



Response of Pyrenean Subalpine Pastures to Continuous Climate Warming and Annual Sporadic Variations

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Abstract: The certainty of global warming is leading to the programming of activities and management practices for a future in which conditions will be very different from today. In the case of subalpine mountain pastures (or upland summer grasslands), it is necessary to know the changes that have taken place in the three most important variables: biomass production, forage quality and diversity. This work was carried out in the high-mountain pastures of the Aigüestortes National Park (located above 2000 m a.s.l.) in the Spanish Pyrenees during a period of twenty years, with sampling every five years. The three most abundant types of pasture of the National park, which occupy 60% of its area (*Festuca eskia*, *Nardus* and *Nardus+Festuca nigrescens*) were taken and used to measure aboveground biomass production by means of cuts, forage quality through bromatological analyses of biomass and Pastoral value, and the diversity through transects. Simultaneously, climatic data from three nearby official climatic stations were collected to relate rainfall and temperature variations to vegetation data. The results show that changes in total production are more linked to annual climatology (more temperature in the growth period, less production), whereas general climate warming leads to a decrease in forage quality (more temperature and more rain in the growth period, higher fiber content) and an increase in specific richness (more temperature more diversity). In the future in order to maintain these highly diverse pastures for optimal feeding of the livestock, a downward adjustment of stocking rates will have to be programmed, in accordance with production and quality trends: the pastures will feed fewer animals.

Keywords: Global Warming, Forage Production and Quality, Diversity, Spanish Pyrenees

1. Introduction

European subalpine pastures are areas of high ecological value due to their floristic composition and the environmental services that they provide by sequestering carbon, stabilizing the upper part of the watersheds and, particularly, providing a cheap and abundant resource for livestock feeding. For millennia, the entire range of the European mountains has been subject to human pressure (forestry, grazing and agriculture), which has modified species distribution and population even in remote areas [1, 2]. However, it is uncertain whether the present vegetation of the subalpine pastures is in a natural equilibrium between climate, management and ecological factors [3]. During the last

century, global surface air temperature has risen by 0.75°C according to the Fourth Assessment Report (AR4) of the IPCC [4, 5] and will continue to rise in the future due to the increase in the atmospheric concentration of greenhouse gases [6]. Plant communities are especially sensitive to fluctuation in their supported stocking rates [7, 8] and to climate warming (the increase in average temperatures and changes in annual rainfall [9-11]). The effects of climate warming on vegetation have also been verified in other mountains of the world (Asia and Europe) [12-15].

The floristic composition of the pastures may be altered by climate change, as opportunistic species can compete better through advanced phenological development [16-18] or because they have better tolerance to stress produced by warming [19, 20]. In general, pastures with high diversity

and with an old grazing history tend to support climate change better due to their greater resilience [21].

Regarding the production of aerial biomass, the results obtained so far report contradictory results, [22, 23] showing an increase in aerial biomass when high-mountain pasture fragments were experimentally transferred to areas with warmer and drier climates. One study [24] demonstrated a reduction in aerial biomass in arid pastures in a “rainfall manipulation experiment”, whereas two others [25, 26] observed no changes.

In the Aigüestortes National Park (ANP) in the Pyrenees, pastures have gone through periods of abandonment or poor exploitation [27], but have maintained their use as pastures for local cattle during the summer. The objectives of this work are 1) to check that the work area has undergone climate changes that have produced variations in average temperature and precipitation over a period greater than 50 years, and 2) to determine whether changes in mean temperature and rainfall

have influenced the characteristics of high-mountain pastures (production, quality and diversity). To this end, over a period of three years, within a period of continuous warming and decreasing of rainfall, it was studied whether changes had occurred in the biomass production, forage quality and diversity of the three most abundant types of pastures (more than 60% of the total) in the ANP, those of *Festuca eskia*, *Nardus stricta* and *Nardus+Festuca nigrescens*, and whether these sporadic climate changes can affect the vegetation’s response to the historical trend of global warming.

