LIFE MIDMACC

Mid-mountain adaptation to climate change

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Report with the 2nd year monitoring results of the implementation action C2

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Executive summary

This deliverable presents the results obtained from monitoring of the pilot experiences during the second year of the monitoring in 2022. 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, the first monitoring campaign was realized in 2021, and this second monitoring campaign has been performed between May and November 2022.

Following the monitoring protocol developed in deliverable 9 (Pascual *et al.*, 2020b), this document includes the results obtained in the pilot experiences of forest management for fire risk prevention and maintenance with extensive livestock farming in Aragon and Catalonia. This deliverable is built over the previous one (DL14. Report with the 1st year monitoring results of the implementation action C2), adding new results and conclusions.

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 and second 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 second 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 2022, ending in November. Monitoring results of 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., 2022b) 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., 2022b).

	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 (2023)
	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 (2023)
	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)
	Forest health status	Forest decline (%) Tree mortality (%) Defoliation (%) Decolouration (%)	Forest health sampling	Initial (2020) After implementing the adaptation measure (2020) Annual survey (autumn 2021-22-23)

	Variable	Measured variables	Methodology	Periodicity
	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 Time to runoff Wetting front Sediment concentration Sediment production	Rainfall simulation experiments	After clearing (2020) Annual simulations (2020-2021-2022-2023)
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)

	Variable	Measured variables	Methodology	Periodicity
	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 and 2nd 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 2022 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) and (Pascual, et al., 2022b).

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).

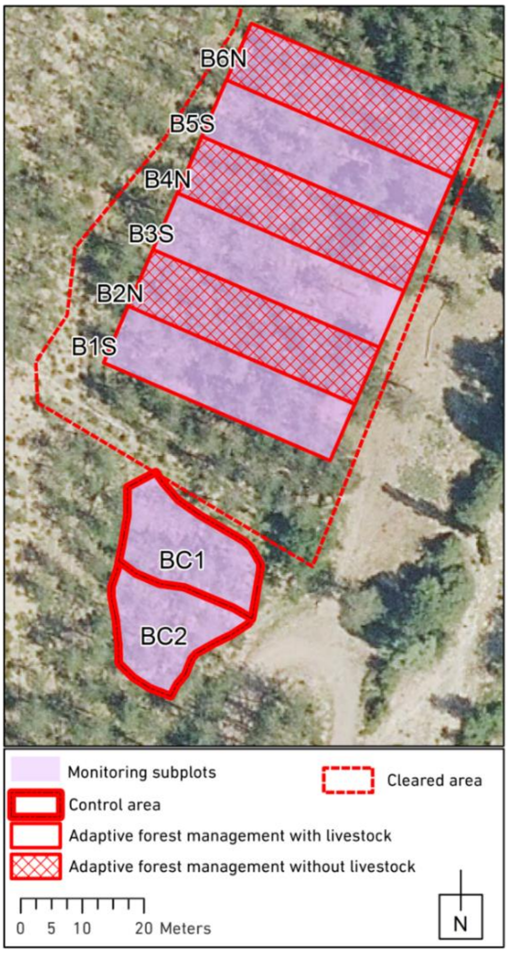


Figure 1. Location of the monitoring plots and replicates of the experimental design.

3.1. Monitoring results of the Soil

3.1.1. Soil characteristics

The initial sampling of the monitoring variables was carried out in June 2020 and the first-year monitoring campaign was carried out in November 2021 once the animals entered three times in the experimental plots during the second year of livestock grazing (spring, summer and autumn 2021). In autumn-winter 2022, during the second-year monitoring campaign, superficial soil samples (0-10 cm) were again taken to analysis the changes in carbon and nitrogen stocks, and samples are currently under analysis. In this deliverable, we present the results of 2021 campaign.

At each monitoring subplot, three soil subsamples were sampled in a depth of 0-10 cm. In each site, 21 points were selected and subsamples were recorded and later combined into one soil composite sample per plot and depth (0-10 cm). In total 9 composite samples were created in La Garcipollera. The samples were analysed by the Pyrenean Institute of Ecology (IPE-CSIC), evaluating the following soil variables: total carbon concentration (Ctotal), total nitrogen concentration (N), organic matter (OM), bulk density (BD), and soil organic carbon (SOC).

The following tables present the mean values at the initial conditions, and after the first year of monitoring and the change occurred in percentage for the main variables (0-10 cm) measured in the experimental plots during the 2021 monitoring campaign in La Garcipollera Research Station. Statistical results did not show significant differences between the management plots and the control plots at the second year of monitoring, neither between the initial conditions and the 2021 values. Some changes could be highlighted. Related to SOC values (Table 2) (i) higher SOC stocks are observed after the first monitoring year, except in the no livestock plots; (ii) the higher increase in SOC stock and higher values are observed in the livestock plots. Related to N stocks (Table 3): (i) an increase in N stocks is observed in the livestock plot; and (ii) the no livestock and control plots show a decrease in N stocks. Related to the Corg/N ratio (Table 4): (i) higher values are observed after the first monitoring year, being significant in the control plots; and (ii) the highest ratio is observed in the control plot.

SOC Mg ha^{-1} (10 cm)	YEAR 0	YEAR 1	Change %
Livestock	53.50	69.28	29.5
No livestock	59.62	47.99	-19.5
CONTROL	43.27	46.11	6.54

Table 2. Soil organic carbon (SOC) stocks of soil samples for the initial conditions and first year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

N Mg ha^{-1} (10 cm)	YEAR 0	YEAR 1	Change %
Livestock	0.35	0.39	13.2
No livestock	0.41	0.23	-43.6
CONTROL	0.25	0.16	-35.0

Table 3. Nitrogen (N) stocks of soil samples for the initial conditions and first year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

Corg/N ratio (10 cm)	YEAR 0	YEAR 1	Change %
Livestock	14.17	17.58	24.1
No livestock	13.95	19.87	42.4
CONTROL	14.47	21.72	91.5

Table 4. Corg/N ratios of soil samples for the initial conditions and first year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

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 2).

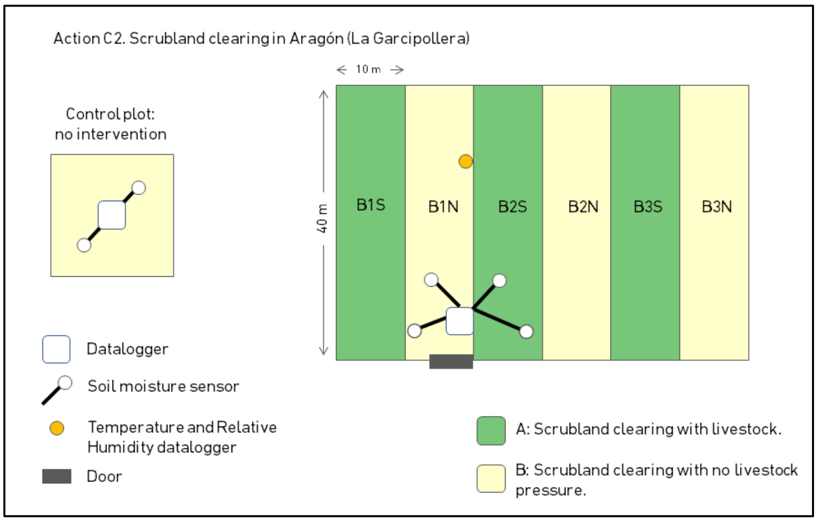


Figure 2. Final diagram of the soil moisture instrumentation.

Figure 3 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. The soil moisture data of the control plots is not available for the last period due to the impossibility to discharge the data on time, but it would be included in the next deliverable. The results show 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 control subplots. Figure 4 shows the results grouped by season.

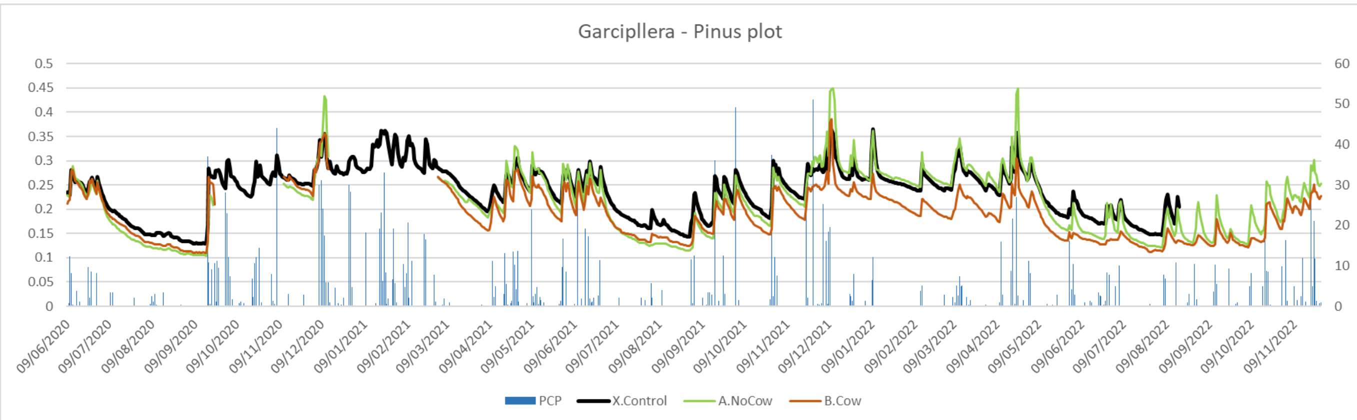


Figure 3. Soil humidity and precipitation in the Pinus nigra experimental plot (La Garcipollera).

