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EFFECTS OF LAND USE (SKI-RESORT VS. TRADITIONAL GRAZING) ON STREAM WATER QUALITY OF TWO PYRENEAN BASINS

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ABSTRACT In two adjoining basins, affected by very different forms of exploitation (traditional pasture and a growing ski-resort, respectively), biweekly samples of streamwater were collected. Of the 11 variables analyzed during four years, only two (temperature and residue on evaporation) were similar in each basin. The differences in most variables are probably due to natural conditions (soil and bedrock). Only the difference in suspended sediment (measured by turbidity and weighing), P and NO_3N are attributed to changes in land use. On average, the mean ratio in the concentration of suspended sediment in the disturbed basin to that in the pastured basin is 5.4. The highest ratio for any given year was 22, and for any given season was 75. The difference in suspended sediment concentrations tends to increase with the expansion of the ski-resort.

INTRODUCTION

The waters of two adjoining basins, one of them affected by a developing ski-resort, Astún, and the other supporting the traditional pastoral exploitation, Canalroya, were sampled during four water year (October 1985 to September 1989).

The "ski" basin is affected by all the works concerning the equipment and exploitation of the recreational resource. These effects may be classified into two main groups:

(a) construction — This includes the development of roads, the channelization of a part of the main stream, and the excavation of refuges and terraces for forestal plantations designed to protect the access roads from snow avalanches. The construction disturbs the soil and surficial material. Construction was initiated in 1976 and continues for maintenance of the ski resort and to increase the size of the resort. Finally, construction is confined to summer and autumn, when the basin is devoid of the snow-mantle.

(b) skiers — Skiers descend on the basin throughout the winter with the highest population occurring during Christmas and Easter vacations and weekends between December and April. People leave organic residues, part of which eventually reaches the stream.

The main effects to be expected from the first type of disturbance, the mechanical one, are increases in the removal of soil that will be eroded and transported to the stream. Higher erosion rates should coincide with seasons of high water yield, such as during snowmelt in the spring, and rainstorms in the summer and autumn. In addition, some chemical erosion can be expected from the exposed soil.

The organic residues may cause increases in streamwater concentrations of some mineral nutrients, such as phosphorus and nitrate. The increases should occur mainly during snowmelt.

The traditional system of pasture exploitation, implies the presence of three types of domestic beasts between July and November: several hundred cows, horses and sheep. The livestock mildly trample the terrain, consume grass (this acts as a feedback system influencing the species composition of the pasture and maintaining the yield), and leave droppings of metabolic residue. The access of part of the residues to the streamflow must be well balanced, as the system has been maintained with this kind of use for centuries. Only the intensity of exploitation has changed, both in numbers of animals and proportions among species. The last tendency is for the size of the herds to diminish.

TABLE 1 Geographic characteristics of the basins.

	Astún	Canalroya
Altitude (min.-max., in m)	1660-2300	1400-2500
Slope (m)	640 (21.3%)	1100 (13.8%)
Size (km^2.)	7.1	15.3
Geographical coordinates	42° 48' N; 0° 30' W	

MATERIAL AND METHODS

The basins

The "ski" basin (Astún), lies mainly (ca. 75%) on Paleozoic graywackes and shales, Permotrias sandstones and mudstones, and Quaternary sediments. The basin is covered in pasture with small areas that are naturally denuded.

The pastured basin (Canalroya), lies on similar materials but with different proportions (ca. 50% graywackes and shales, sandstones, mudstones and Quaternary, plus andesites). Canalroya has a higher proportion of natural denuded surface than Astún. Geographical characteristics are indicated in Table 1.

Some climatic data from a nearby meteorological station, Candanchú (1613 m a.s.l), located between the outlets of both basins, are: mean annual air temperature, 5.2 °C; precipitation, 1916 mm; evapotranspiration (potential and actual), 361 mm (Liso & Ascaso, 1969).

Sampling and chemical analysis

Samples were taken fortnightly, between 9 and 12 hours (a.m.), from October 1985 to September 1989 (92 samplings in 1461 days).

With this pattern of sampling, we have information about conditions on low flow only. Changes in concentrations during high flow caused by rain and snowmelt, which can be very important, are not known. During snowmelt, streamflow varies diurnally (Alvera & Puigdefábregas, 1985) for which maxima are produced in the afternoon.

