RESEARCH

Managing Mountainous Degraded Landscapes After Farmland Abandonment in the Central Spanish Pyrenees

M. MOLINILLO
CIELAT, Facultad de Ciencias
Universidad de Los Andes
5101-Mérida, Venezuela

T. LASANTA
J. M. GARCÍA-RUIZ*
Instituto Pirenaico de Ecología, CSIC
Apartado 202
50080, Zaragoza, Spain

ABSTRACT / Plant succession and pasture resources have been studied in abandoned fields of the central Spanish Pyrenees, in an environment severely affected by strong demographic pressure in the past. Several hydromorphological features (runoff and sediment yield) were also analyzed for different environments of the abandoned fields, in order to forecast the effects of their reclamation and transformation into areas for livestock use. The availability and accessibility of pastures as well as soil and water conservation is related to the process of colonization of *Genista scorpius.* Under a dense shrub cover both runoff and sediment yield are strongly controlled. As the shrub cover becomes open, sediment yield and runoff increase greatly. A dense herbaceous cover yields high runoff coefficients but moderate soil losses. From the results obtained, the possibility of abandoned field reclamation by means of selective clearing of scrub is discussed.

The seasonal imbalance between summer grazing resources and those of the rest of the year constitutes one of the most important problems for the development of extensive stock-breeding in the Pyrenees. In summer, sheep and cows use pastures located above the timberline, which reach a high productivity in a short period of time. Ferrer (1988) calculated that the summer pastures of the central Spanish Pyrenees are enough to feed 68,230 livestock units (considering a cow as one livestock unit and that 6.5 sheep equal one cow) during 120 days. The rest of the year livestock feeds from the fodder resources obtained from agricultural land (mainly cutting meadows), which (with 3% of the total surface) is able to maintain 21,899 livestock units. In the past, this imbalance was even greater, since the fields were cultivated with cereals (wheat and rye) for human consumption.

Transhumance contributed to a solution to the problem during the cold season (November–May), when livestock moved toward the steppes of the Ebro Depression. This is why the number of sheep was very high in past centuries, owing to the great possibilities for feeding large flocks in summer above the timberland and in winter in the lowlands of the Ebro Valley. However, many things have changed in the last few decades from a socioeconomic point of view (see García-Ruíz and Lasanta 1990, 1993): many people migrated to the main cities of northern Spain, and the lack of manpower made difficult the survival of big sheep flocks. Moreover, large areas of the Ebro Depression became irrigated, thus reducing the period of grazing in winter, when the fields are occupied by crops. At the same time, the cultivation of cereals on steep slopes became uneconomic and many fields were abandoned (in some cases, 80% of the historical cultivated surface), in such a manner that only the valley bottoms and perched flats—mainly glaciolacustrine deposits—remain cultivated (Lasanta 1988). Finally, cereals have been substituted by meadows in a generalized way, enlarging the limited possibilities to feed the livestock in winter. In all cases, the number of livestock units is now adjusted to the winter resources—at a community and cattle-dealer level—underconsuming the summer pastures. If, in the traditional system, the number of sheep of the communities was very well correlated to the extent of summer pastures, at present the number of sheep only correlates to the extent of the cultivated surface (García-Ruiz and Lasanta 1993).

It is obvious that the only possibility for increasing livestock numbers is to increase the supply of food in winter. Several alternatives exist: (1) to import fodder from outside the mountains, making the final product more expensive and uncompetitive; (2) to revive the

KEY WORDS: Abandoned fields; Plant succession; Degraded environments; Soil erosion; Runoff; Spanish Pyrenees

*Author to whom correspondence should be addressed.

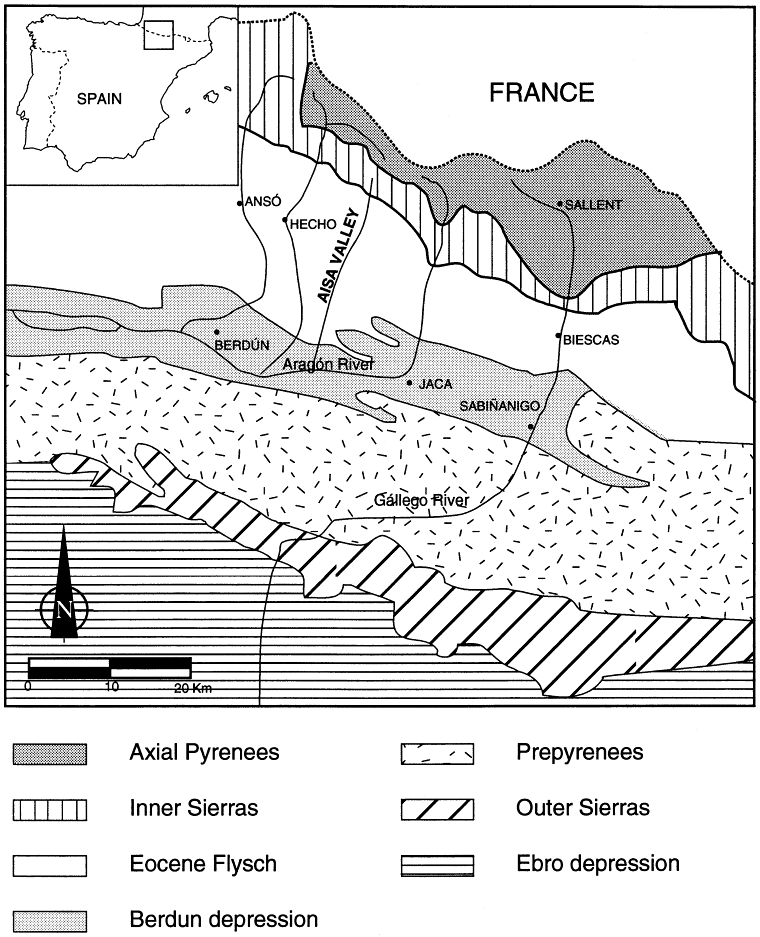

Figure 1. The study area.

transhumance system, an impossibility in the present socioeconomic conditions; and (3) to reclaim the best abandoned fields, for the development of seminatural meadows, directly grazed by the livestock during the cold season and occasionally scythed in summer. This latter alternative is supported by the large area occupied by abandoned fields, but could be counteracted by the effects of such a land-use change on runoff and sediment yield at a hillslope and basin scale.