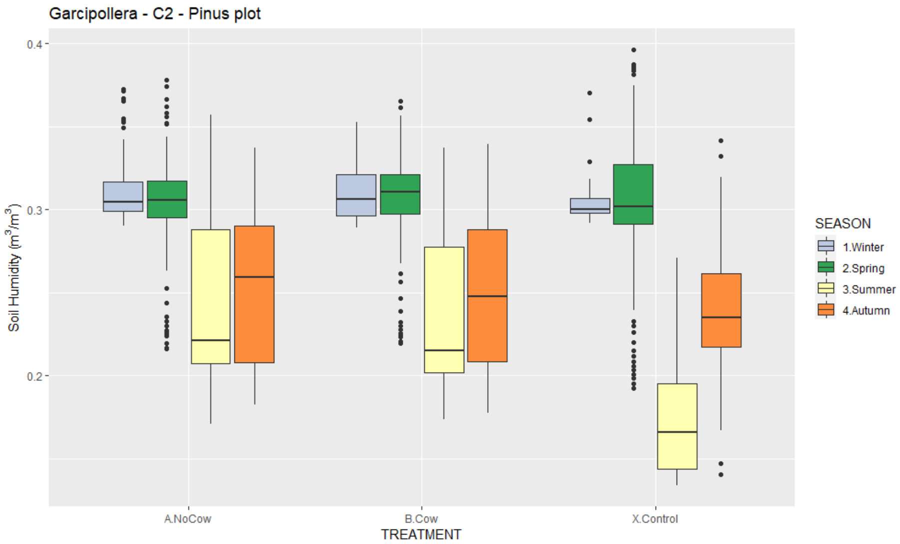


Figure 4. Soil humidity distribution per season and treatment in the Pinus nigra experimental plot (La Garcipollera).

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. The third inventory has been performed between May and November 2022, corresponding to the second monitoring campaign, which results are shown following.

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 in (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 2nd 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 October 2022 during the second monitoring campaign.

Table 5 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the 1st and 2nd monitoring campaigns. Results show that the crown fire hazard has reduced to low hazard in the subplots where forest management was performed. This change is produced because of the reduction of vertical and horizontal fuel continuity, after the scrubland elimination. There is not yet a positive effect of livestock grazing in this hazard, but we expect them in future surveys.

Forest inventory subplot	After implementation 2020		Annual campaign 2021		Annual campaign 2022	
	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard
BC1	B13	Moderate	B13	Moderate	B13	Moderate
BC2	C12	Low	C12	Low	B13	Moderate
B1S	A5	High	A5	High	C9	Low
B3S	C12	Low	A5	High	C12	Low
B5S			C12	Low	C12	Low
B2N	A5	High	A5	High	C12	Low
B4N	C12	Low	B13	Moderate	C10	Low
B6N	B13	Moderate	B13	Moderate	C10	Low

Table 5. Crown fire hazard after implementing the forest management (2020) and in the 1st and 2nd 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 October 2022 during the second monitoring campaign.

Table 6 shows the forest decay after the implementation of the forest management and after the 1st and 2nd monitoring campaigns. The results of the three inventories show not significant differences among treatments, so there is not a positive effect of forest management in the reduction of forest decay (Figure 5, left). This fact can be explained because in the pine forest, forest management affected only the undergrowth without intervention at the tree level. The differences of forest decay among years are notable starting from a mean forest decay of about 8% in 2020, to a mean value of about 31% in 2021 and about 9% in 2022 (Figure 5, right). We think that in 2021 there was an overestimation of forest decay, maybe due to a change in the way of making the visual quantification. The values of 2020 and 2022 are more in consonance we the expected values for forest decay.

Forest inventory subplot	After implementation 2020			Annual campaign 2021			Annual campaign 2022		
	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)	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	1.0	5.0	6.0
BC2	0.0	5.0	5.0	28.0	2.5	30.5	0.5	7.0	7.5
B1S	1.5	4.0	5.5	19.5	7.0	26.5	1.0	6.5	7.5
B2N	0.0	9.5	9.5	29.5	3.5	33.0	1.0	8.5	9.5
B3S	0.0	12.0	12.0	35.0	1.5	36.5	0.0	11.0	11.0
B4N	1.5	7.0	8.5	35.0	1.5	36.5	0.5	7.5	8.0
BS5	0.5	8.5	9.0	24.0	1.0	25.0	0.0	13.5	13.5
B6N	2.0	9.0	11.0	25.5	6.0	31.5	0.0	9.5	9.5

Table 6. Forest decay per forest inventory subplots measured on July 2020, November 2021 and October 2022.

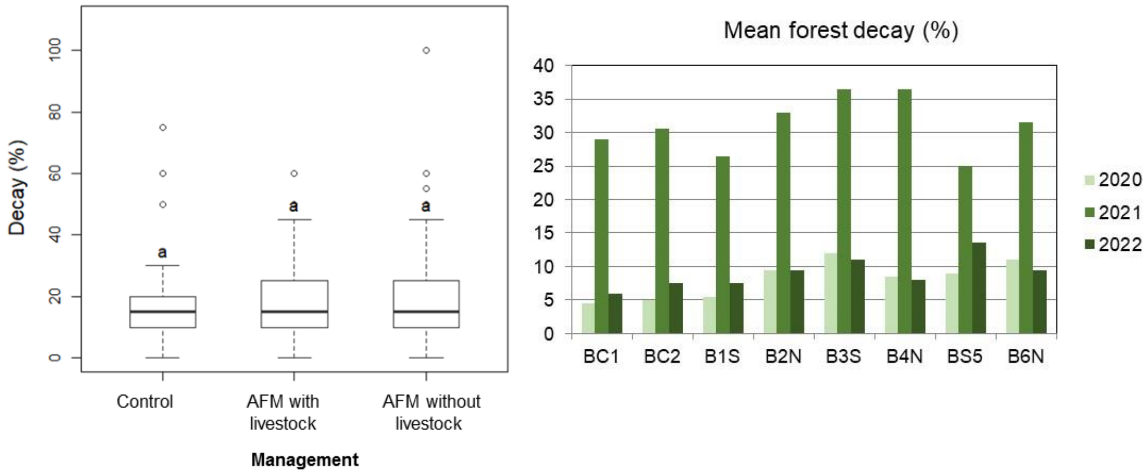


Figure 5. Left: Treatment effect on forest decay *(%) in 2020-21-22. Right: Differences in forest decay (%) between 2020, 2021 and 2022 among forest inventory subplots.*

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 6 shows the effect of the adaptive forest management on vegetation water content in the three years of monitoring (2020-2021-2022). Water content is higher in the treated plots, both with and without livestock, although differences among the plots are not yet significant.

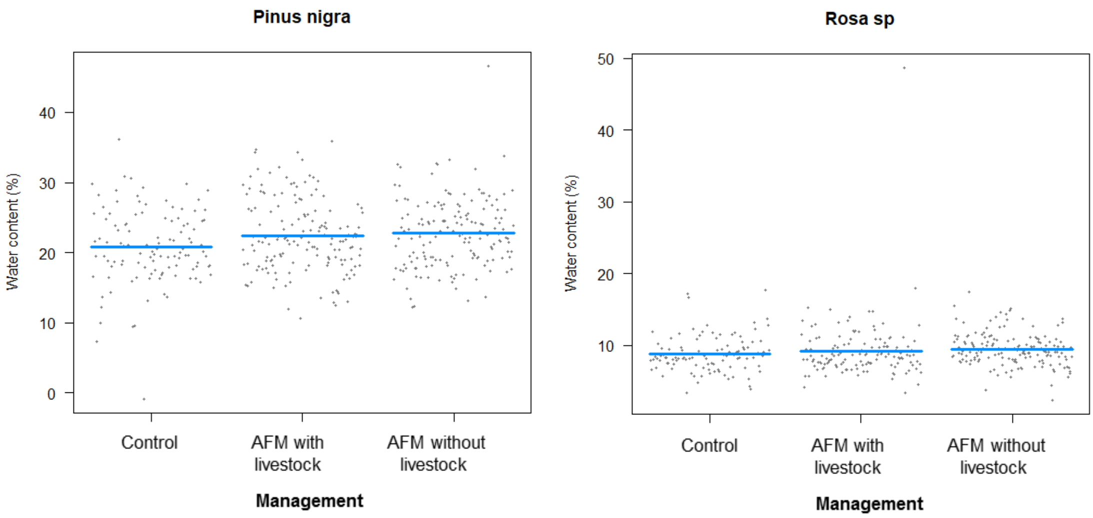


Figure 6. Treatment effect on vegetation water content in the Pinus nigra forest, La Garcipollera.

