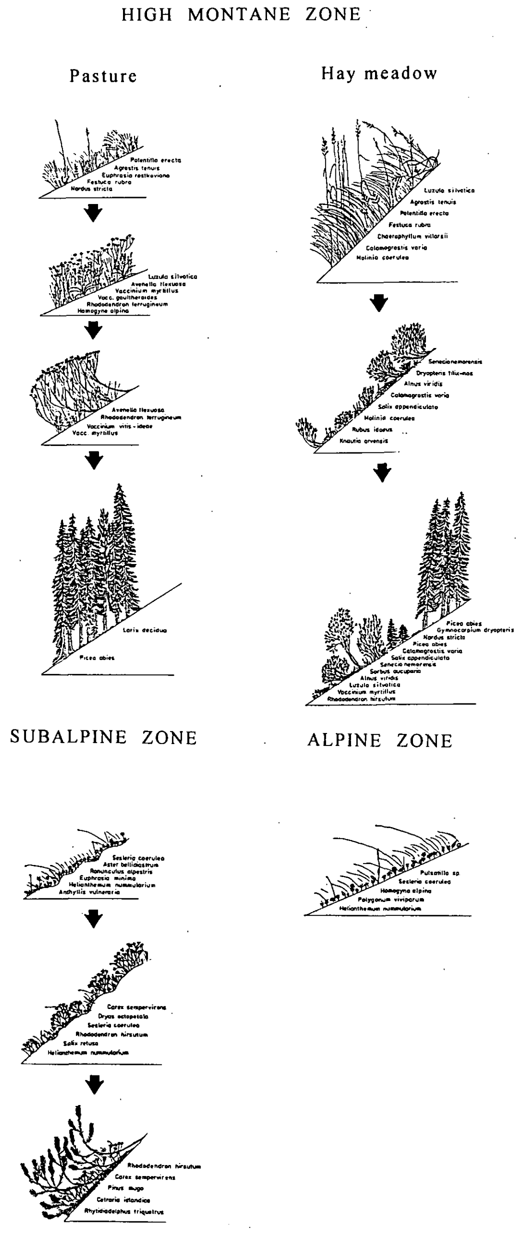



Fig. 2. Ecological studies of the vegetation along transects of successional stages of abandoned areas at various altitudes in Ferleiten Valley (recordings by BUCHNER and HOFBAUER 1991, unpublished). *(Estudios ecológicos de la vegetación a lo largo de transectos de fases sucesionales en áreas abandonadas, a distintas altitudes en el valle de Ferleiten (observaciones de BUCHNER y HOFBAUER, 1991, inéditas).*

The vegetation analyses on variously managed areas on Mt. Bondone offered the opportunity of additional ecological characterisation of the process of succession (see CERNUSCA *et al.*, 1992). Comparing a cultivated meadow, a larch wood and a beech wood, and an area that has been abandoned for some 30 years, the latter showed the broadest spectrum of different life forms (Fig. 3). The meadow was dominated by hemicryptophytes, geophytes and therophytes which have completed their vegetational cycle before mowing takes place, whereas on the abandoned area life forms which are endangered by mowing and grazing (dwarf shrubs, nanophytes and phanerophytes) gained importance. Analysis of species number and diversity showed a significant decline from abandoned alm (97 species), meadow (70 species) to larch wood (48 species) and beech wood (46