The main purpose of this paper is to study the evolution of grazing resources in fields of different ages of abandonment, in relation to plant succession and to the different ways in which the fields are abandoned. Moreover, as one of the most important aims of land management must be to minimize soil erosion risks, information on the hydromorphological functioning of different environments in abandoned fields is also provided as a basis to predict the effects of a generalized retrieval of old fields. The results obtained constitute an information source for reclaiming mountainous lanscapes historically affected by human activities and subject to more or less intense erosion processes.

Study Area

The most detailed studies have been carried out in the Aísa Valley, central Spanish Pyrenees (Figure 1). The total area of the valley is 8154 ha, 19% of which was cultivated at the beginning of the 20th century. The surface occupied by abandoned fields covers an area of 1146 ha, 14.05% of the valley. These are generally located on sunny hillsides, with slopes between 20% and 40%, and at altitudes between 900 and 1200 m, although the highest abandoned fields are found at 1450 m asl.

The relief shows a big contrast between the upper part (the Inner Sierras) and the middle and lower part. The Inner Sierras are composed of limestone and sandstone, with a very craggy relief, narrow divides, and rough cliffs. The Aspe Peak is the highest point in the valley, reaching 2643 m. In the middle and lower part of the valley the Eocene flysch is the only sedimentary formation, resulting in a more homogeneous relief, with smooth divides (up to 2200 m) and regularized slopes. A glacial tongue coming from the cirques of the

Inner Sierras enlarged the main, U-shaped valley, and left large lateral moraines that blocked the tributaries and formed small lakes now infilled with fluviotorrential sediments and occupied by meadows (García-Ruiz and Martí-Bono 1994). Rivers can be defined until recent times by their torrentiality, with very unstable channels as a result of two groups of factors: a rocky substratum with a tendency for the triggering of mass movements, and very intense human activity with strong livestock pressure and agriculture on steep slopes, both responsible for the geomorphological reactivation of hillslopes and channels.

The climate is mountain submediterranean, with precipitation around 800–1000 mm in the valley bottom and 2000 mm at the divides (García-Ruiz and Puigdefábregas 1982). Precipitation is concentrated in spring and winter, with relatively dry summers and irregular autumns. Brown forest, loamy soils prevail, with many stones on the surface, especially in the areas affected by moderate and intense erosion, which in general coincide with the areas most disturbed by human activities (700–1400 m). Soils are poor in organic matter and nutrients and are rich in carbonates (30%–40%), with a pH between 8 and 8.5.

Pinus sylvestris woods dominate on the shady slopes, while on the sunny ones there are small patches of *Quercus gr. faginea*, the remains of massive forests, alternating with submediterranean shrubs (*Buxus sempervirens*, *Genista scorpius*, *Echinospartum horridum*, *Rosa gr. canina*, and *Juniperus communis*).

In the cultivated area only lucerne and cutting meadows can be found to feed the livestock. There are 1800 sheep and 130 cows (year 1995). The abandoned fields are occasionally grazed at the end of spring and at the beginning of autumn. A study of the past and present sources of food for livestock concludes that abandoned fields represent only 5% of the total yearly food (García-Ruiz and Lasanta 1993). In the valley there are three villages (Aísa, Esposa, and Sinués), with a total of 222 inhabitants in 1991.

Methods

Close to Aísa three hillslopes of abandoned fields were selected. The time of abandonment and the present and past land management was ascertained by means of enquiries. The point intercept method was used (Muller-Dombois and Ellenberg 1974) to quantify the density of plant cover and the degree of presence of each plant species on 40 selected fields. In each field 100 samples were made, corresponding to the contact between vegetation and 100 vertical needles distributed on 10 randomly selected transects.

In order to obtain information on runoff and sediment yield, experimental plots with different plant cover densities and erosion processes were monitored. Between 1990 and 1992, 19 closed plots were installed on slopes cultivated between 30 and 50 years ago and now abandoned. All the plots are small in size (from 2.5 to 3.5 m^2). A Gerlach trap was installed at the lower end of the plots, connected to a 62-liter container to collect the water and sediment generated by each rainfall event. After each event, the quantity of water recorded was measured in the field, and a sample was taken to obtain the sediment concentration by evaporating the water at 110°C in the laboratory (Ruiz-Flano, 1993).

The location of the plots took into account the most representative geomorphic microenvironments, previously selected by means of geomorphic transects (see Ruiz-Flano and others 1991, 1992):

- 3 plots with dense shrub cover (100 percent)—under the shrubs there is also a dense herbaceous cover, especially *Brachypodium pinnatum*
- 3 plots with 85% shrub cover and mild sheet wash erosion—small bare areas act as sediment sources
- 3 plots with 65% shrub cover and undermining of the shrub roots
- 4 plots with 40% shrub cover and severe sheet wash erosion—there are many stones on the soil surface (around 75%–80%) and evidence of splash
- 3 plots with 15% shrub cover, the soil being covered by a stone pavement—the upper soil horizons have been eroded
- 3 plots with 85%–90% meadow cover, created by clearing dense shrub cover

As for the data from vegetation, all the species were grouped into three classes to analyze the forage potential. The classification was elaborated taking into account the preferences in the diet of the cattle (Grant and others 1985, El Aich and Rittenhouse 1988, Bóo and others 1993, García-González and others 1990). In the first class (quality 1 or Q_1), grasses, sedges, and herbaceous legumes are included, constituting the group of most attractive pasture. In the third class (quality 3 or Q_3) all the rejected plants are included—those having chemical or mechanical defenses against their consumption; normally they are woody, thorny plants. Finally, the rest of the plants have been included in an intermediate group (quality 2 or Q_2), being consumed by cattle but less than those of the first group (Table 1). An offer of forage (OF) index has been used:

$$OF = (VQ_1)(VQ_2) - (VQ_3)$$

where *VQ* is the value of forage in each quality of each

Table 1. Distribution of plant species into three quality categories

Quality 1	Quality 2		Quality 3
Agrostis capillaris	*Acinos arvensis*	*Aster lynosyrys*	*Clematis vitalba*
Arrhenatherum elatius	*Achillea millefolium*	*Bellis perennis*	*Cornus sanguinea*
Avenula pratense	*Anthericum liliago*	*Carduncellus mitissimus*	*Crataegus monogyna*
Brachypodium pinnatum	*Aphyllantes monspeliensis*	*Cardundellus monspelliensium*	*Genista scorpius*
Briza media	*Blackstonia perfoliata*	*Catananche coerulea*	*Juniperus communis*
Bromus erectus	*Centaurium erythraea*	*Centaurea jacea*	*Ononis spinosa*
Bromus hordeaceus	*Cerestium arvense*	*Cirsium vulgare*	*Potentilla neumanniana*
Carex caryophyllea	*Convolvulus arvensis*	*Crepis nicaeensis*	*Prunus spinosa*
Carex flacca	*Coris monspeliensis*	*Hieracium polisella*	*Rosa* spp.
Carex muricata	*Coronilla scorpioides*	*Jasonia tuberosa*	*Sanguisorba minor*
Coronilla minima	*Galium lucidum*	*Inula conyza*	*Thymus vulgaris*
Cynosorus cristatus	*Galium verum*	*Leucanthemum vulgare*	*Viburnum lantana*
Dactylis glomerata	*Geranium columbinum*	*Picris hieracioides*	
Dorycnium pentaphyllum	*Globularia vulgaris*	*Santolina chamaecyparissus*	
Festuca rubra	*Hypericum perloratum*	*Sonchus asper*	
Hippocrepis comosa	*Linum appressum*	*Tanacetum corymbosum*	
Koeleria vallesiana	*Linum cathastium*	*Xeranthemun inapetum*	
Lolium perenne	*Linum viscosum*	*Bupleurum rigidum*	
Lotus corniculatus	*Onobrychis hispanica*	*Conopodium majus*	
Medicago lupulina	*Phyteuma orbiculare*	*Daucus carota*	
Phleum pratense	*Plantago lanceolata*	*Pimpinella saxifraga*	
Poa angustifolia	*Plantago media*	*Sedum album*	
Poa compressa	*Polygala calcarea*	*Sideritis hirsuta*	
Trifolium dubium	*Primula veris*		
Trifolium ochroleucon	*Prunella lacinata*		
Trifolium pratense	*Ranunculus bulbosus*		
Trifolium repens	*Rhinanthus mediterraneus*		
Trisetum flavescens	*Rumex crispus*		
Vicia sativa	*Scabiosa columbaria*		
	Teucrium chamaedrys		
	Thesium divaricatum		

sample category. The *VQ* value is the result of

$$VQ = (SC)(W)$$

where *SC* is the sum of all of the species of the same quality category present in the sample, and *W* is the weight or importance of each quality category of pasture according to the preferences of cattle. It is considered that the species of quality category 1 have a value of 10, and those of the quality category 2 a value of 2. As for the species of quality category 3, the value varies depending on the percentage of covering of woody species: 10 if such covering is more than 25%, 5 when they cover between 5% and 25%, and 2 when they cover less than 10%. Values of the category 3 can be higher than those of the category 2, since they have a negative sign.

Results

Farmland Abandonment and Plant Succession

When the fields are abandoned, a process of plant colonization starts. It is a complex process in which different variables interact: time, which allows plant succession and an increasing complexity in the structure of the plant community; ecological conditions (both physical and biotic factors) of each abandoned field; and human activity, including the agricultural history of the field as well as the posterior management by means of grazing, fire, and clearing.

In general, the abandoned fields of the central Pyrenees pass through the following succession stages (Figure 2): (1) invasion by herbaceous plants during the first years of abandonment, with some woody shrubs after 10–15 years, (2) spreading and generalized covering by woody shrubs between 10 and 35 years of abandonment, (3) retraction of woody shrubs and a new expansion of herbaceous plants between 35 and 60 years, and (4) entry of young trees in fields of more than 60 years of abandonment. In this last stage, normally in little disturbed areas, the field begins to look like the natural hillslopes.

Land management before farmland abandonment constitutes a control of plant succession (see also Baudry 1991). In general, land cultivated for many years has a poor seed bank, which is the most important