3.3. Monitoring results of the Pastures

The objective is to assess the effect of adaptive forest management and cow grazing on 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. Pasture's productivity and nutritive quality maintenance will enable to support extensive livestock activities in these areas, thus enhancing 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 arranged inside four subplots (1 m^2) at each replicate plot per typology/treatment: control area not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Vegetation surveys are carried out in late spring or early summer (May-June), matching with the vegetation growth peak, in favour of recording the maximum number of species. The first sampling was done in June 2020 to record the initial status of the pasture in the experimental plots. The second monitoring campaign was made in June 2022 to record the intermediate status of the pastures two years after the livestock entrance. A final vegetation survey will be done in June 2023 to study the potential effects of livestock activity over a longer period (after three years of grazing).

In the first sampling, we expected to find a positive effect of 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, which we would observe in both the intermediate and final samplings too. On the other hand, we expected not to find any effect of the livestock treatments in the first year (2020) since vegetation surveys were set previous to cows' entry in the plots, but to find a positive effect of the livestock in the pasture biodiversity along the subsequent years (2022 and 2023).

As we expected, in the first year of monitoring, we found significant differences between the cleared and not cleared areas in all the bare soil cover and the herbaceous and woody species cover, and this effect maintains in the second year of monitoring (Figure 7). Specifically, we found a larger bare soil cover and woody species cover and a lower herbaceous species cover in the control plots (not cleared) than in the cleared plots. Regarding the effect of the livestock, in the first year, we did not find differences between the treatments (livestock versus no livestock) neither for the bare soil nor the herbaceous species cover, but we found significantly more woody species in the plots without livestock. In the second monitoring (intermediate status) we found significant differences between the livestock treatments for the bare soil and woody species cover, but not for the herbaceous species cover.

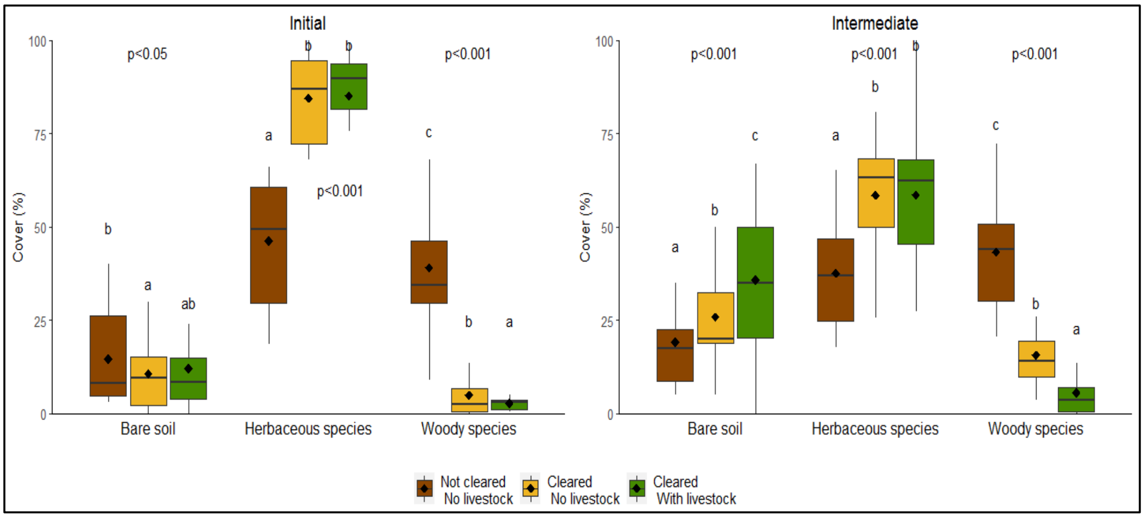


Figure 7. Boxplots showing mean cover (and data variability) of the bare soil, herbaceous species and woody species for each treatment: not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Initial status (first monitoring, 2020) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

In terms of total species richness, we did not find any effects neither of the scrubland clearing nor the livestock in the first monitoring (initial status); however, in the second monitoring (intermediate status) we found higher species richness in plots submitted to grazing than in plots with no livestock activity (Figure 8).

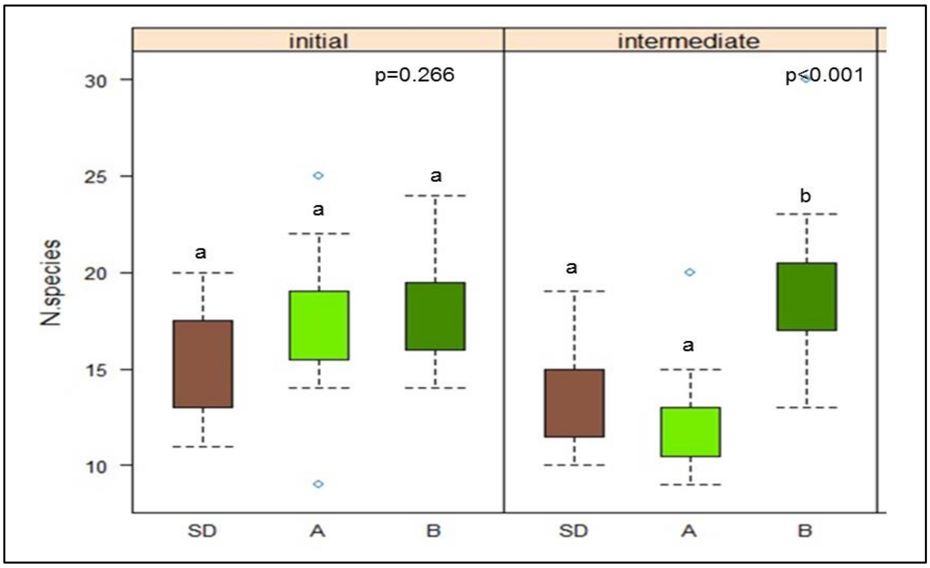


Figure 8. Boxplots showing mean species richness (and data variability) for each treatment: not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Initial status (first monitoring, 2020) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

Nonetheless, if we look at the effects of both the scrubland clearing and the livestock on species composition (specifically by differentiating the species found into functional groups depending on the importance for livestock: grasses, legumes and other families), more significant differences between treatments are found. In the first monitoring, we found a significantly larger cover of grasses in the cleared plots than in the control and a significantly larger cover of legumes in the control than in the cleared areas (woody leguminous species are very abundant in the area), but we did not find significant differences between cleared and not cleared areas for other families (Figure 9). As expected, no significant differences were found between the plots submitted to grazing and those not submitted to grazing for grasses, legumes and others. In the second monitoring, we found both differences between cleared and not cleared areas, and between grazed and not grazed areas for all the functional groups.

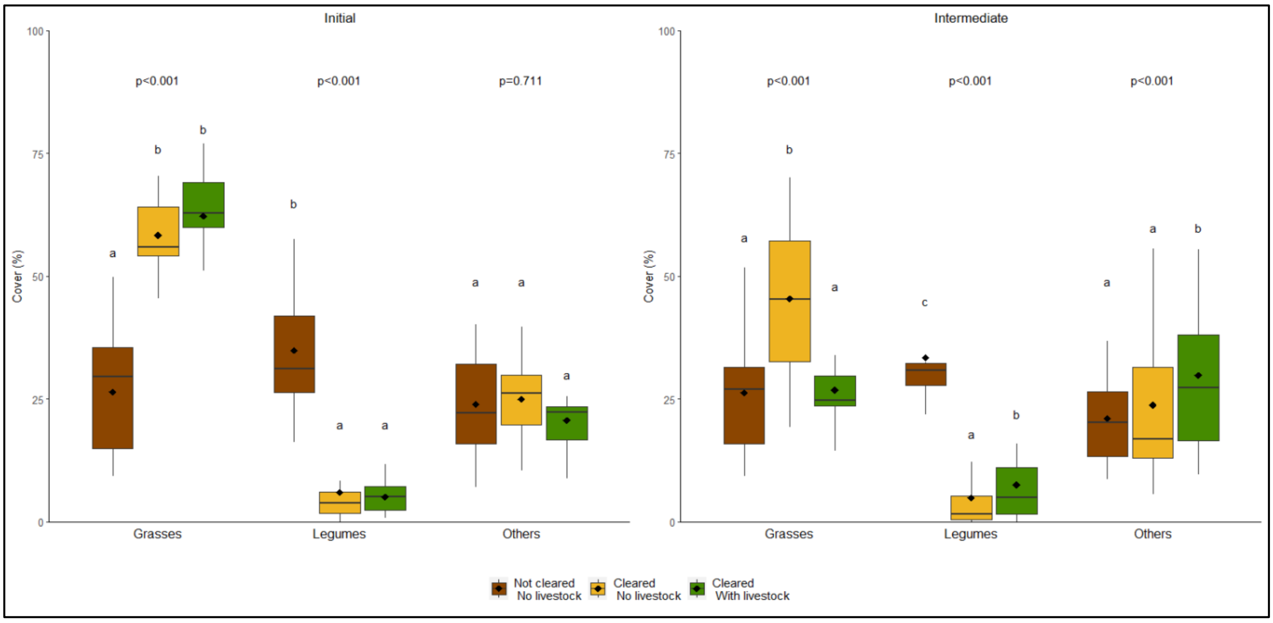


Figure 9. Boxplots showing mean cover (and data variability) of grasses, legumes and other families for each treatment: not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Initial status (first monitoring, 2020) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