2. Materials and Methods

The study was conducted in the ANP (Pyrenees, Spain) during three summer periods (late July of 1995, 2005 and 2015) at 2000-2010 m a.s.l. and in the same localities and pastures (Figure 1). Neither fires, nor pests, nor diseases are disturbances typical of these pastures.

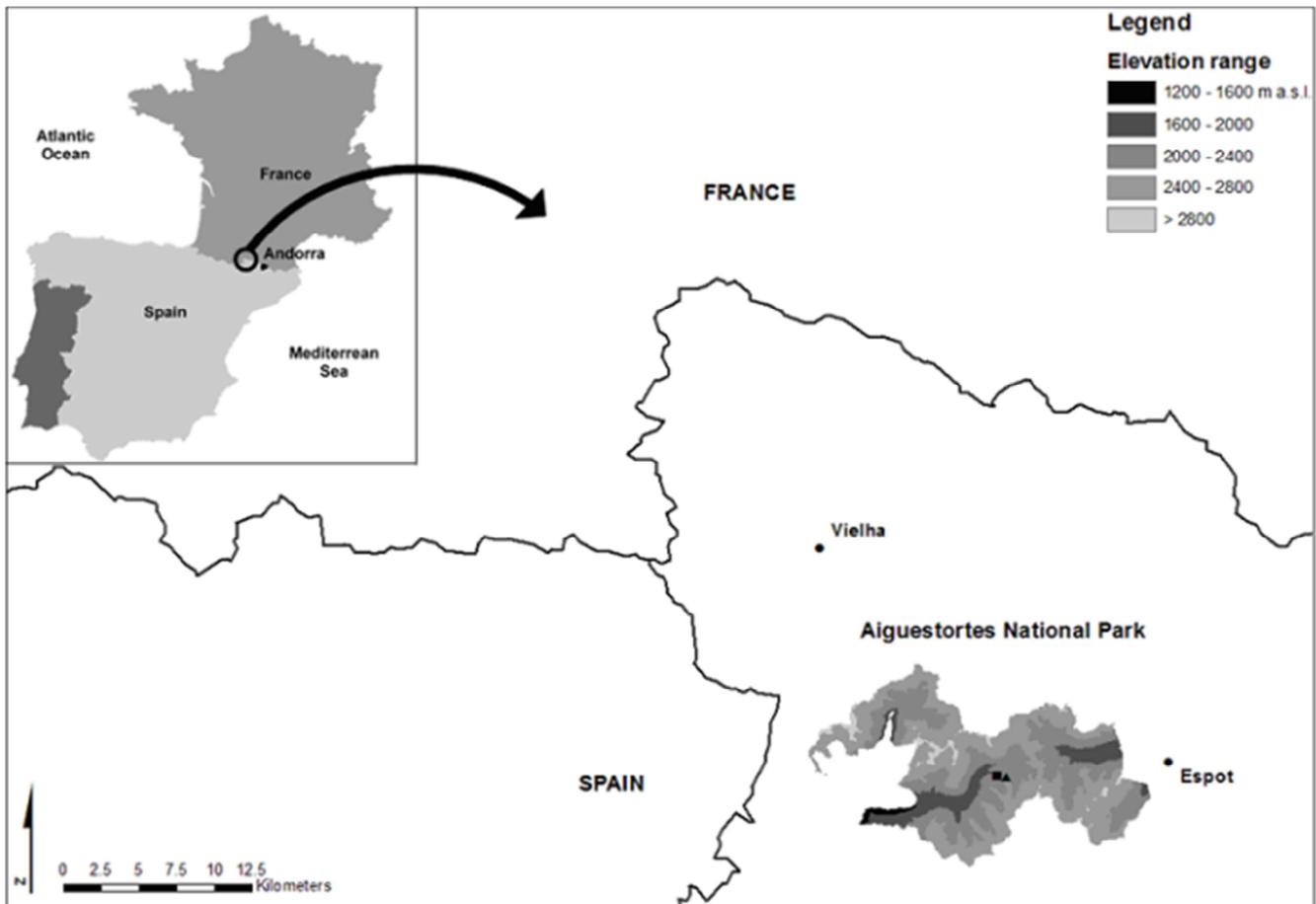


Figure 1. Location of Aigüestortes National Park in the Spanish Pyrenees.

