LIFE MIDMACC

Mid-mountain adaptation to climate change

LIFE18 CCA/ES/001099

Start date of the project: 1st July 2019

Duration of project: 5 years

Deliverable 14

Report with the 1st year monitoring results of the implementation action C2

Due date of deliverable: 12-2021

Actual submission date: 12-2021

Beneficiary leading this deliverable: CREAF

Dissemination level: Public

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Cite as

Pascual D, Pla E, Nadal-Romero E, Lasanta T, Zabalza J, Foronda A, Pueyo Y, Reiné R, Barrantes O, Lana-Renault N, Ruiz P (2021) Report with the 1st year monitoring results of the implementation action C2. Deliverable 14 LIFE MIDMACC.

Executive summary

This deliverable presents the results obtained from monitoring of the pilot experiences during the first year of the monitoring. The pilot experiences were mainly implemented by the end of 2019 and the beginning of 2020, the setting of initial monitoring variables was performed in 2020 and the first monitoring campaign has been realized in 2021, between May and November 2021.

Following the monitoring protocol developed in deliverable 9 (Pascual *et al.*, 2020b), this document includes the first results obtained in the pilot experiences of forest management for fire risk prevention and maintenance with extensive livestock farming in Aragon and Catalonia.

The first section is a short introduction to the deliverable, with a briefly description of the pilot experiments and the main objectives of this deliverable. The second section summaries the monitoring protocol, to have a quick overview of the monitored variables. The third, fourth and fifth sections detail the results of the first monitoring campaigns, in both sites of Aragon and Catalonia. Finally, the sixth section summarizes the main outcomes found in the first monitoring campaign.

Content

1. Introduction

The main objective of the LIFE MIDMACC project is to promote **adaptation to climate change through the implementation and testing of different landscape management measures** in mid-mountain areas of Spain: scrubland clearing, forest management and different assays in vineyards in three study areas (Aragon, La Rioja and Catalonia).

The demonstrative activities have been performed in different pilot sites representative of Mediterranean mid-mountain areas. Once the demonstrative activities have been installed, a **monitoring network has been designed, implemented and started**. The objective of the monitoring is to evaluate the efficiency of the demonstrative activities to improve the adaptation capacity to face climate change threatens and to improve the socioeconomic development of the mid-mountain areas where the landscape management measures have been implemented.

In this report, we present the **results of the first monitoring campaign** related to forest management activities to diminish forest fire risk and improve livestock grazing, carried out in Aragón and Catalonia. Forest adaptive management has consisted on the thinning of trees and scrubland clearing in wooded areas in Aragon (La Garcipollera) and Catalonia (Requesens-l'Albera). In this case, the monitoring campaign has been accomplished along 2021, ending in November. First results monitoring the soils, forests, pastures, infiltration and erosion, and meteorological variables are shown in the following chapters

2. Summary of the monitoring protocol

Deliverable 9 (Pascual *et al*., 2020b) collects all aspects related with the monitoring of pilot experiences. Following, Table 1 summaries the monitored variables in the forest management pilot experiences in Aragon and Catalonia. A more detailed description of each variable, the means to measure, frequency and specifications can be consulted at Pascual *et al.*, 2020b.

	Variable	Measured variables	Methodology	Periodicity
Soil	**Soil characteristics**	Field bulk density pH and electrical conductivity Total carbon concentration Total nitrogen concentration Carbonate content Organic carbon Soil organic carbon and nitrogen stocks Organic matter ¡ Grain size distribution Organic phosphorus Saturated soil moisture Field capacity Wilting point CN ratio	Soil sampling Soil analysis	Initial (2020) Final (2024)
	Soil moisture	Soil water content (SWC)	Humidity sensors and data-loggers	Continuous (2020-2024)
Forest	**Forest structure**	Tree density (trees/ha) Diametric class distribution Tree height (m) Resprouting Canopy cover (%)	Forest inventory	Initial (2020) After implementing the adaptation measure (2020) Final (2024)
	Forest fuel continuity	Crown fire hazard Fuel type cover (%) Fuel height (m) Distance between fuel types (m) Understorey biovolume	Fuel identification and classification Strip biomass transects	Initial (2020) After implementing the adaptation measure (2020) Annual survey (autumn 2021-22-23) Final (2024)
	Forest health status	Forest decline (%) Tree mortality (%) Defoliation (%) Decolouration (%)	Forest health sampling	Initial (2020) After implementing the adaptation measure (2020)

	Variable	Measured variables	Methodology	Periodicity
				Annual survey (autumn 2021-22-23) Final (2024)
	Fuel moisture	Relative water content (RWC)	Forest fuel sampling	Nine measures per year during summer during 4 years (2020-2021-2022-2023).
Pastures	**Biodiversity**	Species richness Specific diversity (Shannon-Wiener index) Species composition (Sorensen index) Species coverage (%) Relative abundance of plant functional types Relative abundance of grasses	Vegetation surveys / sampling	Surveys in late spring: initial (2020), intermediate (2022) and final (2023).
	Pasture production	Yield (kg DM/ha)	Vegetation sampling Sample processing	Surveys in late spring: initial (2020) and final (2023)
	Pasture nutritive quality	Crude protein Cellulose Hemicellulose Neutral-Detergent Fiber (NDF) Acid-Detergent Fiber (ADF) Acid-Detergent Lignin (ADL) Acid-Detergent Ashes (ADA) Digestibility indicators: Digestible Dry Matter (DDM), Dry Matter Intake (DMI) Relative Feed Value (RFV)	Sample processing Chemical analysis	Surveys in late spring: initial (2020) and final (2023)
Rainfall simulation	**Hydrological response and soil erosion**	Runoff coefficient Infiltration rate Time to runoff Ponding time Wetting front Sediment concentration Sediment production Sediment detachment	Rainfall simulation experiments	After clearing (2020) Annual simulations (2021-2022-2023) Final (2024)

	Variable	Measured variables	Methodology	Periodicity
Site meteorological conditions	**Precipitation**	Precipitation	Pluviometers (only in La Garcipollera, Aragon)	Continuous (2020-2024)
	Temperature and relative humidity	Temperature Relative humidity	Temperature and relative humidity data loggers	Continuous (2020-2024)
	Meteorological variables	Maximum temperature Minimum temperature Precipitation Radiation Wind speed	Meteorological station (only in Requesens, Catalonia)	Continuous (2020-2024)

Table 1. Summary of the monitored variables in the forest management pilot experiences in Aragon and Catalonia.

3. Results of the 1st monitoring campaign in the *Pinus nigra* forest, Aragon

The pilot experience has been implemented in La Garcipollera Research Station (Central Pyrenees, Huesca, Spain) in two forests: a reforestation forest of *Pinus nigra* and a mix-forest of a *Fraxinus*. This chapter includes the results of the 2021 campaign in the *Pinus nigra* forest.

Following, we include a summary of the implemented pilot experience and the experimental design of the monitoring network, to facilitate the understanding of the monitoring results. A more detailed description of the implemented actions can be consulted at Pascual *et al.* (2020a, 2020b).

Implemented pilot experience

- Adaptive forest management in 0.58 ha plot consisting in scrubland clearing
- Control plot: An area with no actuation of 0.55 ha.

Monitoring network:

- Three typologies of monitoring plots with a surface of 400 m^2:
  - control plots, without neither forest management nor the entry of livestock (BC);
  - managed plots with livestock (BS);
  - managed plots without livestock (BN).
- For each of monitoring plots, three replicates (B1S-3S-5S, B2N-4N-6N), except in the control area where there was only space for two replicates (BC1-2).

The monitoring network includes three plots of 400 m^2 with its replicates, eight monitoring subplots of 400 m^2 in total (Figure 1).

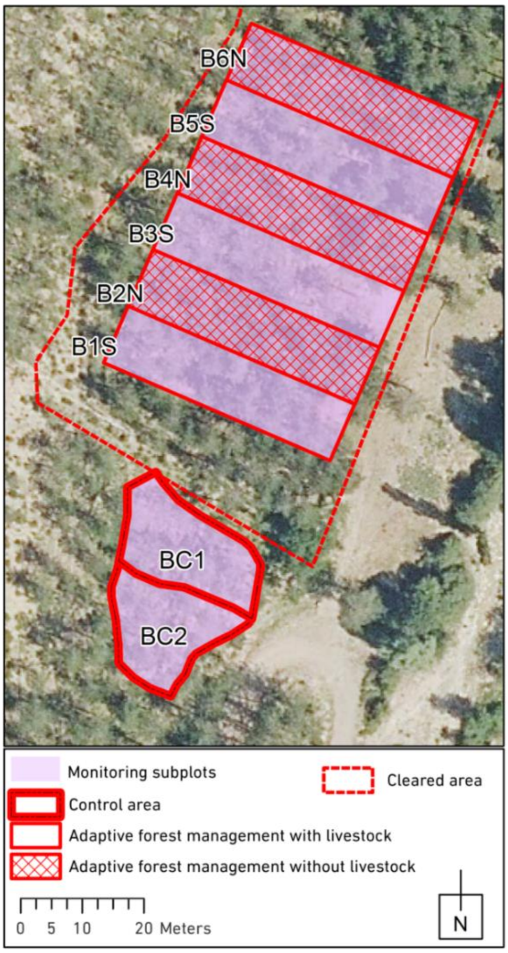


Figure 1. Location of the monitoring plots and replicates of the experimental design.

3.1. Monitoring results of the Soil

3.1.1. Soil characteristics

The initial monitoring variables were carried out in February and June 2020 and the first year monitoring campaign is being carried out at the end of 2021, once the animals have entered three times in the experimental plots (spring, summer and autumn 2021).

At each monitoring subplot, three soil samples were sampled with an auger at 10 cm increments: 0 cm, 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm. In each site, 45 points were selected, and 225 subsamples were recorded and later combined into one soil composite sample per plot and depth. In total 75 composite samples were created in La Garcipollera.

The 75 samples have been analysed by the Pyrenean Institute of Ecology (IPE-CSIC), evaluating the following soil variables: Field bulk density (BD), pH and electrical conductivity (EC), total carbon concentration (Ctotal), total nitrogen concentration (N), carbonate content (CaCO3), organic carbon (Corg), soil organic carbon (SOC) and nitrogen (TN) stocks, organic matter (OM), grain size distribution, organic phosphorus (P), saturated soil moisture (SAT), field capacity (FC), wilting point (WP) and CN ratio.

The following figures present the mean values and standard deviation of the main soil physical and chemical properties (at four depths 0-10, 10-20, 20-30 and > 30 cm) measured in the experimental plots during the initial monitoring variables in La Garcipollera Research Station. Statistical results did not show significant differences between the management plots and the control plots at initial conditions.

Figure 2 shows that all the samples presented pH values higher than 7, corresponding to basic soils (ranging between 7.7 and 8.4). pH values slightly increased with depth in all the cases. In the case of electrical conductivity (Figure 3), mean values in the mineral soil ranged between 129 and 284 µs/cm, being these values higher in the topsoil samples. Organic horizons displayed higher values closed to 500 µs/cm.

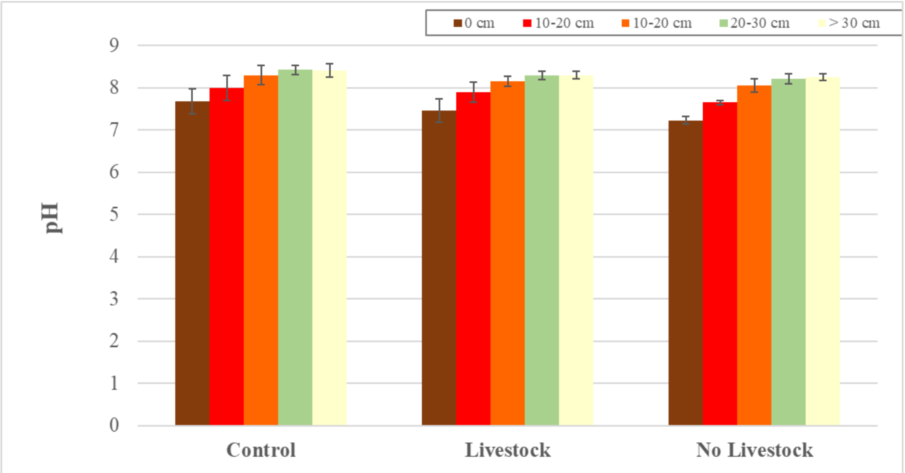


Figure 2. pH values of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Figure 4 presents the mean Corg and N contents. It should be highlighted the high values obtained in the organic topsoil samples (0 cm), with mean values higher than 10. In all the cases, values decreased with depth. Values in the mineral soil samples ranged between 1.5 and 5.8%. Nitrogen values followed the same pattern and mean values in the mineral samples oscillated between 0.1 and 0.4%. In both cases, high standard deviations were obtained in livestock and no livestock plots in all the depths.

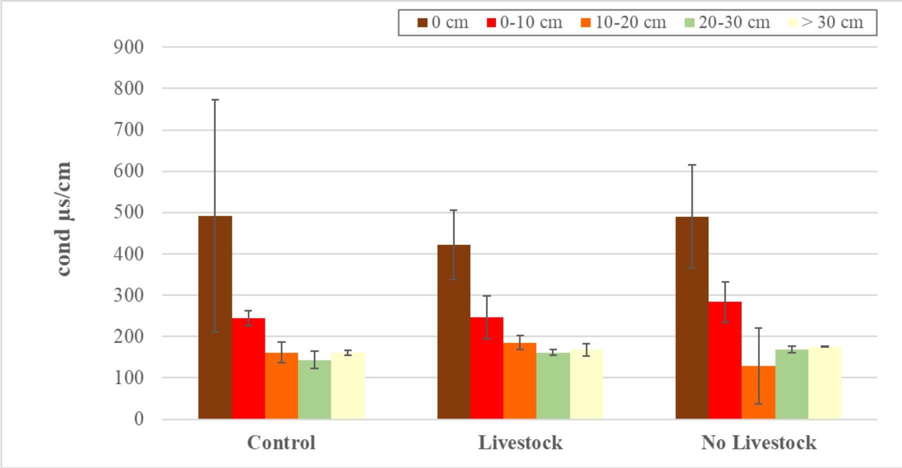


Figure 3. Conductivity values of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

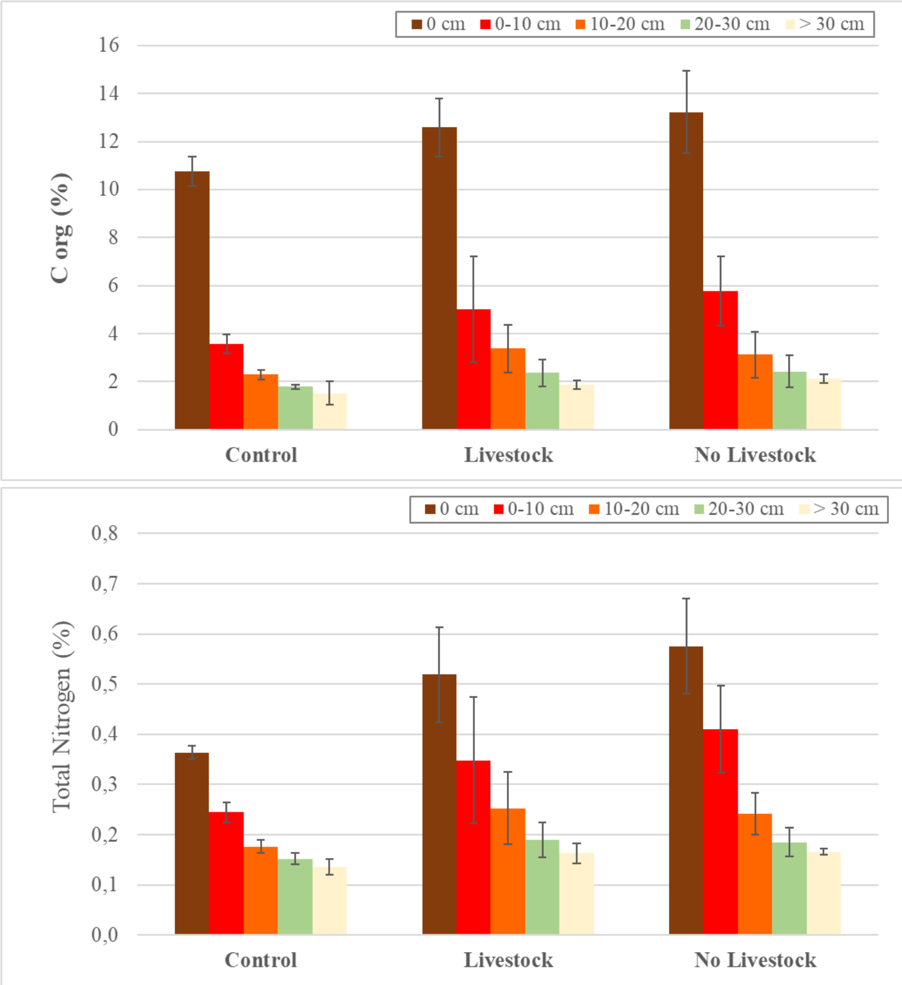


Figure 4. Organic Carbon (C org) and Nitrogen (N) content of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Corg/N ration is an index of the quality of the soil organic substrate. Excluding the organic horizon (0 cm), the Corg/N ratio values varied between 11.1 and 14.6. Lower values were obtained in depth (Figure 5, up). These values indicate that the soil is equilibrated and exist a control between mineral nitrogen and carbon in the soil.

P values sharply decrease in depth (Figure 5, down). Maximum values were around 10 mg/kg P, and minimum values are around one. High standard deviations are recorded in all the cases. Higher values were recorded in the livestock and no livestock plots, probably due to the previous use of the managed area by livestock (cows) and wild animals.