3.3.2. Pasture production and quality

Pasture production and quality samplings are carried out in late spring or early summer (May-June), as well as the biodiversity surveys. 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 made in the 3rd monitoring campaign in June 2023 in order to record the final status of the pastures. We considered that recording the intermediate status of the pastures in terms of production and quality was not relevant because it is a short period of time to achieve significant results. Therefore, vegetation samples were not gathered in the 2nd monitoring campaign and consequently, no results are shown in this report. Results of the initial status of the pasture production and quality are available in the first monitoring report.

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. Here we present the results of the first (2020) and second (2021) year of monitoring. The experiments were always carried out in winter, after the livestock grazed. Although three experiments were performed per treatment (3 replicas) in each campaign, 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.

The control plots and the BN plots (managed without livestock) showed limited hydrological and sedimentological response. For the BN plot, this can be partly due to the lower gradient slope. The response was clearly higher in the cleared plot with livestock, for both runoff and soil erosion (RC=0.10, SC=0.6 g/l and SP=1.3 g/m^2).

Site	Land management	Slope (%)	RI (mm h^{-1})	RC (-)	TR (min)	WF (cm)	SC (g L^{-1})	SP (g m^{-2})
Pinus nigra	Control	21	52.4	0.03	14.8	11.0	0.11	0.4
	BN (AFM without livestock)	15	54.6	0.00	15.2	7.8	0.01	0.0
	BS (AFM with livestock)	21	54.5	0.10	9.5	6.7	0.57	1.3

Table 7. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in Garcipollera in the first (2020) and second (2021) year of monitoring. RI: rainfall intensity (mm h-1), 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 or erosion rate (g m^{-2}).

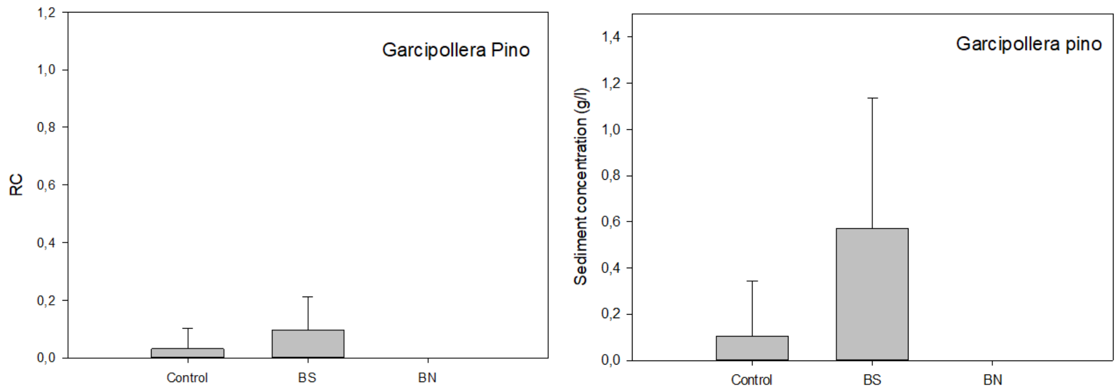


Figure 10. Mean runoff coefficient (RC) and sediment concentration for each treatment: not cleared without livestock (control), cleared without livestock (BN) and cleared with livestock (BS) in Pinus nigra in Garcipollera.

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 11. In this period, until 09-11-2022, the maximum temperature has been 37.6 ºC and the minimum -12.4 (Table 8). The data are continuous (no gaps) and clearly show the annual cycle of temperatures. As the project progresses, comparative analyses between the different Tinytag dataloggers will be carried out.

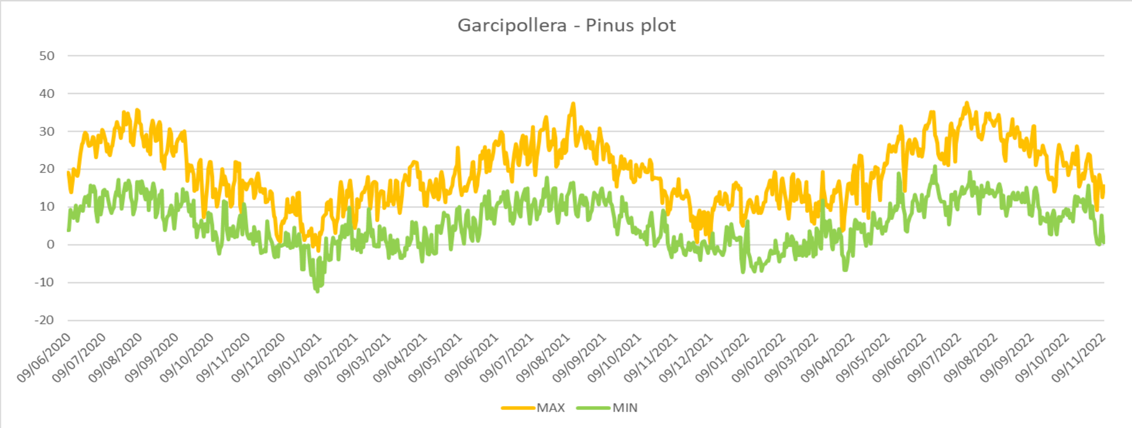


Figure 11. Daily average of minimum and maximum temperature in the Pinus nigra plots.

	Pinus plot	
	Tmax	Tmin
Max	37.6	20.9
Min	-1.6	-12.4
Mean	19.2	5.7

Table 8. Mean minimum and maximum temperature in the Pinus nigra plots.

Figure 12 is a climogram showing monthly averages of maximum temperature, minimum temperature and mean monthly precipitation for the period. 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.

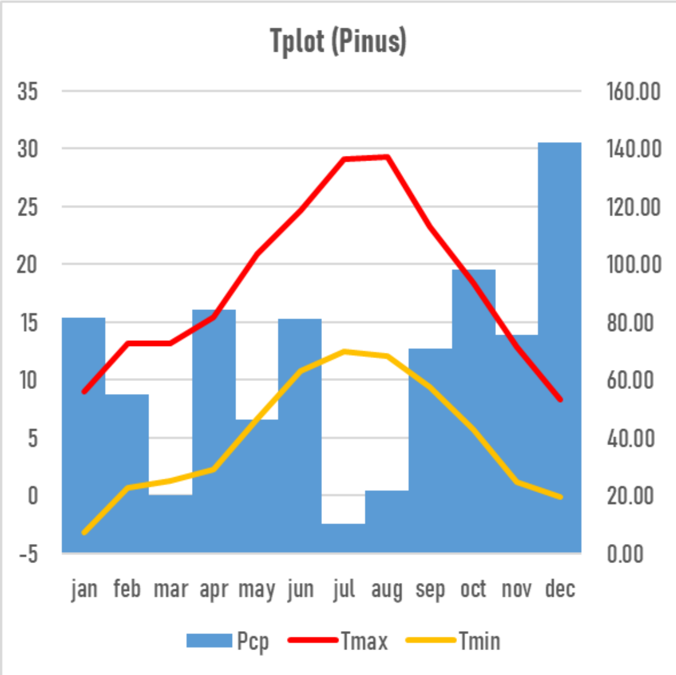


Figure 12. Climogram in the Pinus nigra plot.

4. Results of the 1st and 2nd monitoring campaign in the *Populus* forest, Aragon

This chapter includes the results of the 2022 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) and (Pascual, et al., 2022b).

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 13).