The vegetation composition (species and abundance) was assessed using the point quadrat method [28] with transects of 20 m (100 points per transect). This method may have some limitations (loss of rare species), but it has three benefits: simplicity, large sample size and ease of analysis. In addition, two biomass cuts of 0.5 x 0.5 m were collected in the vicinity of transects for chemical analysis and production. The analysis of the biomass samples cut, and once dried at 70° for 48 h, were

analyzed in a NIRS spectrophotometer in a NIR SYSTEM 6500 [29] to calculate their nutritive components (protein, fiber, fat, etc.). The sampling was done before the arrival of the cattle to the grassland (mid July), but no exclusion from herbivory was performed thereafter, since the wild fauna, such as the chamois, stay for only a short time in these pastures before moving towards high pastures inaccessible for the cattle. The livestock are in pastures from mid-July to late September. This is

important because the stocking rate (Animal Units; per hectare and time of grazing) is one of the perturbations that most influence other variables of the pastoral system [7]. The sampling points had the same soil, orientation and range of altitudes. All the samples were replicated, generating a total of 60 transects and 120 dry biomass measurements.

Climate data covering the period from 1950 to 2015 from two official stations of the Spanish Meteorological Agency (*Agencia Estatal de Meteorología*, AEMET) located near the sampling site (to the north (42° 42' 5" N - 0° 47' 45" E) and south (42° 24' 25" N - 0° 44' 22" E), but at a lower altitude (974 and 838 m a.s.l. respectively) were used to review the variations in precipitation and temperatures. There are other meteorological stations at higher altitudes, but the data series is incomplete and starts in 2000, so was not used. The stocking rate were similar in 1995, 2005 and 2015 (0.2 AU/ha year or 0.6 in the four-month grazing period). Values of dry matter production, "Pastoral value" (forage quality measured through floristic composition method [30]), proportion of functional groups (grasses, legumes, and forbs), species richness (S), Shannon index and values from the chemical analysis of dry matter (i.e. crude protein content, crude fibre and forage units) were compared by analysis of variance (ANOVA). A repeated measures ANOVA was used to test the effect of years and pastures after the normalization of data. The pastures were compared by principal component analysis. All statistical work was carried out using the STATISTICA 6.0 program [31].

Table 1. General characteristics of the three pastures studied. Values are means for the total sampling. S, richness; H', Shannon index; CP, crude protein; CF, crude fibre; FU, forage units (energy); DM, dry matter. In columns, values followed by different letters are significantly different.

Pasture	Diversity		Grasses (% in transects)	Legumes (% in transects)	Forbs (% in transects)
	S	H'			
<i>Festuca eskia</i>	14.21b	1.86b	75.36a	2.27c	22.33b
<i>Nardus stricta</i>	19.79a	2.35a	54.52b	8.32b	36.73a
<i>Nardus stricta</i> + <i>Festuca nigrescens</i>	19.95a	2.20a	63.30b	15.77a	20.92b
LSD test $P < 0.05$	0.02 n=60	0.02 n=60	0.03 n=60	0.01 n=60	0.04 n=60

Table 1. Continued.