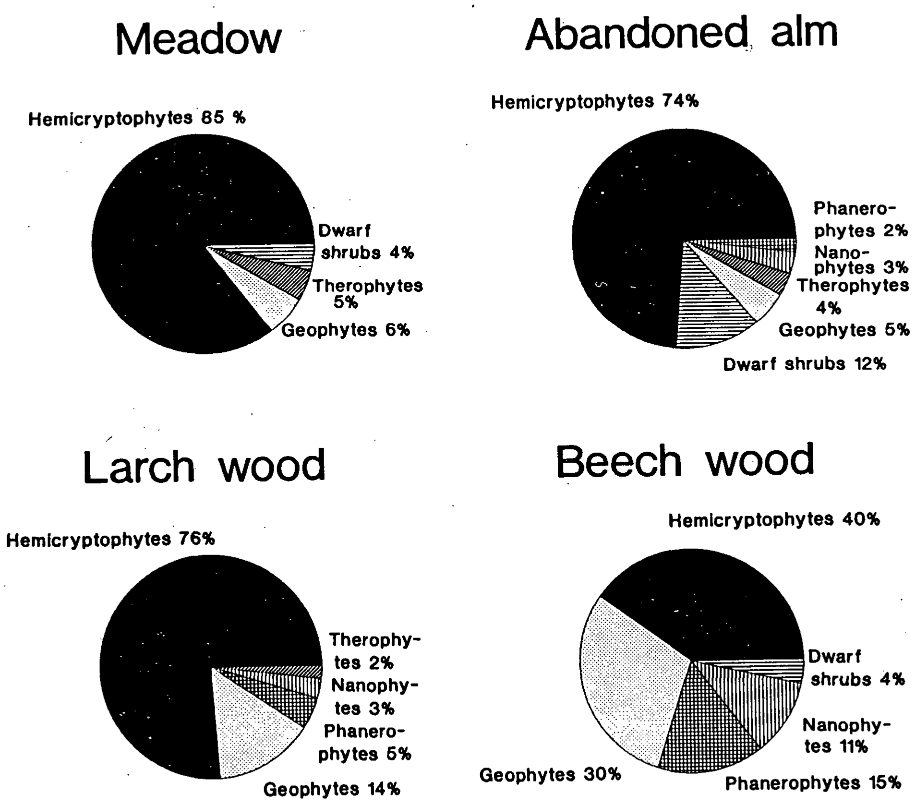



Fig. 3. Life forms (RAUNKIAER) of a managed meadow, of an alm that has been abandoned for 30 years, of a larch wood and a beech wood on Mt. Bondone near Trento (from CERNUSCA et al. 1992). *(Formas biológicas (RAUNKIAER) de un prado trabajado, un pastizal abandonado durante 30 años, un bosque de alerces y un bosque de hayas en el Mte. Bondone, cerca de Trento (de CERNUSCA et al., 1992).*

species). The coexistence of plants of different life forms as well as other groups of species such as plants of meadow, pasture and wood is, according to ALTHER and STÄHLIN (1977), peculiar to unstable stands in which development is still in progress. High diversity can also be an indicator of unstable stands (OSBORNOVA *et al.*, 1990).

### 3.2. *Dynamics of canopy structure, microclimate and photosynthesis, exemplified by two successional processes*

#### 3.2.1. Immediate successional stage after cessation of a pasture (Aveno-Nardetum) near the timberline (1912 m a.s.l.)

Investigations in the Gastein Valley showed that management is the most relevant factor affecting the ecosystem "alm". Once the grazing pressure is removed, an ecological succession immediately sets in. For an abandoned alpine pasture in National Park Hohe Tauern this was impressively illustrated by TAPPEINER & CERNUSCA (1989b). Only one year after abandonment, characteristic changes in the phytomass, canopy structure, microclimate and plant production were noticeable. In the first year the photosynthetically active leaf area (GAI) rose by the factor 7 for grasses and 3 for herbs. Necromass increased by the factor 2.8 in the first year and even rose further in the following years (see Fig. 4). After three years the aboveground phytomass on the abandoned pasture was five times higher and biomass four times higher than at the time when it was still grazed. Fig. 5 allows a true-to-scale comparison of the phytomass of the two stands. Additional investigations on leaf inclination revealed that on the grazed area leaves are less steeply inclined than leaves on the abandoned area. This can be explained by the two different limiting factors governing the two sites. On the grazed area grazing itself is the limiting factor stimulating the development of horizontally inclined leaves. These leaves are least damaged by grazing pressure. In addition, horizontal leaves near the ground preserve the stability of the stand as cattle can graze stands only to a height of 2 cm. Thus losses caused by cattle grazing feed do not endanger hazard stability. After removal of the grazing pressure, light becomes an increasingly decisive limiting factor. In the course of the succession, stand density increases and leaves assume steeper angles in order to obtain a maximum amount of light. This is confirmed by the results of computer predictions for net photosynthesis. On the pasture, light is hardly limiting whereas on the abandoned alm it is the crucial limiting effect on net photosynthesis. Although on the abandoned alm the photosynthetically active leaf surface rose by the factor 5, net photosynthesis was only higher by a factor of 1.5 than on the pasture. Investigations disclosed light as the factor affecting competition immediately after cessation of grazing. Shortage of light consequently changes competition relations and hence species spectra.