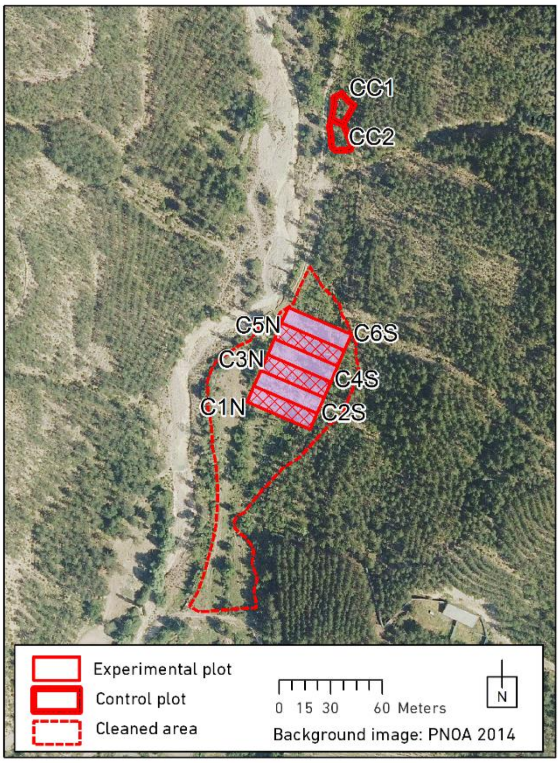


Figure 13. Location of the monitoring plots and replicates of the experimental design.

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. In autumn 2021, during the first-year monitoring campaign, also superficial soil samples (0-10 cm) were taken and in the winter 2022-23 (January 2023) samples will be taken to analysis the changes occurred in the main soil properties related to carbon and nitrogen.

At the initial monitoring variables, at each monitoring subplot, three soil samples were sampled. 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 45 samples have been analysed by the Pyrenean Institute of Ecology (IPE-CSIC), evaluating the following soil variables: 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) and Corg/N ratio.

Figure 14 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-loam and loam texture. Clay values oscillated between 33 and 51%, silt values between 25 and 37%, and sand values between 13 and 40%.

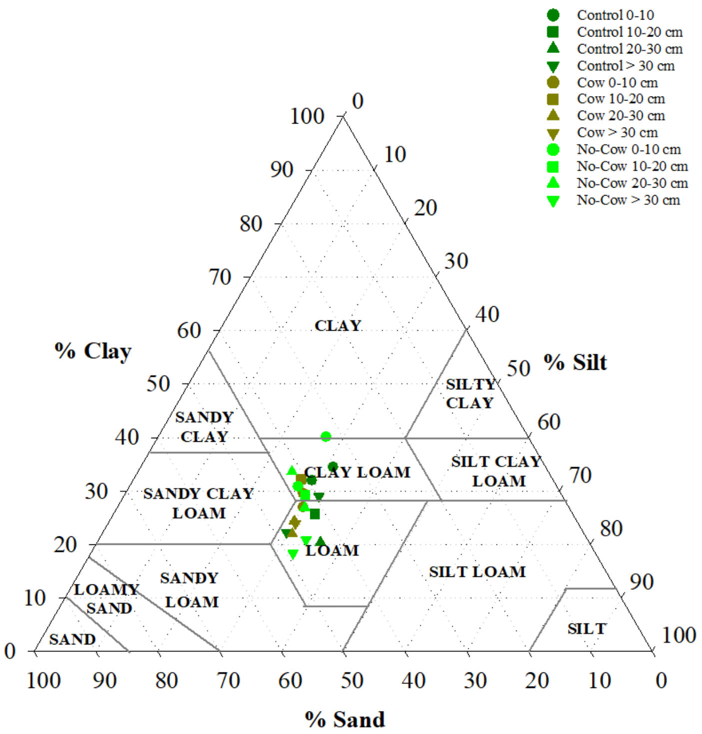


Figure 14. Clay, silt and sand contents (texture) of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

The following figures present the mean values and standard deviation of the SOC and N stocks (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 15 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 162 and 189 Mg ha^{-1} and N stocks between 15 and 23 Mg ha^{-1}.

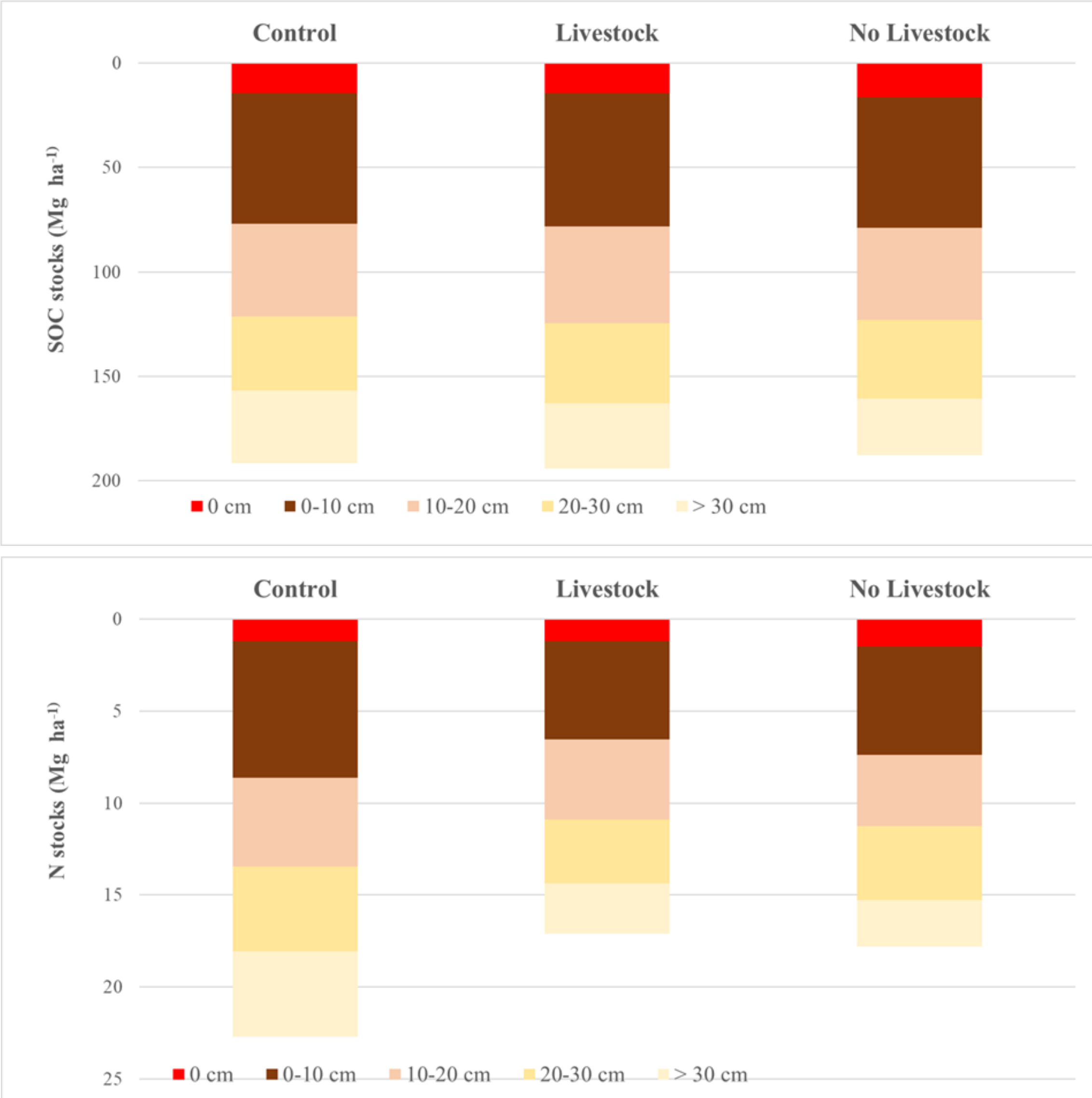


Figure 15. Soil organic carbon (SOC) and nitrogen (N) stocks of soil samples at four depths (0-10, 10-20, 20-30 and 30-40 cm) and in the different plots (control, livestock and no livestock plots).

For the first monitoring campaign, at each monitoring subplot, three soil subsamples were sampled in a depth of 0-10 cm. In each site, 21 points were selected and subsamples were recorded and later combined into one soil composite sample per plot and depth (0-10 cm). In total 9 composite samples were created in La Garcipollera. The samples were analysed by the Pyrenean Institute of Ecology (IPE-CSIC), evaluating the following soil variables: total carbon concentration (Ctotal), total nitrogen concentration (N), organic matter (OM), bulk density (BD), and soil organic carbon (SOC).

