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Evolution of Hay Meadows between 1956, 1986, and 2016 and Its Relation to the Characteristics and Location of the Parcels in the Valley of the River Esera (Pyrenees, Spain)

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Received: 13 January 2020; Accepted: 25 February 2020; Published: 2 March 2020

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Abstract: The uses of the agricultural surface of hay meadows and crops of the mountain areas of the Spanish central Pyrenees are subject to constant transformations. This paper addresses the changes produced in the hay meadows of the Ésera river valley of the central Pyrenees (Spain) regarding the surface and the agronomic and topographic characteristics of the parcels between 1956–1986 and 1986–2016. The cartographed area is 5226 hectares, of which 1941 hectares correspond to 6416 polygons that have been mowed or cultivated on one of the three reference dates. In the period 1956–1986, there is a reduction in the agricultural area of meadows and crops (13.59%) in favor of pastures, forest, urbanized land, and water reservoirs. The surface of the meadows increases to 301.58%, to the detriment of the crops, until almost their disappearance. Between 1986 and 2016, the area of meadows is reduced to 59.11%, and the area of pastures, forests, and urbanized land increases. The topographic characteristics of the parcels with respect to surface, altitude, slope, width, and terracing and distance to the communication routes determine mechanized access and management and discriminate the transformation to pasture and forest.

Keywords: hay meadow; Pyrenees; temporal evolution surface; crop parcel features

1. Introduction

The hay meadows of the Spanish central Pyrenees are used by mowing for hay or silage for winter feeding within the cattle production system. In most cases, they are also grazed in autumn and less frequently at the end of winter [1,2]. Unlike other types of European pastures, they have a relatively close origin in the Middle Ages [3]. They are established as secondary vegetation after deforestation through grazing and mowing and have often been in alternation with agricultural use [4]. Due to their floristic composition, they are considered in the *Arrhenatherion elatioris* and *Triseto-Polygonion bistortae* alliances of *Arrhenatheretalia elatioris*.

The Pyrenees and other mountain regions of Europe have undergone major changes in agricultural uses since the 1950s [5–7]. They affect both the size of the surfaces of the different types of land uses and the location within a specific geographical area and involve a modification of the vegetation and ecosystem. In general terms, these changes imply a decrease in the area of hay meadows and agricultural crops or the intensification of production systems in part of the surface. However, the results of these changes cannot be generalized because they depend on the geographical area and the geographic and temporal observation scale [8–12]. In this sense, the area of crop plots and meadows of two valleys may be the same at a given time, but the proportion of the surface of the valley and hillside plots suitable for mechanization may be different. According to the SIGPAC (Geographic Information System for Agricultural Parcels mapping of the Spanish Ministry of Agriculture and Fisheries, Food, and Environment), in the valleys of the Pyrenees are numerous plots 10 m wide. These plots are not represented at less precise scales than 1:5000. As a consequence, the results of the analysis of changes in land uses will be different according to the topographic scale. It is also necessary to consider that exploitation systems depend on socio-economic factors, in addition to the intrinsic factors linked to mountain areas (such as steep slopes, shallow and unstable soils, abrupt landforms, short vegetative period, low potential productivity, etc.). The most relevant are the variations in time of the agricultural and livestock markets, mechanization, ownership and management of the land, the application of agricultural policy, the competition of land prices with respect to urbanization, the availability of hand of work, the implantation of reservoirs for the production of electrical energy, etc. [13–16].

Most of the literature related to mountain areas in Europe associates changes in the use of hay meadows with variations in flora [17,18], ecosystem diversity [19–22], regeneration of forest communities [23,24] or the effects of climatic variations [25–27]. However, studies that link changes in the use of hay meadows that support the winter feeding of cattle with the variation of the forage area and the agronomic conditions that determine them are less common. This has an impact on the availability (loss) and spatial distribution of own resources of non-intensified livestock systems [28,29] against European guidelines and recommendations [30]. In this regard, the European Union has established a series of measures aimed at maintaining agro-livestock activity and the conservation of hay meadows through the CAP (Common Agricultural Policy) [31–33]. Likewise, Council Directive 92/43/EEC (European Economic Community) considers these meadows as natural habitats of interest (6510 and 6520), and the Natura 2000 Network establishes the need for their conservation and the definition of specific geographical areas [34].

The evaluation of the evolution of mountain hay meadows, and the livestock production systems to which they are associated, must be multidisciplinary and at different scales for the purposes of the CAP 2021–2027 application and conservation policy. Within this strategy, this work is proposed whose objective is the quantification of the evolution of the areas of hay meadows and the relationship with environmental and agronomic factors from 1956 to 1986 and from 1986 to 2016 in the Ésera River valley of the central Spanish Pyrenees. The choice of the study area is motivated by the importance of the surface of the hay meadows within the mountain livestock production system and is representative of the changes that have occurred in recent decades.

