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Sediment Sources During the Traditional Land-Use System in the Spanish Pyrenees

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Abstract. During the traditional land management system intense erosion processes affected the Spanish Pyrenees up to 2200 m a.s.l. The destruction of the upper forest levels and the expansion of the cultivated fields on the sunny, steep slopes greatly increased sediment yield to the river channels. Soil erosion reached its highest values under shifting agriculture, fallow land and, in the shrubland areas, immediately after a wildfire. Both in the subalpine and in the submediterranean areas, deforestation explains not only the main features of the landscape functioning but also the fluvial dynamics.

1. Introduction·

During the so-called traditional land-use system intense erosion processes affected the Spanish Pyrenees up to 2200 m a.s.l. The destruction of the upper forest levels in order to enlarge the extent of summer pastures and the expansion of cultivated fields on the sunny, steep slopes greatly increased sediment yield to the river channels. The consequences of such activities were an increase of mass movements of small size, the development of rills and active headwaters of ravines, and an increase in the torrentiality of rivers with coarse, poorly sorted sediments occupying the whole alluvial plain (García-Ruiz *et al.*, 1996). Many of the traditional sediment sources have since disappeared, due to farmland abandonment and reafforestation, though others remain very active. An important part of the landscape still shows the effects of past human activities (degraded soils, open shrub cover, high stoniness on the soil surface). In fact it is impossible to explain the present landscape organization (and its geomorphic and hydrologic functioning) without information on land-uses and land management during the periods of maximum demographic pressures

In this paper sediment sources are identified by means of field work and geomorphological mapping as well as by means of the results obtained from the "Aísa Valley Experimental Station", where runoff and sediment yield from different traditional land-uses are monitored.

2. The study area

The study has been mainly carried out in the Aisa Valley, in the central-western part of the Spanish Pyrenees (Fig. 1). Most of the valley belongs to the flysch area, with smooth divides decreasing progressively in height towards the south. Slopes range between 20 and 40 percent. This area is characterized by a mountain mediterranean climate. Yearly precipitation varies between 800 mm in the lowest sectors and 2,000 mm in the divides, mainly falling in the cold season (October-May). *Pinus sylvestris* woods prevail on the shady slopes, the rest of the territory being dominated by abandoned fields, small *Quercus gr. faginea* woods and submediterranean shrubs. Over 1700 m, summer pastures have replaced the subalpine forests, which where burnt in the 11th and 12th centuries in order to increase the extent of pastures (Montserrat, 1991) to feed the transhumant livestock. According to Höllermann (1985) this process resulted in a lowering of the lower limit of solifluction, in such a manner that frost action manifests itself even 400 m below the natural timberline.

During the 19th century, coinciding with the maximum demographic pressure, the farmed area, cultivated with cereals, also occupied the slopes. The cultivated area reached its maximum extent (on sunny aspects) between 1,000 and 1,400 m a.s.l. During the 20th century most of the fields on the hillslopes were abandoned (Lasanta, 1988). Meanwhile meadows replaced cereals and on many hillslopes afforestation with conifers was the main land reclamation policy.

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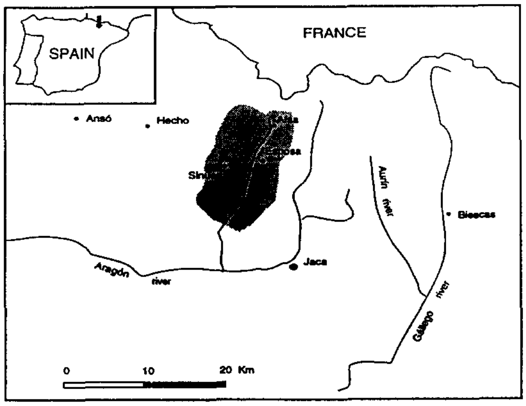

Fig. 1. The study area.

3. Methods

Information on runoff and sediment yield under different plant covers and land-uses was obtained from experimental plots. The "Aisa Valley Experimental Station" is located 1 km east of the village of Aísa, on a field abandoned 35 years ago. Eight closed, 10 x 3 m plots were installed, including in the lower part a Gerlach trap and a simple system of tipping buckets connected to data loggers in order to continuosly record the runoff of each plot. Likewise, a pluviometer is connected to a data logger. In order to monitor the sediment concentration, a part of the runoff is diverted to containers which are emptied after each rainfall event.

The plots, most of them installed in 1991 and the rest in 1993, reproduce different land-uses, some of them very characteristics of the traditional system of land management: shifting agriculture with barley fertilized with ashes, fallow land, cereals (adding chemical fertilizer), burnt plot, dense shrub cover (with the unaltered, original vegetation) and meadows. Several changes have been introduced in the plots: for example, in 1993 the plot in fallow passed into cereal, whilst the cereal plot was left as stubble, initiating a process of abandonment.