The following tables present the mean values at the initial conditions (May 2021), after the first year of monitoring (autumn 2021) and the change occurred in percentage for the main variables (0-10 cm) measured in the experimental plots. Statistical results did not show significant differences between the management plots and the control plots at the first year of monitoring, neither between the initial conditions and the present values. Some changes could be highlighted. Related to SOC values (Table 9) (i) lower SOC stocks are observed after the first monitoring year; (ii) higher values are observed in the livestock and no livestock plots. Related to N stocks (Table 10): (i) a decrease in N stocks is observed in all the plots; and (ii) the livestock and no livestock plots show higher N stocks. Related to the Corg/N ratio (Table 11): (i) higher values are observed after the first monitoring year; and (ii) the highest ratio is observed in the control plot.

SOC Mg ha^{-1} (10 cm)	YEAR 0	YEAR 1	Change %
Livestock	63.77	54.65	-14.3
No livestock	62.32	55.72	-10.6
CONTROL	62.32	43.69	-29.9

Table 9. Soil organic carbon (SOC) stocks of soil samples for the initial conditions and first year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

N Mg ha^{-1} (10 cm)	YEAR 0	YEAR 1	Change %
Livestock	0.42	0.32	-23.7
No livestock	0.46	0.34	-25.5
CONTROL	0.55	0.25	-54.9

Table 10. Nitrogen (N) stocks of soil samples for the initial conditions and first year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

Corg/N ratio (10 cm)	YEAR 0	YEAR 1	Change %
Livestock	11.98	13.54	13.0
No livestock	10.66	15.51	45.5
CONTROL	5.88	17.76	201.9

Table 11. Corg/N ratios of soil samples for the initial conditions and first year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control 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 16).

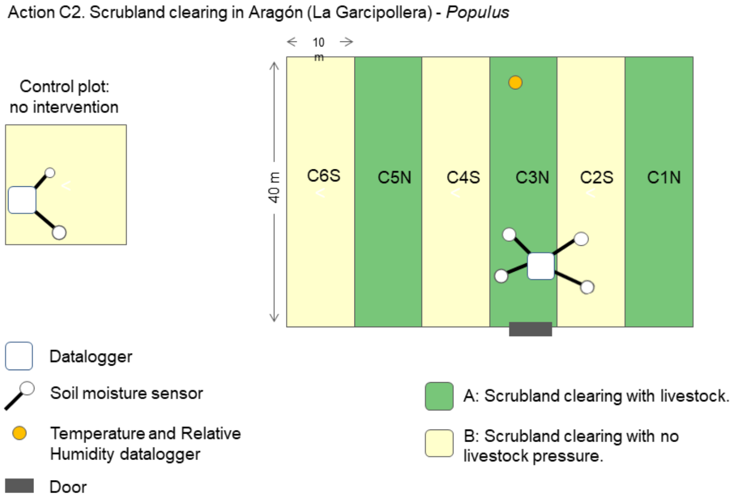


Figure 16. Diagram of the soil moisture instrumentation.

Figure 17 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. As shown in the figure, the sensors installed in the control plot are given some problems and there are two periods (initial and intermediate) without data. The data of the control plots for the last period is not yet available due to the impossibility to discharge the data on time, but it would be included in the next deliverable. 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 18 shows the results grouped by season.

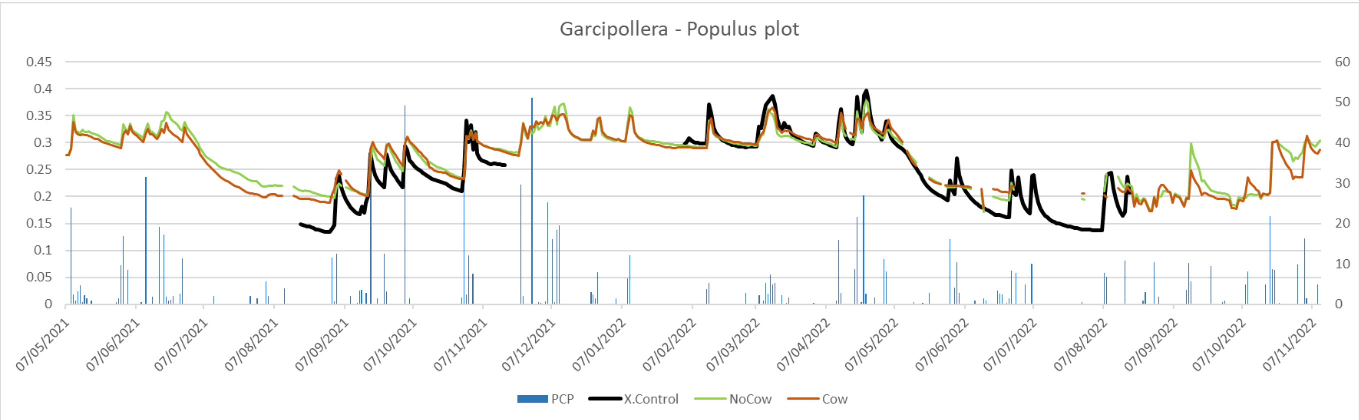


Figure 17. Soil humidity and precipitation in the Populus experimental plot (La Garcipollera).

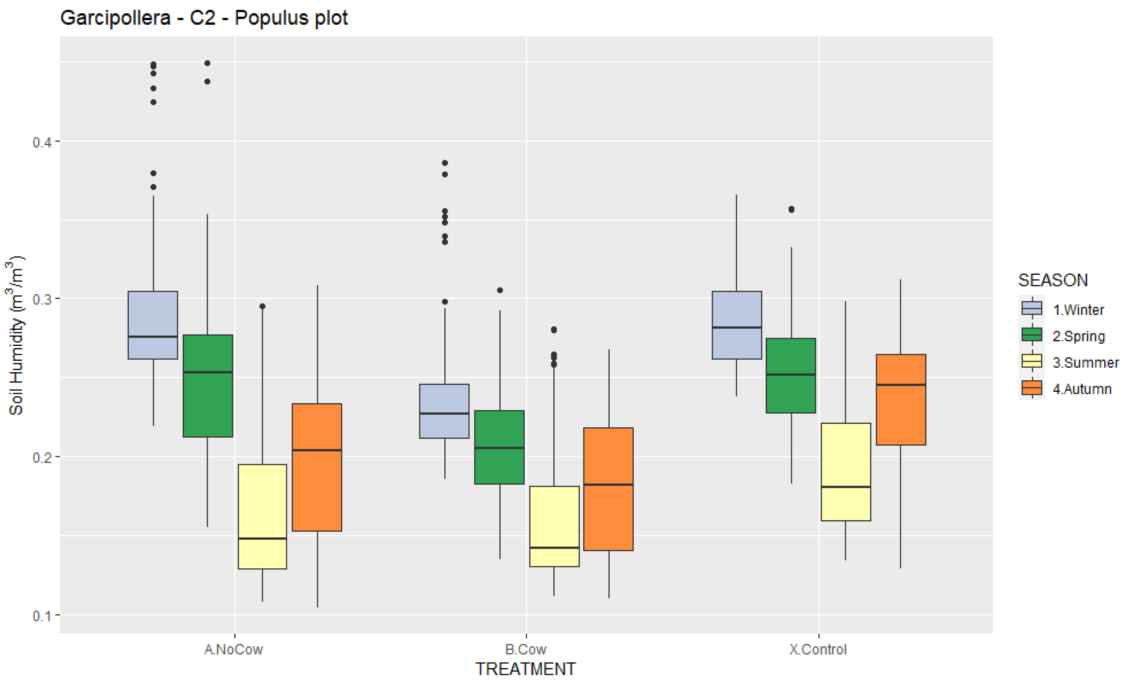


Figure 18. Soil humidity distribution per season and treatment in the Populus experimental plot (La Garcipollera).

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 13). 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 has been performed between May and November 2022, corresponding to the second monitoring campaign, which results are shown following.

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 2nd 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, the initial and after implementation inventories were coincident in May 2021. The annual inventory was performed in October 2022 during the second monitoring campaign.

Table 12 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the 2nd monitoring campaign. Results show that the crown fire hazard continue being low in the subplots where forest management was performed. This fact is due to the reduction of vertical and horizontal fuel continuity after the scrubland elimination. There is not yet a positive effect of livestock grazing in this hazard, but we expect them in future surveys.

Forest inventory subplot	After implementation 2021		Annual campaign 2022	
	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard
CC1	B16	Moderate	B16	Moderate
CC2	B16	Moderate	B16	Moderate
C2S	C13	Low	C13	Low
C4S	B16	Moderate	C13	Low
C6S	C13	Low	C13	Low
C1N	C13	Low	C13	Low
C3N	C13	Low	C13	Low
C5N	C13	Low	C13	Low

Table 12. Crown fire hazard after implementing the forest management (2021) and in the 2nd monitoring campaign.

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, the initial and after implementation inventories were coincident in May 2021. The annual inventory was performed in October 2022 during the second monitoring campaign.