Pasture	Forage quality			Production	
	Pastoral value (0-100)	% CP in DM	% CF in DM	FU ha ⁻¹	DM (kg ha ⁻¹)
<i>Festuca eskia</i>	14.07b	6.09c	33.29a	824b	2756a
<i>Nardus stricta</i>	36.17a	12.17a	26.31b	2163a	1828b
<i>Nardus stricta</i> + <i>Festuca nigrescens</i>	34.32a	9.24b	31.38a	2053a	2616a
LSD test $P < 0.05$	0.000 n=60	0.000 n=120	0.000 n=120	0.02 n=120	0.03 n=120

The relationships between the variables studied in the whole sample are shown in the principal component analysis (Figure 2). As can be seen, axis 1 discriminates between climate variables (temperature and annual rainfall), crude fibre and crude protein, percentage of forbs and production (dry matter) and quality variables (protein content, forage units and legumes) linked to intrinsic aspects of the pastures.

Axis 2 opposes the proportion of grasses of the pastures against the diversity variables (richness and Shannon index),

3. Results

3.1. Characteristics of the Pastures Studied

The pastures studied belong to the type of European subalpine grasslands on acidified substrates that are covered by snow for six months (phytosociological classes *Caricetea curvulae* and *Nardetea strictae* [32]). They are a summer forage resource for feeding livestock from nearby areas and transhumant herds. Their different floristic composition affects their forage values like such as protein and fibre content, energy content (forage units, FU), production (kg of dry matter per hectare), and species diversity in terms of species richness (S) and functional group composition. The average results of all the sampling data are shown in Table 1, where it can be seen that the pastures of *F. eskia* were the worst in biodiversity and forage quality, measured as protein content and {FU}. On the other hand, those of *N. stricta* had the highest protein and energy content but the lowest biomass production and fiber percentage. Grasses were the most abundant species on all the pastures, followed by forbs and legumes. The forage quality differences of the pastures, as well as the productions, are based on their different floristic composition. These values are similar to those obtained in other areas of the Pyrenees by us ourselves and other authors [8, 33, 34, 35].

showing why pastures with a high grass content have a low diversity and a low protein content and quality. This is due to the fact that the grasses of these pastures, such as *F. eskia*, produce large, dry and persistent tillers that prevent the colonization of other species. In spite of this and the presence of endophytes in the populations of *F. eskia* from the Pyrenees [36], it has been observed that this species is eaten by cows and horses at the beginning of the grazing period.

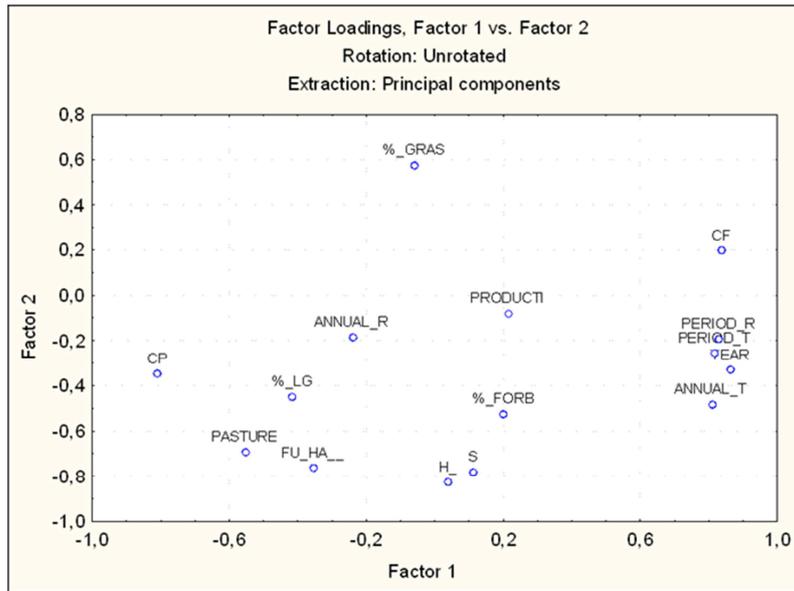


Figure 2. Principal component analysis of the total pastures variables in total sampling: LG, legumes; GRAS, grasses; FORB, forbs; CP, crude protein; CF, crude fibre; pasture, pasture type; FU, forage unit; S, richness; H, Shannon index; PRODUCTI, dry matter production.