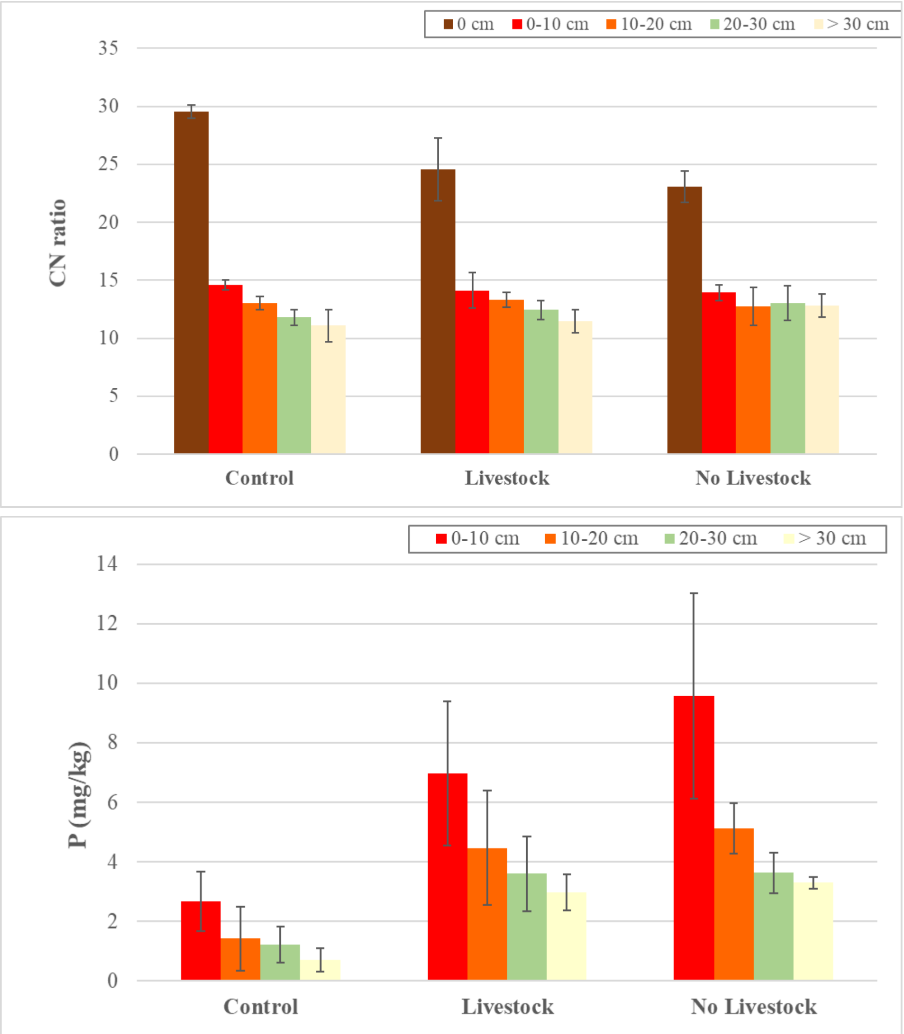


Figure 5. Organic carbon and Nitrogen ratio (CN ratio) and phosphorus (P) content of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Figure 6 shows the CaCO3 content. Values between 39 and 45% were obtained, related to a calcareous lithology in the study area. Low values were recorded in the topsoil, suggesting dissolution processes in the soil.

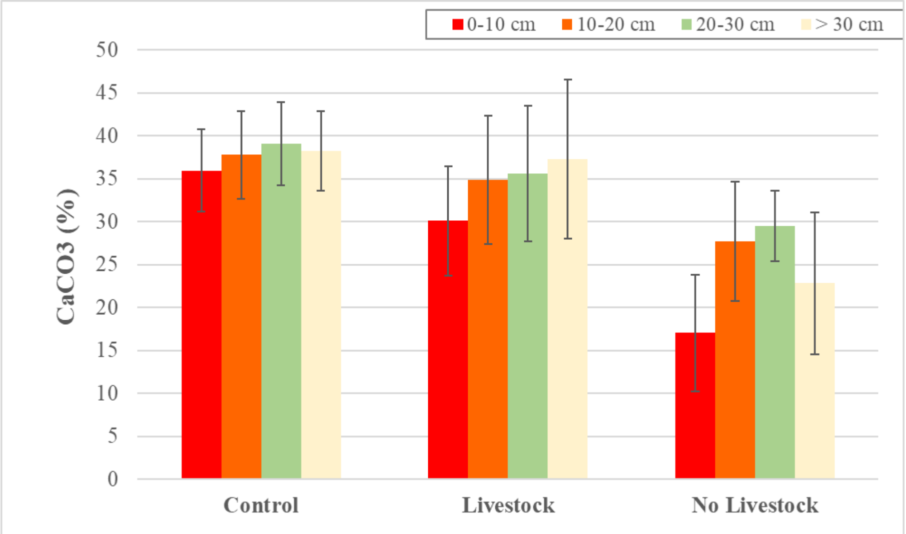


Figure 6. Carbonate content (CaCO3) content of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Figure 7 presents the texture diagram representing the percentages of clay, silt and sand of the different soil samples. Most of the soil samples present a clay texture. Clay values oscillated between 43 and 61%, silt values between 31 and 38%, and sand values between 8 and 19%.

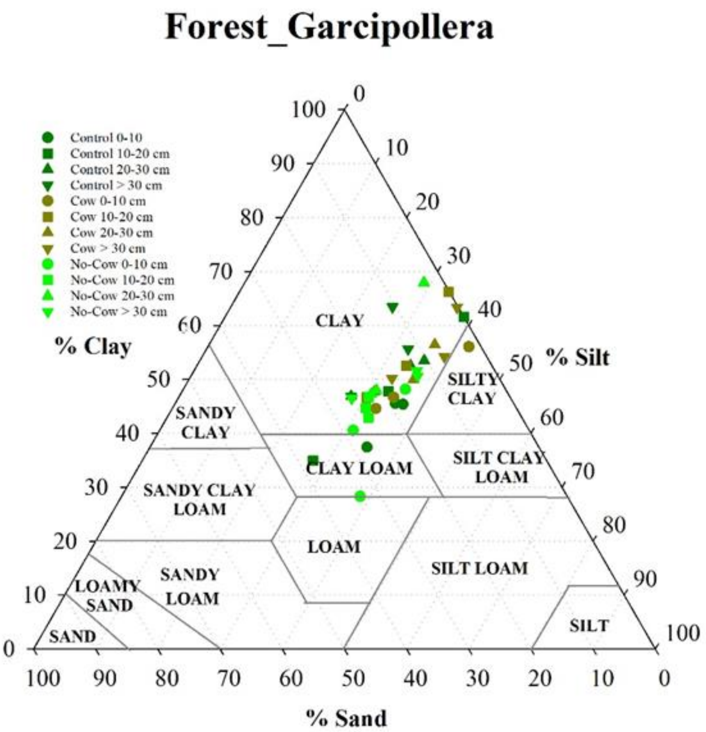


Figure 7. Clay, silt and sand contents (texture) of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Finally, Figure 8 presents the soil organic carbon and nitrogen stocks of the complete soil profile. No significant differences were observed considering the complete profiles, neither considering the different depths. That is a good point, as we can consider that the initial conditions are the same in all the pilot plots. SOC stocks ranged between 120 and 160 Mg ha-1 and N stocks between 10 and 12 Mg ha-1.

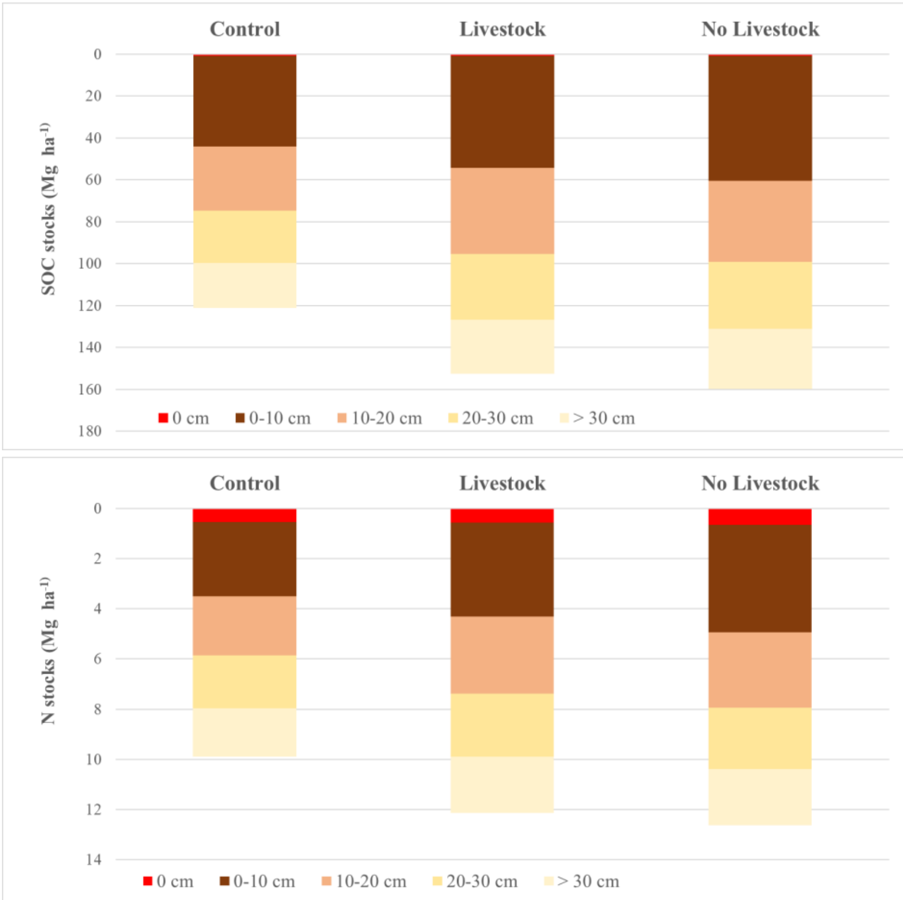


Figure 8. Soil organic carbon (SOC) and nitrogen (N) stocks of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

The first year monitoring campaign carried out in autumn 2021 will provide the first results about the changes occurred in the main soil properties related to carbon and nitrogen in the first 10 cm.

3.1.2. Soil moisture

The sensor network installed to monitor the evolution of the water in the first 20 cm of the soil has been continuously recording since the installation. In the *Pinus nigra* forest, the network consists on 2 dataloggers, one in the treatment plots and another in the control plot. Those dataloggers are connected to two soil moisture sensors in the managed area with livestock, two in the managed area without livestock and two in the control area. In total, 2 dataloggers and 6 soil moisture sensors have been installed (Figure 9).

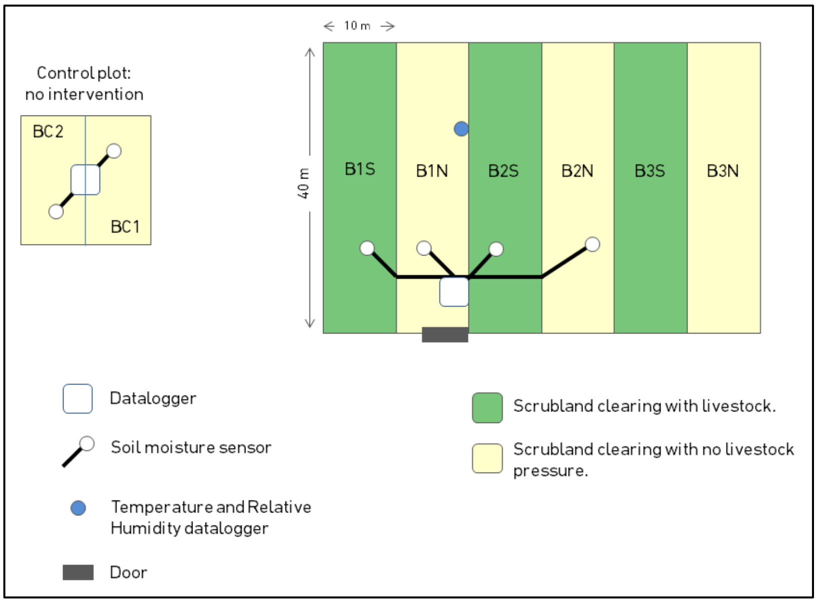


Figure 9. Initial diagram of the soil moisture instrumentation.

However, this initial design was modified along 2021 to solve several problems found. In the original design, one soil moisture sensor was placed in each of the plots B1S, B1N, B2S and B2N. The sensors have a length of 5 m. Thus, the sensors in B1S and B2N needed an extension connector cable to arrive to the subplots, and the connection between the sensors and the cables failed several times due to the entrance of water. For this reason, the extensions were removed from the field and the initial diagram was modified, having now the four sensors directly connected to the datalogger without any extension cable. Thus, plots B1N and B2S now have two sensors each (Figure 10). Since the sensors were change, there were no further failures.

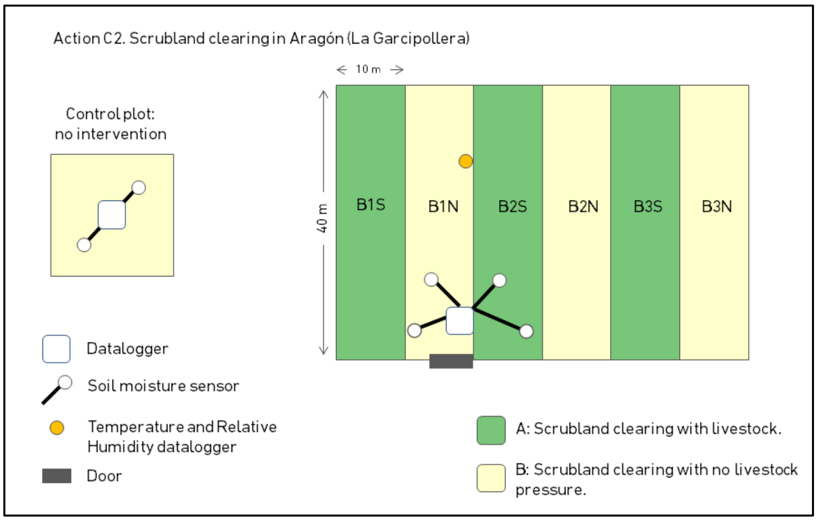


Figure 10. Final diagram of the soil moisture instrumentation.

Figure 11 shows the soil moisture data recorded every hour by the soil moisture sensors installed in the control plot and the mean of the replicates in the plots with and without livestock, together with the rainfall recorded at the AEMET station in Bescós de La

Garcipollera. Despite the lack of data for the periods 23-09-2020 to 11-11-2020 and 15-12-2020 to 02-03-2021, the figure shows the good response of the sensors to the recorded rainfall events, as expected higher values were observed after rainfall events. More results are needed to start extracting conclusions when comparing among treatments and with the control subplots.

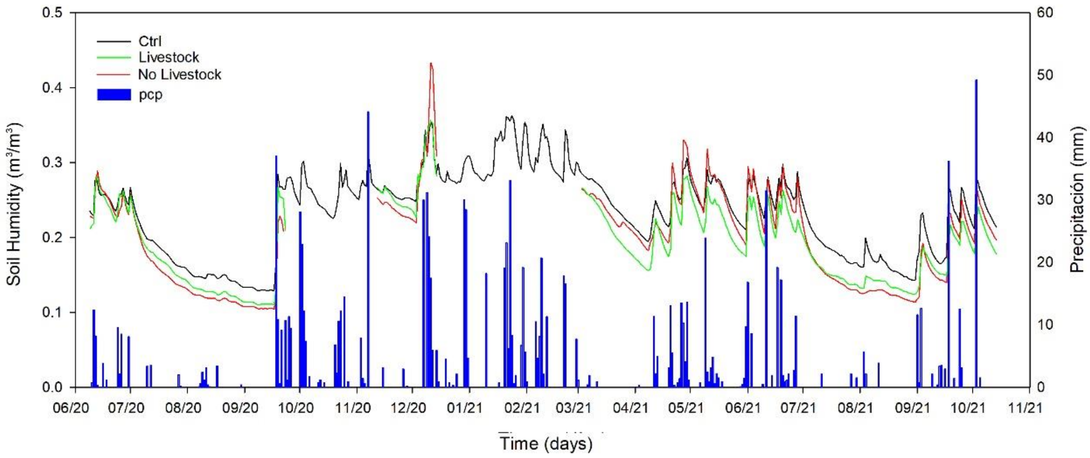


Figure 11. Soil humidity and precipitation in the Pinus nigra experimental plot (La Garcipollera).

3.2. Monitoring results of the Forest

A network of forest indicators or variables has been designed and monitored, based on installation of permanent inventory subplots. In the *Pinus nigra* forest, the network consists of eight rectangular subplots with an area of 400 m^2 (Figure 1). The shape and the surface of the inventory subplot is determined by the size of the monitoring plots. The forest inventory subplots occupy the whole surface of the monitoring plots.

The initial forest inventory was carried out on June 2020, with the objective to set the initial conditions of the forest stand, to follow up its evolution on time. The second inventory was performed between May and November 2021, corresponding to the first monitoring campaign.

3.2.1. Forest structure

Forest structure refers to the distribution and characteristics of the individual trees within the subplot. The monitoring of the forest structure was performed initially and after implementing the forest management, and the differences between both situations were detailed explained at Pascual *et al.* (2020a).

Forest structure will be evaluated again at the end of the project, to compare the initial conditions with the final ones. For this reason, forest structure has not been monitored in the 1st monitoring campaign and results are not shown here.

3.2.2. Forest fuel continuity

Forest fuel continuity refers to the spatial distribution and height of the different strata of the fuel (aerial, ladder or surface cover), which has a direct effect in the vulnerability of the forest to fire risk due to fire propagation. Forest fuel continuity is quantified with two indicators: crown fire hazard and understorey biovolume.

Both indicators are assessed initially, after implementing the forest management, annually (in autumn, only crown fire hazard) and at the end of the project. In this case, as it was explained in Pascual *et al.* (2020a), the initial and after implementation inventories were coincident in July 2020. The annual inventory was performed in November 2021 during the first monitoring campaign.

Table 2 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the 1st monitoring campaign in 2021. Two years is a short series to see results regarding crown fire hazard. Besides, we reported some mistakes in the initial survey (2020) regarding the cover of superficial fuel, for this reason the data from 2020 has to be interpreted in the light of future surveys. Nevertheless, we do not observe big changes between the two surveys.

Forest inventory subplot	After implementation 2020		Annual campaign 2021	
	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard
BC1	B13	Moderate	B13	Moderate
BC2	C12	Low	C12	Low
B1S	A5	High	A5	High
B3S	C12	Low	A5	High
B5S			C12	Low
B2N	A5	High	A5	High
B4N	C12	Low	B13	Moderate
B6N	B13	Moderate	B13	Moderate

Table 2. Crown fire hazard after implementing the forest management (2020) and in the 1st monitoring campaign. The data of B5S in 2020 was missed.

3.2.3. Forest health status

Forest health refers to the status of the forest decline due to climate change effects (mainly droughts) or other related threatens (plagues, diseases …). Forest decline is defined by the degree of defoliation, decolouration or mortality of the individuals of the forest.

Forest health status is assessed initially, after implementing the forest management, annually (in autumn) and at the end of the project. In this case, as it was explained in Pascual *et al.* (2020a), the initial and after implementation inventories were coincident in July 2020. The annual inventory was performed in November 2021 during the first monitoring campaign.

Table 3 shows the forest decay after the implementation of the forest management and after the 1st monitoring campaign in 2021. In 2020, forest decay did not show significant initial differences among treatments. Similar to previous year, in 2021 forest decay didn't show significant differences yet among treatments (Figure 12, left). Data shows that forest decline has worsened in all subplots, starting from a mean forest decay of about 8% in 2020 to a mean value of about 31% in 2021 (Figure 12, right).

Forest inventory subplot	After implementation 2020			Annual campaign 2021		
	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)
BC1	0.0	4.5	4.5	23.0	6.0	29.0
BC2	0.0	5.0	5.0	28.0	2.5	30.5
B1S	1.5	4.0	5.5	19.5	7.0	26.5
B2N	0.0	9.5	9.5	29.5	3.5	33.0
B3S	0.0	12.0	12.0	35.0	1.5	36.5
B4N	1.5	7.0	8.5	35.0	1.5	36.5
BS5	0.5	8.5	9.0	24.0	1.0	25.0
B6N	2.0	9.0	11.0	25.5	6.0	31.5

Table 3. Forest decay per forest inventory subplots measured on July 2020 and November 2021.