2. Materials and Methods

2.1. Area of Study

The area of study is in the valley of the Ésera river in the Pyrenees, in the province of Huesca (Spain). It occupies an area of 5226 ha between 900 and 1700 m and includes the Río Ésera SCI (Natura 2000 Network, ES2410046) of 1759 ha (Figure 1). It is a valley with glacial and river morphology excavated on Paleozoic materials. Hay meadows are found on quaternary deposits of moraines, hillside landslides, alluvial terraces, and even in the flood plain. In some cases, they are on parcels with terraces made of stone wall.

In the altitudinal range considered, the data of the weather station of the town of Benasque (1140 m) show an average annual rainfall of 1144 mm, with November as the month with the highest rainfall (144 mm) and March with the lowest (65 mm). The average annual temperature is 9.3 °C, the coldest month is January (1.0 °C), and the warmest is July (18.9 °C). The forest vegetation is forests of *Pinus sylvestris*, *Quercus faginea* or mixed with *Betula pendula*, *Populus tremula*, *Tilia platyphyllos*, *Fraxinus excelsior*, etc. Hay meadows are secondary communities of *Arrhenatherion elatioris* and *Triseto-Polygonion bistortae* that, in some cases, have been crop fields or were planted with forage species before the 1970s.

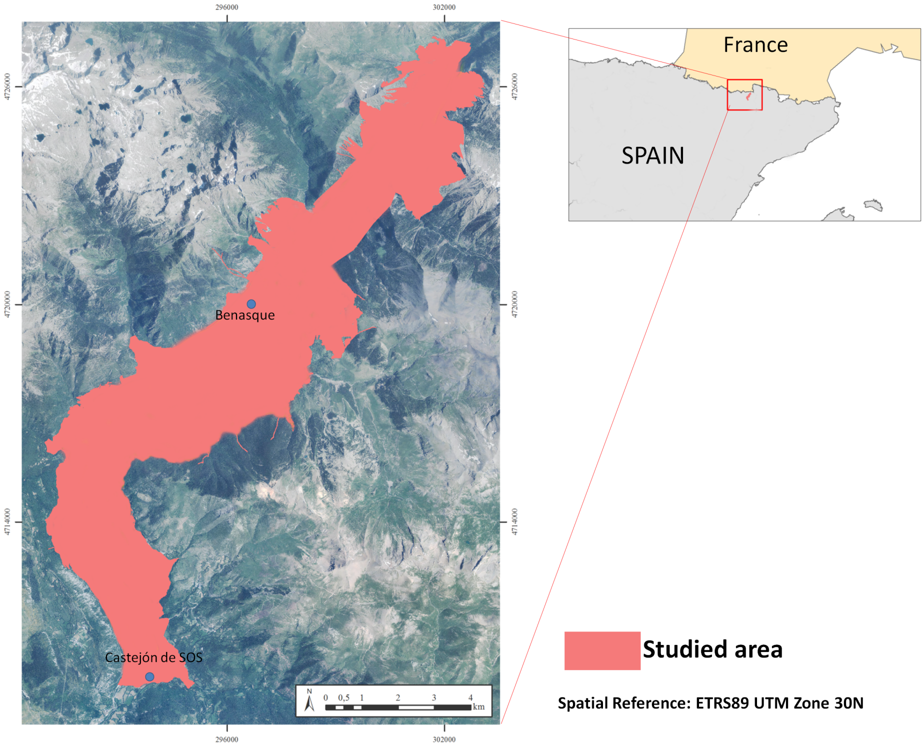

Figure 1. Location of studied area.

2.2. Cartography

The mapping has been made from the aerial photography of 1956, 1986, and 2016 of the National Geographic Institute. The first two have been orthogonalized and georeferenced from the frames while the last are georeferenced orthophotographs. In addition, the SIGPAC mapping of the Ministry of Agriculture and Fisheries, Food, and Environment of 2016 has been used. The basic work scale is 1:10,000, and the minimum area of representation is 0.25 ha and 0.0625 ha in irregular geometry parcels. The polygons have been drawn on the cartography of each of the reference years 1956, 1986, and 2016. The computer software used is ArcGIS 10.5(Environmental System Research Institute, Inc., Redlands, CA, USA). The categories of land uses manually attributed to each polygon and year through photointerpretation are: 1 Meadow, 2 Pasture, 3 Crop, 4 Unproductive, 5 Forest, 6 Urbanized area, 7 Reservoir, 8 Communication route, and 9 Riverbed. It is complemented by review of the polygons in the field, with the statements of the SIGPAC 2016 and with interviews with farmers.

