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A Case Study in the Camero Viejo (Northwestern Iberian System, Spain)

Since the 1950s, the Spanish Mediterranean mountains have become a marginal territory, with few inhabitants and limited economic activity. As a consequence, significant land use changes (farmland abandonment, development of extensive cattle rearing, and reforestation) have taken place, resulting in landscape degradation and new hydromorphological processes. In this article, the process and impact of farmland abandonment in the Camero Viejo (northwestern Iberian System) are described. The authors also studied the geomorphological evolution of terraced fields after cultivation was given up. Runoff rates and sediment yield in abandoned and grazed terraces were measured using a rainfall simulator. Results show that the speed and intensity of the hydrological and erosional response increased if plots were grazed intensively. The study demonstrates that new land management systems in the Camero Viejo, in particular extensive cattle grazing, have generated additional source areas of sediments.

Keywords: *Land use change; landscape change; erosion; terraces; Mediterranean mountains; Iberian System; Spain.*

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Introduction

For centuries, the Mediterranean mountains provided a variety of resources for a relatively high number of inhabitants, whose livelihoods were secured by a dynamic economy (livestock rearing, textile industry, forestry, and diversified agriculture) (Lasanta 1990; MacNeill 1992). However, as of the 1960s, the economic significance of these regions diminished drastically due to their limited possibilities of reacting to market demands and the lack of population. Moreover, environmental conditions in these mountain areas make them unsuitable for new economic activities. Snow does not accumulate enough to enable the development of winter tourism (ski resorts). The landscape, marred by reduced forest cover and extended erosion processes, is not attractive for summer tourism. The Mediterranean mountains have become marginal territories with few inhabitants; cultivation has been almost completely abandoned and livestock numbers have decreased. This evolution has resulted in radical modification of the landscape (García-Ruiz and Lasanta 1993; Douglas et al 1994).

Such processes were monitored by the authors in the Camero Viejo, a massif in the northwestern part of the Iberian System (La Rioja, Spain). Important land management changes due to depopulation and the influence of nearby cities were assessed. This assessment showed that agricultural areas in this mountainous region have been abandoned and recolonized by scrub. Some abandoned fields and hillslopes have been either reforested or are being used for extensive cattle grazing. In short, the physical environment and social conditions in the area have been profoundly modified, reflecting a widespread development throughout the mountain regions in Spain and other Mediterranean countries (Rodriguez-Aizpeolea and Lasanta 1992).

This paper presents information on the type of erosion caused by recent land use changes in the Camero Viejo. The case study shows how the environmental situation in the Spanish Mediterranean mountains has evolved in recent decades. Particular attention was given to erosion processes on abandoned terraces in order to gain some insight into the future development of this form of agricultural landscape.

The study area

The study site, known as the Camero Viejo, includes the high valleys of the Leza and the Jubera, both of which are tributaries of the River Ebro. It covers 392 km^2 and is located in the province of La Rioja (Figure 1). The Camero Viejo is a region classified as mountainous with a moderate elevation, with altitudes ranging between 600 and 1700 m. The dominant lithological types are quartz sandstones, sandstones, and limestones of the Lower Cretaceous (Weald facies). The relief is characterized by very gentle summits, moderately steep slopes, and narrow valley bottoms.

According to García-Ruiz and Martín-Ranz (1992), the climate type is Mediterranean with mountain influences. The annual mean temperature is 10 to 11°C and average precipitation per year ranges between 600 and 800 mm. The highest precipitation values are recorded mainly in spring and autumn. The summer is a very dry season.

Abandoned fields and submediterranean scrub prevail in the study area. On calcareous soils, *Genista scorpius, Thymus vulgaris, Rosmarinus officinalis,* and *Buxus sempervirens* are the most abundant scrub species, while on siliceous soils, *Cistus laurifolius* is most common. Remnants of the original forest exist only in remote places with limited access: small stands of *Fagus sylvatica* and *Quercus pyrenaica* cover the steepest and most inaccessible slopes, particularly on shady sites.