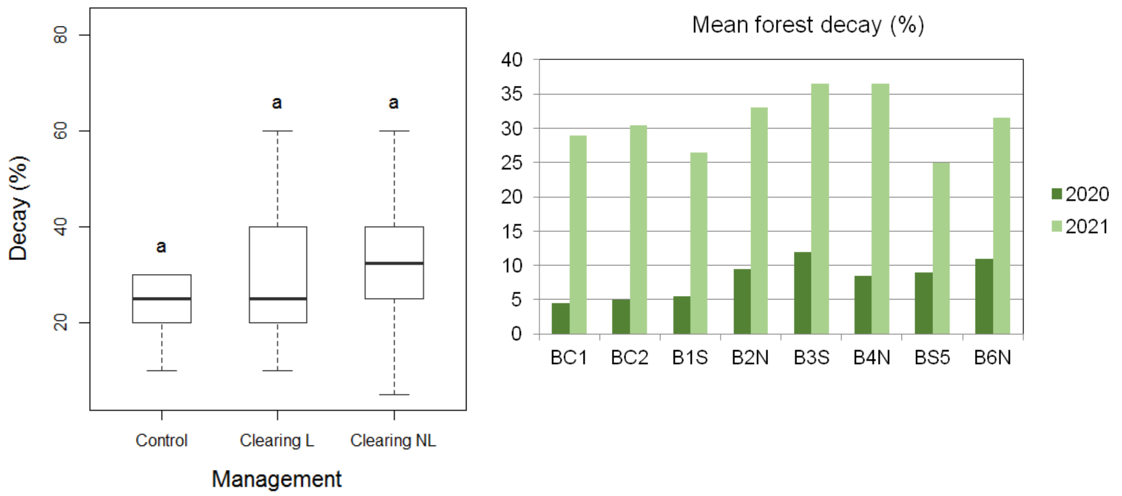


Figure 12. Left: Treatment effect on forest decay *(%) in 2021. Right: Differences in forest decay (%) between 2020 and 2021 among forest inventory subplots.*

3.2.4. Fuel moisture

Fuel moisture refers to the water content present in the vegetation along the dry season (summer), and is related with the flammability and combustibility of the vegetation and, as a result, with fire risk. A higher water contents of the vegetation in periods of elevated fire risk, is translated in a lower flammability and combustibility of the vegetation.

Forest fuel moisture samples are taken about nine times per year, approximately on the following dates: 1/5, 1/6, 15/6, 1/7, 15/7, 1/8, 15/8, 1/9 and 1/10. The sampling is repeated every year until the end of the project (2020, 2021, 2022 and 2023).

Figure 13 shows the effect of the adaptive forest management on vegetation water content in the two years of monitoring. Water content is higher in the treated plots, both with and without livestock, although differences among the plots are not yet significant. Although data for more years is needed, the results of the 2021 show the expected trend.

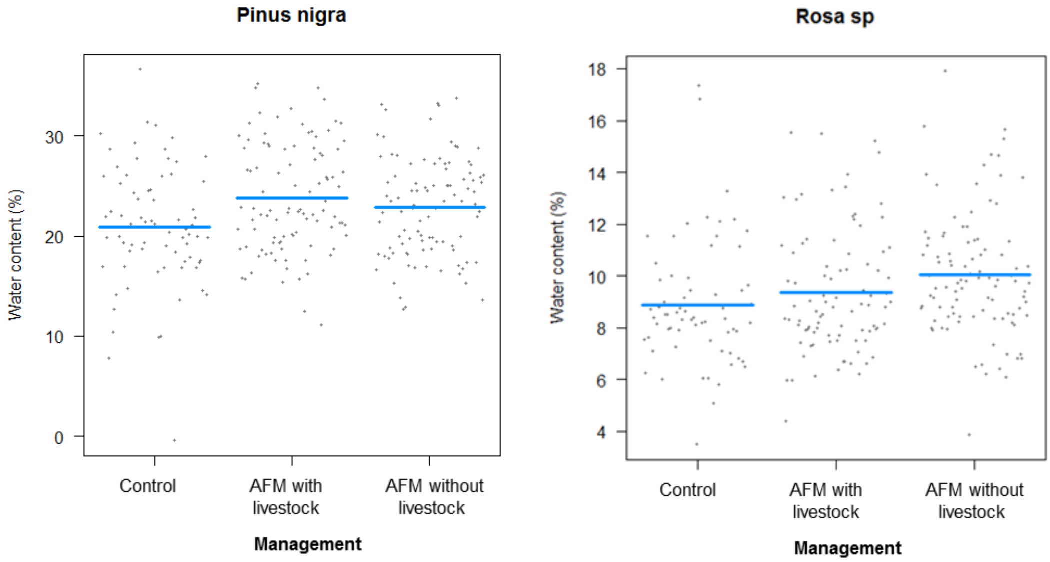


Figure 13. Treatment effect on vegetation water content in the Pinus nigra forest, La Garcipollera.

3.3. Monitoring results of the Pastures

The objective is to assess the effect of the adaptive forest management and cow grazing in pasture production and quality in terms of biodiversity, biomass productivity and nutritive quality. We hypothesize that forest management measures such as scrubland clearing interacting with cow grazing will help maintain biodiverse, productive and highly nutritive herbaceous pastures. Pastures productivity and nutritive quality maintenance will enable to support extensive livestock activities in these areas, thus enhancing the socio-economic development. Moreover, these measures will also restrain scrub encroachment, therefore diminishing the fire risk in these areas.

3.3.1. Biodiversity

Vegetation surveys are carried out in late spring or early summer (May-June). The first sampling was done in June 2020 in order to record the initial status of the pasture in the experimental plots. The second sampling will be done in the 2nd monitoring campaign in June 2022 in order to record the intermediate status of the pastures.

In the first sampling, we expected to find a positive effect of the adaptive forest management in the herbaceous pasture biodiversity, because of the elimination of woody competitors for light, space and nutrients. We expect that this effect will maintain over time in the experimental plots. Indeed, we found higher herbaceous species richness in plots submitted to scrubland clearing than in non-managed plots (Table 4). Specifically, we found significantly more species of hemichryptophytes and therophytes in the cleared areas compared to the control area. Regarding functional types, we found more species being grasses and forbs in the cleared plots than in the control plot. However, we did not find significant differences in the relative abundance of the plants between both treatments.

		Control	AFM (Scrubland clearing)		
Variables		Mean ± SE	Mean ± SE	F	p-value
Shannon index		1.73 ± 0.10	1.94 ± 0.10	2.107	0.1607
Total herbaceous richness		11.58 ± 0.87	16.42 ± 0.86	15.587	**<0.001*** **
Chamaephytes	Richness (n)	0.50 ± 0.19	0.75 ± 0.25	0.6226	0.4385
	Relative cover (%)	2.27 ± 1.06	2.62 ± 1.05	0.0547	0.8173
Hemichryptophytes	Richness (n)	8.50 ± 0.69	12.08 ± 0.71	13.046	**<0.01** **
	Relative cover (%)	88.31 ± 2.74	87.38 ± 2.76	0.0567	0.8139
Geophytes	Richness (n)	0.42 ± 0.19	0.33 ± 0.14	0.1209	0.7314
	Relative cover (%)	1.10 ± 0.58	0.93 ± 0.43	0.0595	0.8095
Therophytes	Richness (n)	1.33 ± 0.19	2.83 ± 0.46	9.1856	**<0.01** **
	Relative cover (%)	2.12 ± 0.50	7.33 ± 3.06	2.815	0.1075
Legumes	Richness (n)	2 ± 0.33	2.17 ± 0.39	0.1089	0.7445
	Relative cover (%)	6.22 ± 2.27	7.08 ± 2.81	0.056	0.8147
Grasses	Richness (n)	3.50 ± 0.31	5.42 ± 0.36	16.209	**<0.001*** **
	Relative cover (%)	71.70 ± 3.73	76.86 ± 2.57	1.298	0.2668
Forbs	Richness (n)	5.25 ± 0.65	8.42 ± 0.76	9.9399	**<0.01** **
	Relative cover (%)	15.88 ± 2.68	14.32 ± 1.61	0.2507	0.6216

Table 4. Effect of the AFM (scrubland clearing) in biodiversity variables: Shannon index, herbaceous species richness and in the richness and relative cover of the different Raunkiaer lifeforms (chamaephytes, hemichryptophytes, geophytes and therophytes) and in the different functional types (legumes, grasses and other forbs).

On the other hand, we expected not to find any effects of the livestock treatments since in the first year (2020), vegetation surveys were set previous to cows entry in the plots. As expected, we found no significant differences between livestock treatments in any of the diversity variables studied (Table 5). In the following vegetation samplings (intermediate and final), we expect to find more diversity in the plots submitted to grazing than in the control plots.

		Livestock	No livestock		
Variables		Mean ± SE	Mean ± SE	F	p-value
Shannon index		1.87 ± 0.07	1.94 ± 0.10	0.3154	0.58
Total herbaceous richness		15.42 ± 0.92	16.42 ± 0.86	0.6351	0.434
Chamaephytes	Richness (n)	1.08 ± 0.34	0.75 ± 0.25	0.6331	0.4347
	Relative cover (%)	3.92 ± 1.43	2.62 ± 1.05	0.541	0.4698
Hemichryptophytes	Richness (n)	11.67 ± 0.63	12.08 ± 0.71	0.1916	0.6658
	Relative cover (%)	91.49 ± 2.38	87.38 ± 2.76	1.2693	0.272
Geophytes	Richness (n)	0.08 ± 0.08	0.33 ± 0.14	2.3023	0.1434
	Relative cover (%)	0.08 ± 0.08	0.93 ± 0.43	3.7344	0.066
Therophytes	Richness (n)	2.33 ± 0.36	2.83 ± 0.46	0.7444	0.3976
	Relative cover (%)	3.60 ± 1.33	7.33 ± 3.06	1.2455	0.2765
Legumes	Richness (n)	2.50 ± 0.38	2.17 ± 0.39	0.3793	0.5443
	Relative cover (%)	4.48 ± 1.00	7.08 ± 2.81	0.7569	0.3937
Grasses	Richness (n)	5.08 ± 0.29	5.42 ± 0.36	0.5269	0.4755
	Relative cover (%)	81.92 ± 1.13	76.86 ± 2.57	3.2411	0.0856
Forbs	Richness (n)	7.58 ± 0.57	8.42 ± 0.76	0.765	0.3912
	Relative cover (%)	12.69 ± 1.21	14.32 ± 1.61	0.6526	0.4278

Table 5. Livestock effect on the scrubland cleared areas in biodiversity variables: Shannon index, herbaceous species richness and in the richness and relative cover of the different

Raunkiaer lifeforms (chamaephytes, hemichryptophytes, geophytes and therophytes) and in the different functional types (legumes, grasses and other forbs).

3.3.2. Pasture production and quality

Pasture production and quality samplings are carried out in late spring or early summer (May-June). The first sampling was done in June 2020 in order to record the initial status of the pasture in the experimental plots. The second sampling will be done in the 2nd monitoring campaign in June 2022 in order to record the intermediate status of the pastures.

In the first sampling, we expected to find a positive effect of the adaptive forest management in the production and quality of the herbaceous pasture because of the elimination of woody competitors for light, space and nutrients. We expect that this positive effect of scrubland clearing will maintain over time in the experimental plots. As we observe in Table 6, there is significantly more herbaceous biomass in the cleared plots than in control plots. Regarding pasture quality, we only found a positive effect of scrubland clearing in the amount of crude protein (PB), hemicellulose and dry matter intake (IMS) but we found no significant differences between cleared and not cleared plots for the rest of the nutritive quality variables measured.

	Control		**AFM (Scrubland clearing)**			
Variables	**Mean ± SE**	**n**	**Mean ± SE**	**n**	**F**	**p-value**
Biomass (kg DM/ha)	333.40 ± 19.48	12	849.00 ± 203.77	12	6.3443	**<0.05***
PB (%)	10.09 ± 0.25	12	11.72 ± 0.28	12	18.917	**<0.001*****
Cellulose (%)	27.06 ± 0.65	12	26.04 ± 1.60	12	0.3557	0.557
Hemicellulose (%)	33.43 ± 1.24	12	28.04 ± 2.85	12	2.9968	**0.0974***
NDF (%)	65.95 ± 1.52	12	59.33 ± 4.32	12	0.1618	0.1618
ADF (%)	32.53 ± 0.43	12	32.19 ± 1.58	12	0.5764	0.4558
ADL (%)	5.46 ± 0.42	12	5.25 ± 0.32	12	0.1607	0.6924
ADA (%)	1.20 ± 0.04	12	1.30 ± 0.10	12	0.9895	0.3307
IMS	1.83 ± 0.05	12	2.18 ± 0.19	12	2.9764	**0.0985***
DMS	63.56 ± 0.33	12	64.53 ± 1.23	12	0.5776	0.4553
VRF	90.33 ± 2.70	12	110.73 ± 12.17	12	2.6805	0.1158

*Table 6. Biomass production and nutritive quality variables in non-managed plots with no livestock and managed plots with no livestock. * Variables: PB=crude protein; Cel=cellulose; Hemi=hemicellulose; NDF=neutral-detergent fiber; ADF=acid-detergent fiber; ADL=acid-detergent lignin; ADA=acid-detergent ashes; IMS= dry matter intake; DMS= digestible dry matter; VRF = relative feed value.*

Contrarily, in the initial status (2020), we expected not to find any effects of the livestock treatments in the herbaceous pasture, neither in production nor in quality since vegetation samples (and their subsequent processing and analyses) were collected previous to the entry of the cows. According to what expected, we did not observe significant differences between livestock treatments neither in the herbaceous biomass production nor in the nutritive quality variables measured (Table 7). In the following vegetation samplings (intermediate and final), we expect to find more biomass with lower nutritive quality in the plots with no grazing (less proteins and digestible fibers). On the contrary, we expect to find less biomass with higher nutritive quality in the plots with cow grazing (more proteins and digestible fibers).

	No livestock		Livestock			
Variables	Mean ± SE	n	Mean ± SE	n	F	p-value
Biomass (kg DM/ha)	849.00 ± 203.77	12	609.31 ± 113.75	12	1.0549	0.3155
PB (%)	11.72 ± 0.28	12	11.35 ± 0.28	12	0.846	0.3677
Cellulose (%)	26.04 ± 1.60	12	27.30 ± 0.59	12	0.5505	0.466
Hemicellulose (%)	28.04 ± 2.85	12	32.85 ± 1.31	12	2.3446	0.14
NDF (%)	59.33 ± 4.32	12	65.06 ± 1.60	12	1.5508	0.2261
ADF (%)	31.29 ± 1.58	12	32.21 ± 0.50	12	0.3106	0.5829
ADL (%)	5.25 ± 0.32	12	4.91 ± 0.26	12	0.6906	0.4149
ADA (%)	1.30 ± 0.10	12	1.35 ± 0.12	12	0.0838	0.7749
IMS	2.18 ± 0.19	12	1.86 ± 0.05	12	2.5315	0.1259
DMS	64.53 ± 1.23	12	63.81 ± 0.39	12	0.3111	0.5826
VRF	110.73 ± 12.17	12	91.98 ± 2.79	12	2.2587	0.1471

*Table 7. Biomass production and nutritive quality variables in scrubland clearing plots with no livestock and scrubland clearing plots with livestock. * Variables: PB=crude protein; Cel=cellulose; Hemi=hemicellulose; NDF=neutral-detergent fiber; ADF=acid-detergent fiber; ADL=acid-detergent lignin; ADA=acid-detergent ashes; IMS= dry matter intake; DMS= digestible dry matter; VRF = relative feed value.*

3.4. Monitoring results of the Rainfall simulations

Rainfall simulations assess the effect of forest management and grazing on the hydrological response and soil erosion. The first experiments (initial conditions) were carried at in October 2020 in the cleared forest subplots without grazing (BN). The experiments in the remaining subplots were carried out in December 2020. Here we present the results of these experiments. Although three experiments were performed per land management type (3 replicas), some results had to be removed because they seemed incorrect (e.g., Runoff Coefficient > 1). This can be due to problems in either the rainfall simulation experiment (e.g., the circular ring is not correctly fixed in the ground) or the post processing of the water samples.

Under initial conditions, the cleared forest without livestock grazing presented a high variability in its hydrogeomorphological response (Table 8), with a runoff coefficient varying between 0 and 0.48 and a SC, SP and SD varying between 0 and 1.71 g/l, 0 and 0.43 g, and 0 and 9.33 g/m^2/h, respectively.

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Pinus nigra	BN (AFM without livestock)	0.00	33.10	NA	10	0.00	0.00	0.00
		0.12	36.36	13.8	10	1.71	0.43	9.33
		0.48	30.30	7.8	10	0.37	0.35	7.60

Table 8. All hydrogeological and sedimentological variables extracted from rainfall simulations in La Garcipollera in October 2020 (initial conditions). Simulations without runoff are represented in Time to runoff variable with a NA and with a 0 value in Sediment concentration, production, and detachment. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Pinus nigra	BN	0,20±0,25	33,25±3,03	10,8±6,9	10±0	0,69±0,90	0,26±0,23	5,64±4,96

Table 9. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in simulations in La Garcipollera in October 2020 (initial conditions). All values have a n=3. All values represent mean ± standard error. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

In December, there was only runoff and sediment response in the cleared forest with livestock (BS) (Tables 3 and 4). The control plots and the BN plots (treated without livestock) showed no runoff nor sediment response. The mean RC in BS was 0.15, TR was 10.5 min and SC, SP and SD was 0.26 g/l, 0.86 g and 5.74 g/m2/h, respectively. These first results suggest a higher hydrogeomorphological response under treated and grazed conditions.

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Pinus nigra	Control	0.00	18.41	NA	5	0.00	0.00	0.00
		0.00	28.09	0.0	0	0.00	0.00	0.00
	BN (AFM without livestock)	0.00	14.57	15.2	10	0.00	0.00	0.00
		0.00	40.58	NA	10	0.00	0.00	0.00
	BS (AFM with livestock)	0.07	24.30	15.2	10	0.13	1.13	2.82
		0.22	27.04	5.8	8	0.40	0.58	8.66

Table 10. All hydrogeological and sedimentological variables extracted from rainfall simulations in La Garcipollera in December 2020. Simulations without runoff are represented in Time to runoff variable with a NA and with a 0 value in Sediment concentration, production, and detachment. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Pinus nigra	Control	0.00±0.00	23.25±6.84	0.00±0.00	3±3.54	0.00±0.00	0.00±0.00	0.00±0.00
	BN	0.00±0.00	27.57±18.39	7.6±10.71	10±0.00	0.00±0.00	0.00±0.00	0.00±0.00
	BS	0.15±0.11	25.67±1.94	10.5±6.59	9±1.41	0.26±0.19	0.86±0.39	5.74±4.13

Table 11. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in simulations in La Garcipollera in December 2020. All values have a n=2. All values represent mean ± standard error. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

3.5. Site meteorological conditions

The registration of the meteorological conditions is key to understand the evolution of previous variables along the project duration. With this objective, we have installed air temperature sensors, relative humidity sensors and rain-meters or weather stations to record in continuum these variables.