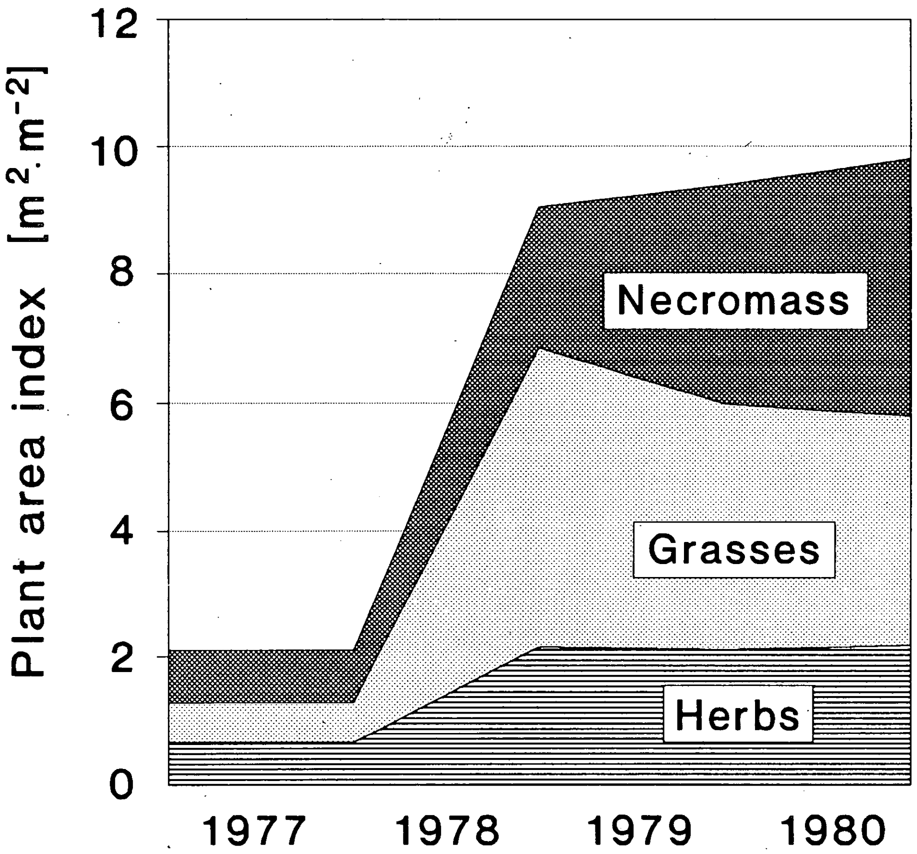



Fig. 4. Time course of total plant area index (PAI), green area index (GAI) of herbs and grasses, as well as the area of necrotic matter in the alpine pasture at 1.912 m. a.s.l. The alpine pasture was last grazed by cattle in 1977 (from TAPPEINER and CERNUSCA, 1989b). *(Evolución en el tiempo del índice de área total de las plantas (PAI), índice de área foliar (AI) de las hierbas y área de materia muerta en el pasto alpino a 1.912 m. de altitud. Este lugar fue pastado por última vez en 1977 por ganado vacuno (de TAPPEINER y CERNUSCA, 1989b).*

The most recent phytosociological investigations on Mt. Bondone gave support to these results (CERNUSCA *et al.*, 1992). On the abandoned alm, as compared to the meadow, the proportion of half-shade and shade indicators increased. On abandoned alm, degradation of the dead plant matter was very slow due to the high proportion of lignified and fibrous structures. Nutrients therefore remain for a relatively long time in an unavailable organic form. Shortage of nutrients promotes the number and diversity of species (OSBORNOVA *et al.*, 1990), and is of competitive advantage to the so-called