3.2. Climatic Results

Climatic conditions at the nearby climate stations in the last 65 years show a constant increase ($y = 0,0239x + 8,9904$) in annual mean temperature and a slight decrease ($y = -0,8285x + 941,27$) in total annual precipitation (rain + snow) in the study area (following a saw-tooth pattern), with a change of trend from the average for the period (1950–2015) occurring in 1984 (Figure 3).

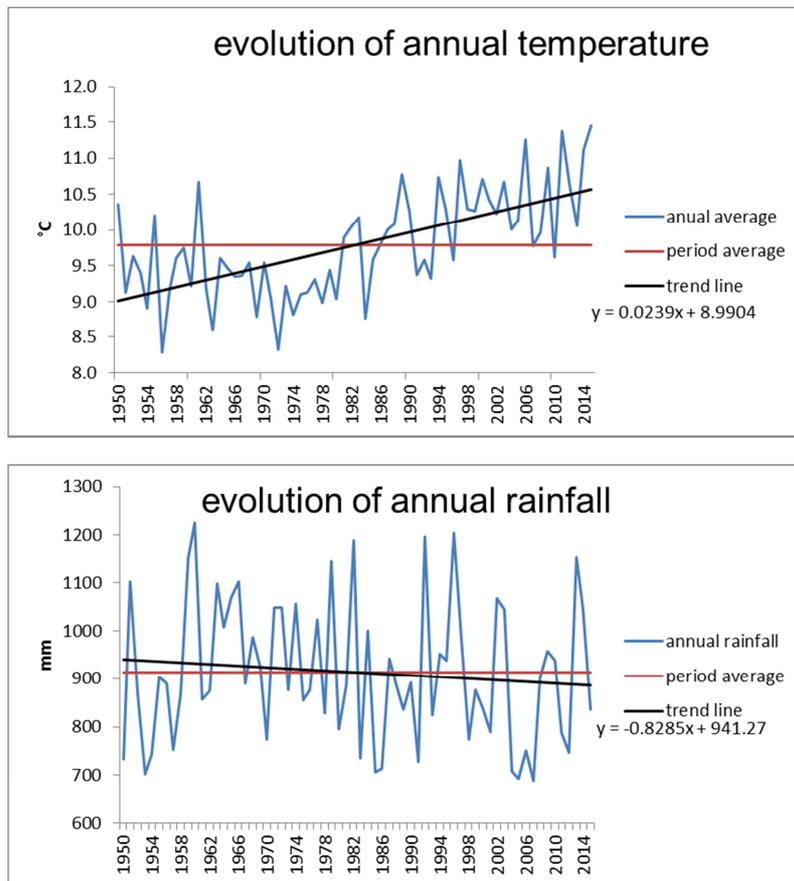


Figure 3. Evolution of average annual temperature and total rainfall in the study zone in the last 65 years. Temperature is the annual average and rainfall is the total for the year.

The calculations using climate data from stations close to the study area show a total increase in the annual mean temperature of 1.1°C and a decrease in rainfall of 102 mm in the last 65 years, with constant fluctuations that follow a saw-tooth pattern.

The three-year sampling period showed variations from the general trend (Table 2).

Table 2. Average temperature (°C) and total rainfall (mm) during the sampling years and the growth period (April to July). - In columns, values followed by different letters are significantly different at $P < 0.05$.

Sampling years	Temperature °C				Precipitation mm			
	Annual average	Difference from the 65-year average (9.79)	Average in the growth period	Difference from the 65-year average (13.95)	Annual precipitation	Difference from the 65-year average (913.52)	Precipitation in the growth period	Difference from the 65-year average (330.4)
1995	10.28a	+0.49	14.03a	+0.08	938.2	+24.68	286.45	-42.95
2005	10.14a	+0.35	15.53b	+1.58	692.7	-220.82	271.4	-59
2015	11.45b	+1.66	16.25c	+2.3	835.6	-77.92	339.45	+9.05

The growth period data included information from April to late July of the same year, corresponding to the time that elapses from the beginning of the thaw to the flowering of most species. In terms of temperature, the sampling years showed a progressive warming, and total precipitation showed a gradual decrease, except in the growth period of 2015, highlighting 2005 as an extremely warm year.