Maximum, minimum temperature, and relative humidity were recorded on Tinytag Dataloggers every 15 minutes from 09-06-2020 as shown in Figure 14. In this period, until 02-12-2021, the maximum temperature has been 37.5 ºC (14-08-2021) and the minimum -12.4 (08-01-2021). In this case, the data are continuous (no gaps) and clearly show the annual cycle of temperatures and humidity. As the project progresses, comparative analyses between the different Tinytag dataloggers will be carried out.

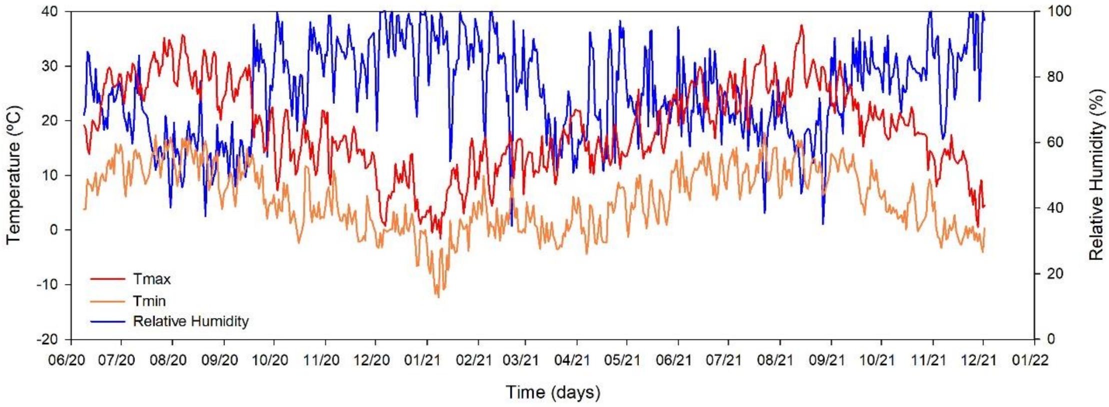


Figure 14. Daily average of minimum and maximum temperature and relative humidity in the Pinus nigra experimental plot.

Figure 15 is a climogram showing monthly averages of maximum temperature, minimum temperature and mean monthly precipitation for the period 06-2020 to 11-2021. The low rainfall in March is striking. In fact, on the Iberian Peninsula, the average value barely reached 17 mm, compared to the 47 mm of the average value for the reference period (1981-2010). Throughout the project, the data recorded in this and the other thermometers will be compared with studies carried out on a regional scale, in order to contextualise our results.

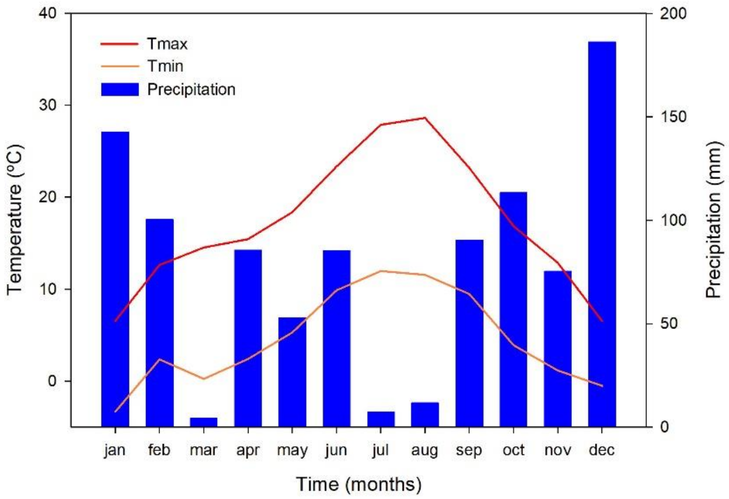


Figure 15. Climogram in the Pinus nigra experimental plot.

4. Results of the 1st monitoring campaign in the *Populus* forest, Aragon

This chapter includes the results of the 2021 campaign in the *Populus* forest in Aragon.

Following, we include a summary of the implemented pilot experience and the experimental design of the monitoring network, to facilitate the understanding of the monitoring results. A more detailed description of the implemented actions can be consulted in Pascual *et al.* (2020a, 2020b).

Implemented pilot experience

- Adaptive forest management in 0.86 ha plot consisting in scrubland clearing. mainly *Genista scorpius*
- Control plot: An area with no actuation of 0.554 ha.

Monitoring network:

- Three typologies of monitoring plots with a surface of 400 m^2:
  - control plots, without neither forest management nor the entry of livestock (CC);
  - managed plots with livestock (CS);
  - managed plots without livestock (CN).
- For each of monitoring plots, three replicates (C2S-4S-6S, C1N-3N-5N), except in the control area where there was only space for two replicates (CC1-2).

The monitoring network includes three plots of 400 m^2 with its replicates, eight monitoring subplots of 400 m^2 in total (Figure 16).

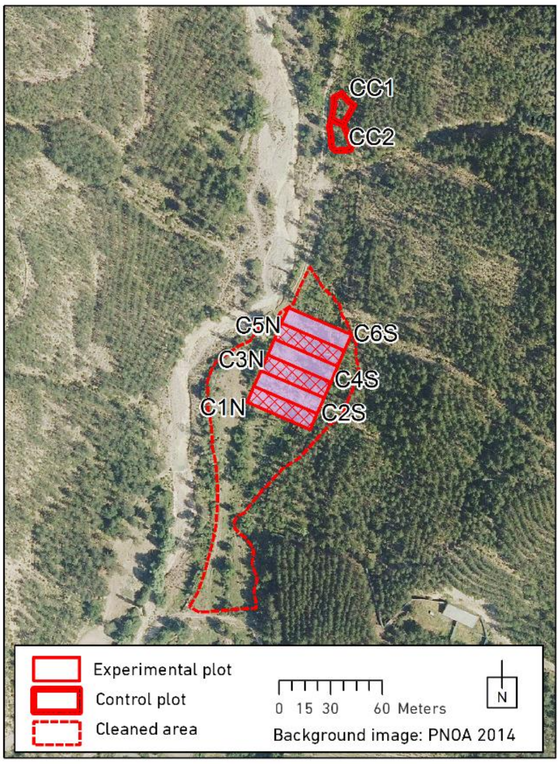


Figure 16. Location of the monitoring plots and replicates of the experimental design.

4.1. Monitoring results of the Soil

4.1.1. Soil characteristics

The initial monitoring variables were carried out in May 2021 due to the delay in the installation of the experimental plots.

At each monitoring subplot, three soil samples were sampled with an auger at 10 cm increments: 0 cm, 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm. In each site, 45 points were selected, and 225 subsamples were recorded and later combined into one soil composite sample per plot and depth. In total 75 composite samples were created in La

Garcipollera. The 75 samples have been analysed by the Pyrenean Institute of Ecology (IPE-CSIC), evaluating the following soil variables: Field bulk density (BD), pH and electrical conductivity (EC), total carbon concentration (Ctotal), total nitrogen concentration (N), carbonate content (CaCO3), organic carbon (Corg), soil organic carbon (SOC) and nitrogen (TN) stocks, organic matter (OM), grain size distribution, organic phosphorus (P), saturated soil moisture (SAT), field capacity (FC), wilting point (WP) and CN ratio

In this report, only the results related to five variables are presented: pH, electrical conductivity, carbonate content, organic matter and phosphorus content. The following figures present the mean values and standard deviation of these variables at different depths. Statistical results did not show yet significant differences between the management plots.

Figure 17 shows that all the samples presented pH values higher than 7, corresponding to basic soils. Mean values ranged 7.7 and 8.3 and slightly increased with depth in all the cases. Electrical conductivity mean values ranged between 169 and 276 µs/cm, being these values higher in the first 0-10 cm of the soil.

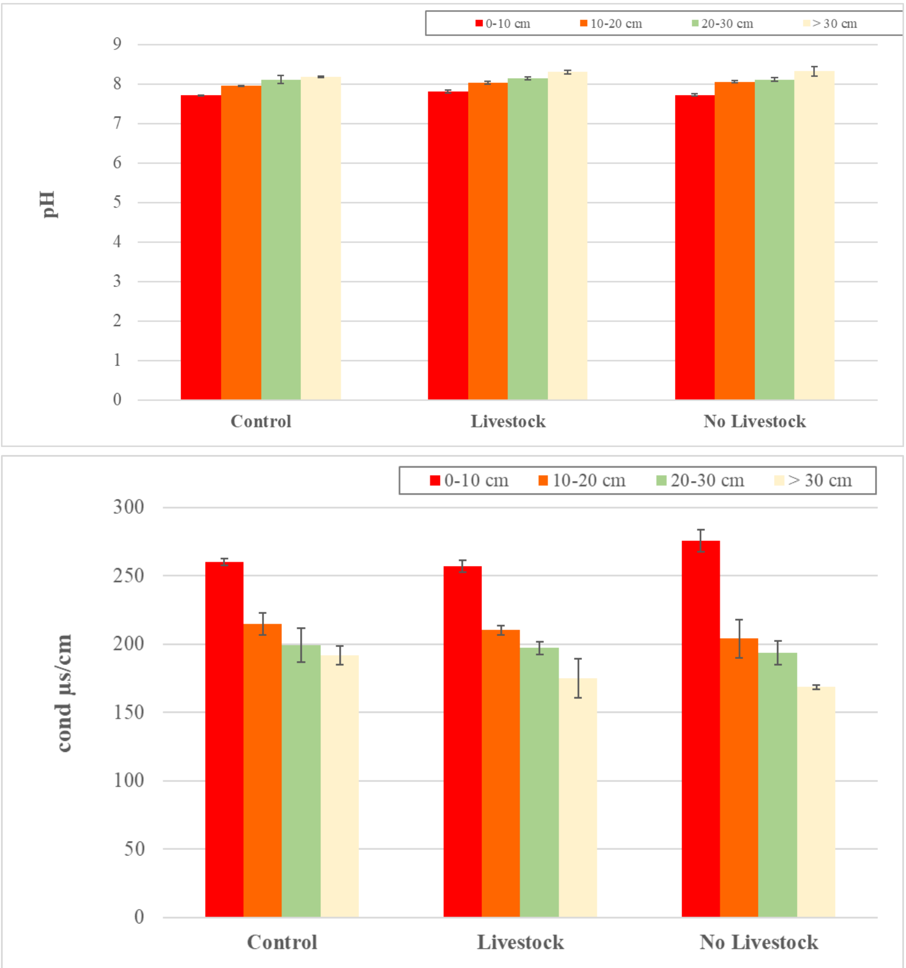


Figure 17. pH values (up) and electrical conductivity (down) of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Figure 18 presents the soil organic matter mean contents and standard deviation. Excluding the organic substrate (not included in the figure) the mean contents oscillated between 3.1 and 8.6%. Values decreased with depth, with high standard deviations in the deepest layers.

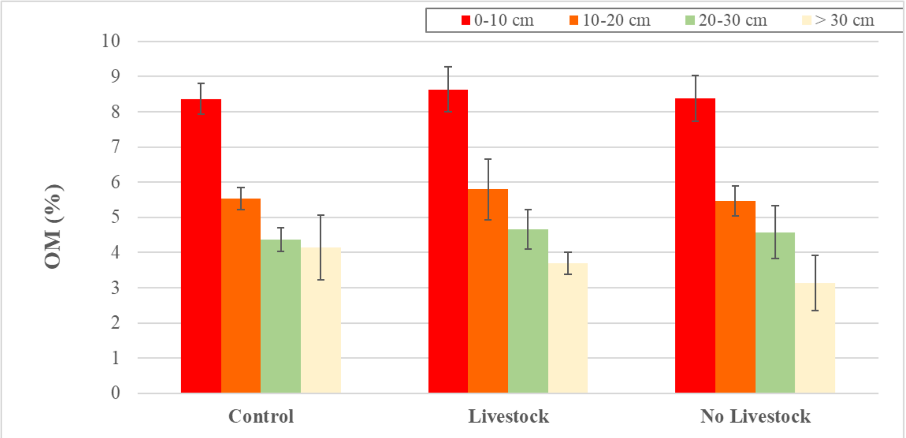


Figure 18. Organic matter (OM) of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Phosphorous content presented higher variability, with standard deviation (Figure 19). Higher values were recorded in the topsoil and a decreasing trend was observed related with depth. Mean values oscillated between 1.6 and 7.4 mg/kg.

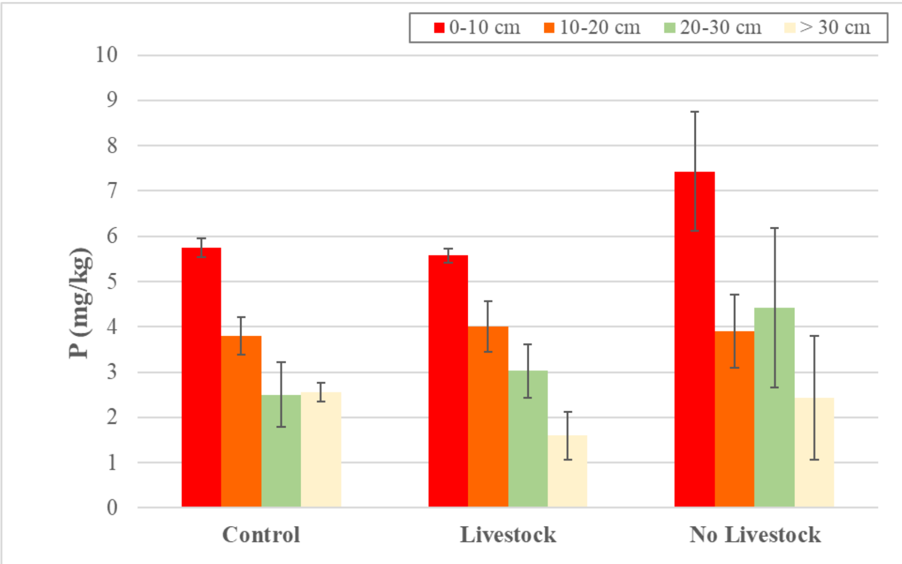


Figure 19. Phosphorus (P) content of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

Finally, Figure 20 shows the CaCO3 content in the different plots. Values oscillated between 29 and 40%, high values related to a calcareous lithology in the study area. High standard deviation was observed in all the cases, especially in depth soil layers.

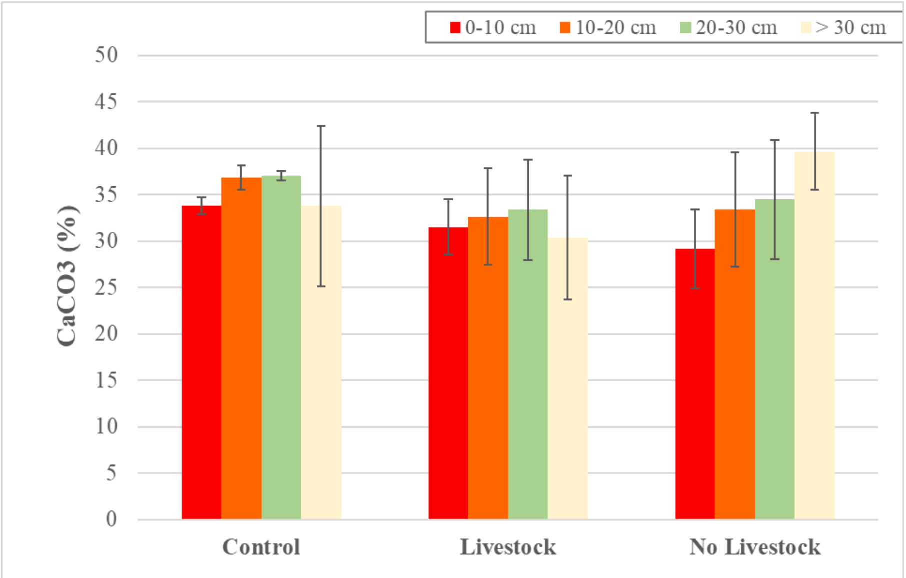


Figure 20. Carbonate content (CaCO3) content of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

4.1.2. Soil moisture

The sensor network installed to monitor the evolution of the water in the first 20 cm of the soil has been continuously recording since the installation. In the *Populus* forest, the network consists on 2 dataloggers, one in the treatment plots and another in the control plot. Those dataloggers are connected to two soil moisture sensors in the managed area with livestock, two in the managed area without livestock and two in the control area. In total, 2 dataloggers and 6 soil moisture sensors have been installed (Figure 21).

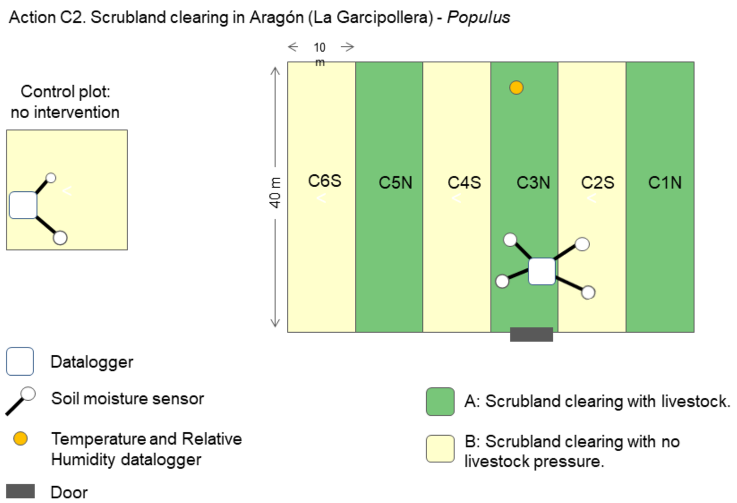


Figure 21. Diagram of the soil moisture instrumentation.

Figure 22 shows the soil moisture data recorded every hour by the sensors installed in the control plot and the mean of the replicates in the plots with Livestock and without

Livestock together with the rainfall recorded at the AEMET station in Bescós de La Garcipollera. In this case, the series are still too short to be compared among treatments. Data recording started on 07-05-2021 and is updated until 16-11-2021. In the case of the sensors installed in the control plot and due to a problem with the datalogger installed (in this occasion a HOBO micro-station was installed), the series began on 19-08-2021. The figure shows the good response of the sensors to the recorded rainfall events, as expected higher values were observed after rainfall events. More results are needed to start extracting conclusions when comparing among treatments and with the control subplots.

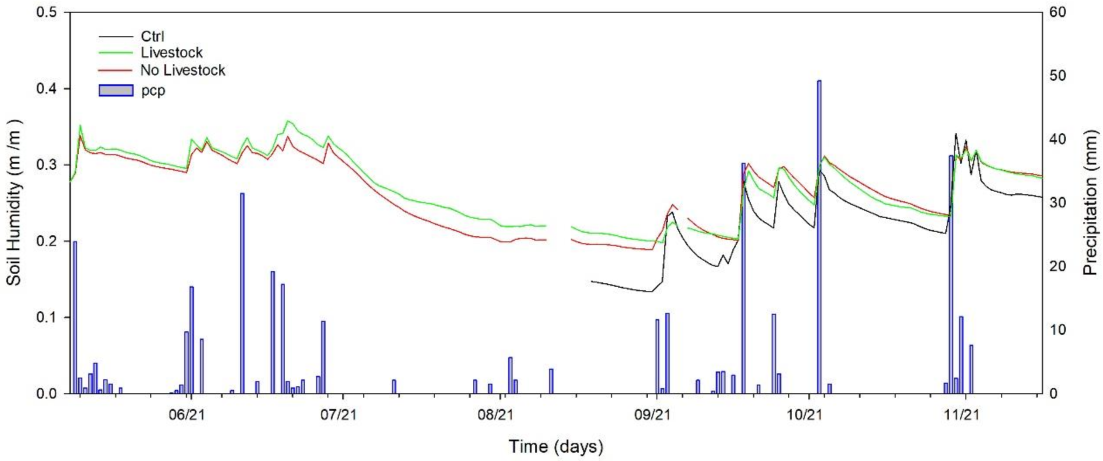


Figure 22. Soil humidity and precipitation in the Populus experimental plot (La Garcipollera)

4.2. Monitoring results of the Forest

A network of forest indicators or variables has been designed and monitored, based on installation of permanent inventory subplots. In the *Populus* forest, the network consists of six rectangular subplots with an area of 400 m^2 and two control plots with similar surface (Figure 16). The shape and the surface of the inventory subplot is determined by the size of the monitoring plots. The forest inventory subplots occupy the whole surface of the monitoring plots.