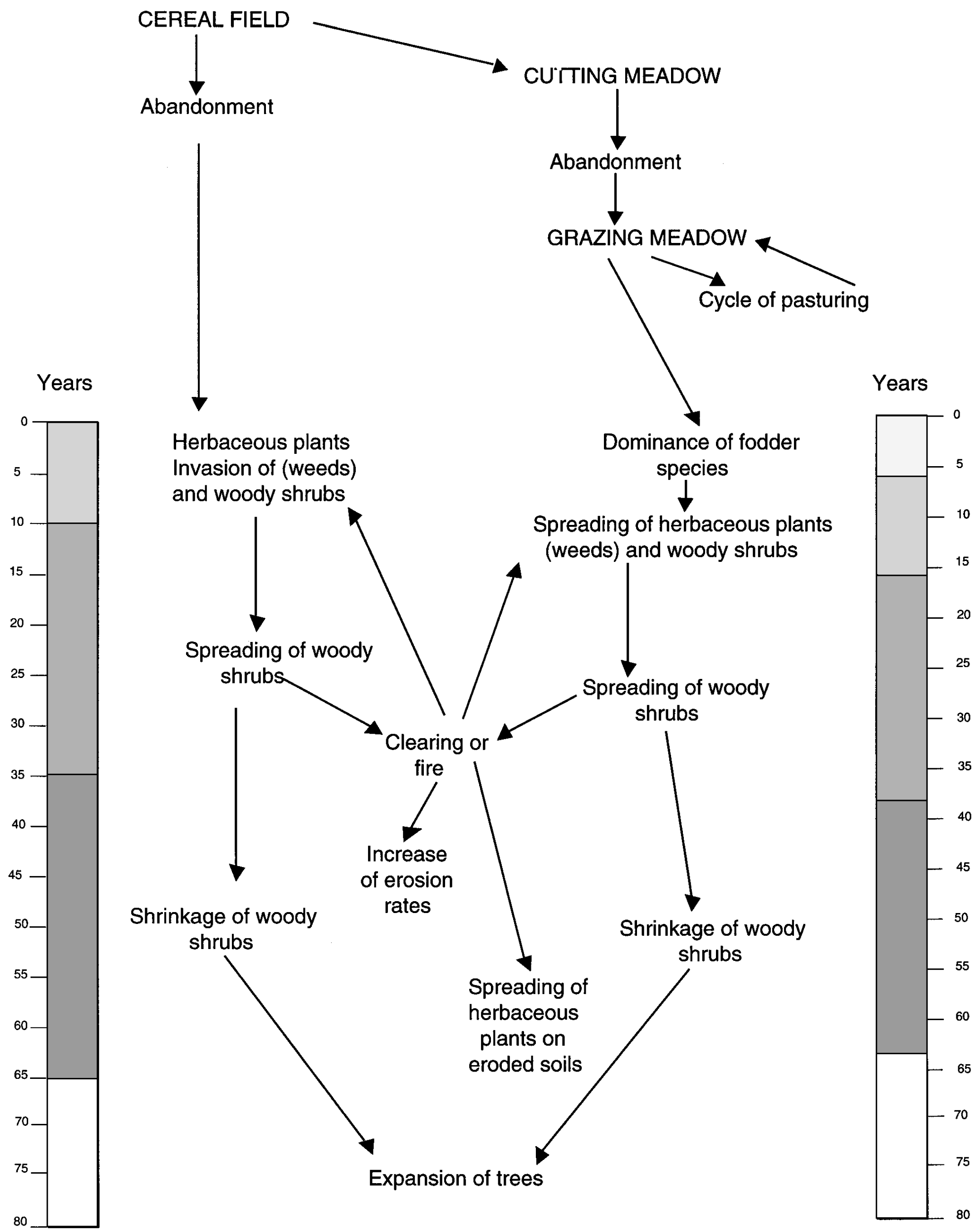

Figure 2. The evolution of abandoned fields in the Spanish Pyrenees.

problem for soil conservation after farmland abandonment (Brown 1991). Two possibilities exist: abandonment from cereal stubble and from meadows. In the first case, weeds quickly penetrate: *Leucanthemum vulgare, Hypochaeris radiata, Aster linosyris, Galium lucidum.* After 10 years some graminaceous and leguminous plants of high grazing value (*Poa compressa, Medicago lupulina, M. sativa, Carex flacca, Bromus erectus, Brachypodium pinnatum*) and some woody shrubs colonize the field. On the other hand, in the fields abandoned as meadows, a strong competition is established at the beginning between the species characteristic of the cultivation stage (i.e., *Trifolium pratense, T. repens, Poa angustifolia, Dactylis glomerata*) and other invading species (*Hypochoeris radiata, Convolvulus arvensis, Daucus carota, Plantago lanceolata, Conopodium majus,* and *Ranunculus bulbosus* are among the most representative). It is interesting to point out that the greatest differences between both types of abandonment occur during the first years, the evolution being very similar after 15 years of abandonment.

The invasion of woody species (*Genista scorpius, Rosa* *ssp.*, and *Crataegus monogyna*) starts after 10–15 years. *Genista scorpius*—the most characteristic shrub of the abandoned fields—slowly penetrates from the border of the field to the center, while *Rosa* ssp. has a random distribution since the seeds are dispersed through the excrement of birds. A very characteristic association of this stage is mainly composed of *Bromus erectus, Carex flacca, Galium lucidum,* and *Genista scorpius.*

After 35 years of abandonment, the density of woody shrubs decreases, and herbaceous plants and shrubs of the middle and final successional stages prevail, such as *Thesium divaricatum, Hippocrepis carnosa, Coronilla minima, Onobrychis hispanica, Rhynanthus mediterraneus, Thymus vulgaris, Cephalaria leucantha, Juniperus communis, Dorycnium pentaphyllum,* and *Linum apressum.* In the 60-year-old fields, some trees colonize the fields (i.e., *Pinus sylvestris* and, in the best cases, *Quercus gr. faginea*), with *Juniperus communis.*

Plant Colonization and Availability of Pastures

The different stages of plant succession represent important changes in the potential for pastures. In the fields abandoned as meadows (Figure 3A), the high quality fodder (quality 1) undergoes a decrease during the first 15 years of abandonment, due to the progressive disappearance of the typical species of the meadows, substituted by others of lower quality. Between 15 and 40 years, the maximum spreading of *Genista scorpius* occurs, impeding grazing, in spite of the presence of a high proportion of herbaceous plants under the shrub cover. After 40 years, the quality of the pastures gradually improves, since the presence of *G. scorpius* decreases.

In the fields abandoned as cereal stubble (Figure 3B), the bare soil is quickly colonized by fodder species of group 2. Plants of good fodder quality increase their contribution after 5 years, reaching much higher values as time since abandonment increases. From 10 years on, *Genista scorpius* covers most of the field, in a similar way to that seen in the fields abandoned as meadows, and then decreases after 35 years. In fact, the differences between a field abandoned as meadow and as cereal stubble mostly appear during the first 10 years after abandonment. Figure 4 shows that high levels of forage availability relate to recently abandoned fields, especially starting from meadows rather than from cereal stubble. However, some years later, the total offer of forage decreases, although quality 1 is similar in both fields. After 8 years of abandonment, the most important difference is the contribution of quality 3, which is greater in the field abandoned as cereal stubble.

Variability of Offer of Forage According to Management of Abandoned Fields

Land management after abandonment conditions the offer of forage both in quantity and in quality. Three types of disturbances are considered—fire, clearing, and intensive grazing—which modify the stages of plant succession. Traditionally, the shepherd tried to improve the accessibility and quality of the best hillslopes by means of fire and clearing, thus increasing the offer of forage (Puigdefábregas and Balcells 1970).

In Figure 5 the forage offer of 16 fields abandoned 15–20 years ago is compared according to different land management strategies. The results show that disturbance gives rise to higher levels of fodder availability, especially after total clearing. The use of fire also provides high values of forage offer, although the effects on soil erosion and sustainability must be considered in the long term (see below). In fact, the burning of the shrub cover increases the short-term accessibility of grasslands, although a few years later some woody species such as *Genista scorpius* show a strong recovery, even more than in the nonburnt fields. Partial clearing of schrubs gives values very similar to the field not affected by a heavy disturbance.

Runoff and Sediment Yield Under Different Covers and Land Uses

In order to compare soil erosion and runoff under different plant covers, small experimental plots were used. Figure 6 gives information on runoff and sediment concentration from each plot. It is important to note that these measurements are only for comparative purposes, that is, to show orders of magnitude of overland flow and erosion in different environments; in no case can they be used as absolute coefficients or rates. Obviously, the characteristics of the plots—due to size, exhaustion of sediment, modifications of the soil caused by their installation, and the interruption of natural overland flow by plot boundaries—reduce the absolute validity of the data, but the results are good indicators of the differences between the environments.

Plots with dense shrub cover record the lowest runoff coefficients, because of the effect of the vegetation, which encourages infiltration in a deep and-well structured soil, increasing rainfall interception at the same time. In fact, almost all the precipitation is utilized in the plot, with very little output of water in the form of surface runoff, but as the density of the shrub cover decreases, the quantity of runoff increases by several orders of magnitude, suggesting that once the opening of the shrub cover begins, overland flow increases more than might be expected.