The following parameters have been associated to each cartographic polygon: Polygon surface (ha), Minor polygon diameter (m), Altitude (m), Slope (°), EW orientation index (AspEW), NS orientation index (AspNS), Potential radiation (kWh/m^2 year), Distance to communication routes, and Terrace and Contiguity with pasture and forest polygons. The surface of the polygon, the smallest diameter of the polygon (maximum length of the axis perpendicular to the major axis) and the contiguity with pasture and forest polygons have been obtained from the GIS (Geographic Information System). The Distance to the communication pathways has been measured as the shortest distance to the communication pathways for motor vehicles in 1956, 1986, and 2016 from the mapping. The altitude, slope, orientation, and potential radiation have been obtained from the Digital Terrain Model (DTM) of 20 m of IDEARAGÓN [35]. The orientation of each polygon has been transformed into the AspNS and AspEW indices, corresponding to the cosine and sine of the angle [36]. AspNS and AspEW values range between 1 and −1 and indicate the position between N and S and between E and W, respectively). The presence of a built terrace has been assigned in the photointerpretation.

Comparisons of the characteristics of the meadow and crop parcels within the same year and of the changes in use between different years have been made using the t-Student tests with the

Levene and chi-square test for quantitative and qualitative variables, respectively (SPSS Statistics 26.0, International Business Machines Corporation, Armonk, NY, USA).

3. Results

The results are presented in four sections. The first two correspond to the surfaces of each land use and to the characteristics of the fields of meadows and crops. In the third, the changes of use are exposed in time; in the fourth, the relationship between changes in the use of meadows and crops and the characteristics of the parcels.

3.1. Land Use Surfaces by Years

Eight thousand, five hundred and sixty-nine polygons representing 5225.93 ha corresponding to 9 land uses have been mapped in 1956, 1986, and 2016 (Table 1, Figures 2–4). In all three scenarios, the use with the largest area corresponds to forest (between 43.50% and 55.60%). In 1956, the meadows, crops, and pastures occupy 10.50%, 26.30%, and 13.04%. In 1986, the meadows are 31.67%, the pastures 14.73%, and the crops have almost disappeared with 0.13% of the surface. Finally, in 2016, the meadows represent 18.72%, the pastures 15.06%, and the crops are kept residual with 0.04% of the total. The rest of the land uses have proportions of less than 5%.

Table 1. Area of land uses in the years 1956, 1986, and 2016 of the mapped area.

Land use	Surface (ha)		
Years	**1956**	**1986**	**2016**
Meadow	548.78	1655.02	978.29
Pasture	681.47	769.53	786.77
Crop	1374.62	6.96	2.25
Unproductive	2.31	3.91	5.92
Forest	2273.52	2357.96	2905.58
Urbanized area	35.39	76.81	196.04
Reservoir	0.00	51.46	52.99
Communication route	92.41	92.54	95.34
Riverbed	217.43	211.75	202.76
Total	5225.93	5225.93	5225.93

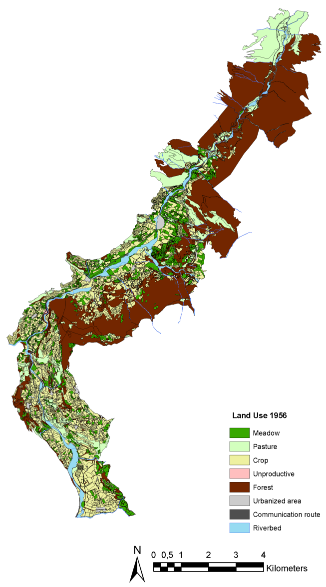

Figure 2. Land uses in 1956.

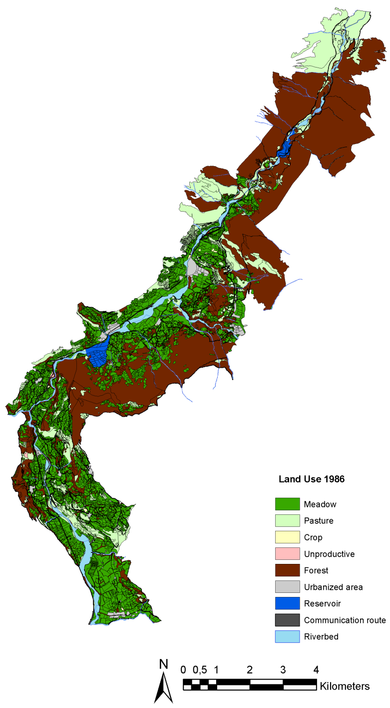

Figure 3. Land uses in 1986.