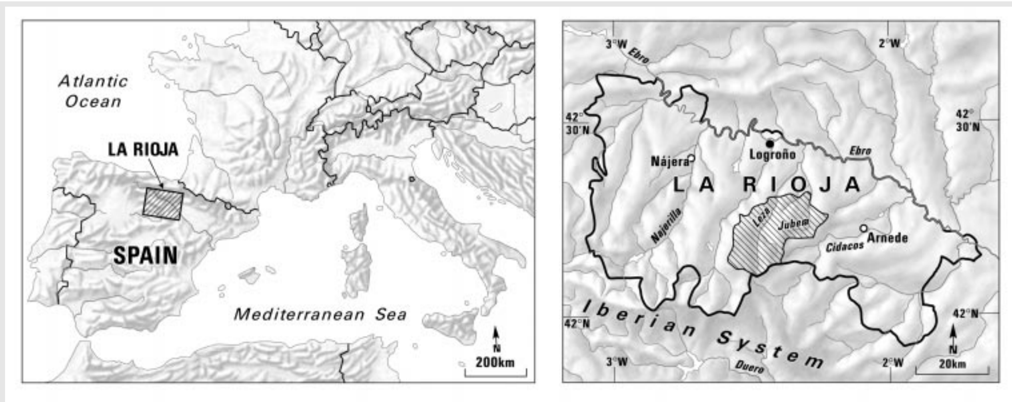


FIGURE 1 Location of the study area. (Maps by Andreas Brodbeck)

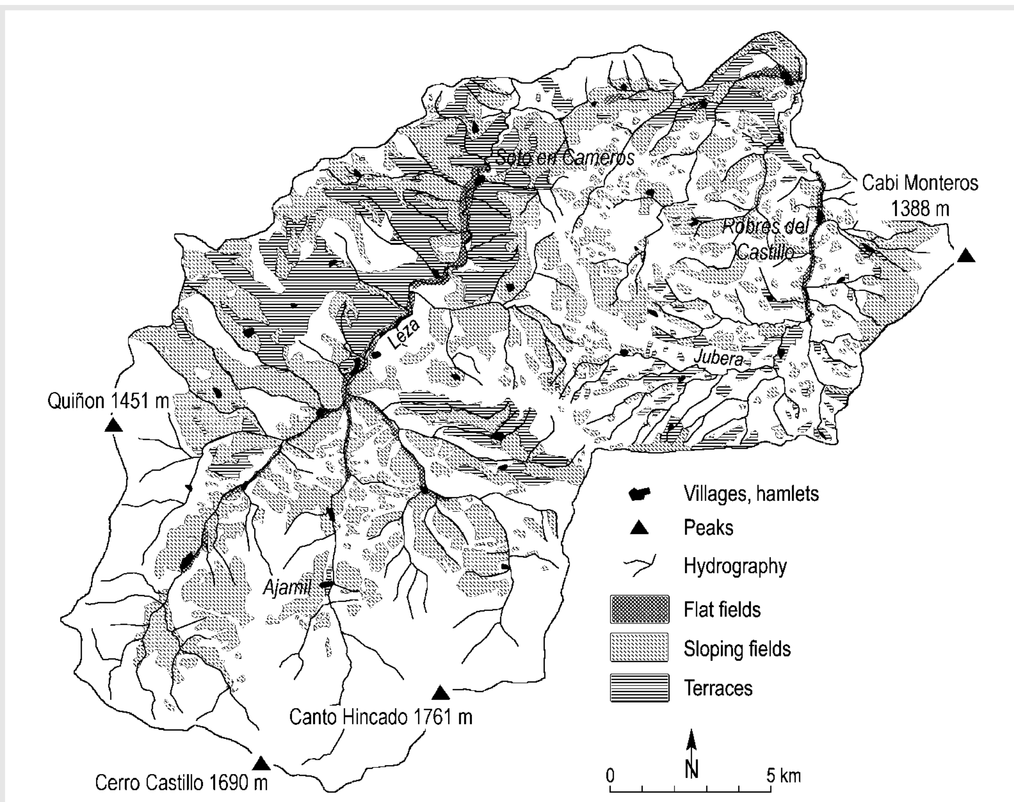


FIGURE 2 Historical farmland and types of fields in the high valleys of the Leza and Jubera (Camero Viejo). The map was drawn on the basis of aerial photographs (1956 and 1977) and was adapted by means of a GIS.