4. Results

Aerial photographs from the beginning or middle of the 20th Century reveal the predominance of unstable channels in the Pyrenean rivers. The Cinca river, for example, was characterized by a large, unstable alluvial plain with several channels and isolated bars which totally lacked plant cover. The pictures suggest that, at that time, sediment sources were very active and floods were frequent and violent. Rubio & Hernández (1990) arrived at similar conclusions for the nearby Ara river.

In a detailed study, Martínez-Castroviejo & García-Ruiz (1990) showed that, in 1956, just before farmland abandonment and reafforestation, the Ijuez and Aurín rivers were extremely torrential. The alluvial plain -around 200 m width- was occupied by a large accumulation of coarse sediments. Plant cover was absent. The arrival of materials to the channel was by means of debris flows, forming large and chaotic accumulations of boulders, blocks and gravels. This is a generalized phenomenon in the rivers of the flysch area, where plant cover disturbance historically reached its maximum extent, both at the subalpine and in the submediterranean belts.

The effects of forest clearance resulted in important advances of the Ebro Delta towards the Mediterranean sea from the Middle Ages (Maldonado 1972). It can be easily deduced that if a greater contribution of fine sediments reached the Delta, a greater volume of sediments was yielded in the mountain, in whose river channels the coarsest sediments were retained, precisely those which were responsible for the torrential morphology of the alluvial plains.

García-Ruiz & Puigdefábregas (1982) and García-Ruiz et al. (1990) showed that the destruction of the upper forest level resulted in an increase of mass movements affecting the soil horizons, mainly planar slides (Puigdefábregas & García-Ruiz, 1984) on rectilinear slopes. Practical field observations support the conclusion that slopes of more than 30 degrees have incurred extensive mass movements. Once the soil has been carried away, a dense network of rectilinear, small integrated rills occupy the upper part of the hillslopes, alternating with terracettes and active headwaters of ravines. González *et al.* (1995) demonstrated using GIS procedures that many of the geomorphic processes between 1700 and 2200 m a.s.l. are related to past forest clearance. Furthermore, Montserrat (1991) has shown that an increase in detritic sedimentation occurred in small lakes of glacial origin, deposition occurring over a level of ashes, corresponding to the effect of generalized use of fires for land clearance in the subalpine belt.

In the same way, Puigdefabregas & Alvera (1986) confirmed that the substitution of dense pine forest by summer pastures has resulted in both an increase in runoff and sediment transfer. A comparison was made between two basins, one covered by pastures above the forest and the other with a dense forest of *Pinus sylvestris* and *Pinus uncinata*. The average runoff from the pastures (12.9 $l/s/km^2$) is twice that from the forest (6.2 $l/s/km^2$). Suspended sediments are ten times greater in areas under pasture. These results show how strongly the hydromorphic behaviour of formerly wooded slopes has been disturbed.

Deforestation of the middle mountain, especially on the sunny slopes, also had dramatic consequences, since human activities were more intensive than in the summer pastures. For centuries the hillslopes located between 700 and 1,500 m have been burnt, overgrazed and farmed with different types of fields: the permanent, sloping fields had several structures for soil conservation (drainage channels and stone walls at the lower end), whilst shifting agriculture produced fields without soil protection measures on the steepest, straight and convex slopes.

In order to know the effects of traditional land management, plots of the "Aísa Valley Experimental Station" reproduce the hydromorphological functioning of several land-uses. Fig. 2 shows the average sediment concentration once the extreme records have been