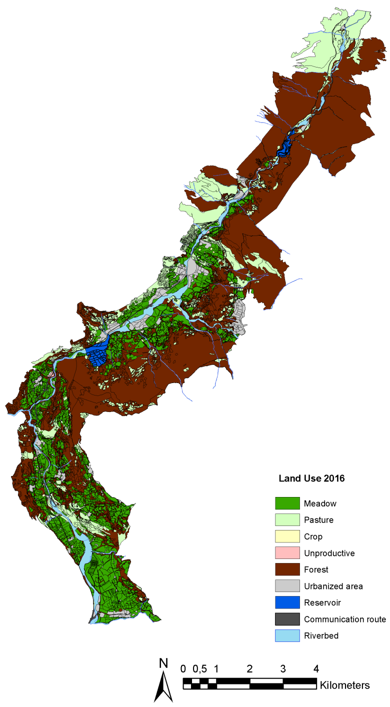

Figure 4. Land uses in 2016.

3.2. Characterization of the Fields of Meadows and Crops

Of the 5225.93 ha mapped, there are 6416 polygons that, in one of the three reference dates, have been a hay meadow or cultivation and that represent 1941.00 ha. The characteristics of the variables considered of the meadow and crop polygons of 1956 and 1986 and of the meadow in 2016 are shown synthetically in Table 2. The 2016 crops are not included because they are considered residual (2.25 ha in 7 polygons).

As can be seen, the meadow and crop parcels have values within the same range for all the variables considered. However, comparisons of each variable of the meadow and crop polygons of the same year using the t-Student and chi-square test (Table 2) show significant differences. In 1956, there are significant differences that indicate that the meadows have higher altitude, slope, AspEW (more to the E), lower AspNS (more to the S), and potential radiation and less amount of parcels with terraces. On the contrary, there is no difference in surface area, minor diameter, distance to the communication roads, and contiguity with pasture and forest polygons. In 1986, the significant differences indicate that it is also the meadows that have the highest altitude and slope and, in addition, greater distance to the communication routes and greater proportion of contiguity with pasture and forest polygons.

Table 2. Characteristics and comparison of the meadow and crop parcels of 1956 and 1986 and the 2016 meadow. t-Student test for the quantitative variables and chi square for the qualitative variables between the meadow and crop parcels in 1956 and 1986 (n = number of the parcels).

			1956			
Variables	**Meadow**		**Crop**		**Meadow vs. Crop**	
Quantitative	**Mean**	**SD**	**Mean**	**SD**	**Sig. t-Student**	**Levene**
Superface (ha)	0.31	0.46	0.30	0.43	ns	(a)
Minor polygon diameter (m)	25.09	19.21	26.08	18.94	ns	(a)
Altitude (m)	1159.77	123.42	1144.87	155.60	***	(a)
Slope (°)	17.32	8.93	16.30	9.82	***	(a)
AspEW	−0.10	0.63	−0.21	0.63	***	(a)
AspNS	−0.08	0.63	−0.04	0.60	*	(a)
Potential radiation (KWh/m^2 year)	1298.25	43.02	1305.49	43.40	***	(a)
Distance routes (m)	86.85	94.23	92.29	101.31	ns	(a)
Qualitative	**no**	**yes**	**no**	**yes**	**Sig. chi square**	
Terrace	1748	12	3623	982	***	
Contiguity pasture and forest	849	911	2297	2308	ns	
	n = 1760		n = 4605			
			1986			
	Meadow		**Crop**		**Meadow vs. Crop**	
Quantitative	**Mean**	**SD**	**Mean**	**SD**	**Sig. t-Student**	**Levene**
Superface (ha)	0.30	0.45	0.26	0.24	ns	(a)
Minor polygon diameter (m)	26.01	19.34	28.76	15.12	ns	(a)
Altitude (m)	1141.35	148.71	1047.96	121.83	**	(a)
Slope (°)	15.47	8.98	5.74	3.88	***	(a)
AspEW	−0.20	0.62	−0.18	0.53	ns	(a)
AspNS	−0.02	0.62	0.09	0.56	ns	(a)
Potential radiation (kWh/m^2 year)	1305.51	42.82	1307.20	24.09	ns	(a)
Distance routes (m)	88.94	100.91	28.74	15.39	**	(a)
Qualitative	**no**	**yes**	**no**	**yes**	**Sig. chi square**	
Terrace	4845	601	27	0	ns	
Contiguity pasture and forest	2265	3181	22	5	***	
	n = 5446		n = 27			
		2016				
	Meadow					
Quantitative	**Mean**	**SD**				
Superface (ha)	0.41	0.57				
Minor polygon diameter (m)	32.49	21.89				
Altitude (m)	1099.43	143.97				
Slope (°)	11.06	7.01				
AspEW	−0.25	0.57				
AspNS	0.04	0.60				
Potential radiation (kWh/m^2 year)	1307.58	37.29				
Distance routes (m)	62.43	51.97				
Qualitative	**no**	**yes**				
Terrace	2335	69				
Contiguity pasture and forest	925	1479				
	n = 2404					

Sig: significance levels; (*) = $p < 0.05$, (**) = $p < 0.01$, (***) = $p < 0.001$, ns = not significant. Test Levene (a) Equal variances are assumed.