The initial forest inventory was carried out on May 2021, with the objective to set the initial conditions of the forest stand, to follow up its evolution on time. The second inventory will be performed in 2022.

4.2.1. Forest structure

Forest structure refers to the distribution and characteristics of the individual trees within the subplot. The monitoring of the forest structure was performed initially and after implementing the forest management, and the differences between both situations was detailed explained at Pascual *et al.* (2020a).

Forest structure will be evaluated again at the end of the project, to compare the initial conditions with the final ones. For this reason, forest structure has not been monitored in the 1st monitoring campaign and results are not shown here.

4.2.2. Forest fuel continuity

Forest fuel continuity refers to the spatial distribution and height of the different strata of the fuel (aerial, ladder or surface cover), which has a direct effect in the vulnerability of the forest to fire risk due to fire propagation. Forest fuel continuity is quantified with two indicators: crown fire hazard and understorey biovolume.

Both indicators are assessed initially, after implementing the forest management, annually (in autumn) and at the end of the project. In this case, as it was explained in Pascual *et al.* (2020a), the initial and after implementation inventories were coincident in May 2021. The 1st annual inventory will be performed in autumn 2022, for this reason, results are not shown here.

4.2.3. Forest health status

Forest health refers to the status of the forest decline due to climate change effects (mainly droughts) or other related threatens (plagues, diseases …). Forest decline is defined by the degree of defoliation, decolouration or mortality of the individuals of the forest.

Forest health status is assessed initially, after implementing the forest management, annually (in autumn) and at the end of the project. In this case, as it was explained in Pascual *et al.* (2020a), the initial and after implementation inventories were coincident in May 2021. The 1st annual inventory will be performed in autumn 2022.

Figure 23 shows the forest decay in 2021 per treatment. In this year, forest decay did not show significant initial differences among treatments. Data for more years is needed to find trends and get conclusions.

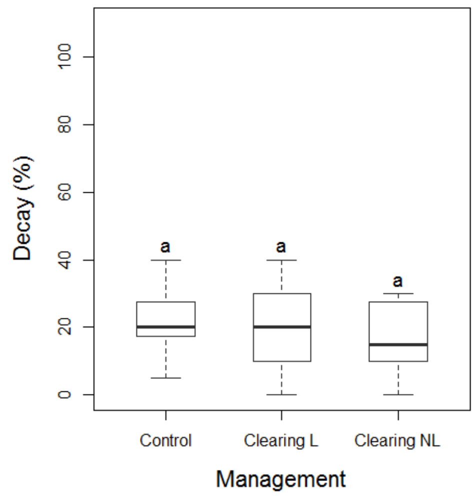


Figure 23. Treatment effect on forest decay (%) in 2021

4.2.4. Fuel moisture

Fuel moisture refers to the water content present in the vegetation along the dry season (summer), and is related with the flammability and combustibility of the vegetation and, as a result, with fire risk. A higher water contents of the vegetation in periods of elevated fire risk, is translated in a lower flammability and combustibility of the vegetation.

Forest fuel moisture samples are taken about nine times per year, approximately on the following dates: 1/5, 1/6, 15/6, 1/7, 15/7, 1/8, 15/8, 1/9 and 1/10. The sampling is repeated every year until the end of the project (2021, 2022 and 2023).

Figure 24 shows the effect of the adaptive forest management on vegetation water content in 2021. Water content is higher in the *Populus* treated plots, both with and without livestock, although differences among the plots are not yet significant. Data for more years is needed to find trends and get conclusions.

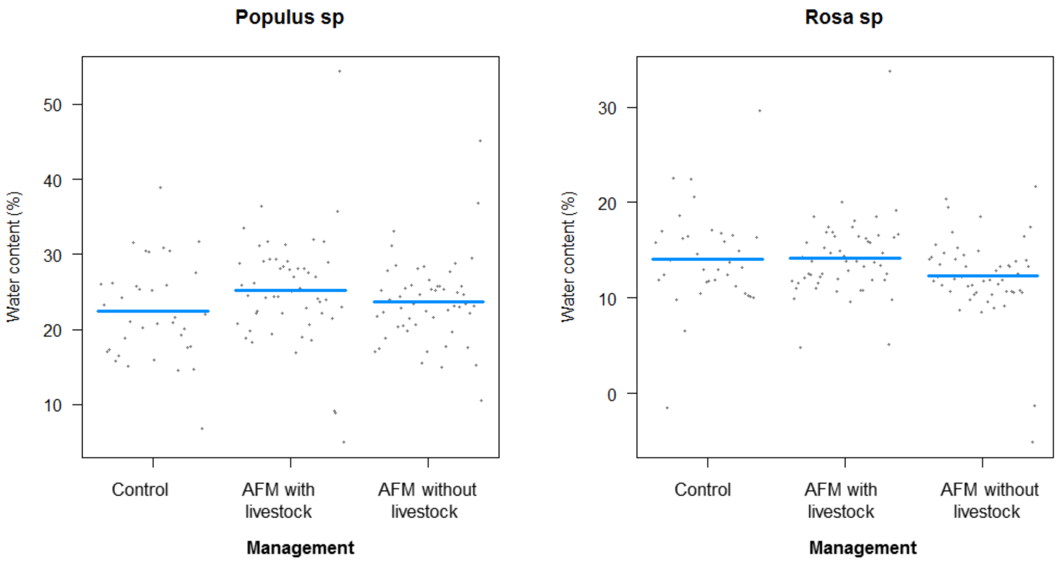


Figure 24. Treatment effect on vegetation water content in the Populus forest, La Garcipollera.

4.3. Monitoring results of the Pastures

The objective is to assess the effect of adaptive forest management and cow grazing in pasture production and quality in terms of biodiversity, biomass productivity and nutritive quality.

4.3.1. Biodiversity

Vegetation surveys are carried out in late spring or early summer (May-June). The first sampling was done in June 2020 in order to record the initial status of the pasture in the experimental plots. The second sampling will be done in the 2nd monitoring campaign in June 2022 in order to record the intermediate status of the pastures.

In the first sampling, we expected to find a positive effect of the adaptive forest management in the herbaceous pasture biodiversity, because of the elimination of woody competitors for light, space and nutrients. We expect that this effect will maintain over time in the experimental plots. Indeed, we found a higher Shannon diversity index and herbaceous species richness in plots submitted to scrubland clearing than in non-managed plots (Table 12). Specifically, we found more richness of therophytes in managed plots. We also found more relative cover of hemichryptophytes and therophytes. Regarding functional types, we found more richness of legumes and forbs and a higher relative cover of legumes and grasses.

Variables		Control Mean ± SE	AFM Mean ± SE	F	p-value
Shannon index		1.99 ± 0.12	2.40 ± 0.03	11.518	**<0.01****
Total herbaceous richness		13.75 ± 0.97	19.50 ± 0.74	22.125	**<0.001*****
Chamaephytes	Richness (n)	0.58 ± 0.15	0.92 ± 0.19	1.8723	0.185
	Relative cover (%)	1.45 ± 0.45	2.29 ± 1.10	0.4994	0.4872
Hemichryptophytes	Richness (n)	11.17 ± 0.77	13.00 ± 0.72	3.0458	0.0949
	Relative cover (%)	88.31 ± 2.74	87.38 ± 9.57	20.86	**<0.001*****
Geophytes	Richness (n)	0.17 ± 0.11	0.58 ± 0.19	3.481	0.07547
	Relative cover (%)	0.12 ± 0.08	1.36 ± 0.56	4.8472	**<0.05***
Therophytes	Richness (n)	1.83 ± 0.37	4.58 ± 0.50	19.735	**<0.001*****
	Relative cover (%)	5.47 ± 1.80	16.03 ± 2.68	10.678	**<0.01****
Legumes	Richness (n)	1.08 ± 0.31	3 ± 0.30	19.465	**<0.001*****
	Relative cover (%)	4.93 ± 2.05	14.42 ± 2.61	8.1591	**<0.01****
Grasses	Richness (n)	4 ± 0.33	4.92 ± 0.38	3.3696	0.0799
	Relative cover (%)	58.50 ± 3.52	46.96 ± 3.12	6.0355	**<0.05***
Forbs	Richness (n)	8.67 ± 0.61	11.17 ± 0.69	7.3442	**<0.05***
	Relative cover (%)	36.57 ± 3.22	36.63 ± 2.48	0.0003	0.9872

Table 12. Effect of the scrubland clearing in biodiversity variables: Shannon index, herbaceous species richness and in the richness and relative cover of the different Raunkiaer lifeforms (chamaephytes, hemichryptophytes, geophytes and therophytes) and in the different functional types (legumes, grasses and other forbs).

On the other hand, we expected not to find any effects of the livestock treatments since in the first year (2020), vegetation surveys were set previous to cows entry in the plots. As expected, we found no significant differences between livestock treatments in any of the diversity variables studied in the herbaceous pasture (Table 13).

Variables		No livestock Mean ± SE	Livestock Mean ± SE	F	p-value
Shannon index		2.36 ± 0.07	2.40 ± 0.03	0.3176	0.5787
Total herbaceous richness		18.67 ± 1.18	19.50 ± 0.74	0.3585	0.5554
Chamaephytes	Richness (n)	0.50 ± 0.15	0.92 ± 0.19	2.8947	0.103
	Relative cover (%)	2.27 ± 0.93	2.29 ± 1.10	0.0002	0.99
Hemichryptophytes	Richness (n)	13.08 ± 0.96	13.00 ± 0.72	0.0048	0.9454
	Relative cover (%)	91.49 ± 2.38	87.38 ± 9.57	0.6804	0.4183
Geophytes	Richness (n)	0.50 ± 0.15	0.58 ± 0.19	0.1158	0.7369
	Relative cover (%)	1.69 ± 0.64	1.36 ± 0.56	0.1481	0.7041
Therophytes	Richness (n)	4.25 ± 0.45	4.58 ± 0.50	0.2479	0.6235
	Relative cover (%)	13.45 ± 2.96	16.03 ± 2.68	0.416	0.5256
Legumes	Richness (n)	3.08 ± 0.47	3 ± 0.30	0.0224	0.8824
	Relative cover (%)	14.74 ± 3.25	14.42 ± 2.61	0.0059	0.9393
Grasses	Richness (n)	4.17 ± 0.37	4.92 ± 0.38	2.0296	0.1683
	Relative cover (%)	45.84 ± 3.03	46.96 ± 3.12	0.0663	0.7991
Forbs	Richness (n)	11.08 ± 0.68	11.17 ± 0.69	0.0074	0.9324
	Relative cover (%)	38.12 ± 2.59	36.63 ± 2.48	0.1715	0.6828

Table 13. Livestock effect on the scrubland cleared areas in biodiversity variables: Shannon index, herbaceous species richness and in the richness and relative cover of the different Raunkiaer lifeforms (chamaephytes, hemichryptophytes, geophytes and therophytes) and in the different functional types (legumes, grasses and other forbs).

4.3.2. Pasture production and quality

Pasture production and quality samplings are carried out in late spring or early summer (May-June). The first sampling was done in June 2020 in order to record the initial status of the pasture in the experimental plots. The second sampling will be done in the 2nd monitoring campaign in June 2022 in order to record the intermediate status of the pastures.

In the first sampling, we expected to find a positive effect of the adaptive forest management in the production and quality of the herbaceous pasture because of the elimination of woody competitors for light, space and nutrients. We expect that this positive effect will maintain over time in the experimental plots. Contrarily to what expected, we did not observe significant differences between the control plots and the ones submitted to scrubland clearing for the biomass production. Regarding the nutritive quality of the herbaceous pasture, we only found an effect of the scrubland clearing in the ADL (Acid-Detergent Lignin), being higher in the scrubland clearing area. We did not find significant differences between treatments for any of the other variables studied (Table 14).

	Control		AFM (Scrubland clearing)			
Variables	**Mean ± SE**	**n**	**Mean ± SE**	**n**	**F**	**p-value**
Biomass (kg DM/ha)	853.33 ± 99.98	12	1050 ± 170.64	12	0.9888	0.3308
PB (%)	9.66 ± 0.16	12	10.03 ± 0.25	12	1.5376	0.228
Cellulose (%)	26.07 ± 1.58	12	23.10 ± 0.76	12	2.8806	0.1038
Hemicellulose (%)	30.25 ± 1.60	12	26.81 ± 1.21	12	2.9318	0.1009
NDF (%)	60.76 ± 3.51	12	56.39 ± 1.53	12	1.3052	0.2656
ADF (%)	30.51 ± 1.98	12	29.58 ± 0.74	12	0.1936	0.6643
ADL (%)	4.43 ± 0.53	12	6.48 ± 0.45	12	8.5428	**<0.01****
ADA (%)	2.69 ± 0.27	12	3.22 ± 0.36	12	1.4058	0.2484
IMS	2.14 ± 0.26	12	2.14 ± 0.05	12	0.0005	0.9828
DMS	65.14 ± 1.54	12	65.86 ± 0.58	12	0.1944	0.6636
VRF	111.25 ± 18.49	12	109.63 ± 3.44	12	0.0075	0.9318

*Table 14. Biomass production and nutritive quality variables in non-managed plots with no livestock and scrubland clearing plots with no livestock. * Variables: PB=crude protein; Cel=cellulose; Hemi=hemicellulose; NDF=neutral-detergent fiber; ADF=acid-detergent fiber; ADL=acid-detergent lignin; ADA=acid-detergent ashes; IMS= dry matter intake; DMS= digestible dry matter; VRF = relative feed value.*

Contrarily, in the initial status (2020), we expected not to find any effects of the livestock treatments in the herbaceous pasture, neither in production nor in quality since vegetation samples (and their subsequent processing and analyses) were collected previous to the entry of the cows. According to what expected, we did not observe significant differences between livestock treatments neither in the herbaceous biomass production nor in any nutritive quality variables studied (Table 15).

	No livestock		Livestock			
Variables	Mean ± SE	n	Mean ± SE	n	F	p-value
Biomass (kg DM/ha)	1050 ± 170.64	12	953.33 ± 105.24	12	0.2325	0.6344
PB (%)	10.03 ± 0.25	12	10.58 ± 0.41	11	1.4287	0.2453
Cellulose (%)	23.10 ± 0.76	12	24.18 ± 0.79	11	0.9613	0.338
Hemicellulose (%)	26.81 ± 1.21	12	27.34 ± 1.48	11	0.0761	0.7854
NDF (%)	56.39 ± 1.53	12	57.21 ± 6.58	11	0.1097	0.7438
ADF (%)	29.58 ± 0.74	12	29.88 ± 0.66	11	0.0907	0.766
ADL (%)	6.48 ± 0.45	12	5.70 ± 0.44	11	1.514	0.2321
ADA (%)	3.22 ± 0.36	12	2.61 ± 0.18	11	2.1822	0.1545
IMS	2.14 ± 0.05	12	2.12 ± 0.07	11	0.0676	0.7974
DMS	65.86 ± 0.58	12	65.62 ± 0.51	11	0.0916	0.7652
VRF	109.63 ± 3.44	12	108.21 ± 4.41	11	0.0655	0.8005

*Table 15. Biomass production and nutritive quality variables in scrubland clearing plots with no livestock and scrubland clearing plots with livestock. * Variables: PB=crude protein; Cel=cellulose; Hemi=hemicellulose; NDF=neutral-detergent fiber; ADF=acid-detergent fiber; ADL=acid-detergent lignin; ADA=acid-detergent ashes; IMS= dry matter intake; DMS= digestible dry matter; VRF = relative feed value.*

4.4. Monitoring results of the Rainfall simulations

Rainfall simulations assess the effect of forest management and grazing on the hydrological response and soil erosion. As this plot was installed in February 2021, here we present only the results of the experiments carried out under initial conditions in May 2021, in the control and cleared forest subplots without grazing (BN). Although 3 experiments were performed per land management type (3 replicas), some results had to be removed because they seemed incorrect (e.g., Runoff Coefficient > 1). This can be due to problems in either the rainfall simulation experiment (e.g., the circular ring is not correctly fixed in the ground) or the post processing of the water samples.

Under initial conditions, the hydrological response was higher in the control plot, with a mean RC of 0.42 and a mean time to runoff of 6.9 min (Table 17). One reason may be the lower vegetation cover (60 and 70%) in some control plots and their higher hillslope gradient (> 35% vs <7%). The high variability of the data suggests the need of more experiments to obtained more robust results.

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Fraxinus	Control	0.33	18.60	6.8	NA	0.40	0.67	8.73
		0.65	8.95	6.5	2	0.87	0.58	18.80
		0.28	8.80	7.5	NA	0.12	0.22	2.49
	BN (AFM without livestock	0.51	17.50	5.3	3	0.58	0.70	12.58
		0.01	10.65	13.0	4	0.00	0.00	0.00

Table 16. All hydrogeological and sedimentological variables extracted from rainfall simulations in La Garcipollera in May 2021. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Fraxinus	Control	0.42±0.20	12.12±5.62	6.9±0.00	2±0.00	0.46±0.38	0.49±0.24	10.00±8.23
	BN	0.26±0.35	14.08±4.84	9.17±5.42	3.50±0.71	0.29±0.41	0.35±0.50	6.29±8.90

Table 17. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in simulations in La Garcipollera in May 2021. All values have a n=3, except BN in Fraxinus with n=2. All values represent mean ± standard error. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

4.5. Site meteorological conditions

The registration of the meteorological conditions is key to understand the evolution of previous variables along the project duration. With this objective, we have installed air temperature sensors, relative humidity sensors and rain-meters or weather stations to record in continuum these variables.

Maximum, minimum temperature, and relative humidity were recorded on Tinytag Dataloggers every 15 minutes from 07-05-2021 as shown in Figure 25. In this period, until 21-07-2021, the maximum temperature has been 32.5 ºC (19-07-2021) and the minimum -0.05 (13-05-2021).