The greatest runoff is from plots where the shrub

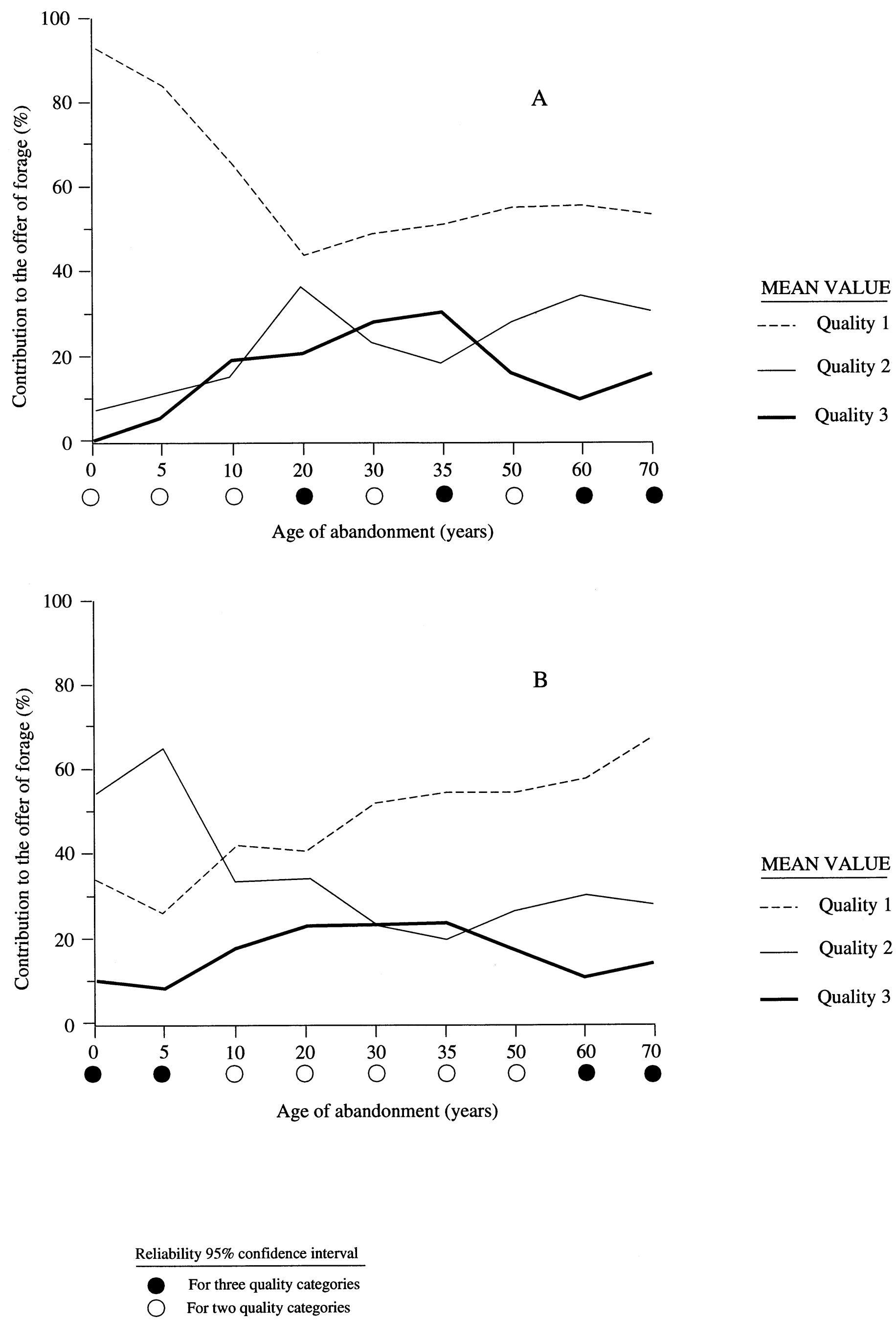

Figure 3. The evolution of the offer of forage according to the age of abandonment. **A:** Fields abandoned as meadow. **B:** Fields abandoned as cereal stubble.

cover is 40%–60%, and surprisingly, plots with the least shrub cover (15%) yield a moderate quantity of runoff—even lower than plots with 85% of shrub cover. This is probably due to the high quantity of stones on the surface (stoniness equal to 100%), which encourages infiltration, as several authors have shown (see, for example, Poesen and others 1994). Thus, a clear trend can be established between the most dense and the most open shrub cover, showing a sudden increase of runoff when the presence of bushes diminishes, up to a threshold beyond which overland flow decreases again due to the high stoniness, evidence of a previous stage of intense soil erosion.

A very interesting point is that meadows yield high quantities of surface water, with very similar measurements to those of the highest values from the open shrubland (see also Dunne and Leopold 1978).

Sediment yields can be analyzed in terms of both

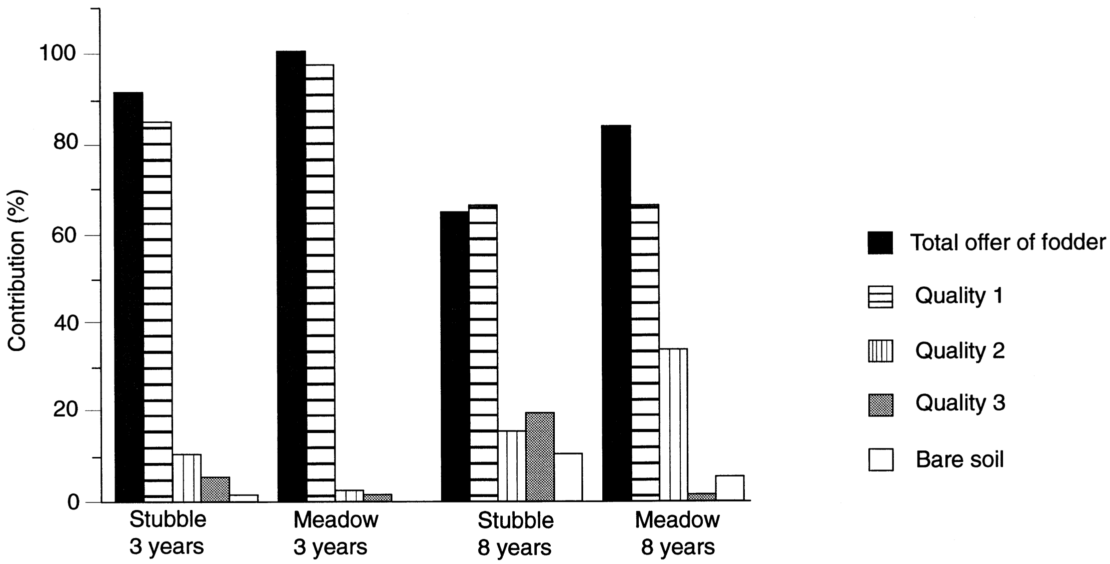

Figure 4. Comparison of the offer of forage between fields abandoned as cereal stubble and meadow.