Methods

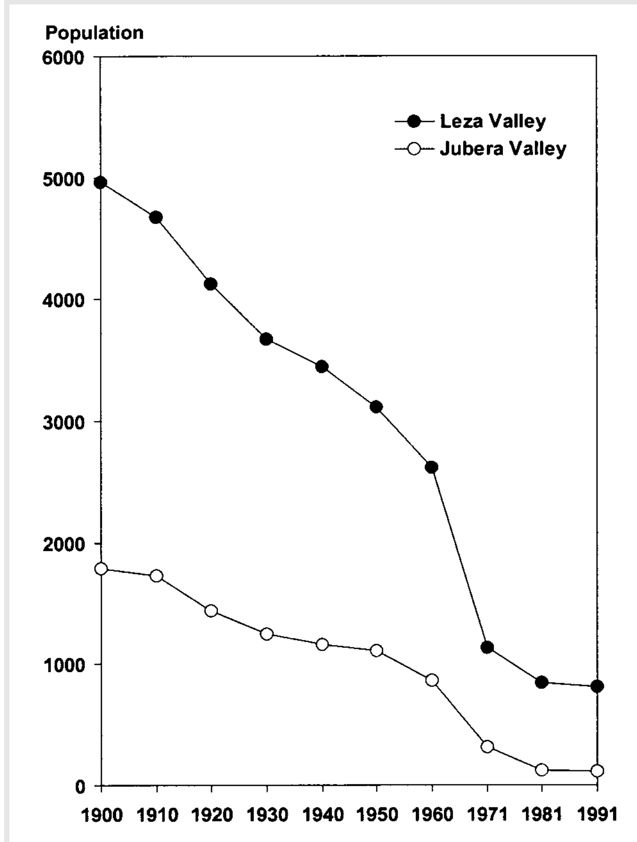
Several methods were used to obtain information on recent land use changes and resulting erosion processes. Aerial photographs taken in 1956, 1977, and 1991 were used to draw land use maps in order to determine how the landscape evolved during these 35 years. Three types of abandoned fields (terraces, sloping fields, and flat fields) and forest areas were given particular attention in this mapping process. The data were digitalized by means of a Geographical Information System (GIS). It was thus possible to reconstruct the process of farmland abandonment and reforestation in a relatively comprehensive manner.

A total of 86 terraced fields with various topographical and geoecological features (different altitudes, lithological types, soils, aspects, slope angles, and slope shapes) were selected for a detailed study. Topographical, botanical, and geomorphological data were collected from each field. Two types of erosion process were studied: slides, resulting in collapsed terrace walls and massive soil movement, and sheet wash erosion.

The length, width, and depth of each slide were measured. Outfall volume was calculated as a function of these factors (Haigh 1984). The data were correlated with different topographical variables (slope gradient and aspect) and the terrace features (plot length, plot width, terrace wall height, and terrace wall length).

Runoff and erosion due to low frequency/high magnitude events were studied with the help of rainfall simulation tests. The authors conducted 26 experiments on abandoned terraces with different types of vegetation cover and degrees of grazing intensity. The median rainfall intensity used in our experiments was 75 mm/h (standard deviation 14.8). In each experiment, rainfall was simulated for a period of 45 minutes on a plot of 1385 cm^2 surrounded by an iron ring that allowed overland flow to escape. The rainfall simulator is described in Cerdà (1999) and Lasanta et al (2000). During the experiment, the following parameters were recorded: time until runoff begins (in seconds), runoff (in mm/h), runoff coefficient (in percentage), wetting front (the depth to which the water has penetrated the soil by the end of the test, in cm), mean sediment concentration (in g/L), and erosion rate (in $g/m^2/h$).

FIGURE 3 Demographic trends in the Camero Viejo (1900–1991).