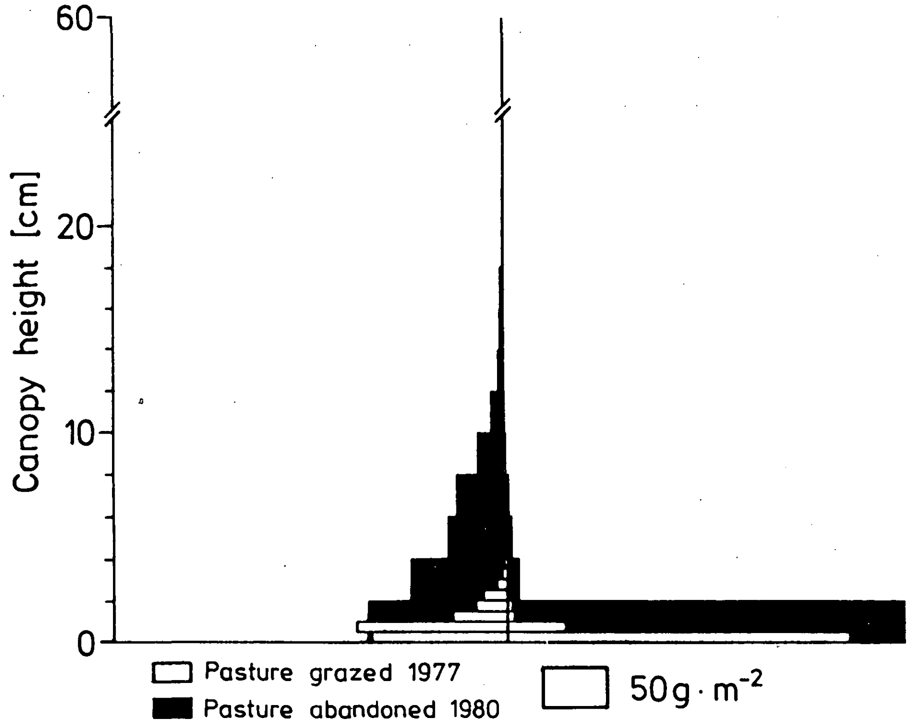



Fig. 5. Comparison of the stratification of phytomass in the grazed and the abandoned pasture drawn to scale. Dry mass (g DM $m^{-2}$) of photosynthetically active components is depicted to the left of the ordinate, while mass of photosynthetically inactive components and litter is located to the right (from TAPPEINER and CERNUSCA, 1989b). *(Comparación de la estratificación de la fitomasa en puertos pastados y abandonados, dibujada a la misma escala. La masa seca (g DM $m^{-2}$) de componentes fotosintéticamente activos se dibuja a la izquierda de la ordenada, mientras que la de los componentes inactivos y la hojarasca se sitúa a la derecha; de TAPPEINER y CERNUSCA, 1989b).*

stress-tolerant types (stress-strategy types after GRIME, 1979, modified according to CHAPIN, 1980). Under such conditions the dynamics of succession is increasingly determined by species possessing a certain degree of tolerance to scarcity of nutrients. Such species have a low rate of growth, a continuous increase in biomass, a higher and more stable shoot/root ratio, and evergreen leaves (e.g. dwarf shrubs).

### 3.2.2. Successional stages of green alder (*Alnus viridis* [Chaix.] DC.)

As depicted in chapter 4.1. the successional process below the timberline on humid, nutrient rich habitats is determined by alder and its growth dynamics (KÖRNER & HILSCHER, 1978). As in trees, shoot elongation of the alder is rapid at first, and hence they form extremely dense canopies. Detailed investigations in Gastein Valley and in the National Park Hohe Tauern revealed that 20- to 30-year-old alder stands form a very dense leaf layer in the upper third of the canopy. This layer absorbs 60% of the incoming radiation (see Fig. 6). Thus only an insignificant undergrowth of grasses, herbs, and dwarf shrub is able to develop. The conditions for the growth of spruce seedlings seem to be bad in this phase (see also CERNUSCA *et al.*, 1978). With increasing age of the alder stands the percentage of photosynthetically inactive plant-parts increases; the utilization of radiation for plant production therefore decreases and the alder stands become less dense. Fig. 6 reveals strikingly that the canopy of 45-year-old alder bushes absorbs merely 30% of incoming radiation; 18% penetrates to the soil. About 50 years after cessation of land use, more favourable conditions for the change from the "alder phase" to the "forest phase" are given, at least as far as light conditions are concerned.