Another aspect to consider is the geometry of the parcels in relation to the presence or not of the terrace. The comparison of the parcels with and without a terrace that in 1956 were meadows and crops according to the area and minor diameter shows significant differences (t-Student test, $p = 0.000$). Those with a terrace have smaller surface averages (0.16 ha vs. 0.33 ha) and a minor diameter (19.02 m vs. 26.06 m).

3.3. Evolution of Land Use Surface

Changes and persistence of land uses in the periods 1956–1986 and 1986–2016 are shown in surface area (ha) and in proportion of surface area with respect to the beginning of the interval in Tables S1 and S2 (Supplementary Data). Persistence of use, decreases, and increases can be observed for different uses. The net balance of the area of the meadows increases between 1956 and 1986 to 301.58% and decreases to 59.11% between 1986 and 2016. The crops, which in 1956 have an area 2.51 times greater than the meadows, are residuals in 1986 (7 ha) and 2016 (2 ha). The area of pasture (112.92% and 102.24%) and forest (103.71% and 123.22%) have an increasing trend in the two periods considered. The urbanized surface also has the same tendency but in a more pronounced way with a proportion of 217.02% in 1986 compared to 1956 and 255.22% in 2016 compared to 1986. The areas occupied by water reservoirs appear between 1956 and 1986, and they remain stable in 2016. Finally, the lands considered unproductive and the communication routes both increase their surface and that of the riverbed decreases. Synthetically, the most relevant net changes from 1956 to 1986 are the increase in meadows, the decrease in crops, the increase in urbanized areas and the appearance of reservoirs, and, from 1986 to 2016, the decrease in meadows and crops and the increase of urbanized areas.

When considering the meadows between 1956 and 1986, it is observed that 83.64% is maintained and 85.90% of the cultivation area is transformed into a hay meadow. There is also a transition to pasture (6.91%) and to forest (4.64%) and, conversely, and to a lesser extent, from pasture and forest to meadow (2.15% and 0.02%). The crops are reduced to 6.96 ha and, in addition to their transformation to grassland, they pass to pasture (6.45%) and forest (3.69%). The increase in urbanized area and reservoirs occurs on meadow land (2.64% and 1.41%) and cultivation (1.97% and 1.59%) and, in the case of reservoirs, to the detriment of forest surface and riverbeds.

In the period 1986 to 2016, there is a reduction to 59.11% of the area of meadows of 1986. Of the area of meadows of 1986, 58.58% is maintained and 23.77% is transformed into forest, 11.12% to pasture, and 6.04% to urbanized land. The rest of the changes are less important, and the cultivation area is anecdotal with 2.25 ha. It should also be noted that 20.35% of the pasture area has been transformed into forest.

3.4. Analysis of Changes or Persistence of Meadows and Crops and the Characteristics of the Parcels

The most relevant land use changes that affect meadows and crops are pasture, forest, urbanized land, and reservoirs. The increase in urbanized area and reservoirs is due to factors related to tourism and industry and, therefore, is not linked to agronomic factors. The three most important change scenarios that depend on agronomic factors are the transformation of crops to meadows and meadows to pasture and forest between 1956 and 1986 and, finally, from meadow to pasture and forest between 1986 and 2016. The following offers the analysis of the three transformations based on the characteristics of the parcels.

3.4.1. Comparison of the Characteristics of the 1956 Crop Parcels That Have Changed to Meadows versus Those That Have Been Transformed to Pasture and Forest in 1986

Of the 4605 cultivated parcels mapped in 1956 and in 1986, they have been transformed into meadow 3880 (84%) and pasture and forest 635 (14%). The comparison of the cultivation parcels that have been transformed into a meadow with respect to those that have been made to pasture and forest shows significant differences in all the variables (Tables 3 and 4). The meadows have upper averages in surface, minor diameter, orientation to the N and potential radiation, and smaller in altitude, slope, orientation W, and distance to the communication routes. The presence of a terrace on the parcel also presents significant differences and is mostly among the crops that have been transformed into pasture and forest than those that have made it into a meadow. The contiguity with polygons of pasture and forest does not show differences in the change to meadow or pasture and forest.

Table 3. Characteristics and comparison of the parcels that have been transformed into a meadow or pasture and forest in the different scenarios. Quantitative variables expressed in mean.