Results

Past and present land use systems

The traditional form of land use in the Iberian System until the end of the 19th century involved exploitation of all available resources. Additionally, pastoral resources outside the region were exploited through transhumance. In the 17th century, La Rioja had more than 400,000 sheep. Most of the livestock fed on the pastures of the Iberian System in summer. In October, sheep herds were slowly driven to the south and southwest of Spain to feed on the *dehesas* (open evergreen woodlands with silvopastoral land use) of the Extremadura and La Mancha. In May, the sheep returned to the Iberian System following the same route.

Historical documents and pollen analysis (Moreno Fernández 1994; Gil et al 1996) show that a great deal of land was plowed to feed the growing population as of the 18th century. The first aerial photographs (1956) and the GIS data used in this study indicate that an estimated 15,964 ha (ie, 41% of the study area; see Figure 2) were cultivated in the Camero Viejo until the 1950s. The farmed area was probably larger at the peak of the region's demographic development around the middle of the 19th century.

Depending on the inclination of their fields, farmers in the Camero Viejo used different cultivation methods. In 1956, flat fields represented only 3% of the total farmed area (Figure 2). They were well fertilized and irrigated. On slopes near villages, terraces were built to preserve the soil, support the infiltration of water, and increase yields. Terraces represented 28% of the total cultivated area (4412 ha). The rest of the farmed area (69%) consisted of sloping fields. Some of these fields were worked permanently (one year with cereals, the next in fallow) while others were cultivated sporadically (in times of great population growth), with long fallow periods.

The traditional land management system went into decline toward the end of the 19th century, when the population started to emigrate to those areas in Spain where industrialization was in full swing. However, for several decades, the features of the landscape hardly changed. A high percentage of the fields continued to be worked and livestock (sheep) numbers were still large. The system collapsed completely in the 1950s and 1960s. New land use types emerged and had major geoecological impacts.

Figure 3 shows the demographic trends in the two valleys in the study area. The 6754 inhabitants registered in 1900 represented a population density of 17

FIGURE 4 Erosion and spread of scrub on high terraces abandoned since the 1940s or 1950s. The 20–25° slope is concave. The terraces are located at a considerable distance from the village of Terroba, Leza Valley. (Photo by L. Ortigosa)

FIGURE 5 Collapse of a terrace wall at the foot of a hill near a village resulting from hydrological pressure higher up (Soto en Cameros, Leza Valley). Fields in this gently sloping area were only abandoned within the last 10 years. (Photo by L. Ortigosa)

inhabitants/km^2. In 1995, the population decreased to 927 inhabitants (2.3 inhabitants/km^2), which constitutes a loss of 86.2%.

Previously cultivated land was definitively abandoned and started being recolonized by scrub (Figure 4). Some abandoned fields and hillslopes were afforested with *Pinus sylvestris* for the control of hydrologic and geomorphic processes. By 1995, only 99 ha were still being farmed in the study area; abandoned fields thus represented 99.4% of the agricultural area and 40.4% of the entire study area. The number of sheep fell dramatically. In 1995, only 3307 sheep were counted in the Camero Viejo (official census of La Rioja Government).

TABLE 1 Soil masses moved by landslides on terraced land (in m^3 detached per 100 m of terrace wall) depending on the kind of hillslope and the position of the terrace.

	Position of terrace on hillslope			
Curvature of hillslope	High	Middle	Low	Mean (in m^3)
Concave	33.93	34.56	72.80	47.09
Convex	18.97	36.65	6.20	20.60
Straight	18.66	23.79	21.97	21.47

A further land use change has taken place: cattle have replaced sheep because they can be grazed extensively, making the presence of shepherds almost unnecessary. Cattle tend to graze mainly in abandoned fields closer to the villages that are not invaded by scrub; they hardly ever venture on fields located far from the villages or on steep slopes. This new farming system is thus extensive in terms of manpower but intensive in terms of stress on the land.