Table 13 shows the forest decay after the implementation of the forest management and after the 2nd monitoring campaign. The results of the two inventories show not significant differences among treatments, so there is not a positive effect of forest management in the reduction of forest decay (Figure 19, left). This fact can be explained because in the populous forest, forest management affected only the undergrowth without intervention at the tree level. The differences of forest decay among years are notable starting from a mean forest decay of about 22% in 2021 to a mean value of about 46% in 2022 (Figure 19, right). The extreme dry summer and year 2022 had a direct effect on populous decay.

Forest inventory subplot	After implementation 2021			Annual campaign 2022		
	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)
CC1	18.3	0.0	18.3	20.0	20.0	40.0
CC2	24.0	0.0	24.0	21.3	21.3	42.5
C1N	27.0	0.0	27.0	27.5	40.0	67.5
C2S	39.2	0.0	39.2	23.8	11.3	35.0
C3N	20.7	0.0	20.7	31.4	20.7	52.1
C4S	13.8	0.0	13.8	20.0	14.4	34.4
C5N	16.7	0.0	16.7	36.7	16.7	53.3
C6S	16.4	0.0	16.4	25.0	15.8	40.8

Table 13. Forest decay per forest inventory subplots measured on May 2021 and October 2022.

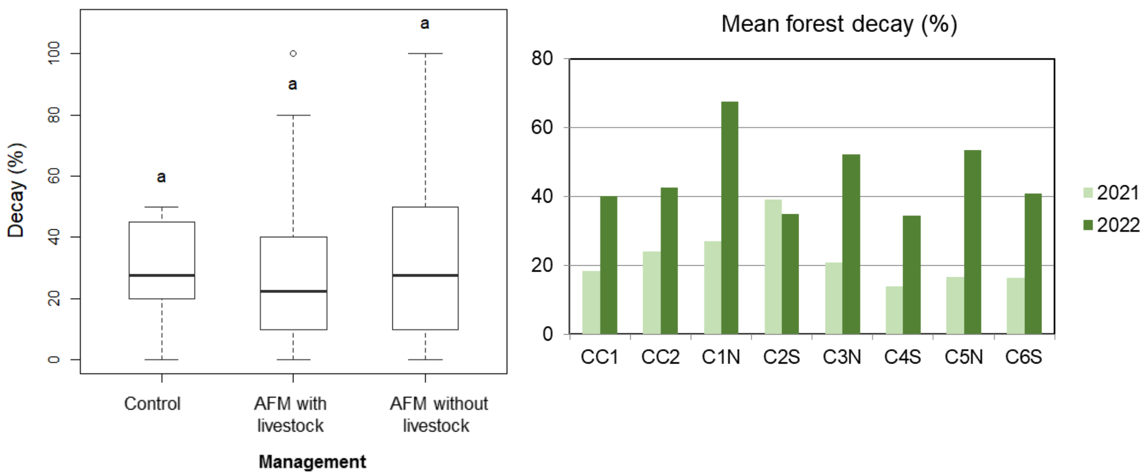


Figure 19. Left: Treatment effect on forest decay *(%) in 2021 and 2022. Right: Differences in forest decay (%) between 2021 and 2022 among forest inventory subplots.*

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 20 shows the effect of the adaptive forest management on vegetation water content in 2021 and 2022. Water content is higher in the *Populus* treated plots, both with and without livestock, although differences among the plots are not yet significant. This trend is not yet observed in the undergrowth specie (*Rosa sp.*). Data for more years is needed to find trends and get conclusions.

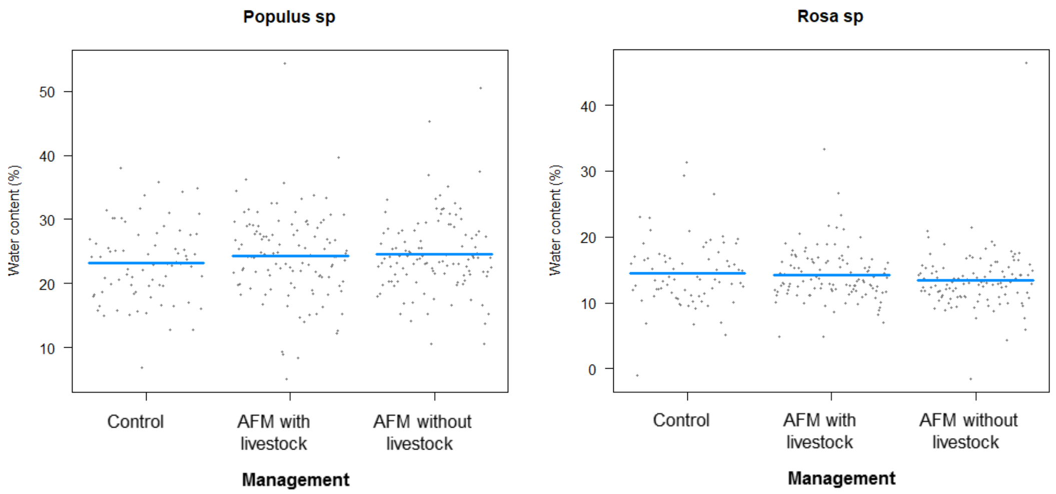


Figure 20. Treatment effect on vegetation water content in the Populus forest, La Garcipollera.

4.3. Monitoring results of the Pastures

The objective is to assess the effect of 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. Pasture's 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.

4.3.1. Biodiversity

Vegetation surveys are arranged inside four subplots (1 m^2) at each replicate plot per typology/treatment: control area not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Vegetation surveys are carried out in late spring or early summer (May-June), matching with the vegetation growth peak, in order to record the maximum number of species. The first sampling was done in June 2021 to record the initial status of the pasture in the experimental plots. The second monitoring campaign was made in June 2022 to record the intermediate status of the pastures one year after the livestock entrance. A final vegetation survey will be done in

June 2023 to study the potential effects of livestock activity over a longer period (after two years of grazing).

In the first sampling, we expected to find a positive effect of 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, which we would observe in both the intermediate and final samplings too. On the other hand, we expected not to find any effect of the livestock treatments in the first year (2020) since vegetation surveys were set previous to cows' entry in the plots, but to find a positive effect of the livestock in the pasture biodiversity along the subsequent years (2022 and 2023).

As we expected, in the first year monitoring, we found significant differences between the cleared and not cleared area for all the bare soil cover and the herbaceous and woody species cover (Figure 21). Specifically, we found a larger bare soil cover and woody species cover and a lower herbaceous species cover in the not cleared plots than in the cleared plots. This effect maintains in the intermediate status, specifically for herbaceous and woody species cover. In the intermediate status, there are no significant differences between control plots and cleared plots without livestock for the bare soil cover. Regarding the effect of the livestock, in the first year we did not find differences between the treatments (livestock versus no livestock) for the bare soil cover and the herbaceous and woody species cover. The herbaceous and woody species cover is not significantly different between treatments in the second monitoring either (only one year after livestock activity). However, we found significantly more bare soil cover in plots submitted to livestock than in the plots not submitted to livestock.

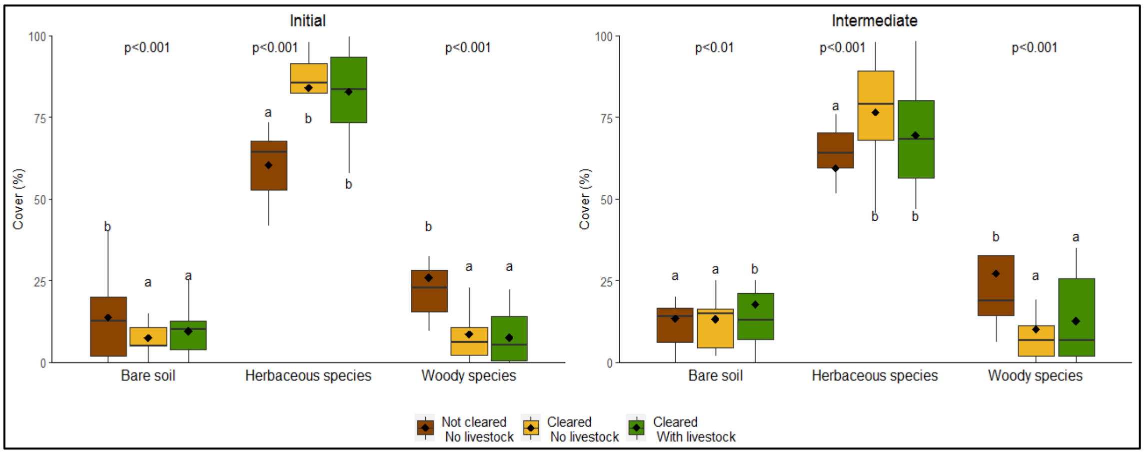


Figure 21. Boxplots showing mean cover (and data variability) of the bare soil, herbaceous species and woody species for each treatment: not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Initial status (first monitoring, 2021) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

In terms of total species richness, in the initial monitoring we found significant differences between the control plots and the cleared plots not submitted to livestock but, contrarily to what expected, we did not find differences between the control plots and the cleared plots submitted to livestock (Figure 22). However, in the second monitoring (intermediate status) we found higher species richness in both cleared plots than in the control plots. We did not find significant differences between the plots submitted to grazing and the plots without livestock activity.