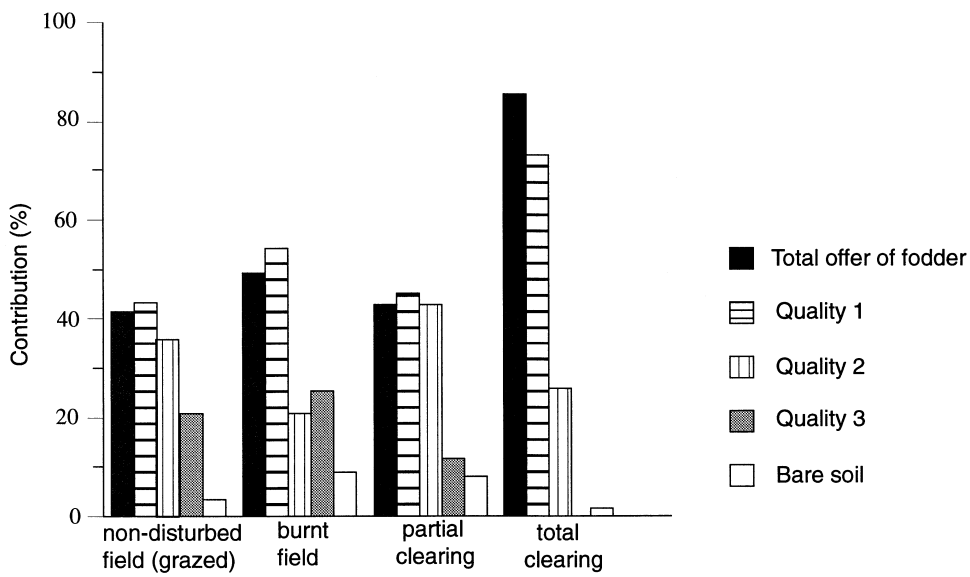

Figure 5. The offer of forage according to land management.

sediment concentration (milligrams per liter) and soil loss (milligrams per square meter^2). Both measures are very similar, although interesting trends can be distinguished. Plots with a dense shrub cover record the lowest concentration, followed by the meadows. The highest sediment concentration is recorded in the plots with 60% shrub cover. In plots with 15% shrub cover the water contains almost as much sediment as the more hydrologically active plots. From this one can conclude that stones encourage infiltration but that runoff can still mobilize sediments, probably from between and under the stones (Lekach and Shick 1982).

The soil loss data show that plots with a dense shrub cover have a moderate behavior with very small sediment output. When plant cover density is reduced from 100% to 85%, sediment yield multiplies 10-fold, demonstrating the importance of a nearly complete plant cover. As the density of plant cover decreases, soil loss increases rapidly, reaching the highest values around 40%–60% shrub cover. Meadows have a moderate soil loss, although erosion is higher than in the areas of dense shrub cover. From a hydromorphological point of view this means that meadows yield much water but it is relatively sediment free (see also Ruiz-Flano and

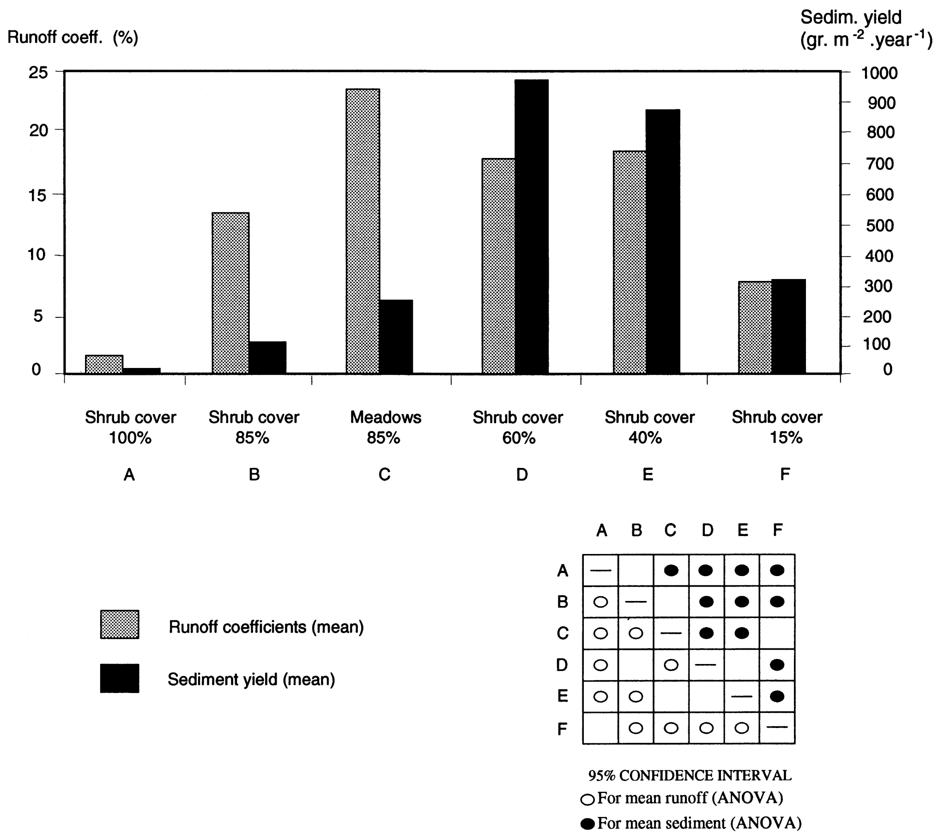

Figure 6. Runoff and sediment yield under different plant covers.

others 1992), and this is why selective clearing can be considered as a good management strategy for abandoned lands.