	Transformation of Crop to Meadow or Pasture and Forest. 1956–1986			Persistence and Transformation from Meadow to Meadow or to Pasture and Forest. 1956–1986			Persistence and Transformation from Meadow to Meadow or to Pasture and Forest. 1986–2016		
Quantitative Variables	**Meadow**	**Pasture and forest**	**Sig**	**Meadow**	**Pasture and forest**	**Sig**	**Meadow**	**Pasture and forest**	**Sig**
Superface (ha)	0.30	0.22	*** 2	0.30	0.31	ns 1	0.41	0.21	*** 2
Minor polygon diameter (m)	26.61	20.13	*** 2	24.54	25.41	ns 2	32.52	20.33	*** 2
Altitude (m)	1134.17	1212.36	*** 2	1155.62	1195.81	*** 1	1100.11	1184.58	*** 2
Slope (°)	14.98	25.92	*** 2	16.79	23.23	*** 1	11.11	19.97	*** 2
AspEW	−0.24	−0.01	*** 2	−0.11	−0.04	ns 2	−0.25	−0.18	*** 2
AspNS	0.00	−0.36	*** 2	−0.07	−0.19	** 2	0.03	−0.05	*** 2
Potential radiation (kWh/m^2 year)	1308.15	1285.81	*** 2	1298.57	1293.10	ns 2	1307.60	1303.51	** 2
Distance routes (m)	90.81	104.83	** 1	84.7	109.66	*** 1	62.73	117.84	*** 2

Sig: significance based on t-Student test: (**) = $p < 0.01$, (***) = $p < 0.001$, ns = not significant. Levene test: (1) Equal variances are assumed (2) Equal variances are not assumed.

Table 4. Characteristics and comparison of the number of the parcels (n) that have been transformed or not into a meadow or pasture and forest in the different scenarios. Qualitative variables.

		Transformation of Crop to Meadow or Pasture and Forest. 1956–1986		Persistence and Transformation from Meadow to Meadow or to Pasture and Forest. 1956–1986		Persistence and Transformation from Meadow to Meadow or to Pasture and Forest. 1986–2016	
Qualitative Variable		**no**	**yes**	**no**	**yes**	**no**	**yes**
Terrace	Meadow	3286	594	1509	7	2311	68
	Pasture and forest	247	388	200	5	2227	520
	Sig	***		**		***	
	n	3880		1516		2379	
Contiguity pasture and forest	Meadow	1900	1980	743	773	908	1471
	Pasture and forest	330	305	77	128	1124	1623
	Sig	ns		**		*	
	n	635		205		2747	

Sig: significance based on chi square test: (*) = $p < 0.05$, (**) = $p < 0.01$, (***) = $p < 0.001$, ns = not significant.

3.4.2. Comparison of the Characteristics of the 1956 Meadow Parcels That Have Been Maintained as a Meadow against Those That Have Been Transformed into Pasture and Forest in 1986

One thousand, seven hundred and sixty of parcels in 1956 meadow mapped have remained in 1986 as meadow 1516 (86%) and have evolved to pasture and forest 205 (12%). The comparison of meadow parcels that have remained as a meadow with respect to those that have been transformed into pasture and forest shows significant differences in some of the variables (Tables 3 and 4). The meadows that have been maintained present upper averages in N orientation and are lower in altitude, slope, and distance to the communication routes. The presence of terrace and the contiguity with polygons of pasture and forest of the parcel also present significant differences and are the majority among the meadows that have been transformed into pasture and forest compared to those that have remained as a meadow. On the contrary, the variables surface, minor diameter, orientation W, and potential radiation have no relation.

3.4.3. Comparison of the Characteristics of the 1986 Meadow Parcels That Have Been Maintained as a Meadow against Those That Have Been Transformed into Pasture and Forest in 2016

Of the 5446 meadow parcels mapped in 1986, 2379 (44%) have been maintained in 2016, and 2747 (50%) have evolved into pasture and forest. Among them, significant differences are observed (Tables 3 and 4) in the characteristics of the parcels. Those that have been maintained as a meadow have upper averages in surface area, minor diameter, AspNS, potential radiation and are lower in altitude, slope, AspEW, and distance to the communication routes. There are also significant differences in the presence of a terrace that indicate a greater proportion in those that are transformed into pasture and forest and those that are contiguous with pasture and forest polygons that have a greater proportion in those that remain as a meadow.

4. Discussion

The area corresponding to meadows and crops in the studied area has suffered a progressive decrease with respect to 1956 of 13.59% in 1986 and 49.02% in 2016. This reduction is linked to exogenous factors derived from changes in the productive and market systems [13,37,38], to the adaptation of the productive systems to the characteristics of the environment, and to the dynamics of the farms themselves (size, labor, capitalization capacity, inheritance, etc.) that are not contemplated here [1,39–42]. This phenomenon is not exclusive and is recognized in other mountain agro-livestock areas [14,23,43–47]. Conversely, there has been an increase in the area of forest, pasture, urbanized land, and reservoirs for hydroelectric purposes. The increase in urbanized area and reservoirs is not linked to agronomic factors. However, it should be noted that it occurs mostly at the cost of parcels of meadows and crops of optimal agronomic characteristics located in the valley bottoms and close to the communication routes.