Erosion on sloping fields and abandoned terraces

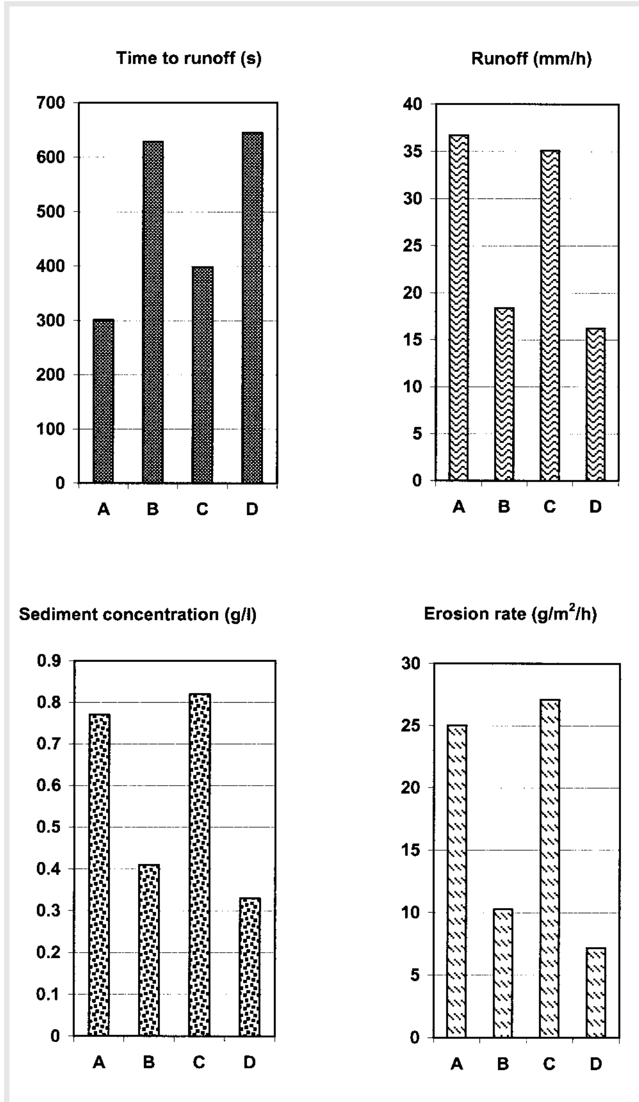
Abandonment of cultivation and soil conservation practices as well as introduction of extensive cattle grazing have led to many cases of erosion.

Sheet wash erosion prevails on sloping fields. The presence or absence of this erosion process depends not only on the physical state of each field but also on how long ago cultivation was abandoned and how the field has been used since then. Immediately after cultivation was abandoned, mild or severe sheet wash erosion usually appeared. Wherever natural vegetation (especially shrubs) took over and eventually covered the field, erosion stopped. Stability was only disturbed when the shrub cover was repeatedly burned. In the latter case, erosion processes resulted in microenvironments of stone pavements.

The most important erosion process observed on terraced fields was the collapse of terrace walls as a consequence of massive soil movement (small landslides; see Figure 5). Landslides generate an arcuate surface failure and leave the small scarp of the terrace unprotected and susceptible to erosion. On average, each slide was found to move 3.31 m^3 of soil and terrace wall. The volume of soil moved was calculated to be 38.80 m^3/100 m of wall.

Correlations between the landslides and various features of the plots were calculated in order to establish the factors that contribute to landslides. The results showed no clear connection between the events and the plot features. There was a significant and positive correlation between the volume of the landslides and the height of the terrace wall ($r = 0.659$, significant to 0.001) and between the volume of the landslides and the slope gradient ($r = 0.237$, significant to 0.1). It is easy to explain these results: a steeply inclined slope forced the farmer to build higher terrace walls, thus increasing the volume of accumulated soil and its tendency to slide down the slope. However, the most influential factor in this erosion process seems to be the slope's hydrological function. The highest landslide rate (72.8 m^3/100 m of terrace wall) was observed on concave slopes, particularly on the lower part of hillslopes (Table 1). Terraces located in these areas receive water from the upper part of the hillslopes. Moreover, their deep and loam-sandy soils retain more moisture. The more a soil's weight increases due to its absorption of water, the greater the likelihood is that a landslide will be triggered (Arnáez et al 1992).

FIGURE 6 Runoff and erosion on abandoned terraces. A, talus at the foot of terrace walls; B, level soil (cultivated field); C, heavily grazed terraces; D, lightly grazed terraces.