Ecophysiological investigations on alder stands of different ages in the National Park Hohe Tauern provided an additional aspect for the analysis of green alder succession. Neither water balance nor carbon balance was found to be the important effect governing structural changes in stands of green alder. It is assumed, that hormonal aspects are crucial for the "alder - succession".

### 3.3. *Surface runoff on abandoned alms*

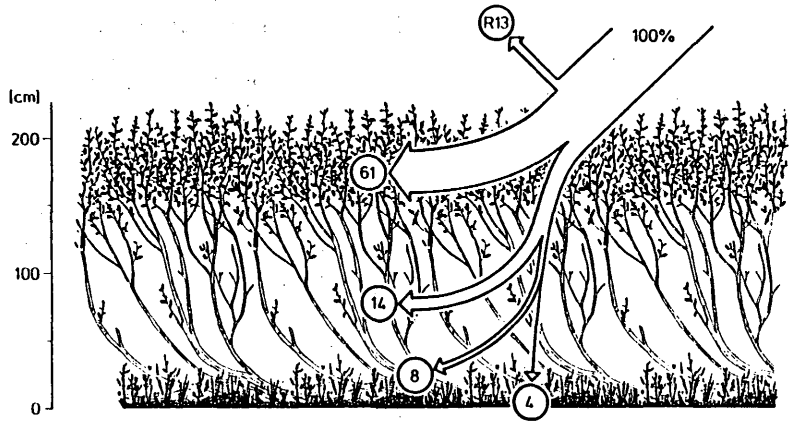
In alpine regions, due to the potential dangers of erosion and torrents, water balance is of remarkable importance (CERNUSCA, 1991a). Comprehensive investigations showed that changes in vegetation and soil are vigorous on surface runoff in alpine ecosystems (see Table 2).

TABLE 2

Vegetation types and averaged relation runoff/precipitation, (data from BUNZA 1978, 1984, 1989).

| *Vegetation type* | *averaged relation runoff/precipitation* |
|---|---|
| Dwarf shrubs | 0.10 |
| Coniferous wood | 0.15 |
| Mixed wood | 0.15 |
| Green alder stand | 0.16 |
| Tall shrubs | 0.30 |
| Meadow | 0.43 |
| Pasture | 0.52 |
| Resown area (ski run) | 0.64 |

Alnetum 30 years old




Alnetum 45 years old

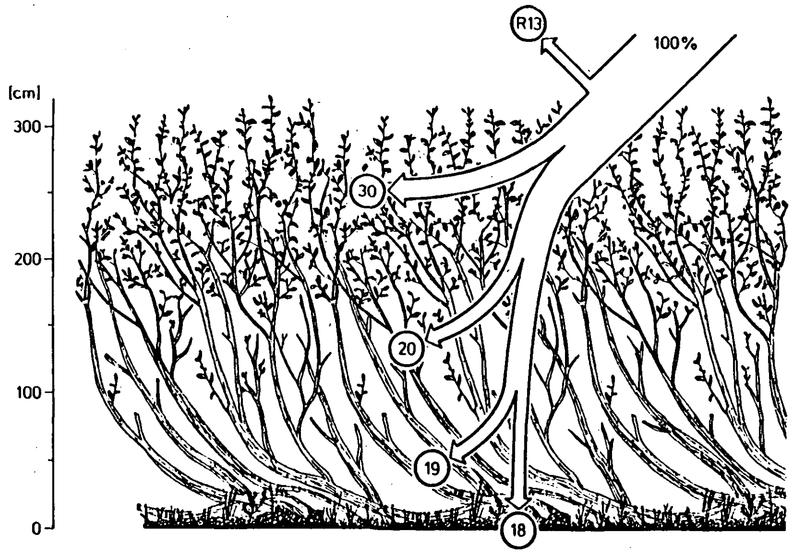



Fig. 6. Absorption of photosynthetically active radiation in individual layers in a 30 years old and a 45 years old Alnetum (*Alnus viridis* [Chaix.] DC.). 100% of incoming radiation equals about 1400 µmol.m$^{-2}$.s$^{-1}$. *(Absorción de la radiación fotosintéticamente activa en los distintos estratos de dos comunidades de Alnetum (Alnus viridis Chaix. DC.). de 30 y 45 años de edad. 100% de radiación incidente equivale a unos 1.400 µmol.m$^{-2}$.s$^{-1}$).*

In the National Park Hohe Tauern BUNZA (1978, 1984, 1989) demonstrated effects of a changed vegetation on surface runoff by means of irrigation experiments. Investigations showed that abandonment of alms and ensuing succession diminishes surface runoff and soil erosion remarkably. When alder, dwarf shrubs and young trees overgrow pastures a general stabilization of the terrain occurs. On an area that has been abandoned for 20 years and is now dominated by a dense alder stand, the total runoff amounted to only 16% of the total rainfall, whereas on an adjacent, intensively managed pasture the total runoff amounted to between 35% and 71%.