It is important to consider that in other experimental works (see García-Ruiz and others 1995) shifting agriculture—a frequent type of land use before farmland abandonment—yields very high values of sediments, much more than dense shrub cover and meadows. The same authors, using two plots burnt in 1991 and 1993, demonstrated that the use of fire suddenly increases suspended sediment concentration—ten times more than in shifting agriculture and 100 times greater than in dense shrub cover or meadows—but a few months later the values of suspended sediment concentrations almost equal those prevailing before fire. In fact, the recovery by *Rosa* ssp. and *Genista scorpius* was very rapid. This behavior confirms that wildfire encourages intense soil erosion during the first months after the fire and that plant recolonization quickly reduces soil erosion.

Discussion and Conclusions

During the period of maximum demographic pressure, the central Spanish Pyrenees were very active from a geomorphological point of view (García-Ruiz and others 1996a). In fact, many fields, especially on the sunny slopes, show a very high stoniness on the soil surface, proof of intense erosion processes carrying away fine particles. Some results obtained from experimental plots show that shifting agriculture and the alternation of cereal crops and fallow land yielded much sediment, being to a large extent the cause of lanscape degradation (García-Ruiz and others 1995). At present, farming activity has been abandoned and the geomorphic activity seems to be more restricted as a consequence of plant colonization after farmland abandonment.

Plant succession in abandoned fields shows a great variability (Keever 1983, Collins and Adams 1983) owing to the land management before and after the abandonment and to the effects of topography in mountain areas. The evolution of these abandoned fields has very important consequences on the availability of pastures during the cold season. It is important to take into account that in the Pyrenees a dramatic imbalance exists between summer and winter food resources for cattle, and this is why the old cultivated areas are normally grazed.

In the central Spanish Pyrenees there are two possibilities of farmland abandonment, according to the land use immediately before the desertion: from cereal stubble and from meadows. Plant succession follows different patterns during the first 15 or 20 years, but the species colonizing the fields very soon became almost the same, passing through a stage of more open shrub cover and herbaceous species. The results described in this paper demonstrate that the quality and quantity of the fodder offer is at its highest values at the beginning of the colonization process, but it suddenly decreases during the stage of dense shrub cover, when, in spite of the presence of dense grasses under the bushes, the fields are not accessible for cattle due to the mechanical defenses (thorns) of the plants. For livestock this is an important problem since this means that a large surface in each valley is underused for at least 20 or 25 years, that is, the time of prevalence of a dense cover of woody species. Owens and others (1991) also point out that the abundance of woody species is negatively related to an efficient use of pastures.

The natural plant succession and forage availability can be disturbed by means of fire and clearing. Both strategies break the trend towards a dense shrub cover and start a new process of colonization, increasing—at least for some years—the fodder offer. However, it is interesting to note that after a fire the field remains free of thorny shrubs for very few years, since the germination of *Genista scorpius* seeds is encouraged by the passage of fire. Another factor of disturbance is the livestock itself: if sheep and cows graze the fields after the abandonment, the stage of dense shrub cover can be delayed several decades more or may even not occur; this is the same for fields cleared and grazed with appropriate stocking rates (Gibson and others 1987), encouraging the development of a dense herbaceous cover, which hinders the growth of woody species and delays plant succession (Grime 1987).

On the other hand, farmland abandonment has quite positive effects for runoff control and soil conservation. The evolution toward a dense shrub cover means a reduction of overland flow and sediment yield, above all in comparison with the hydrological functioning of cereals cultivated on steep slopes. All the available information confirms that during the traditional agricultural system—until the middle of the 20th century—the hillslopes were affected by an intense geomorphic activity and the rivers showed the consequences of intense and frequent floods (García-Ruiz and others 1995). Most of these processes under 1600 m asl were related to human activities (cultivation of around 30% of the territory on steep slopes, overgrazing, forest wasting), as González and others (1995) demonstrated using GIS procedures and geomorphological mapping. In the last few decades, farmland abandonment and afforestation partially reduced the access of sediment to the channels.

If this evolution can be considered as positive, it has also a negative counterpart: it reduces the availability and accessibility of grasses to feed livestock, thus increasing the imbalance between summer and winter resources. The use of fire is not a good solution since it improves the quality of pastures for only a few years, increasing sediment yield during the first months after the fire. Clearing of some fields located in the best topographic conditions (concavities, lower part of the hillslopes, perched flats) seems to be a better management strategy: it very much improves the availability of forage for decades, increases biodiversity (White 1979, Armesto and Pickett 1985), and decreases the risk of natural, extensive wildfires, and the hydromorphological functioning does not show a dramatic increase in sediment concentration. Nevertheless, it is difficult to evaluate the effects of the foreseen increase in overland flow, probably affecting to some extent the stability of the fluvial channels (García-Ruiz and others 1996b). In other studies where grazing encourages the maintenance of a dense herbaceous cover, increases of good quality water at a basin scale have been recorded (Hanson and others 1970, Lusby 1970). McIvor and others (1995) demonstrated that a dense cover of pastures gives good protection to the soil, pointing out that when cover exceeds a critical level—estimated at 30%–40% in pastures—runoff and soil loss are minimal. Below this critical level both increase rapidly as cover decreases. The results obtained from experimental plots suggest that a combination of patches of dense shrub cover—especially where soil is thin or where there is more erosion risk—and grazing meadows is the best method for soil conservation and for optimizing forage production, thus increasing the availability of food for livestock in winter, as well as biodiversity (West 1993) and the aesthetic quality of the landscape. This is a compromise between the evolution of abandoned fields toward more and more dense and complex plant cover, on one hand, and a reincorporation of the abandoned fields into the productive system of the local population, on the other hand.

Acknowledgments

This paper was written with the financial support of the project ‘‘Erosión del suelo tras el abandono de explotaciones agrícolas en montaña media: interacciones con las estrategias de colonización vegetal, los usos del suelo y la disponibilidad de nutrientes'' (AMB 93-0806) and ''Sediment yield and runoff as a consequence of land-use changes in mountain areas'' (AMB96-0401), both funded by the CICYT. One of the authors also had a grant from the Spanish Agency of International Cooperation. The authors gratefully acknowledge the critical comments and the revision of the English manuscript by Dr. Sue White and the field support from Jenninfer Rivas.

Literature Cited

Armesto, D. J., and S. T. A. Pickett. 1985. Experiments on disturbance in old field plant communities: impact on species richness and abundance. *Ecology* 66:230–240.