3.3. Effects of Continuous Warming on Pasture Diversity

Data from the last 65 years corroborate a progressive warming of the study area (1.2°C in total), which is in

agreement with the results obtained by the IPCC of 2014 [37] of 0.2°C per decade in the whole of the Pyrenees. However, the diversity values indicate a positive trend: a significant increase in species richness and Shannon H' index on all pastures, which is not counteracted by sudden annual changes in temperature or rainfall (Table 3).

This increase in richness is due to the increase in forbs species, whose proportion correlates positively with the increase in annual temperature (significant value of 0.5, Table 4) and negatively with annual precipitation (rain and snow accumulated from the spring of the previous year until the moment of sampling).

Table 3. Forage quality variables (CP, CF, FU), diversity (S, H') and dry matter production (DM) from the sampling years in the three pastures studied. CP, crude protein; CF, crude fibre; FU, forage units (energy); S/H', diversity index: (richness and Shannon); DM, dry matter production, kg/ha. In the columns, values followed by different letters are significantly different for $P < 0.05$ (least significant difference test).

year	<i>F. eskia</i>					<i>Nardus</i>					<i>Nardus + F. nigrescens</i>				
	CP	CF	FU	S/H'	DM	CP	CF	FU	S/H'	DM	CP	CF	FU	S/H'	DM
1995	10.a	35.3	734.6	12.5b/1.8b	2815a	13.2a	22.6	1967	18.2b/2.2	1719b	13a	25b	2110.1	16.3b/1.9b	2746a
2005	6.9b	32.4	681.3	14.8b/1.9b	1651b	15.3a	22.6	244.0	25.3a/2.6	1917b	12a	24b	1942.2	22.8a/2.2a	1228b
2015	5.4b	33.6	967.5	18.2a/2.2a	2966a	9.8b	27.4	1887	23.7a/2.6	2020a	8.3b	33a	2163.3	23.8a/2.4a	2762a

Table 4. Matrix of correlations between studied variables; values in bold are significant (r ; rainfall; t , mean temperature, annual and growth period). DM, dry matter production, kg/ha; FU, forage unities-energy; CP, crude protein; CF, crude fibre; S/H', diversity index: (richness and Shannon); LG, legumes; GRAS, grasses; FORB, forbs. Marked correlations are significant at $P < 0.05$.

	year	pasture	annual t	growth period t	annual r	growth period r
year	1.00					
pasture	-0.2	1.00				
annual t	0.8	-0.1	1.00			
growth period t	0.9	-0.2	0.7	1.00		
annual r	-0.4	0.2	0.1	-0.6	1.00	
growth period r	0.7	-0.2	0.9	0.6	0.1	1.00
DM	0.1	-0.2	0.2	-0.6	0.3	0.20
FU/ha	0.00	0.7	0.1	0.0	0.0	-0.16
CP	-0.5	0.8	-0.5	-0.4	0.1	-0.56
CF	0.5	-0.6	0.6	0.5	-0.1	0.65
S	0.5	0.5	0.3	0.5	-0.3	0.12
H'	0.3	0.5	0.3	0.3	0.0	0.04
% GRAS	-0.1	-0.3	-0.4	0.1	-0.6	-0.14
% LG	-0.2	0.4	0.0	-0.3	0.4	-0.16
% FORB	0.2	0.2	0.5	0.0	0.5	0.23

Table 4. Continued.