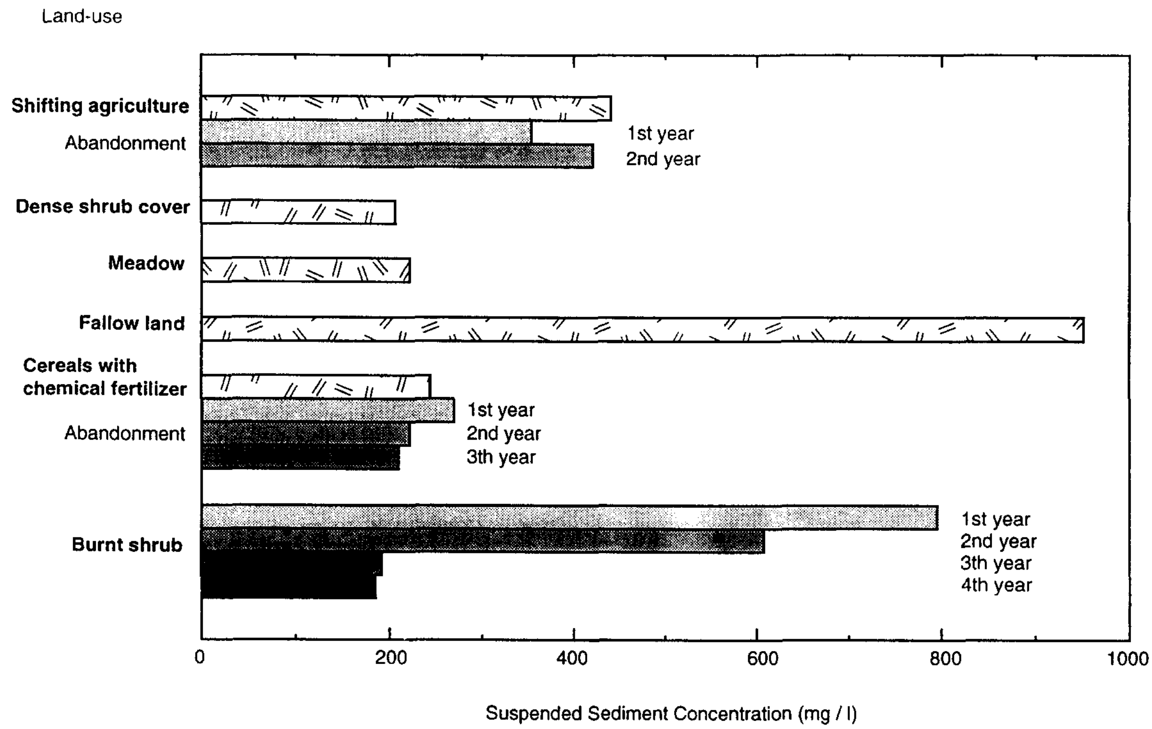

Fig. 2. Suspended sediment concentration in runoff from different land-uses. "Aisa Valley Experimental Station".

eliminated. Sediment concentration shows the highest values in the plot in fallow, where the soil has been worked and lacks protective plant cover. Likewise, the use of fire results in high yields of sediment, especially during the two first years after the fire, whilst during the 3rd and the 4th years the values of sediment concentration equal those characteristic of dense shrub cover. Shifting agriculture also presents very high soil losses, due to the low productivity of cereals fertilized with ashes. On the other hand, cereals with chemical fertilizer have a very good hydromorphological behaviour, very similar to that of the shrub cover and meadows.

Runoff coefficients confirm the previous trend, since the highest values are recorded for shifting agriculture, the plot in fallow and the burnt plot. The consequence is a high sediment yield precisely in the plots characterizing the traditional land-uses. The results demonstrate that cereal cropping on steep slopes -especially in the case of shifting agriculture- is responsible for soil erosion and land deterioration of many mountain hillslopes. Likewise, the use of fire -in order to substitute the thorny shrub cover by herbs- had very negative consequences since during the following one or two years the values of soil erosion and nutrient losses were very high (García-Ruiz *et al.*, 1995 a and b). Geomorphological mapping of the flysch area (García-Ruiz & Puigdefábregas, 1982) shows that on the deforested hillslopes sheet wash erosion prevails, together with rilling (in the middle and lower slopes occupied by shrubs), debris flows and active headwaters of ravines. Frequently, some slumps and deep landslides may reach the fluvial channels, but they are not linked to land-uses.

The result of this geomorphic activity is not only the above mentioned accumulation of debris in the alluvial plains, but also a change in the size of sediments that arrive at the channels. Fig. 3 shows the evolution of the mean grain size (b axis, in mm) along a strech of the Aurin river. After 10 kilometres from the headwater, the mean size decreases until the kilometre 12, when grain size again suddenly increases, coinciding with the arrival of tributaries coming from the sectors traditionally cropped, grazed and burnt. This anomalous change in the size of sediments can not be attributed to a change in lithology or in the slope of the tributary basins, because the whole Aurin basin in the flysch sector is very homogeneous. The cause of this change must be an increase in the sediment transport capacity of the tributaries, draining deforested basins with more intense floods (Ortigosa & García-Ruiz, 1995) and higher sediment yield from the slopes.

5. Conclusions

During the traditional land management system two source areas yielded enormous volumes of sediment. Accelerated soil erosion affected both the subalpine belt and the sunny aspects of the submediterranean hillslopes. In the first case planar slides, rills and terracettes were the result of a generalized deforestation of the upper forest level with the aim of increasing the extent of summer pastures. The study of sediments in lakes confirms the sudden increase of sedimentation rates and the substitution of organic by detritic sediments (Montserrat, 1991). In the second case the cultivation of steep hillslopes with cereals and the alternance with periods of fallow yielded many sediments and is responsible for land degradation on many hillslopes, at present covered by open, little protective shrubs on straight and convex sectors. The frequent use of fire also contributed to increase the sediment load in the ravines and rivers. In any case, both in the subalpine and in the submediterranean areas, deforestation explains not only the main features of the landscape functioning and plant cover structure, but also the fluvial dynamics, overloaded by sediments arriving from the most intensively managed areas.

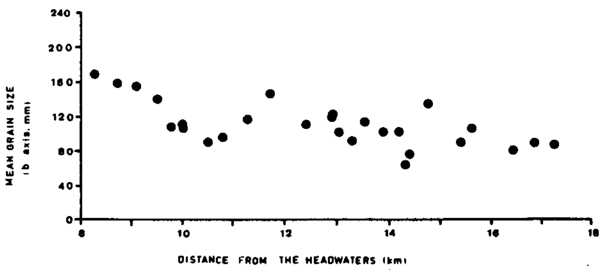

Fig. 3. The evolution of mean grain size in the Aurín River

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