Baudry, J. 1991. Ecological consequences of grazing extensification and land abandonment: Role of interactions between environment, society and techniques. *Options Méditerranéennes,* 15:13–19.

Bóo, R. M., L. I. Lindstrom, O. R. Elía, and M. D. Mayor. 1993. Botanical composition and seasonal trends of cattle diets in Central Argentina. *Journal of Range Management* 46:479–482.

Brown, V. K. 1991. Early successional changes after land abandonment: the need for research. *Options Méditerranéennes,* 15:97–101.

Collins, S. L., and D. E. Adams. 1983. Succesion in grassland: Thirty-two years of change in central Oklahoma. *Vegetatio* 35:165–175.

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. Freeman and Co., San Francisco, 818 pp.

El Aich, A., and L. R. Rittenhouse. 1988. Herding and forage ingestion by sheep. *Applied Animal Behaviour Science* 19:279–290.

Ferrer, C. 1988. Los recursos pascícolas en el Pirineo aragonés. XVIII Reunión Científica de la S.E.E.P. pp. 23–65.

García-González, R., R. Hidalgo, and C. Montserrat. 1990. Patterns of livestock use in time and space in the ranges of the western Pyrenees: A case study in the Aragon Valley. *Mountain Research and Development* 10:241–255.

García-Ruiz, J. M., and T. Lasanta. 1990. Land-use changes in the Spanish Pyrenees. *Mountain Research and Development* 10(3):267–279.

García-Ruiz, J. M., and T. Lasanta. 1993. Land-use conflicts as a result of land-use changes in the central Spanish Pyrenees. A review. *Mountain Research and Development* 13(3):213–223.

García-Ruiz, J. M. and C. Martí-Bono. 1994. Rasgos fundamentales del glaciarismo cuaternario en el Pirineo aragonés. Pages 17–32 *in* C. Martí-Bono and J. M. García-Ruiz (eds.), El glaciarismo surpirenaico: Nuevas aportaciones. Geoforma Ediciones, Logrono.

García-Ruiz, J. M., and J. Puigdefábregas. 1982. Formas de erosión en el flysch eoceno surpirenaico. *Cuadernos de Investigación Geográfica* 8:85–128.

García-Ruiz, J. M., T. Lasanta, L. Ortigosa, P. Ruiz-Flano, C. Martí, and C. González. 1995. Sediment yield under different land uses in the Spanish Pyrenees. *Mountain Research and Development* 15(3):229–240.

García-Ruiz, J. M., T. Lasanta, P. Ruiz-Flano, L. Ortigosa, S. White, C. González, and C. Martí. 1996. Land-use changes and sustainable development in mountain areas: A case study in the Spanish Pyrenees. *Landscape Ecology* 11(5):267–277.

García-Ruiz, J. M., S. White, A. Gómez-Villar, R. Martínez-Castroviejo, C. González, and L. Ortigosa, 1996b. Channel adjustments as a result of land-use changes in small basins of the Central Pyrenees. *Zeitschriftfuer Geomorphologie* (submitted)

Gibson, C. W. D., H. C. Dawkins, V. K. Brown, and M. Jepsen. 1987. Spring grazing by sheep: Effects on seasonal changes during early old field succession. *Vegetatio* 70:33–43.

González, C., L. Ortigosa, C. Martí, and J. M. García-Ruiz. 1995. Use of a geographical information system to study the spatial organization of geomorphic processes in mountain areas. *Mountain Research and Development* 15(3):241–249.

Grant, S. A., D. E. Suckling, H. K. Smith, L. Torvell, T. Forbes, and J. Hodgson. 1985. Comparative studies of diet selection by sheep and cattle: The hill grasslands. *Journal of Ecology* 73:987–1004.

Grime, J. P. 1987. Dominant and subordinate components of plant communities: Stability and diversity. Pages 413–427 *in* A. Gray, M. J. Crawley, and P. J. Edwards (eds.), Colonization, succession and stability. Blackwell, London.

Hanson, C. R., A. R. Kuhlman, C. J. Erikson, and J. K. Lewis. 1970. Grazing effects on runoff and vegetation in the western south Dakota rangeland. *Journal of Range Management* 23:418–420.

Keever, C. 1983. A retrospective view of old field succession after 35 years. *American Midland Naturalist* 110:397–495.

Lasanta, T. 1988. The process of desertion of cultivated areas in the central Spanish Pyrenees. *Pirineos* 132:15–36.

Lekach, J., and A. P. Shick. 1982. Suspended sediment in desert floods in small catchments. *Israel Journal of Earth Sciences* 31:144–156.

Lusby, G. C. 1970. Hydrologic and biotic effects of grazing vs. non grazing near Grand Junction, Colorado. *Journal of Range Management* 23:256–260.

McIvor, J. C., J. Williams, and C. J. Gardener. 1995. Pasture management influences runoff and soil movement in the semi-arid tropics. *Australian Journal of Experimental Agriculture* 35:55–65.

Muller-Dombois, D., and H. Ellenberg. 1974. Aims and method of vegetation ecology. John Wiley & Sons, New York.

Owens, M. K., K. L. Launchbaugh, and J. H. Holloway. 1991. Pasture characteristics affecting spatial distribution of utilization by cattle in mixed brush communities. *Journal of Range Management* 44:118–123.

Poesen, J. W., D. Torri, and K. Bunte. 1994. Effects of rock fragments on soil erosion by water at different spatial scales: A review. *Catena* 23(1–2):141–166.

Puigdefábregas, J., and Balcells, E. 1970. Relaciones entre la organización social y la explotación del territorio en el valle del Roncal. *Pirineos* 98:53–89.

Ruiz-Flano, P. 1993. Procesos de erosión en campos abandonados del Pirineo. Geoforma Ediciones, Logrono, 191 pp.

Ruiz-Flano, P., T. Lasanta, J. M. García-Ruiz, and L. Ortigosa. 1991. The diversity of sediment yield from abandoned fields of the central Spanish Pyrenees. *IAHS Publ.* 203:103–110.

Ruiz-Flano, P., J. M. García-Ruiz, and L. Ortigosa. 1992. Geomorphological evolution of aandoned fields. A case study in the central Pyrenees. *Catena* 19(3–4):301–308.

West, N. E. 1993. Biodiversity of rangelands. *Journal of Range Management* 46:2–13.

White, P. S. 1979. Pattern, process, and natural disturbance in vegetation. *Botanical Review* 45:229–299.