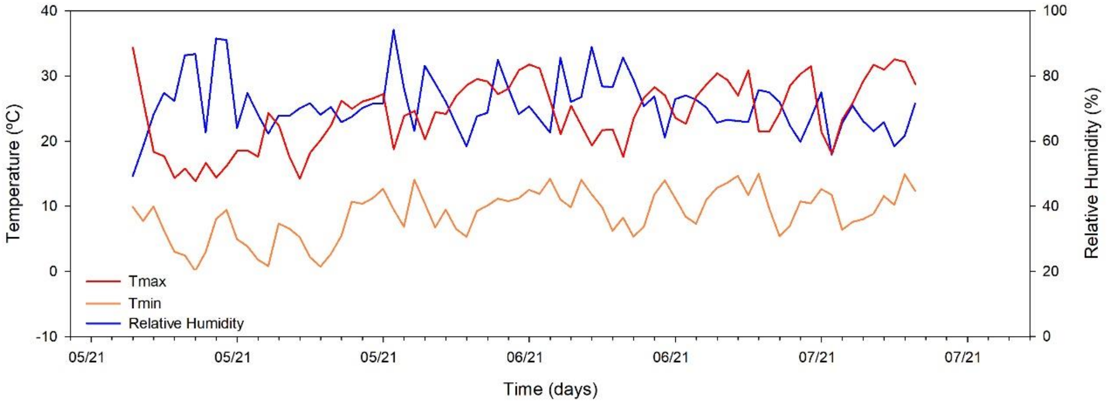


Figure 25. Daily average of minimum and maximum temperature and relative humidity in the Populus experimental plot.

5. Results of the 1st monitoring campaign, Catalonia

The pilot experience has been implemented in a Holm oak forest in the lower part of the Eastern Pyrenees, specifically, in the Requesens estate

Following, we include a summary of the implemented pilot experience and the experimental design of the monitoring network, to facilitate the understanding of the monitoring results. A more detailed description of the implemented actions can be consulted in Pascual *et al.* (2020a, 2020b).

Implemented pilot experience

- Adaptive forest management in a Holm oak forest area of 1.15 ha consisting of selective thinning and scrubland clearing. Within the area, two different pilot experiences are developed depending on the livestock management:
    a. A sub-area of 5,520 m^2 where livestock will enter.
    b. A sub-area of 5,978 m^2 where livestock will not enter.
- Control plot: An area with no actuation of 1.47 ha.

Monitoring network:

- Three typologies of monitoring plots with a surface of 1,000 m^2:
    - control plots, without neither forest management nor the entry of livestock (BC);
    - managed plots with livestock (BTAR);
    - managed plots without livestock (BTSR).
- For each of monitoring plots, three replicates (BC7-8-9; BTAR1-2-3 and BTSR4-5-6).

The monitoring network includes three plots of 1,000 m^2 with its replicates, nine monitoring subplots of 1,000 m^2 in total (Figure 26).

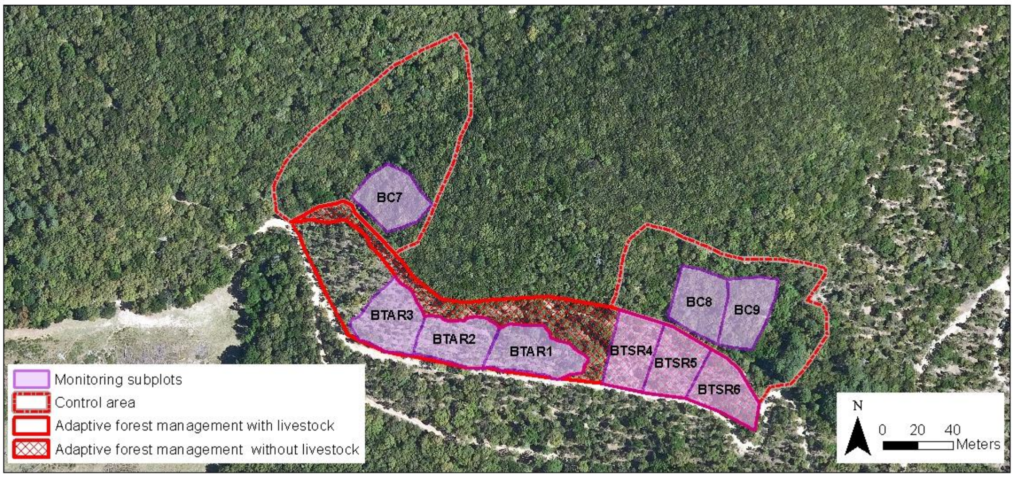


Figure 26. Location of the monitoring plots and replicates of the experimental design.

5.1. Monitoring results of the Soil

5.1.1. Soil characteristics

The first soil samplings were carried out in June 2020. At each monitoring subplot, three soil samples were sampled at two different depths: 0-10 cm and >10cm. The three samples were combined into one soil composite sample per monitoring subplot and depth. The samples were taken as follow:

- In the forest area (AFM), the samples were taken in the 9 monitoring subplots (BC7-8-9; BTAR1-2-3 and BTSR4-5-6) for the 2 depths (9 subplots * 2 depths * 3 subsamples = 54 subsamples). The subsamples were combined into 18 composite samples.
- In the recovered old pasture field (OPF), samples were taken in two plots with livestock and two plots without livestock (CAR6-4, CSR2-3) for the 2 depths (4 plots * 2 depths * 3 subsamples = 24 subsamples). The subsamples were combined into 8 composite samples.

In total 26 composite samples were created. The 26 samples have been analysed by the Pyrenean Institute of Ecology (IPE-CSIC), evaluating the following soil variables: Field bulk density (BD), pH and electrical conductivity (EC), total carbon concentration (Ctotal), total nitrogen concentration (N), carbonate content (CaCO3), organic carbon (Corg), soil organic carbon (SOC) and nitrogen (TN) stocks, organic matter (OM), grain size distribution, organic phosphorus (P), saturated soil moisture (SAT), field capacity (FC), wilting point (WP) and CN ratio.

Figure 27 shows that all the samples presented pH values lower than 6, corresponding to acid soils (ranging between 4.97 and 5.64). pH values slightly decreased with depth, except in the old pasture field (OPF) with livestock plot. In the case of electrical conductivity (Figure 28), mean values in the mineral soil ranged between 129 and 284 µs/cm, being these values higher in the topsoil samples. Organic horizons displayed higher values closed to 500 µs/cm.

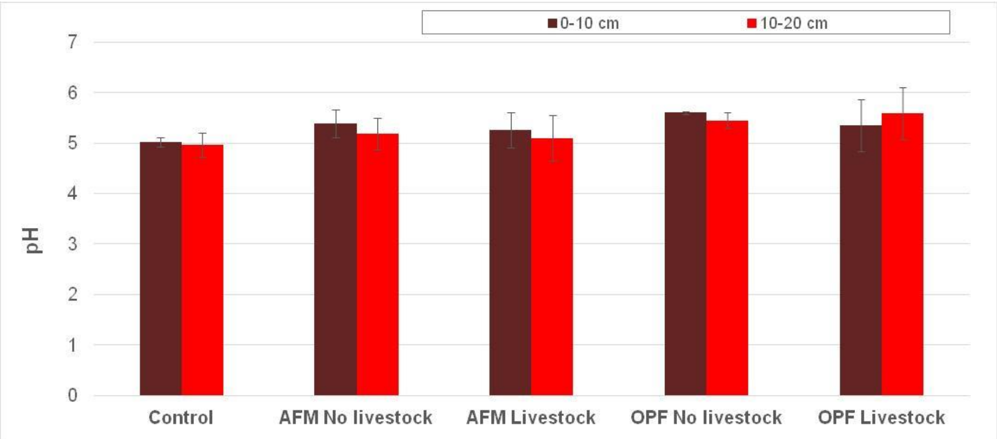


Figure 27. pH values of soil samples at two depths (0-10, and >10 cm) and in the different plots.

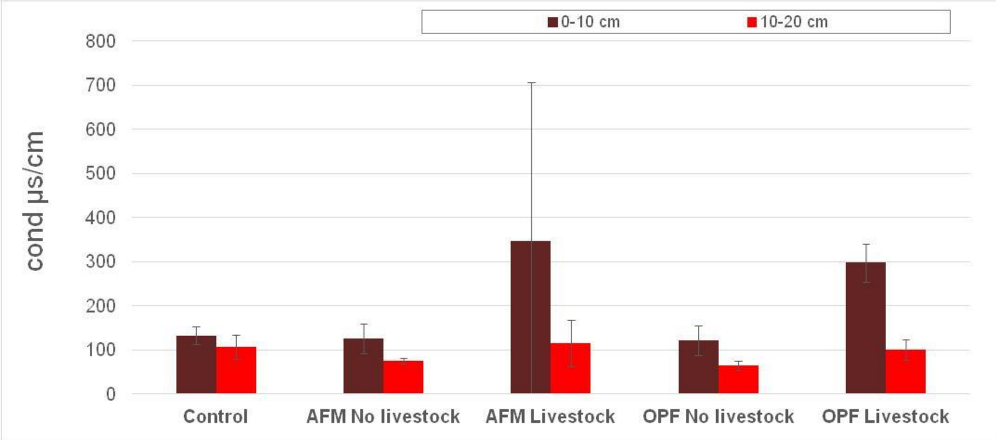


Figure 28. Conductivity values of soil samples at two depths (0-10, and >10 cm) and in the different plots.

Figure 30 presents the mean Corg. In all the cases, values decreased with depth. Values in the mineral soil samples ranged between 1.4 and 5.6%, very lows values for a forest soil, were values around 20% were expected. This fact can be explained because the soil is sandy loam soil, with a low percentage of clay, and carbon is usually uptake by clay. Nitrogen values followed the same pattern and mean values in the mineral samples oscillated between 0.1 and 0.3%.

Corg/N ration is an index of the quality of the soil organic substrate. The Corg/N ratio values varied between 10.6 and 20.8 (Figure 31 up). These values indicate that the soil is equilibrated and exist a control between mineral nitrogen and carbon in the soil.

P values decrease in depth (Figure 31 down). Maximum values were around 10.6 mg/kg P, and minimum values were around 2.3. High standard deviations are recorded in all the cases. Higher values were recorded in the AFM with livestock plots, probably due to the fertilizer effect of the livestock (cows) that had already entered one time (May 2020).

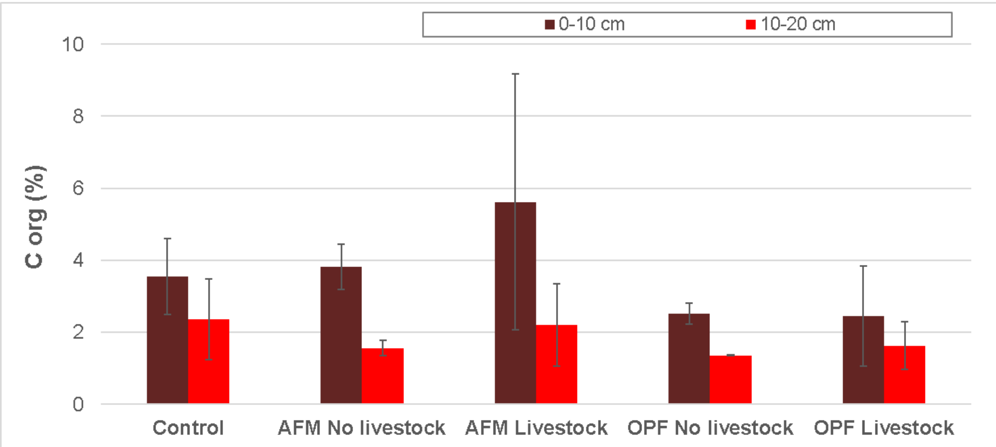


Figure 29. Organic Carbon (C org) content of soil samples at two depths (0-10, and >10 cm) and in the different plots.

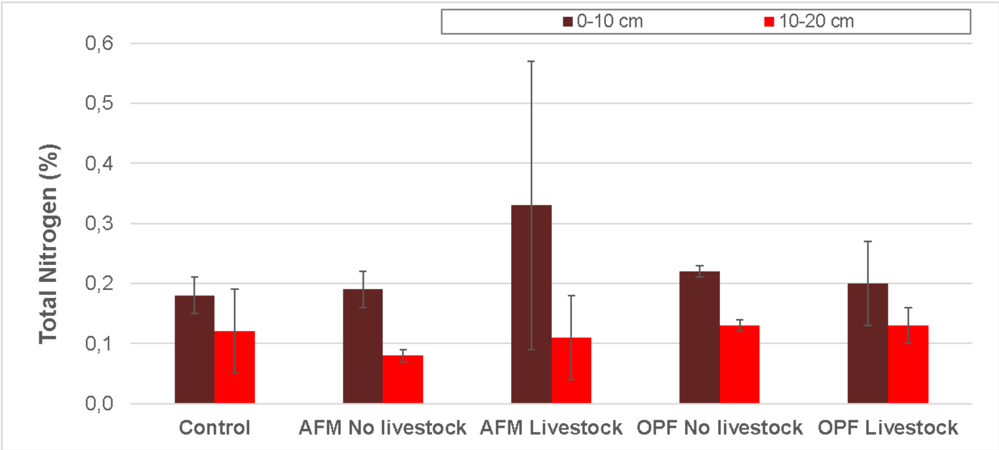


Figure 30. Nitrogen (N) content of soil samples at two depths (0-10, and >10 cm) and in the different plots.

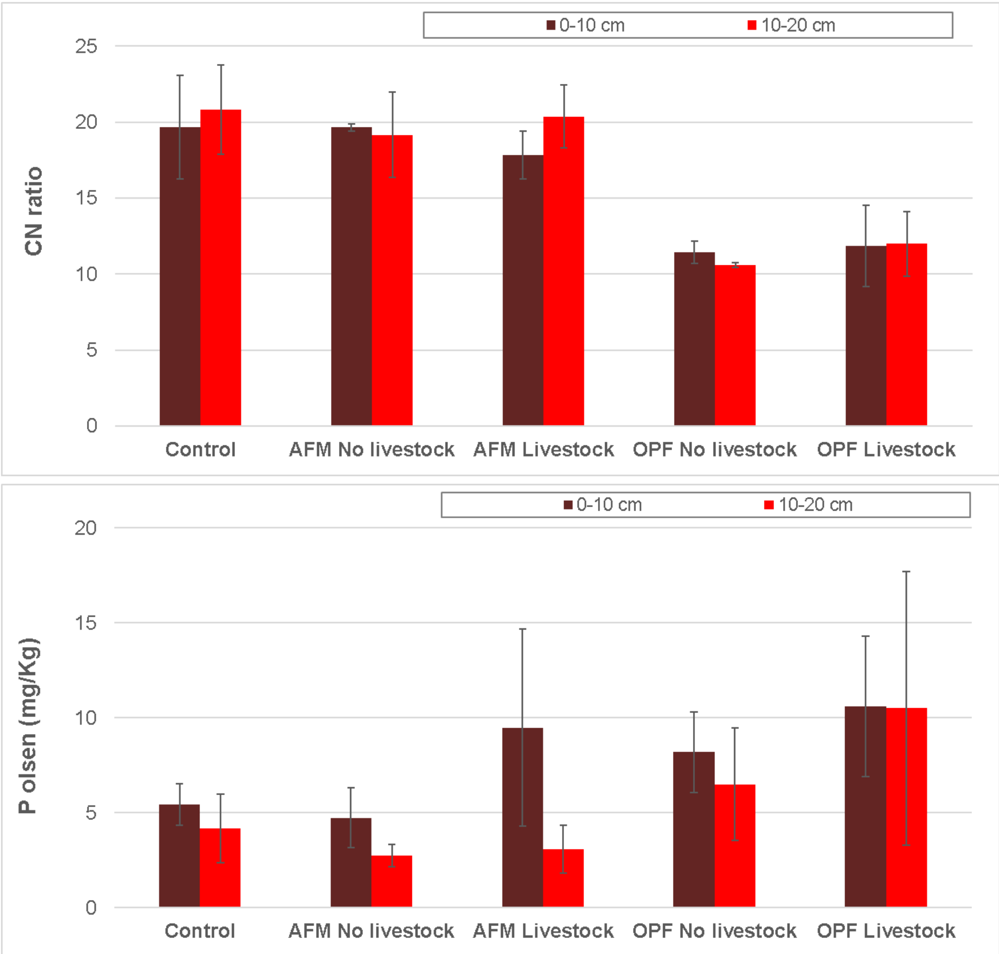


Figure 31. Organic carbon and Nitrogen ratio (CN ratio) and phosphorus (P) content of soil samples at two depths (0-10, and >10 cm) and in the different plots.

Figure 32 presents the texture diagram representing the percentages of clay, silt and sand of the different soil samples. Most of the soil samples present a sandy loam texture. Clay values oscillated between 15 and 45%, silt values between 5 and 35%, and sand values between 55 and 80%.

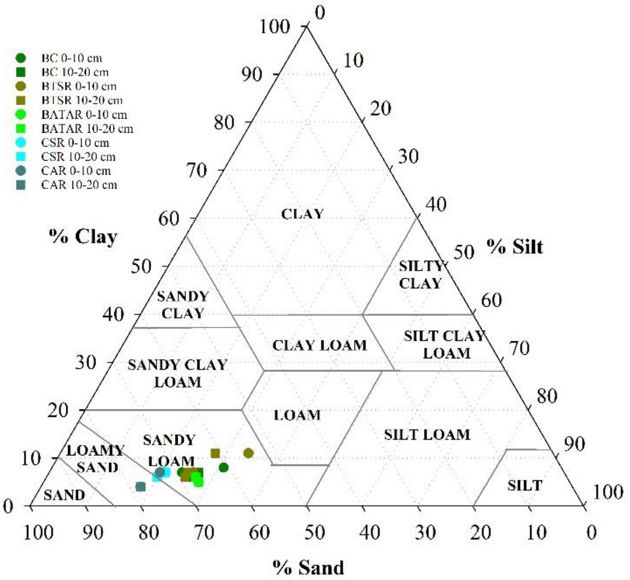


Figure 32. Clay, silt and sand contents (texture) of soil samples at two depths (0-10, and >10 cm) and in the different plots.

5.1.2. Soil moisture

The sensor network installed to monitor the evolution of the water in the first 20 cm of the soil has been continuously recording since the installation. The network consists on 5 dataloggers, four in the treatment plots and one in the control plot. Those dataloggers are connected to two soil moisture sensors per treatment and replica. In total, 5 dataloggers and 18 soil moisture sensors have been installed (Figure 33).

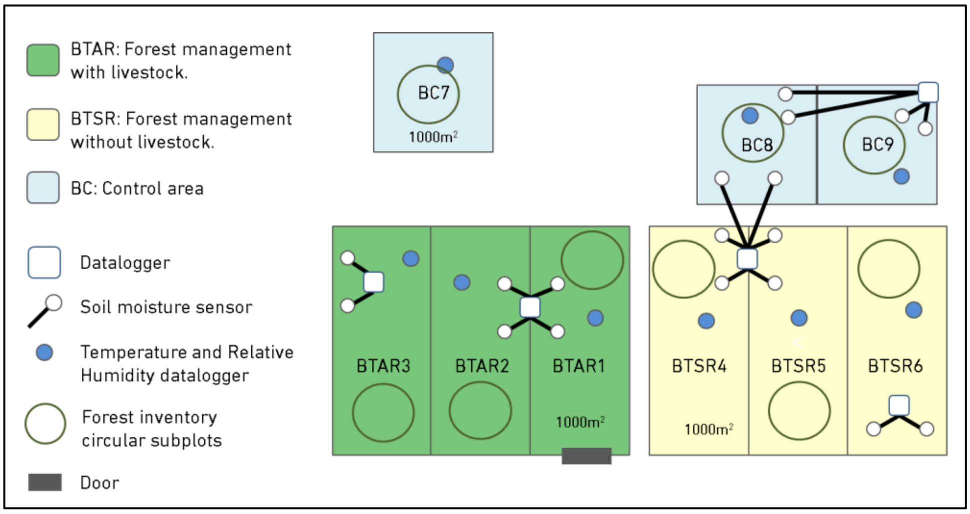


Figure 33. Diagram of the livestock and monitoring subplots.