Temperature was measured in the stream. In the laboratory, samples were analyzed for specific conductivity and turbidity in the untreated water. After filtering through a Millipore filter, the suspended sediments were calculated. In the filtered water the residue on evaporation (at 105°C) and the following mineral nutrients were determined: Ca, Mg (atomic absorption spectrophotometry), Na, K (emission spectrometry), P (total dissolved phosphorus: digestion with persulfate and colorimetry of molybdenum blue-ascorbic acid), NO_3N (colorimetry after reduction to NO_2).

*TABLE 2 Mean values (geometric for variables labelled *; arithmetic for all others) for all samples in both streamwaters (AS, Astún or "ski" basin; CR, Canalroya, pastured basin). Concentrations in mg l^{-1}, except where noted. Low. and upp. are the lower and upper confidence limits at 95%, respectively, and Min. and Max.are the extreme values.*

Parameter	Site	Mean	low.	upp.	Min.	Max.	Range	Nr.
Temperature (°C)	AS	7.7	6.2	9.3	-2.4	23.4	25.8	70
	CR	7.8	6.8	8.9	1.9	16.9	15.0	70
Conductivity	AS	108	99	117	10	258	248	92
(µS/cm at 25°C)	CR	116	110	121	61	171	110	92
Turbidity (NTU)	*AS	3.6	2.4	5.2	0.16	550	550	92
	CR	0.6	0.5	0.8	0.07	17	17	90
Susp. sediment	*AS	9.8	7.2	13.2	0.3	311	311	92
	CR	1.8	1.3	2.4	0.0	78.4	78.4	92
Residue evaporation	AS	70.1	64.5	75.7	16.7	138.3	121.6	92
	CR	73.2	68.1	78.3	18.8	151.7	132.9	92
Ca	AS	16.7	14.5	18.9	5.4	69.2	63.8	88
	CR	19.9	18.3	21.5	5.4	45.6	40.2	88
Mg	AS	4.08	3.69	4.47	0.49	8.44	7.95	88
	CR	3.26	3.04	3.47	0.63	5.96	5.33	88
Na	AS	1.44	1.28	1.59	0.19	5.05	4.85	88
	CR	1.31	1.23	1.39	0.35	2.42	2.07	88
K	AS	0.37	0.31	0.42	0.06	1.29	1.23	88
	CR	0.25	0.23	0.27	0.10	0.55	0.45	88
P (µg l^{-1})	*AS	6.8	5.4	8.4	0.0	178	178	88
	CR	3.9	3.3	4.6	0.0	19.9	19.9	88
NO_3N (µg l^{-1})	*AS	98.3	66.9	14	0.0	797	797	87
	CR	63.7	46.8	86.9	0.0	359	359	88

RESULTS AND DISCUSSION

Mean Values

The mean values of the 92 samples (only 88 for the individual solutes, Ca to N; and 70 for temperature) are presented in Table 2.

For four variables (turbidity, sediments, P and NO_3N), of which the concentrations were highly variable (see Min. and Max. values, and range, in Table 2), the geometric means are reported. Thus, the influence of some very high values on the means is decreased. For the other variables, which have a lower variability, arithmetic means are reported, as these are similar to geometric ones.

The means are statistically different (Student's T test) between basins for all variables, except temperature and residue on evaporation (Table 3). The mean values for temperature and residue on evaporation are very similar: temperature, 7.7 (AS) and 7.8°C (CR); residue, 70.1 (AS) and 73.2 mg l^{-1}(CR). The concentrations of almost all variables are greater in the waters of Astún than in those of Canalroya (Tables 2 and 3), with the exceptions of temperature, conductivity, residue on evaporation, and calcium. Differences between conductivities were small. Calcium is the only nutrient whose value is appreciably greater in the waters of Canalroya (AS/CR = 0.86). The greatest differences are found in solid components, turbidity (6 times greater in Astún), and suspended sediments (5.4 times).

The first question that arises is: what differences in concentrations are attributable to the differences in land use between the basins? We have no previous data of the waters before disturbance (the former use was also pastoral). The rock composition is similar between basins, and probably controlled the major ion chemistry before disturbance.

TABLE 3 Variables ordered by decreasing t_s (Student's test). The degree of significance of the test and the ratios of values in Astún to those in Canalroya are indicated.

Variable	sign.	t_s	AS/CR
Suspended sediment	0.0001	9.019	5.44
Turbidity	0.0001	6.613	6.00
Mg	0.0001	6.402	1.25
P	0.0001	4.849	1.74
Ca	0.0001	-4.809	0.84
K	0.0001	4.560	1.48
Specific Conductance	0.0109	-2.599	0.93
NO_3N	0.0279	2.237	1.54
Na	0.0421	2.063	1.10
Residue on evaporation	0.1133	-1.599	0.96
Temperature	0.7340	-0.341	0.97

In most cases, the ratios between the values of Astún and Canalroya are small (Table 3), and probably the influence of use in concentrations falls to four variables, those whose ratios are greater: sediments and turbidity (two expressions of the same property), and P and NO_3N.