	DM	FU/ha	CP	CF	S	H'	% GRAS	% LG	% FORB
year									
pasture									
annual t									
growth period t									
annual r									
growth period r									
DM	1.00								
FU/ha	-0.01	1.00							
CP	-0.30	0.59	1.00						
CF	0.25	-0.40	-0.78	1.00					
S	-0.05	0.69	0.29	-0.09	1.00				
H'	0.16	0.63	0.25	-0.17	0.8	1.00			
% GRAS	-0.22	-0.17	0.06	-0.09	-0.1	-0.3	1.00		
% LG	0.10	0.42	0.31	-0.39	0.2	0.2	-0.40	1.0	
% FORB	0.15	0.10	-0.14	0.17	0.1	0.4	-0.91	0.1	1.0

As shown in Figure 3, the increase in the annual mean temperatures and the decrease in rainfall during the last few years are not progressive but follow a saw-tooth pattern. It has been verified that the floristic composition of the pastures in functional groups (grasses, legumes and forbs) is altered

by specific changes of temperature and rainfall, both annually and during the growth period (Figure 4). The year 2005 showed differences in precipitation from 1995 and 2015 in both the total and the growth period (Table 2).

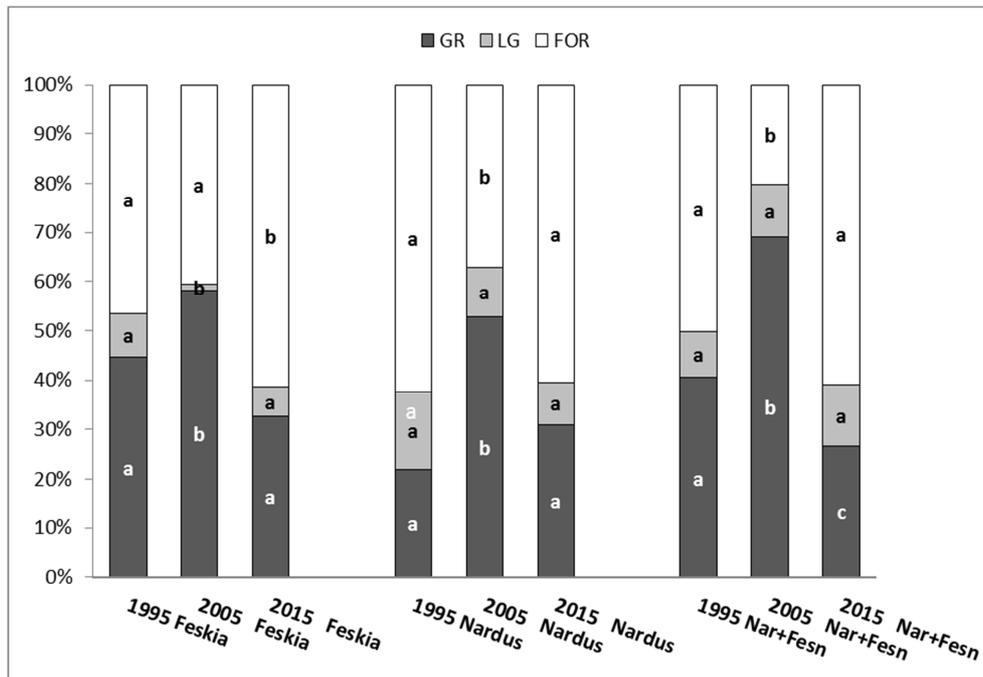


Figure 4. Evolution of functional groups (%) in the three pastures. GR, grasses; LG, legumes; FOR, forbs. Lower-case letters compare the same functional group in the same pasture between sampling years at $p < 0.05$.

Also, the mean annual temperature dropped in 2005 but increased during the growth period, leading us to conclude that 2005 was a dry year with a positive trend of temperature increase, showing 221 mm less rainfall than the 65-year average. This decrease influenced the proportion of functional groups of the pastures, because in 2005 there was a significant increase in the proportion of grasses at the expense of legumes in the *F. eskia* pastures and at the expense of forbs in the *Nardus* pastures (Figure 4); these proportions fell again in 2015 when annual rainfall increased.