Sheet wash erosion was also found on terraced fields. Figure 6, Table 2, and Table 3 show hydrological and sedimentological results of rainfall simulation tests. These results differed depending on what section of a

TABLE 2 Hydrological and erosional response in different sectors (see also Figure 6).

	Talus at the foot of terrace wall	Level soil	Anova (*P*)
Time to runoff (seconds)	301	629	0.278
Runoff (mm/h)	36.7	18.5	0.043
Runoff coefficient (%)	49.7	17.7	0.003
Wetting front (cm)	12.7	19.1	0.254
Sediment concentration (g/L)	0.77	0.41	0.078
Erosion rate (g/m^2/h)	25.0	10.2	0.030

TABLE 3 Hydrological and erosional response on abandoned terraces with different grazing intensity (see also Figure 6).

	Heavily grazed	Lightly grazed	Anova (*P*)
Time to runoff (seconds)	398	645	0.314
Runoff (mm/h)	35.1	16.2	0.008
Runoff coefficient (%)	41.4	15.7	0.003
Wetting front (cm)	9.8	21.1	0.008
Sediment concentration (g/L)	0.82	0.33	0.002
Erosion rate (g/m^2/h)	27.1	7.1	0.000

terrace (Figure 7) was affected and how the field was used. The talus at the foot of a terrace wall (accumulation of material that has been eroded from fields above) produced high runoff coefficient values (49.7%) and had low wetting front values (12.7 cm as an average). These areas were very prone to erosion: the erosion rate obtained by means of the rainfall simulation test was 25 g/m^2/h. This hydromorphological behavior was caused by the talus gradient and the scarce plant cover in this section of terraces. Where the soil was level on a terrace, erosion rates were more moderate (Table 2).

Cattle grazing plays a significant role in accelerating erosion on recently abandoned terraces. Native cattle have been replaced by imported breeds that are poorly adapted to the difficult environmental conditions in the Camero Viejo. As a consequence, cattle tend to graze only on the better abandoned fields (flatter terraces, closer to the villages, and with herbaceous vegetation). Constant grazing impedes the growth of the vegetal cover. The stronger the decrease in vegetation cover, the greater is the severity of erosion and runoff (Evans 1998). Moreover, cattle trample the soil and generate small clearings on which erosion processes operate (Condon et al 1969). Table 3 shows hydrological and sedimentological data that were obtained in abandoned and grazed terraces in the Camero Viejo. Intensively grazed plots with scarce plant cover had a low infiltration rate (wetting front = 9.8 cm) and the highest runoff values (runoff coefficient 41.4%) in the study area. On these plots, runoff began 398 seconds after the rainfall event had started. On lightly grazed plots, runoff began much later (after 645 seconds) and the runoff coefficient was moderate (15.7%). The erosional response also depended on the use of the terraces. The highest sediment concentrations (27.1 g/m^2/h) were found on intensively grazed terraces.

Discussion and conclusions

The traditional land management system in the Camero Viejo had various effects on soil conservation. Deforestation and certain agricultural practices (especially shifting cultivation on steep slopes) caused serious erosion. Using experimental plots, García-Ruiz et al (1996a) showed that shifting cultivation, fallow, and shrub fire to fertilize fields increased the sediment yield. With the help of a GIS model of the Camero Viejo, García-Ruiz et al (1996b) demonstrated that the areas showing most signs of erosion coincided with those that farmers were exploiting most heavily. Gómez-Villar (1996) pointed out that many alluvial fans are a direct result of deforestation and agriculture in mountain areas.