Figure 34 shows the soil moisture data recorded every hour by the soil moisture sensors installed in the control plot and the mean of the replicates in the plots with AFM with and without livestock. There is some missing information in the sensors located in the treated area without livestock, because wild boars dug up the sensors and broke some of them.

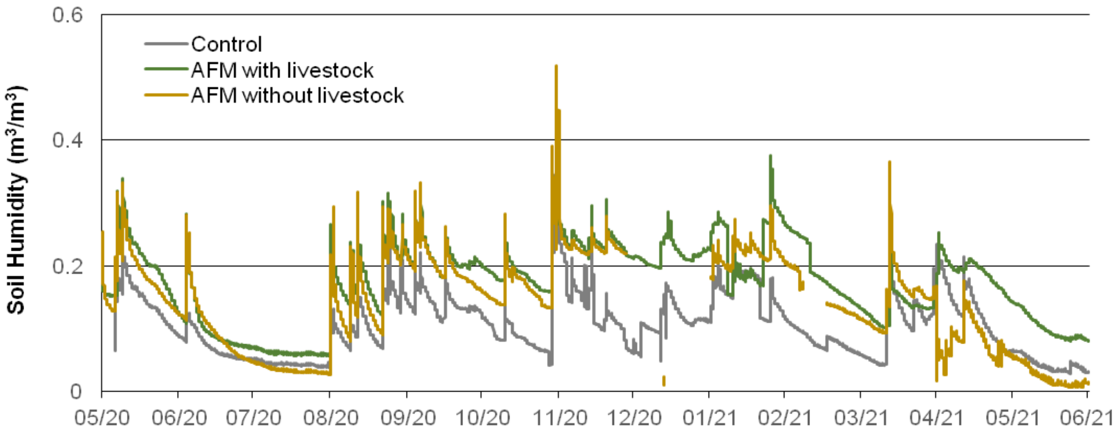


Figure 34. Soil humidity and precipitation in the Holm oak experimental plot (Requesens).

5.2. Monitoring results of the Forest

A network of forest indicators or variables has been designed and monitored, based on installation of permanent inventory subplots. The network consists of nine circular plots (radius 10 m) with an area of 314 m^2 (Figure 35).

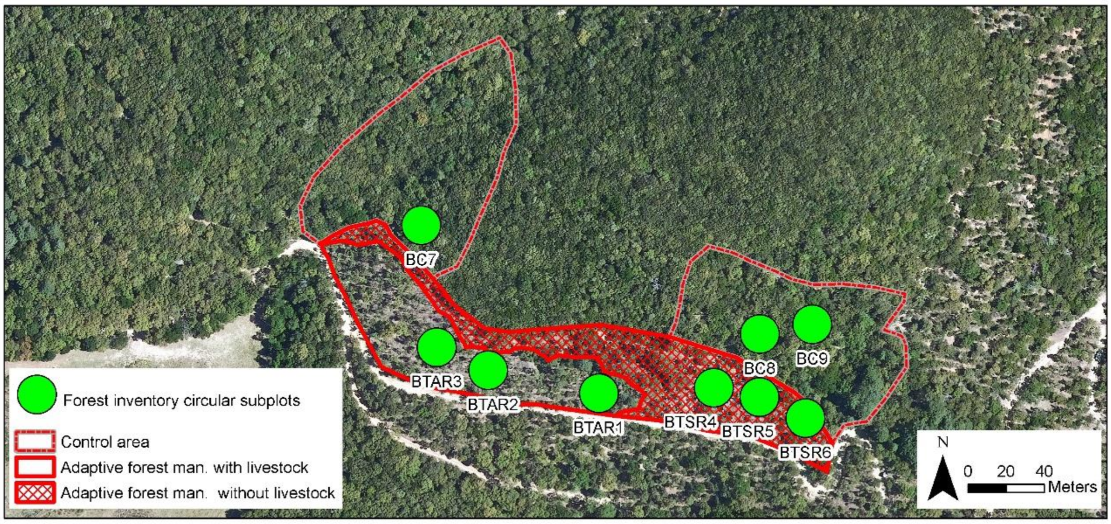


Figure 35. Location of the circular inventory subplots in Catalonia.

The initial forest inventory was carried out on May 2020, with the objective to set the initial conditions of the forest stand, to follow up its evolution on time. The second inventory was performed between May and November 2021, corresponding to the first monitoring campaign.

5.2.1. Forest structure

Forest structure refers to the distribution and characteristics of the individual trees within the subplot. The monitoring of the forest structure was performed initially and after implementing the forest management, and the differences between both situations was detailed explained at Pascual *et al.* (2020a).

Forest structure will be evaluated again at the end of the project, to compare the initial conditions with the final ones. For this reason, forest structure has not been monitored in the 1st monitoring campaign and results are not shown here.

5.2.2. Forest fuel continuity

Forest fuel continuity refers to the spatial distribution and height of the different strata of the fuel (aerial, ladder or surface cover), which has a direct effect in the vulnerability of the forest to fire risk due to fire propagation. Forest fuel continuity is quantified with two indicators: crown fire hazard and understorey biovolume.

Both indicators are assessed initially, after implementing the forest management, annually (in autumn the crown fire hazard) and at the end of the project. In this case, as it was explained in Pascual *et al.* (2020a), the initial and after implementation inventories were coincident in May 2020. The annual inventory was performed in November 2021 during the first monitoring campaign.

Table 18 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the 1st monitoring campaign in 2021. Results show that the crown fire hazard has reduced to low hazard in the subplots where forest management and the recovery of pastures was performed. This change is produced because the livestock has favoured the maintenance of a low understorey and pastures, through the three times in which the livestock have grazed in the area. In this sense, this first results are in consonance with the expected impact of the action implemented.

Forest inventory subplot	After implementation 2020		Annual campaign 2021	
	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard
BC7	B9	Moderate	B9	Moderate
BC8	B9	Moderate	B9	Moderate
BC9	B9	Moderate	B9	Moderate
BTAR1	B16	Moderate	C16	Low
BTAR2	B16	Moderate	C16	Low
BTAR3	B16	Moderate	C16	Low
BTSR4	B16	Moderate	B16	Moderate
BTSR5	B16	Moderate	B16	Moderate
BTSR6	B16	Moderate	B16	Moderate

Table 18. Crown fire hazard after implementing the forest management (2020) and in the 1st monitoring campaign (2021).

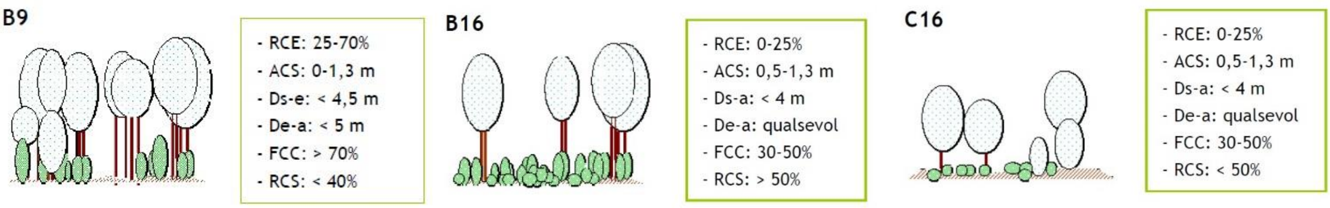


Figure 36. Description of the structure type B9, B16 and C13 with moderate and low crown fire hazard following Piqué et al. 2011.

5.2.3. Forest health status

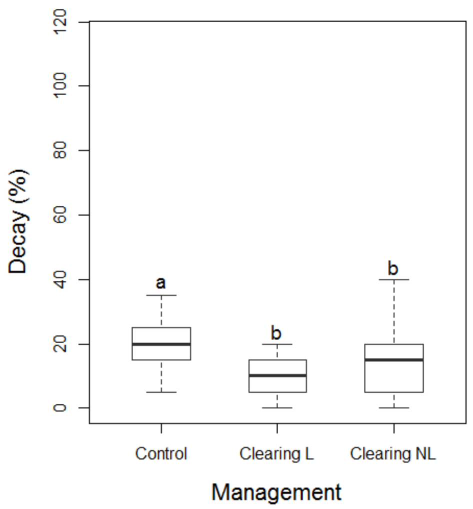
Forest health refers to the status of the forest decline due to climate change effects (mainly droughts) or other related threatens (plagues, diseases …). Forest decline is defined by the degree of defoliation, decolouration or mortality of the individuals of the forest.

Forest health status is assessed initially, after implementing the forest management, annually (in autumn) and at the end of the project. In this case, as it was explained in Pascual *et al* (2020), the initial and after implementation inventories were coincident in May 2020. The annual inventory was performed in November 2021 during the first monitoring campaign.

Table 19 shows the forest decay after the implementation of the forest management and after the 1st monitoring campaign in 2021. In 2020, forest decay did not show significant initial differences among treatments. In 2021, we observe a significant difference between control and both treatments plots, with higher decay in control plots (Figure 37). Data shows that forest decline has slightly worsened, starting from a mean forest decay of about 12.5% in 2020 to a mean value of about 15% in 2021. Figure 38 shows that the application of forest management together with livestock management is able to reverse the decay trend, although the differences among treatments are not yet significant. We need more years of monitoring to confirm this trend.

Forest inventory subplot	After implementation 2020			Annual campaign 2021		
	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)
BC7	13.0	1.0	14.0	6	15.5	21.5
BC8	12.5	2.0	14.5	6	16.5	22.5
BC9	10.0	0.5	10.5	5.5	14.5	20
BTAR1	0.5	4.0	4.5	3	7.5	10.5
BTAR2	0.5	4.7	5.2	1.9	5.5	7.4
BTAR3	8.5	14.5	23.0	1.7	6.5	8.2
BTSR4	10.5	1.5	12.0	4	13	17
BTSR5	8.0	1.5	9.5	4	8.5	12.5
BTSR6	18.5	1.0	19.5	4	19.5	23.5

Table 19. Forest decay per forest inventory subplots measured on May 2020 and November 2021.



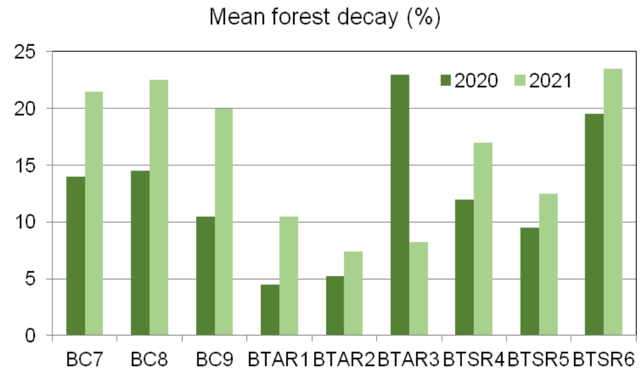


Figure 37. Left: Treatment effect on forest decay (%) in 2021. Right: Differences in forest decay (%) between 2020 and 2021 among forest inventory subplots.

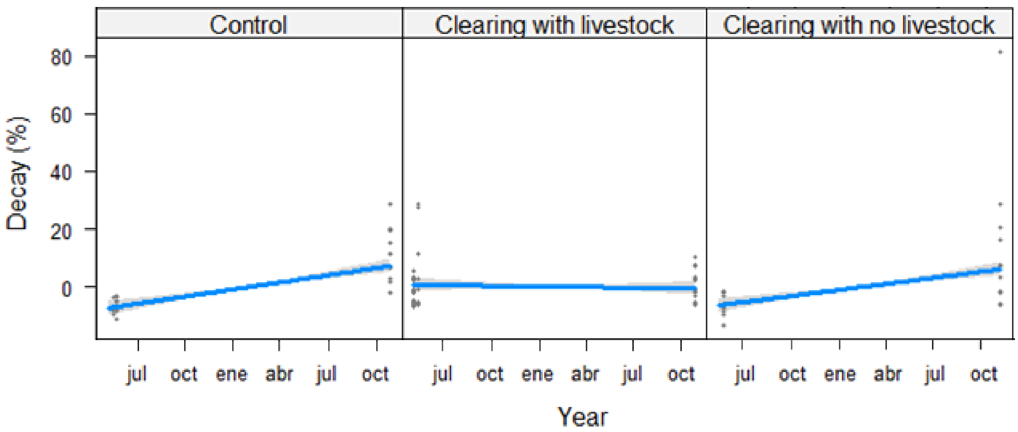


Figure 38. Treatment effect on Holm oak decay in Requesens, from 2020 to 2021.

5.2.4. Fuel moisture

Fuel moisture refers to the water content present in the vegetation along the dry season (summer), and is related with the flammability and combustibility of the vegetation and, as a result, with fire risk. A higher water contents of the vegetation in periods of elevated fire risk, is translated in a lower flammability and combustibility of the vegetation.

Forest fuel moisture samples are taken about nine times per year, approximately on the following dates: 1/5, 1/6, 15/6, 1/7, 15/7, 1/8, 15/8, 1/9 and 1/10. The sampling is repeated every year until the end of the project (2020, 2021, 2022 and 2023).

Figure 39 shows the effect of the adaptive forest management on vegetation water content in the two years of monitoring. Fire risk has been reduced in the treated plots, both with and without livestock, and the differences among the two years are significant. Although data for more year are needed, the results of the 2021 show the expected trend.

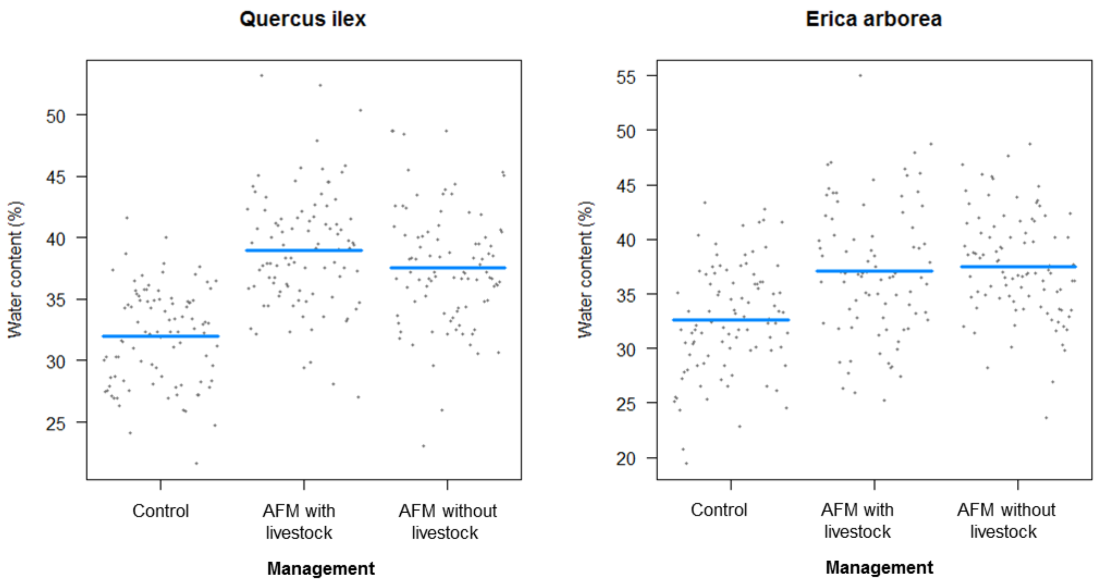


Figure 39. Treatment effect on vegetation water content in Requesens.

5.3. Monitoring results of the Pastures

The objective is to assess the effect of the adaptive forest management (selective thinning and scrubland clearing) and cow grazing in pasture production and quality in terms of biodiversity, biomass productivity and nutritive quality.

5.3.1. Biodiversity

Vegetation surveys are carried out in late spring or early summer (May-June). The first sampling was done in July 2020 in order to record the initial status of the pasture in the experimental plots. The second sampling will be done in the 2nd monitoring campaign in June 2022 in order to record the intermediate status of the pastures.

In the first sampling, we expected to find a positive effect of the adaptive forest management in the herbaceous pasture biodiversity, because of the elimination of woody competitors for light, space and nutrients. We expect that this effect will maintain over time in the experimental plots. Indeed, we found a higher Shannon diversity index and higher herbaceous species richness in plots submitted to forest management than in non-managed plots (Table 20). Regarding the Raunkiaer lifeforms, we found significantly more species of hemichryptophytes and therophytes in the plots submitted to forest management than in the control plot (non-managed). Specifically, therophytes show significantly more relative cover in the managed plots than in the control plot. We also found significantly more grass and forb species in the managed plots than in the control plot, showing the forbs especially higher relative cover in the managed plots.

Variables		AFM Mean ± SE	Control Mean ± SE	F	p-value
Shannon index		0.89 ± 0.12	0.35 ± 0.16	7.3037	**<0.05***
Total herbaceous richness		4.42 ± 0.67	1.25 ± 0.46	15.185	**<0.001*****
Chamaephytes	Richness (n)	0.08 ± 0.08	0 ± 0	1	0.3282
	Relative cover (%)	1.19 ± 1.19	0 ± 0	1	0.3282
Hemichryptophytes	Richness (n)	2.33 ± 0.36	1.17 ± 0.44	4.2441	**0.051***
	Relative cover (%)	-	-	-	-
Geophytes	Richness (n)	0 ± 0	0 ± 0	-	-
	Relative cover (%)	0 ± 0	0 ± 0	-	-
Therophytes	Richness (n)	2 ± 0.46	0.08 ± 0.08	16.77	**<0.001*****
	Relative cover (%)	47.79 ± 9.23	2.78 ± 2.78	21.782	**<0.001*****
Legumes	Richness (n)	0.17 ± 0.11	0 ± 0	2.2	0.1522
	Relative cover (%)	1.03 ± 0.71	0 ± 0	2.1409	0.1576
Grasses	Richness (n)	1.42 ± 0.29	0.67 ± 0.22	4.2227	**0.051***
	Relative cover (%)	35.83 ± 9.23	32.26 ± 11.43	0.0589	0.8105
Forbs	Richness (n)	2.83 ± 0.51	0.58 ± 0.26	15.693	**<0.001*****
	Relative cover (%)	63.14 ± 9.16	17.74 ± 8.03	13.879	**<0.01****

Table 20. Effect of the AFM in biodiversity variables: Shannon index, herbaceous species richness and in the richness and relative cover of the different Raunkiaer lifeforms (chamaephytes, hemichryptophytes, geophytes and therophytes) and in the different functional types (legumes, grasses and other forbs).

On the other hand, we expected not to find any effects of the livestock treatments since in the first year (2020), vegetation surveys were set previous to cows entry in the plots. As expected, we found no significant differences between livestock treatments neither in the Shannon diversity index nor in the herbaceous species richness (Table 21). In addition, we did not find significant differences between treatments for any of the Raunkiaer lifeforms. However, we found significant differences between treatments in the richness and relative cover of grasses and forbs, what was not expected in the initial status.