- 1956–1986

Regarding the changes between 1956 and 1986, within the aforementioned context of loss of agricultural land, the drastic reduction of crops and the increase of hay meadows stand out. Most of the fields are transformed into meadows (85.90%) and 10.14% are transformed into pasture and forest (6.45% to pasture and 3.69% to forest). It can also be noted that, in the same period, 83.64% of the existing meadows remain, but 11.60% is transformed into pasture and forest (6.91% in pasture and 4.69% in forest). Consequently, the net balance of the area of the meadows increases between 1956 and 1986 to 301.58%, and the crops, which in 1956 have an area 2.51 times greater than the meadows, are residual in 1986 (7 ha).

In the period 1956–1986, the growth in the area of the meadows is linked to the increase in feed cattle fed in winter with hay and decrease in sheep, mule, and agricultural self-consumption [37,39,40,48,49]. At the same time, there is the transition from manual labor and transportation with horses to mechanization of forage production (tractor, mower, and baler). However, this phenomenon does not coincide, for the same period, with other valleys of the Pyrenees. According to Mottet et al. [43], the initial proportion between cultivation and meadow is much smaller (0.2), and there is a decrease in the area of hay meadow to 56% (mainly in the 60s and 70s). In other valleys [49,50], there is a substantial reduction in the meadows between 1935 and 1970. It should be noted that, in the case of the French Pyrenees, the transformation from cultivation to meadow starts at the beginning of the 20th century [44]. Our results are also discrepant, not the transformation processes, with those contributed by García Ruiz et al. [51] for the Spanish Central Pyrenees as a whole, in which the proportion of land area between cultivation and meadows goes from 7.33 in 1950 to 0.14 in 1991. Regarding the results of Fanlo et al. [52], in the Pyrenees of Lleida, similar processes are observed with a crop/meadow ratio of 2.34 in 1956 and the practical disappearance of the crop in 2000. The meadows pass from 13.99% of the surface to 11.28% not directly comparable for being the year 2000 and for not making reference to the changes of crop to meadow in 1986.

Regarding the transformations or maintenance of crops and meadows in the period 1956–1986, there are relations with the characteristics and location of the parcels (Tables 3 and 4). As noted above, the characteristics of the 1956 meadows and crops parcels are within the same range of values. In spite of this, the meadows present higher average values in altitude, slope, orientation E and S, and lower in radiation and number of parcels with terrace but not in surface, minor diameter, distance to the communication routes, and contiguity with pasture and forest polygons (Table 2). In fact, excluding parcels with terraces of very steep slopes or terraces of high areas of traditional agricultural use, crops and meadows alternated on the same parcel or were even mixed use [39,48]. Given these characteristics, the parcels that have been transformed from cultivation to meadow compared to those that have made it to pasture and forest have greater surface area, minor diameter and potential radiation, lower altitude and slope, majority orientation to N and W, are closer to the communication routes, and the majority have no terrace. In the case of the meadows, those of lower altitude and slope have been maintained, with a majority orientation to the N, closer to the roads and in greater proportion without terrace neither contiguity with pasture and forest. The characteristics of surface, minor diameter, altitude, slope, distance to the communication routes, and absence of terrace are decisive, in both cases, for the transition of the management of the meadows manually in 1956 [39] to the total mechanization of the work observed in 1986 [41,43,53]. On the contrary, the orientation and radiation, despite showing differences in some cases, do not allow a clear interpretation.

However, these parameters that are related to the change to pasture and forest are not independent. In this sense, the higher altitude and slope would have to be linked to the difficulty of establishing mechanized access tracks since they had been cultivated or meadow in 1956 when access was by means of cavalries. This is supported by the absence of differences between the meadow and crop parcels with respect to the distance to the communication routes in 1956 and the differences in 1986 when the access roads had already been built (Table 2). Lasanta [53] and Tasser and Tappeiner [54] also identify the lack of access as a priority factor in the transit from cultivation or meadow to pasture and forest. Likewise, the terraces built for the cultivation on slopes of steep slopes are related to the small area and smaller diameter and, therefore, are not suitable for mechanization. This abandonment of terraced cultivation occurs on similar dates in comparable mountain valleys, as other authors also point out [43,51,55].

Regarding meadow parcels, it is observed that those that are contiguous with pasture and forest polygons have been transformed into pasture and forest in a greater proportion than those that do not come into direct contact. On the contrary, this situation is not detected in the transformation of the cultivation parcels to meadow or pasture and forest. This fact also occurs when no differences have been found between meadow and crop parcels in 1956 in relation to contiguity with pasture and forest. It is difficult to compare with studies of other territories of similar characteristics where meadows and crops have coexisted and the contiguity with pasture and forest polygons is contemplated. Both facts could be related to the grouped arrangement in the form of contiguous terraces of the cultivation parcels and more dispersed in the case of meadows.