In contrast with the majority of these areas where human impacts resulted in a great amount of soil loss,

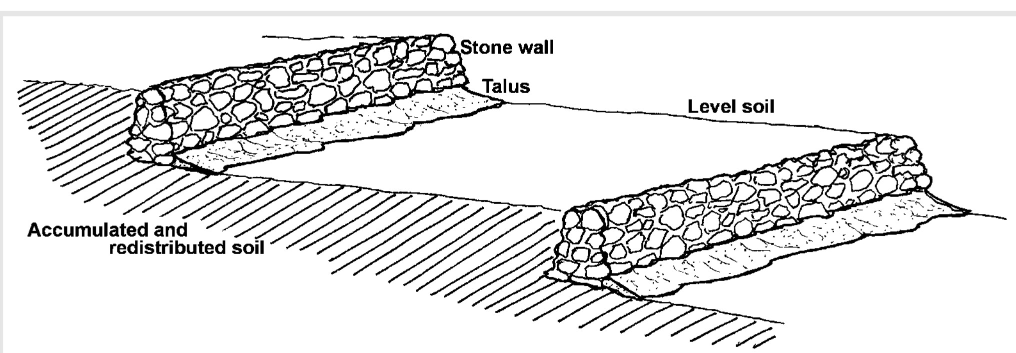


FIGURE 7 Sectors of an abandoned terrace. (Drawing by Karl Herweg)

on some hillslopes, farmers struggled to conserve and improve the soil until the 1950s. They constructed terraces consisting of small plots with stone walls and used them for intensive cultivation. The walls retained the soil, and a network of ditches diverted the runoff away from the plots. The damage caused by collapsing walls due to heavy rainfalls was quickly repaired by farmers in order to prevent further intense erosion. Most of these terraces remained in good condition until recently. In their studies of other Mediterranean mountain regions, several authors have highlighted the role of agricultural terraces as an effective soil conservation method in the past (Ron 1966; Chisci 1986; Gallart et al 1994).

In the course of the 20th century, the Camero Viejo underwent deep transformation as a result of the sharp decrease in population and the fact that farmers were giving up cultivation practically everywhere in this mountain region, especially as of the 1950s. The abandonment of traditional practices and the development of new land management systems (extensive livestock rearing, hunting, afforestation) have led to changes in the landscape and in the dynamics of soil preservation and degradation.

Currently the sloping fields that were abandoned many years ago and are situated mainly on high and middle slopes far away from the villages are covered with dense scrub or afforestation and are not being used. In these fields, the end of cultivation brought about a reduction of soil loss due to the rapid growth of vegetation. In a few areas, however, processes of overland flow are visible, particularly sheet wash erosion. Sloping fields that were seriously damaged by cropping and where plant succession was frequently interrupted by fire in the past have tended to develop patches of stone pavement due to soil erosion. Similar processes have been observed in abandoned sloping fields in the Central Pyrenees (Ruiz Flaño and García-Ruiz 1991; Ruiz Flaño et al 1991).

On recently abandoned terraces located on very gentle slopes close to villages, soils are deep and fertile and have a herbaceous cover. Consequently, these fields are used for intensive grazing. Runoff and erosion are caused in certain areas by heavy cattle concentrations and overgrazing. But landslides observed in these terraced areas are usually generated today by hydrological changes introduced previously on hillslopes when these were cultivated. Terraces were made to increase infiltration and prevent runoff. They undoubtedly had a positive effect by regulating the hydrological dynamics of the hillslopes and reducing the incidence of sediment transport. However, intensive manpower was needed to guarantee the stability of the terraces. When the terraces were abandoned due to changing demographic and economic conditions, the drainage system lost its effectiveness, resulting in soil saturation and initiating massive soil movements.

To conclude, the new land uses in Spain's Iberian System (in particular the Camero Viejo) have generated important new source areas of sediments. In the traditional system, sediment sources coincided with the extensively managed areas (deforested slopes for grazing or shifting cultivation), while the intensively managed areas (for permanent cultivation) were more stable from a hydromorphological perspective. The farmers used techniques to avoid soil erosion on slopes in order to ensure high production levels. The new land uses induced by depopulation and changed economic conditions encourage the regrowth of vegetation over large areas, thus bringing about a positive geomorphological change toward a steady behavior. By contrast, the areas that were traditionally better preserved have become the main sources of sediment. In these sites, conservation practices have been neglected and the new land management system (especially extensive cattle grazing) does not include soil preservation measures.

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REFERENCES

Arnáez J, Ortigosa L, Oserín M. 1992. Descripción y cuantificación de procesos de erosión en bancales abandonados. *In:* López Bermúdez F, Conesa C, and Romero Díaz MA, editors. *Estudios de Geomorfología en España.* Murcia: Sociedad Española de Geomorfología, pp 193–202.