In the light of the present investigations the effect of abandonment of meadows and pastures on the danger from torrents will be demonstrated by the example of a torrent in the Gastein Valley (cf. Fig. 7). The catchment area of this torrent is 1 $km^2$. Simulated heavy rainfall was 30 mm in 15 minutes. This simulation corresponds to an event likely to occur once in 20 years. Assuming the whole alm as being grazed and thus giving a total runoff of 40% of total rainfall, the peak of discharge of the torrent would be 9.8 $m^3.s^{-1}$. Assuming the whole alm as being abandoned, and subsequently being dominated by alder, and with a total runoff of 16% of total rainfall, the peak of discharge would decrease to 3.7 $m^3.s^{-1}$.

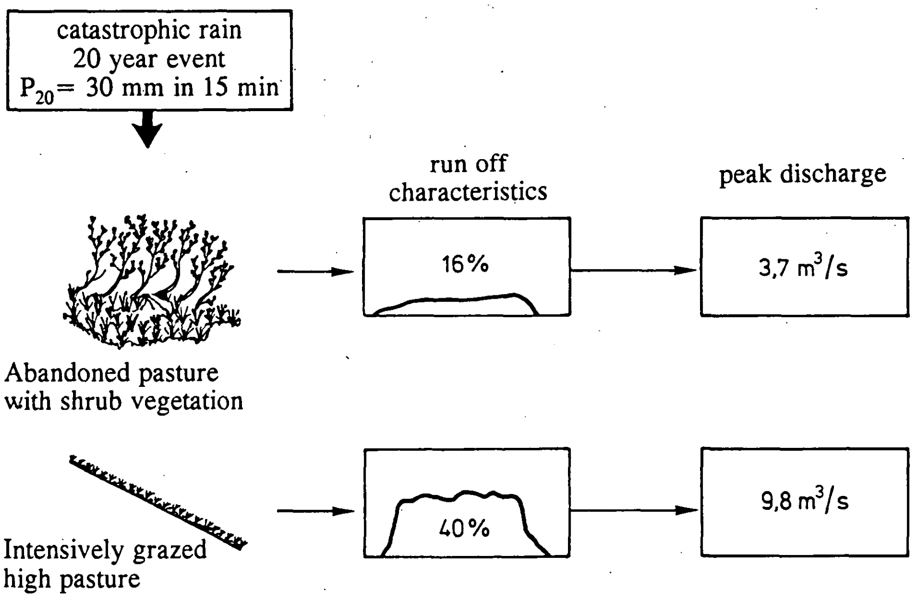



Fig. 7. Evaluation of effects of abandonment of alms on danger of torrents from a 1 $km^2$ catchment area in the mountain range Hohe Tauern. Rainstorm experiment corresponds to a catastrophic event likely to occur once in 20 years. *(Evaluación de los efectos del abandono de pastizales sobre el peligro de acarcavamiento en una cuenca de 1 km² en la cordillera del Alto Tauern. El experimento de lluvia simulada corresponde a un evento catastrófico con periodo medio de retorno de 20 años).*

Findings on the stabilization of water balance on abandoned alms in Gastein Valley and in the National Park Hohe Tauern were confirmed in their general tendency by measurements of infiltration on Mt. Bondone. A remarkable increase in the rate of infiltration could be seen from managed meadow to the abandoned alm and the beech wood (see Fig. 8).