- 1986–2016

After the notable increase in the hay meadows between 1956 and 1986, the decreasing evolution of the meadows between 1986 and 2016 is quantitatively important. The net balance assumes that, of the 1655 hectares mapped in 1986, 978 hectares (59.11%) were passed in 2016. The transformations of the most relevant meadows in this period are pasture and forest (34.89%) and urbanized land (6.04%), and the cultures are anecdotal. The process is common to other areas of mountain meadows, but the times are not always coincident [46,55–57].

When considering the changes to pasture and forest or persistence of the meadows, it is observed that the parcels that have been maintained as a meadow are those of greater surface area, minor diameter and radiation, lower altitude, slope and distance to the communication routes, mainly oriented to the N and E, and lower proportion of terraces (Tables 3 and 4). Since practically all the meadow parcels in 1986 were mechanized, the surface reduction occurs in the most unfavorable.

However, this is not produced exclusively by the lower agronomic aptitude but by the conjunction of several factors [16].

First of all, it should be noted that, in this area of the Pyrenees, unlike other regions in Europe [7,29,44,47,58–62], there has been no intensification (sowing, irrigation, fertilization, etc.) on the part of the meadows that have allowed an increase in productivity [63] that compensates for forage production derived from the reduction of the surface. Consequently, it is possible to think that the decrease in the area of meadows is linked to the downtrend of the forage needs conserved for the period of housing. The estimated reduction in this period is 60% of the cattle [64–67].

The changes that have occurred in the structure of livestock farms also influence the reduction in the number and total area of hay meadows. The reduction in the number of farms and the increase in their surface area and in the herd size has meant simplification of management [44,68]. These management changes have been directed towards grazing meadows to the detriment of mowing or the alternation between grazing and mowing. The transformation of the hay meadow to pasture and forest is a secondary succession, with different paths and stages [17,18,25], which depends on various factors but usually involves the progressive introduction of shrubs. Even if they are grazed, the lack of mowing allows the appearance of shrubs [55,69–71] and, therefore, the consequent decrease in the amount of pasture to feed the cattle between autumn and spring.

In relation to the evolution of the meadows as they present contiguity with polygons of pasture and forest, it is observed that it is greater in those that remain as a meadow than in those that evolve into pasture and forest. Inverse phenomenon to that found in other mountain areas [70,72,73] and that may be related to parameters that have not been considered [74] as the tree border that traditionally accompanies the meadows of this area of the Pyrenees [75].

5. Conclusions

The most relevant changes in the use of hay meadows and crops between 1956 and 1986 are the general reduction of the area (13.59%), the increase in the area of meadows (301.58%), mainly to the detriment of crops, and the practical disappearance of crops. In the same period, there is an increase in the area of pastures (112.92%), forests (103.71%), urbanized lands (217.02%), and the construction of water reservoirs, mainly in fields of meadows and crops. These transformations occur at the same time as agricultural mechanization, the construction of access roads, and the increase of cattle. The mechanization requirements regarding access (altitude, slope, and distance to the communication routes) and parcel management (surface, minor diameter, slope, and terracing) determine the transit to pasture and forest of those that could be exploited as cultivation or meadow with horses and manually. The effect of the contiguity of the meadow and crop parcels with grassland or forest areas in the transformations is detected in the case of meadows but not in the case of crops.

In the period from 1986 to 2016, there is a reduction in the area of meadows to 59.11% that occurs at the same time as the decrease in the total amount cattle and the simplification of the management of the meadows by decreasing the number of livestock holdings and increase its size. The transformation occurs, as in the previous period, in favor of pastures (11.12%), forests (23.77%), and urbanized land (6.04%). Considering that, in 1986, the parcels were mechanized, those most unfavorable were transformed to pasture and forest according to the same parameters of the changes between 1956 and 1986. No effect is detected with respect to the contiguity of meadow parcels with pasture and forest areas in their transformation or maintenance.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4395/10/3/329/s1, Table S1:Changes in land use in surface area (ha) and proportion of land area (%) compared to the beginning of the 1956–1986 interval, Table S2: Changes in land use in surface area (ha) and proportion of land area (%) compared to the beginning of the 1986–2016 interval.

Author Contributions: All authors (Joaquín Ascaso, Ramón Reiné and Olivia Barrantes) have contributed to the different components of the work. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been funded by the SOS Praderas project within the Interreg Sudoe Program 2014–2020 (European Regional Development Fund (ERDF)) through the Department of Rural Development and Sustainability of the Government of Aragon.

Acknowledgments: The authors are grateful for the technical collaboration of J. Domingo and M. Gartzia (cartography), for the administration of D. Guzmán of Department of Rural Development and Sustainability of the Government of Aragon and M. Escar for the English review.

Conflicts of Interest: The authors declare no conflict of interest.

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