Cerdà A. 1999. Simuladores de lluvia y su aplicación a la geomorfología. Estado de la cuestión. *Cuadernos de Investigación Geográfica* 25:45–84.

Chisci G. 1986. Influence of change in land-use management in the acceleration of degradation phenomena in Apennines hilly areas. *In:* Chisci G and Morgan RPC, editors. *Soil Erosion in the European Community. Impact of Changing Agriculture.* Rotterdam: AA Balkema, pp 3–16.

Condon RW, Newman JC, Cunningham GM. 1969. Soil erosion and pasture degeneration in central Australia. Part I. Soil erosion and degeneration of pastures and topfeeds. *Journal of Soil Conservation, New South Wales* 25:47–92.

Douglas TD, Kirkby SJ, Critchley RW, Park GJ. 1994. Agricultural terrace abandonment in the Alpujarra, Andalucia, Spain. *Land Degradation & Rehabilitation* 5:281–291.

Evans R. 1998. The erosional impacts of grazing animals. *Progress in Physical Geography* 22(2):251–268.

Gallart F, Llorens P, Latrón J. 1994. Studying the role of old agricultural terraces on runoff generation in a Mediterranean small mountainous basin. *Journal of Hydrology* 159:291–303.

García-Ruiz JM, Arnáez J, Terrero E, Valle J, Ortigosa L. 1996b. Identificación de factores de control de la actividad geomorfológica en montaña media: aplicación de técnicas SIG en Camero Viejo, La Rioja. *Zubía Monográfico* 8:43–60.

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

García-Ruiz JM, Martín-Ranz MC. 1992. *El Régimen de los Ríos Riojanos.* Logroño: Instituto de Estudios Riojanos.

Gil MJ, Tomás R, Núñez E, Martínez Abaigar J. 1996. Acción humana sobre el medio natural en la sierra de Cameros a partir del análisis polínico. *Zubía Monográfico* 8:29–41.

Gómez-Villar A. 1996. *Conos Aluviales en Pequeñas Cuencas Torrenciales de Montaña.* Logroño: Geoforma Ediciones.

Haigh MJ. 1984. Landslide prediction and highway maintenance in the Lesser Himalaya, India. *Zeitschrift für Geomorphologie. Neue Folge* 51:17–37.

Lasanta T. 1990. Diversidad de usos e integración espacial en la gestión tradicional del territorio en las montañas de Europa occidental. *In:* García-Ruiz JM, editor. *Geoecología de las Áreas de Montaña*. Logroño: Geoforma Ediciones, pp 267–295.

Lasanta T, García-Ruiz JM, Pérez-Rontomé C, Sancho-Marcén C. 2000. Runoff and sediment yield in a semi-arid environment: the effect of land management after farmland abandonment. *Catena* 38:265–278.

MacNeill JR. 1992. *The Mountains of the Mediterranean World: An Environmental History.* Cambridge: Cambridge University Press.

Moreno Fernández JR. 1994. *El monte público en La Rioja durante los siglos XVIII y XIX: aproximación a la desarticulación del régimen comunal*. Logroño: Gobierno de La Rioja.

Rodriguez-Aizpeolea J, Lasanta T. 1992. Los bancales en la agricultura de la montaña mediterránea: una revisión bibliográfica. *Pirineos* 139:105–123.

Ron L. 1966. Agricultural terraces in the Judean Mountains. *Israel Exploration Journal* 16:33–49.

Ruiz Flaño P, García-Ruiz JM. 1991. Distribución espacio-temporal de los microambientes geomorfológicos en campos abandonados en pendiente (Valle de Aísa, Pirineo aragonés). *Cuadernos de Investigación Geográfica* 17(1–2):89–101.

Ruiz Flaño P, Lasanta T, García-Ruiz JM, Ortigosa L. 1991. The diversity of sediment yield from abandoned fields of the Central Spanish Pyrenees. *International Association of Hydrological Science (IASH) Publications* 203:105–110.