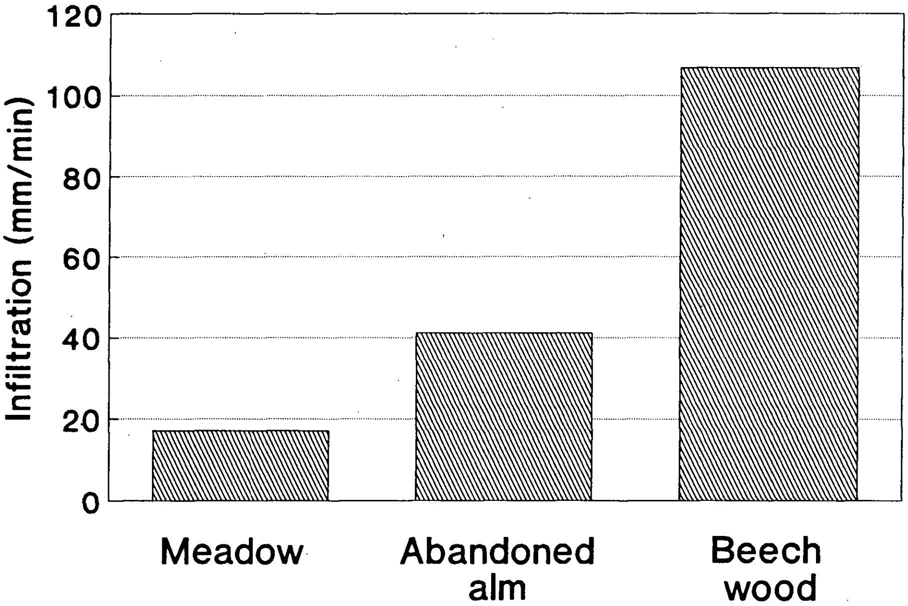



Fig. 8. Infiltration on a managed meadow, an area that has been abandoned for 30 years, and a beech wood on Mt. Bondone near Trento (I). *(Infiltración en un prado trabajado, un área abandonada desde hace 30 años y un bosque de hayas en Monte Bondone, cerca de Trento (I).*

## 4. Conclusions

From an ecological point of view alpine pastures and meadows are environments changed by man. For centuries, management maintained an artificial stability. Once grazing pressure or mowing is removed, a succession process sets in immediately. The course of succession is determined by elevation, exposure, underlying rock, and by nutrient- and water supplies. In the National Park Hohe Tauern phytosociological investigations showed in general that the course of the succession process becomes simpler and shorter with increasing altitude. Detailed ecosystem studies on two subalpine successions (1. abandoned alm Aveno-Nardetum with dwarf shrub succession and 2. abandoned Poa-Prunelletum with green alder succession) disclosed light as the crucial factor for succession after cessation of grazing.

Further, investigations on Mt. Bondone demonstrated the additional importance of available nutrients on progressive succession.

The present investigations showed that abandonment can bring about serious changes in the water regime of the landscape. On an area that has been abandoned for 20 years and is now dominated by a dense stand of green alder the total runoff amounted to only 16% of total rainfall (catastrophic event), whereas on an adjacent, intensively managed pasture, total runoff amounted to between 35% and 71%. Regarding the water regime, a general stabilization of the terrain occurs when dwarf shrubs, green alder and young trees overgrow pastures. These findings in the Austrian Central Alps are confirmed, at least in their general trend, by measurements of infiltration on Mt. Bondone.

The results presented in this paper provide us with preliminary criteria for evaluating the ecological significance of agriculture in alpine regions. Such criteria are fundamental requirements for assessing payments to farmers for continuing management. Criteria for the sum paid should be the concrete effects on the welfare of the population, such as the recreational value of the landscape, protection against landslides and avalanches, the significance of an intact alpine region as a source of drinking water, and exploitation of hydraulic power (CERNUSCA, 1991b). As an illustration: results at present available for the Hohe Tauern have revealed that management of alms can result in economic advantages for the hydraulic power industry. Water runoff is 3% higher on managed areas than on woodland. This economic advantage was calculated for a catchment area in the Austrian Alps from KÖRNER *et al.*, (1989) and amounts to the equivalent of 1200 Austrian Schillings per year and hectar.

In all regions of the Alps, payment for continued management would ensure preservation of agricultural areas according to ecological principles. A detailed mapping of sites and biotopes should be available to provide the basis upon which decisions as to the ecological advisability of management of the individual areas could be made. In addition, a documentation of the potential consequences of reduction in management for the entire alpine region is recommendable.

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