This effect is corroborated by the correlations between the climatic variables and the percentage of each group (Table 4): the wetter the years, the lower the proportion of grasses and the higher the proportion of legumes and forbs.

3.4. Effects of Continuous Warming on Forage Quality

Given that these pastures are used to feed the livestock of the area, it is interesting to determine how their food value has changed in recent years. The protein content of the pastures shows a significant negative correlation when there

is an increase in mean annual temperature, growth period temperature and growth period rainfall, whereas the fibre content shows an increase when the above variables increase (Table 3 and 4). On the other hand, there is no relationship between the energy content of the pastures (FU) and environmental changes. In conclusion, progressive warming induces a loss of the food quality (protein) of these pastures and the tendency is maintained by annual changes.

3.5. Climate Warming and Biomass Production

In this work, DM (dry matter) production showed no general trend, but was positively affected by total annual rainfall (significant correlation 0.3, Table 4), decreasing in 2005 to 221 mm less than the 65-year average. The increase in rainfall in the growth period may explain the increase in biomass production of pastures in 2015 compared with the other sampling years (see the results for DM production in Table 3). On the other hand, a temperature increase in the growth period reduces production, because the "spring" time of species development is shortened (significant correlation -0.6).

4. Conclusions

The results obtained from the climatic data studied (1950 to 2015) are in line with those of the OPCC1 project, although they find a temperature warming of 1.2° higher than ours which is 1.1° [38]. The annual accumulated precipitation measured by us shows a decrease in the last 65 years, a similar effect to that obtained in OPCC1 project.

The majority of studies carried out predict a generalized loss of species due to progressive global warming, or a displacement of species towards higher latitudes in both Europe and North America [39-43]. In the case of the species of pasture communities located in subalpine mountain areas, the disappearance may be due to phenological and physiological changes that alter the growth of the species [44], but these communities can also be enriched by the arrival of warmer-climate species that compensate for any losses. The latter is what happens in the pastures studied: over the years the specific richness (S) and the Shannon index (H') have increased significantly.

As stated in the introduction, the results obtained in other works regarding the effect of warming on the production of biomass do not show a clear relationship. This may be because some measurements were taken through experiments [23, 45] consisting of moving turf from mountain pastures to lower altitudes with milder winter temperatures, obviating the fact that mountain pastures are usually covered by snow for a period of 4-5 months. Also, one study [46] made changes in temperature, rainfall, radiation and snow persistence in an "in situ" climate manipulation experiment designed to study the responses of an ungrazed subalpine meadow to climate warming, but they found contradictory results according to the groups of species: shrubs increased the biomass, graminoids showed no differences and forbs diminished in response to warming. The real conditions of

our study show a significantly positive relationship of annual rainfall with production and a negative one with temperature in the growth period.

The future seems bleak for the management of grazing in high-mountain pastures. It would be advisable to warn farmers that, if the mean annual temperature and the growth period temperature increase, the forage will lose quality due to the decrease in the percentage of good species such as legumes, and consequently protein, and a progressive increase in forbs, which have a high proportion of fibre. This process may also be accompanied by a decrease in biomass if the growth period temperature rises, although this may be compensated in the rainiest years.

It is curious to observe in one of the last published works [47], that the driving forest dynamics at the tree line in the Catalan Pyrenees is more related with the impact of the cessation or decrease of pasture grazing, that with the climate change effect. These results, together with our research, corroborate the need to maintain livestock grazing on these pastures.

Consequently, in order to maintain these diverse pastures for optimum feeding of livestock, a downward adjustment of stocking rate will have to be programmed, in accordance with production and quality trends: the pastures will feed fewer animals in hot years (less forage and less protein). On the other hand, the results suggest an increase in species biodiversity in pastures, with the arrival of other species and a development of opportunists.

Author Contributions

All authors listed, have made substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflicts of Interest

The authors declare that they have no competing interests.

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