Variables		Livestock Mean ± SE	No livestock Mean ± SE	F	p-value
Shannon index		0.89 ± 0.12	0.94 ± 0.11	0.109	0.7444
Total herbaceous richness		4.42 ± 0.67	4.58 ± 2.02	0.0353	0.8527
Chamaephytes	Richness (n)	0.08 ± 0.08	0 ± 0	1	0.3282
	Relative cover (%)	1.19 ± 1.19	0 ± 0	1	0.3282
Hemichryptophytes	Richness (n)	2.33 ± 0.36	3.08 ± 0.45	1.7036	0.2053
	Relative cover (%)	-	-	-	-
Geophytes	Richness (n)	0 ± 0	0 ± 0	-	-
	Relative cover (%)	0 ± 0	0 ± 0	-	-
Therophytes	Richness (n)	2 ± 0.46	1.50 ± 0.23	0.9429	0.3421
	Relative cover (%)	47.79 ± 9.23	56.85 ± 7.16	0.6012	0.4464
Legumes	Richness (n)	0.17 ± 0.11	0.33 ± 0.19	0.5789	0.4548
	Relative cover (%)	1.03 ± 0.71	0.36 ± 0.24	0.8264	0.3732
Grasses	Richness (n)	1.42 ± 0.29	3.17 ± 0.30	17.9	**<0.001*** **
	Relative cover (%)	35.83 ± 9.23	93.93 ± 2.50	36.921	**<0.001*** **
Forbs	Richness (n)	2.83 ± 0.51	1.08 ± 0.31	8.678	**<0.01** **
	Relative cover (%)	63.14 ± 9.16	5.71 ± 2.52	36.509	**<0.001*** **

Table 21. Livestock effect on the AFM areas in biodiversity variables: Shannon index, herbaceous species richness and in the richness and relative cover of the different Raunkiaer lifeforms (chamaephytes, hemichryptophytes, geophytes and therophytes) and in the different functional types (legumes, grasses and other forbs).

5.3.2. Pasture production and quality

Pasture production and quality samplings are carried out in late spring or early summer (May-June). The first sampling was done in June 2020 in order to record the initial status of the pasture in the experimental plots. The second sampling will be done in the 2nd monitoring campaign in June 2022 in order to record the intermediate status of the pastures.

In the first sampling, we expected to find a positive effect of the adaptive forest management in the production and quality of the herbaceous pasture because of the elimination of woody competitors for light, space and nutrients. We expect that this positive effect will maintain over time in the experimental plots. As we observe in Figure 40 (left), there is significantly more herbaceous biomass in the managed plots than in control plots. Nutritive quality variables are not shown because they are still being processed in the laboratory (stuck due to chemical reagents lack supplies).

Contrarily, in the initial status (2020), we expected not to find any effects of the livestock treatments in the herbaceous pasture, neither in production nor in quality since vegetation samples (and their subsequent processing and analyses) were collected previous to the entry of the cows. Contrarily to what expected, we found significant differences in biomass production between livestock treatments, being higher in the plots submitted to grazing (Figure 40, right).

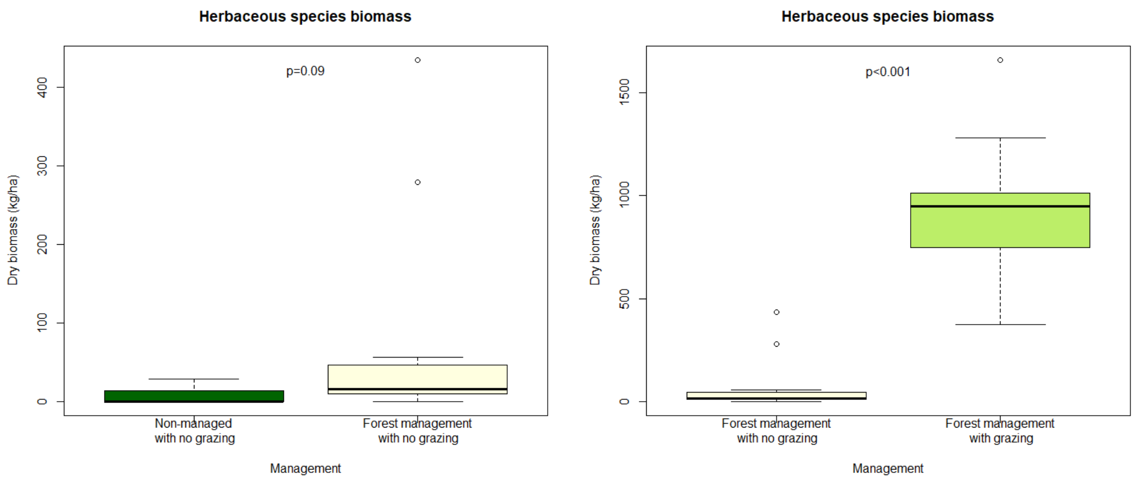


Figure 40. Left: Biomass production (kg of dry matter/ha) in the non-managed plots (control) and in the forest management plots not submitted to grazing. Right: Biomass production (kg of dry matter / ha) in the area submitted to forest management activities in both the plots with no grazing and plots with grazing.

5.4. Monitoring results of the Rainfall simulations

Rainfall simulations assess the effect of forest management and grazing on the hydrological response and soil erosion. The annual campaign in Catalonia was performed in October 2020. Here we present the results of this first monitoring campaign. Although 3 experiments were performed per land management type (3 replicas), some results had to be removed because they seemed incorrect (e.g., Runoff Coefficient > 1). This can be due to problems in either the rainfall simulation experiment (e.g., the circular ring is not correctly fixed in the ground) or the post processing of the water samples.

In Requesens, the hydrogeomorphological response was higher in the plots without livestock (BTRS), with a mean runoff coefficient (RC) of 0.63 and a sediment detachment (SD) of 72 g/m^2/h, followed by the control plot with a mean RC of 0.47 and a SD of 46.2 g/m^2/h (Table 23). The managed plot with livestock (BTAR) showed a very low hydrological response (mean RC = 0.01) and low sediment response (mean SD = 0.82 g/m^2/h). These contrasting results between the two managed plots are most probably due to their differences in the herbaceous cover, with 65-100% cover in the BTAR plots and a lack of herbaceous cover in the BTRS plots. However, the high variability of the data, especially for the BTRS plots, suggests the need of more experiments to obtained more robust results.

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Quercus ilex	Control	0.52	24.05	3.5	10	4.63	4.56	100.17
		0.80	27.90	5.3	10	1.24	0.86	26.92
		0.10	27.40	5.3	10	0.53	3.30	11.52
	BTSR (AFM without livestock	1.08	30.15	2.6	5	6.15	2.77	133.09
		0.18	26.00	4.3	6	0.50	1.02	10.94
	BTAR (AFM with livestock	0.01	16.70	3.6	9	0.01	0.55	0.22
		0.00	18.55	4.8	9	0.08	8.05	1.69
		0.00	22.75	7.5	10	0.03	5.03	0.54

Table 22. All hydrogeological and sedimentological variables extracted from rainfall simulations in Requesens in October 2020. Simulations without runoff are represented in Time to runoff variable with a NA and with a 0 value in Sediment concentration, production, and detachment. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

Site	Land management	RC (-)	IR (mm h^{-1})	TR (min)	WF (cm)	SC (g L^{-1})	SP (g)	SD (g m^{-2} h^{-1})
Quercus ilex	Control	0.47±0.35	26.45±2.09	4.7±1.02	10±0.00	2.13±2.19	2.91±1.88	46.20±47.37
	BTSR	0.63±0.64	28.08±2.93	3.5±1.19	5±0.35	3.33±3.99	1.90±1.24	72.01±86.37
	BTAR	0.01±0.00	19.33±3.10	5.3±1.98	9±0.58	0.04±0.04	4.54±3.77	0.82±0.77

Table 23. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in simulations in in Requesens in October 2020. All values have a n=3, except in BTRS with n=2. All values represent mean ± standard error. RC: Runoff coefficient (mm mm^{-1}), IR: Infiltration rate (mm h^{-1}), TR: Time to runoff (min), WF: Wetting front (cm), SC: Sediment concentration (g l^{-1}), SP: Sediment production (g) and SD: Sediment detachment (g m^{-2} h^{-1}).

5.5. Site meteorological conditions

The registration of the meteorological conditions is key to understand the evolution of previous variables along the project duration. With this objective, we have installed air temperature sensors, relative humidity sensors and rain-meters or weather stations to record in continuum these variables.

Meteorological conditions are continuously recorded since May 2018, with some disruptions due to extreme meteorological events that stopped the records temporarily. Currently, we are building a homogenous meteorological data series, using previous years before project starting and refilling gaps using weather stations near the pilot location (Figure 41).

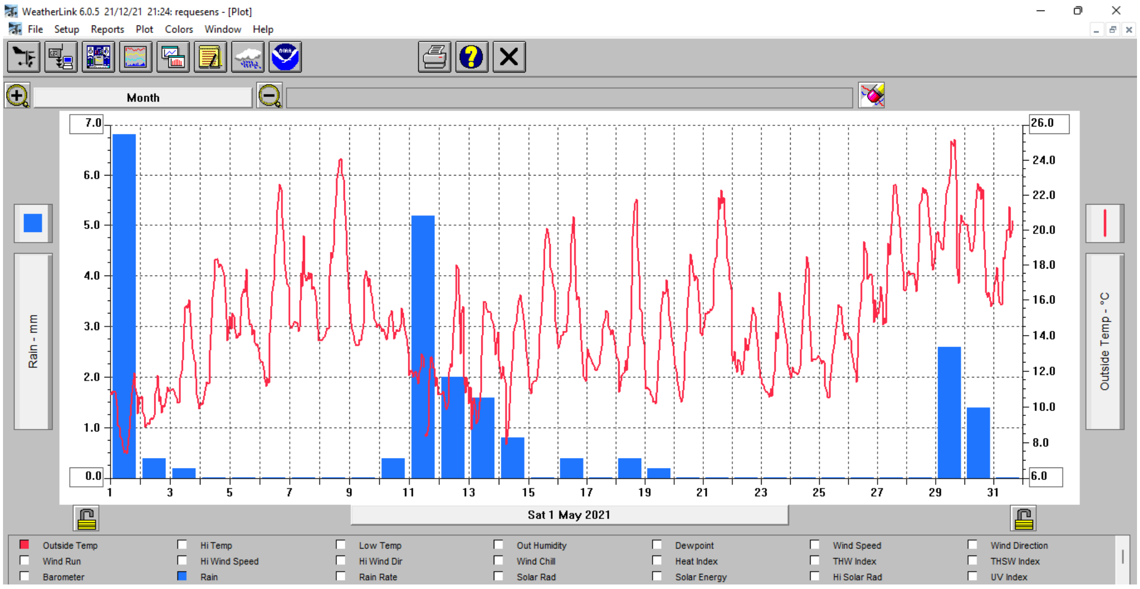


Figure 41. Detailed outputs of the weather station located in Requesens pilot area.

6. Conclusions

The main objective of this deliverable is to present the **results of the first monitoring campaign developed in 2021** of the action C.2: Climate change adaptation measure: Forests management in Aragon and Catalonia.

Main outcomes of this first monitoring campaign are:

***Pinus nigra* forest in Aragon**		
Soil	Soil characteristics	75 composite samples have been analysed. Soils are basic with clay structure. Organic topsoil present high values of organic carbon and nitrogen, and the percentage decreased with depth. The Corg/N ratio values, an indicator of the quality of the soil, indicate that the soil is equilibrated and exist a control between mineral nitrogen and carbon in the soil. Soil organic carbon and nitrogen stocks show no significant differences between the different plots (control livestock and without livestock), setting a good starting point to monitor changes in future campaigns.
	Soil moisture	The sensor network was installed in 2020, although some arrangement were done in 2021 to reinstate some failed sensors. Soil moisture data has been recorded continuously from June 2020 until November 2021, showing a good response of the sensors to the recorded rainfall events
Forest	Forest structure	There is not annual monitoring of this variable
	Forest fuel continuity	No major changes are observed in crown fire hazard between the initial survey (2020) and the monitoring campaign (2021). More time is needed to observe a reduction of the crown fire hazard in the treated plots.
	Forest health status	Forest decay did not show significant initial differences among treatments in 2021, similar to 2020.Forest decline has worsened in all subplots, starting from a mean forest decay of about 8% in 2020 to a mean value of about 31% in 2021.
	Fuel moisture	Fuel moisture was higher in the treated plots, both with and without livestock, although differences among the plots were not yet significant, with the aggregated data from 2020 and 2021. Although data for more years is needed, the results of the 2021 show the expected trend.
Pastures	Biodiversity	We found higher herbaceous species richness in plots submitted to AFM than in non-managed plots as expected, because of the elimination of woody competitors for light, space and nutrients. Regarding functional types, we found more species being grasses and forbs in the treated plots than in the control plot. However, we did not find significant differences in the relative abundance of the plants between both treatments. Besides, we found no significant differences between livestock treatments in any of the diversity variables studied as expected, because vegetation surveys were set previous to cow's entry in the plots.
	Pasture production and quality	We found significantly more herbaceous biomass in the treated plots than in control plots as expected, because of the elimination of woody competitors for light, space and nutrients. Regarding pasture quality, we only found a positive effect of AFM in the amount of crude protein (PB), hemicellulose and dry matter

		intake (IMS) but we found no significant differences between treated and not treated plots for the rest of the nutritive quality variables measured. We did not observe significant differences between livestock treatments neither in the herbaceous biomass production nor in the nutritive quality variables measured as expected, because of vegetation samples were collected previous to the entry of the cows. Besides, we expected to find less biomass with higher nutritive quality in the plots with cow grazing (more proteins and digestible fibers).
Rainfall simulations		We found a higher hydrogeomorphological response under managed and grazed conditions, compared with control and no grazed subplots
Site meteorological conditions		Maximum, minimum temperature, and relative humidity are recorded continuously from June 2020.
***Populus* forest in Aragon**		
Soil	Soil characteristics	75 composite samples have been analysed. Soils are basic. Organic matter decreased with depth, with high standard deviations in the deepest layers. Phosphorous content presented high variability, with higher values recorded in the topsoil and a decreasing trend with depth.
	Soil moisture	The sensor network was installed in 2021. Soil moisture data has been recorded continuously from June 2021 until November 2021, showing a good response of the sensors to the recorded rainfall events
Forest	Forest structure	There is not annual monitoring of this variable
	Forest fuel continuity	The 1st annual inventory will be performed in autumn 2022 (because the AFM was implemented in 2021).
	Forest health status	The 1st annual inventory will be performed in autumn 2022 (because the AFM was implemented in 2021). Forest decay in 2021 did not show significant differences among treatments. Data for more years is needed to find trends and get conclusions
	Fuel moisture	Fuel moisture was higher in the *Populus* treated plots in 2021, both with and without livestock, although differences among the plots are not yet significant. Data for more years is needed to find trends and get conclusions
Pastures	Biodiversity	We found higher Shannon diversity index and herbaceous species richness in plots submitted to AFM than in control plots as expected, because of the elimination of woody competitors for light, space and nutrients. Regarding functional types, we found more richness of legumes and forbs and a higher relative cover of legumes and grasses in the treated plots than in the control. Besides, we found no significant differences between livestock treatments in any of the diversity variables studied as expected, because vegetation surveys were set previous to cow's entry in the plots.
	Pasture production and quality	We did not observe significant differences between the control plots and the ones submitted to AFM for the biomass production, contrary to expected, Regarding the nutritive quality of the herbaceous pasture, we only found an effect of the AFM in the ADL (Acid-Detergent Lignin), being higher in the treated area. Besides, we found no significant differences between livestock treatments neither in the herbaceous biomass production nor in any nutritive quality variables studied.

Rainfall simulations		We found a higher hydrogeomorphological response in the control subplots than in the managed ones. One reason may be the lower vegetation cover (60 and 70%) in some control plots and their higher hillslope gradient (> 35% vs <7%). The high variability of the data suggests the need of more experiments to obtained more robust results.
Site meteorological conditions		Maximum, minimum temperature, and relative humidity are recorded continuously from May 2021.
***Quercus ilex* forest in Catalonia**		
Soil	Soil characteristics	26 composite samples have been analysed. Soils are acid, with sandy loam structure. Organic carbon content decreased with depth and obtained values were lower than expected for a forest. The Corg/N ratio values indicate that the soil is equilibrated and exist a control between mineral nitrogen and carbon in the soil. P values decrease in depth, and higher values were recorded in the AFM with livestock plots, probably due to the fertilizer effect of the livestock (cows) that had already entered one time (may 2020).
	Soil moisture	The sensor network was installed in 2021. Soil moisture data has been recorded continuously from May 2020 until November 2021, showing a good response of the sensors to the recorded rainfall events.
Forest	Forest structure	There is not annual monitoring of this variable
	Forest fuel continuity	Crown fire hazard in control plots and plots without livestock have not changed among inventories, maintaining in a moderate risk. However, crown fire hazard has reduced to low hazard in the subplots where forest management and the recovery of pastures was performed. This change is produced because the livestock has favoured the maintenance of a low understorey and pastures, through the three times in which the livestock have grazed in the area.
	Forest health status	Forest decline has slightly worsened, starting from a mean forest decay of about 12.5% in 2020 to a mean value of about 15% in 2021. In 2021, we observe a significant difference between control and both treatments plots, with higher decay in control plots. Comparing 2020 and 2021, forest decline in plots with AFM and livestock showed a decreased trend in forest decline, suggesting that management is able to reverse the decay trend, although the differences among treatments are not yet significant.
	Fuel moisture	The evolution of fuel moisture between 2020 and 2021 showed that fire risk has been reduced in the treated plots, both with and without livestock, and the differences among the two years are significant.
Pastures	Biodiversity	We found higher Shannon diversity index and herbaceous species richness in plots submitted to AFM than in control plots as expected. Regarding functional types, we found significantly more grass and forb species in the managed plots than in the control, showing the forbs especially higher relative cover in the managed plots. Besides, we found no significant differences between livestock treatments neither in the Shannon diversity index nor in the herbaceous species richness or in any of the Raunkiaer lifeforms. However, we found significant differences between treatments in the richness and relative cover of grasses and forbs, what was not expected in the initial status.

	Pasture production and quality	We found significantly more herbaceous biomass in the treated plots than in control plots as expected. Nutritive quality variables are still being processed in the laboratory. Contrarily to expected, we found significant differences in biomass production between livestock treatments, being higher in plots with grazing.
Rainfall simulations		We found a higher hydrogeomorphological response in the managed plots without livestock (BTRS), whereas the managed plots with livestock (BTAR) showed a very low hydrological response. These contrasting results between the two managed plots are most probably due to their differences in the herbaceous cover, with 65-100% cover in the BTAR plots and a lack of herbaceous cover in the BTRS plots. However, the high variability of the data, especially for the BTRS plots, suggests the need of more experiments to obtained more robust results.
Site meteorological conditions		Maximum, minimum temperature, and relative humidity are recorded continuously from May 2021. Besides, meteorological variables are continuously recorded since May 2018.

7. References

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