The differences in variable means allude to differences in the natural conditions of the basins. The ratios provide an estimate of the magnitude of the differences between basins. The differences in the concentrations or levels for several variables between the Astún and Canalroya also were evaluated using data collected during the first semester of 1983 from a sub-basin of Astún (named Escalar; Puigdefábregas & Alvera, 1986), a pristine watershed. Only sediments, residue on evaporation, conductivity, Na, K, Ca and P were studied at that time. The ratios of the mean concentrations for all samples collected during winter and spring (equivalent to the first semesters of the four years of sampling) for Escalar to those for Astún and Canalroya are similar except for two variables, suspended sediment and P. These ratios are listed in Table 4.

The suspended sediment concentrations in the streamwater from this pristine sub-basin, Escalar, are less than those for the whole basin, Astún; this was expected given the disturbance in the remainder of the basin. The suspended sediment concentrations of Escalar are greater than those in the pastured basin, Canalroya.

The phosphorus concentrations of Escalar are 5 times lower than those for the Astún, but they are only 2 times lower (or half) those of Canalroya. The values of the other variables studied in Escalar are less than those in either of the other basins, and the differences between the ratio of these constituent concentrations in Escalar with each of the basins are small. These small differences suggest that the basins are somewhat comparable for these seasons.

TABLE 4 The ratios of mean concentrations of samples collected from winter through spring among basins: ES, Escalar or pristine basin; AS, Astún or "ski" basin; and CR, Canalroya, pastured basin.

	ES/AS	ES/CR	AS/CR
Sediments	0.39	1.37	3.5
P	0.20	0.54	2.7
Specific Conductance	0.58	0.50	0.9
Na	0.65	0.76	1.2
K	0.47	0.55	1.2
Ca	0.40	0.33	0.8

McCashion & Rice (1983), estimate that 40 percent of the total erosion associated with commercial timberland, was caused by the road system. In the ski-resort, all works are similar (construction of roads, ski-lifts, buildings), and the erosion results from them. The erosional effects of the ultimate aim of the resort, the skiing itself (Price, 1985), must be negligible in comparison with its implementation. As the basin is deforested, there is no pruning effect of skis on branches or seedlings.

Some increases of sediment yields due to road construction, reported elsewhere, are similar to the concentration increases observed here. For example, Megehan *et al.* (1986) reported an average increase of 5 times, as a result of construction of forest roads on granitic slopes in Idaho. Walling & Gregory (1970, in Gregory & Walling, 1983), reported a 10-fold increase in sediment concentrations due to building activity in a small basin in Devon. Fredriksen (1970, in Gregory & Walling, 1983), reported an increase of 39 times in suspended load after patch-cut with roads at a forested catchment in Oregon.

Much greater increases in suspended sediment transport were noted in other studies. Wolman & Schick (1967, in Gregory & Walling, 1983), found an increase of 200 times for building activity in Maryland. The same rise was found by Vice *et al.* (1969, in Gregory & Walling, 1983) after the construction of a highway (comparing disturbed with grass areas).

Gregory & Walling (1983) also found increases in the solute load, explaining it by the disturbance of the soil mantle and the exposure of bedrock. We find more solutes in the natural basin, and we think this would be the normal situation. In the disturbed terrain overland flow increases, and water moves faster and more superficially, with fewer opportunities to percolate and leach the soil and increase solute concentrations.

TABLE 5 Mean seasonal values of the variables measured (for unities, see Table 1). The asterisks (*) indicate statistically different means between Astún and Canalroya. Autumn: October-December; Winter: January-March; Spring: April-June; Summer: July-September.

	Autumn		Winter		Spring		Summer	
Site	AS	CR	AS	CR	AS	CR	AS	CR
Temperature	4.5	* 5.8	2.3	* 4.2	7.8	8.2	16.6	* 13.4
Conductivity	113.	122.	111.	122.	69.	* 87.	135.	131.
Res. evap.	77.2	79.4	62.5	65.8	49.2	* 62.8	91.7	85.5
Turbidity	3.2	* 0.4	2.2	* 0.6	3.1	* 1.0	7.0	* 0.5
Sediments	11.1	* 1.3	8.3	* 1.4	10.7	* 4.8	9.6	* 1.0
Ca	16.7	* 21.1	21.2	22.7	9.0	* 13.9	19.2	* 21.6
Mg	4.64	* 3.55	4.35	* 3.73	2.05	2.16	5.37	* 3.54
Na	1.35	1.36	1.82	* 1.33	0.87	0.97	1.65	1.61
K	0.38	* 0.22	0.38	* 0.24	0.17	* 0.24	0.55	* 0.30
P	5.8	4.1	9.9	* 3.6	4.8	4.1	6.9	* 3.9
NO_3N	172.	* 66.	134.	85.	68.	57.	54.	47.

Seasonal values

Table 5 shows the mean seasonal values for the variables. From the 44 paired means, only 27 (61%) are significantly different statistically, with a similar distribution between seasons.

This table shows (but not as clearly as if all individual seasons were represented), the only pattern of seasonal change in concentrations, that of dilution caused by the spring increases of flow due to melting snow. This effect, produced by mixing of low concentration meltwaters which reach the channel rapidly and more concentrated baseflow, is observed in conductivity, residue on evaporation, Ca, Mg, Na in both streamwaters, and in K and P only in Astún.

The others, i.e. turbidity, suspended sediment, NO_3N (P and K in Canalroya) do not present a regular pattern in the oscillations of their values. During spring snowmelt and summer and autumn rainstorms in the pastured basin, suspended sediment concentrations increase with increases in streamflow, as expected (Alvera & Puigdefábregas, 1986; Puigdefábregas & Alvera, 1985). In the disturbed basin, the suspended sediment concentrations also increase with increases in streamflow, but the maximum sediment yield is controlled more by disturbance than by discharge. The maximum sediment yield occurs with rainstorms during summer when disturbance is at a maximum.

Finally, changes during the 4 years of sampling will be discussed. The ratios for turbidity and suspended sediment among streamwaters in each basin(AS/CR), changed markedly in last year (Table 6).

The concentration of sediments during the last year is almost 20 times higher in the disturbed basin than in the pastured one (6 times higher than in previous years). For turbidity, the values are 25 times higher (5 times higher than in previous years).

TABLE 6 Ratios between means of turbidity and sediments for Astún/Canalroya, in the 4 years and the 16 seasons sampled.

Season	Turbidity AS/CR Year				Susp. sediments AS/CR Year			
	1	2	3	4	1	2	3	4
Autumn	3.7	11.0	5.5	18.3	2.4	9.2	8.3	20.4
Winter	2.3	4.8	4.3	4.0	1.7	6.2	9.4	11.3
Spring	1.3	1.7	1.2	60.8	1.1	2.1	1.2	18.3
Summer	7.0	5.2	8.6	145.4	8.9	7.1	3.2	73.6
Year	3.0	4.5	3.3	25.0	2.2	5.9	3.9	22.3

These changes were probably caused by increased construction in the ski-resort, mainly for new buildings. The changes were observed in each season during this last year of sampling (Table 6) and were most pronounced for the last summer; about 150 times for turbidity and 75 times for suspended sediment concentrations.

CONCLUSIONS

From the facts presented, it can be seen that the massive disturbance of soils increases the outputs of suspended sediments, to greater than 75 times on a seasonal basis (last summer) or 20 times, on average, in the last year, due to the increase of the size of the ski-resort.

In the undisturbed basin, the proportion of suspended sediment output, estimated from concentrations, is about 2.5% of the total (suspended + dissolved). In the disturbed basin, the disturbance increases the proportion of sediments to about 12% or about 5 times greater.

Accepting that both basins have a very similar specific discharge, with such concentrations of suspended sediments and solutes, the disturbed one exports about 2.5 times more sediment than the natural one (and its size is only half the other). The output of solutes, for which the concentrations in streamwater are similar in each basin, is twice as much in the larger basin, which corresponds to the difference in drainage area. These differences correspond to low flow conditions only. During high flow, it is possible that differences in the concentrations of suspended sediment between basins could be even greater.

The other output that seems related to the disturbance is that of phosphorus, probably due to organic pollution. During the last year, the concentrations of P in Astún were twice that in Canalroya; but the differences in the concentration of nitrate, seem to be diminishing.

An investigation of the excavation in the disturbed basin, by field work or with aerial photography, will allow us to evaluate the concentrations of sediments in streamwater. In this way, the actual influence of the ski-resort on the erosional processes of the basin, perhaps will confirm the results from this study on the differences in concentrations of streamwaters.

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