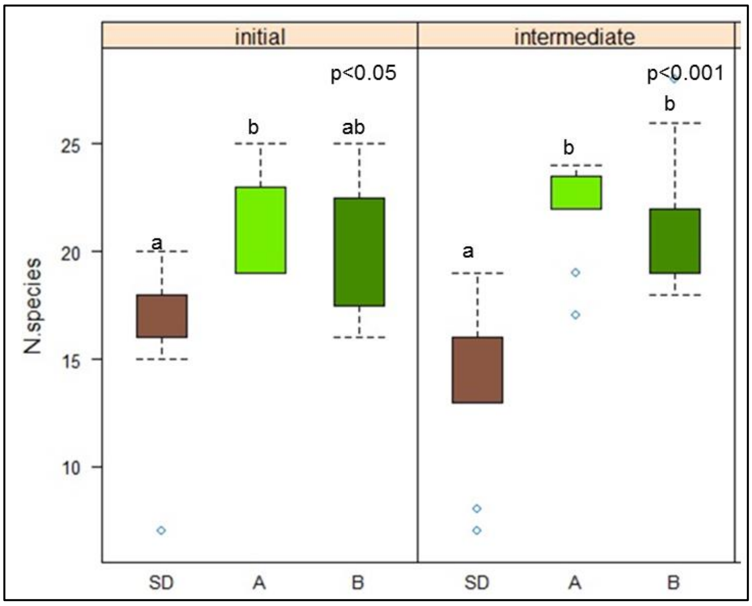


Figure 22. Boxplots showing mean species richness (and data variability) for each treatment: not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Initial status (first monitoring, 2021) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

Regarding species composition by differentiating the species into functional groups (grasses, legumes and other families), we found a significantly larger cover of legumes and a lower cover of other families in the control plots than in the cleared plots for both the initial and intermediate conditions (Figure 23). Woody leguminous species are very abundant in the scrubland in this area. The clearing effect is not so evident for the grasses since significant differences were found only between the control and cleared plots submitted to livestock in the initial conditions and between the control and cleared plots not submitted to livestock in the intermediate conditions. A potential inter annual variability in grasses production due to meteorology may be shown in this case. We did not find an effect of the livestock activity for legumes and other families neither in the initial conditions nor in the intermediate conditions (only one year after livestock activity). However, we found a significantly larger cover of grasses in plots not submitted to livestock than in plots submitted to livestock in the intermediate status.

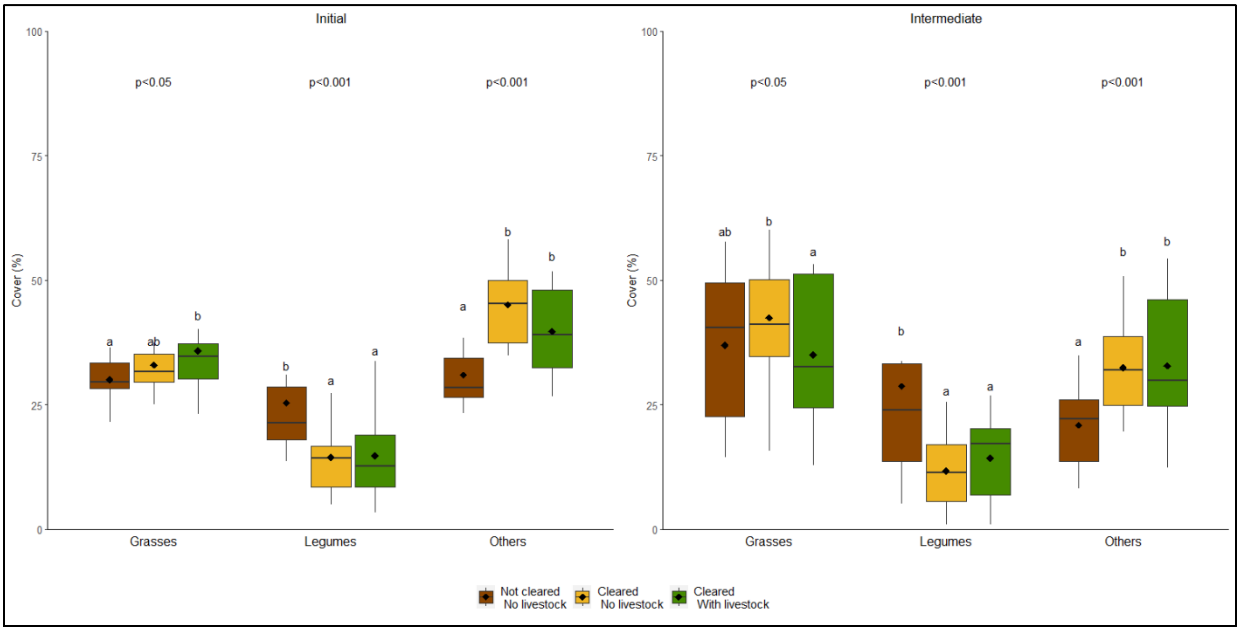


Figure 23. Boxplots showing mean cover (and data variability) of grasses, legumes and other families for each treatment: not cleared without livestock (SD), cleared without livestock (A) and cleared with livestock (B). Initial status (first monitoring, 2021) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

4.3.2. Pasture production and quality

Pasture production and quality samplings are carried out in late spring or early summer (May-June), as well as the biodiversity surveys. The first sampling was done in June 2021 in order to record the initial status of the pasture in the experimental plots. The second sampling will be made in the 3rd monitoring campaign in June 2023 in order to record the final status of the pastures. We considered that recording the intermediate status of the pastures in terms of production and quality was not relevant because it is a short period of time to achieve significant results. Therefore, vegetation samples were not gathered in the 2nd monitoring campaign and consequently, no results are shown in this report. Results of the initial status of the pasture production and quality are available in the first monitoring report.

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 the results of the first monitoring campaign, carried out at the end of 2021. The hydrological and sedimentological response in the control plot was high, probably due to the high slope gradient. If we compare the plots under treatment, the cleared plot with livestock produced slightly more water and more sediment (RC=0.32, SC=0.18 g/l, SP=1.7 g/m^2) than the one without livestock (RC=0.27, SC=0.15 g/l, SP=2.6 g/m^2).

Site	Land management	Slope (%)	RI (mm h^{-1})	RC (-)	TR (min)	WF (cm)	SC (g L^{-1})	SP (g m^{-2})
Populus	Control	28	80.0	0.27	6.1	20.0	0.18	2.6
	BN (AFM without livestock)	12	71.5	0.00		1.7	0.00	0.0
	BS (AFM with livestock)	12	72.5	0.32	3.7	4.3	0.15	1.7

Table 14. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in Garcipollera in the first (2020) and second (2021) year of monitoring. RI: rainfall intensity (mm h-1), 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 or erosion rate (g m^{-2}).

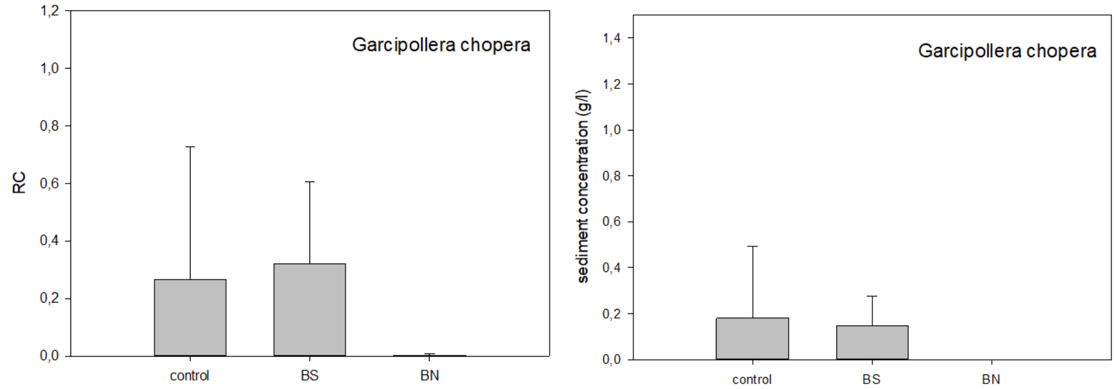


Figure 24. Mean runoff coefficient (RC) and sediment concentration for each treatment: not cleared without livestock (control), cleared without livestock (BN) and cleared with livestock (BS) in Populus in Garcipollera.

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 09-11-2022, the maximum temperature has been 38.5 ºC and the minimum -7.7 (Table 15).

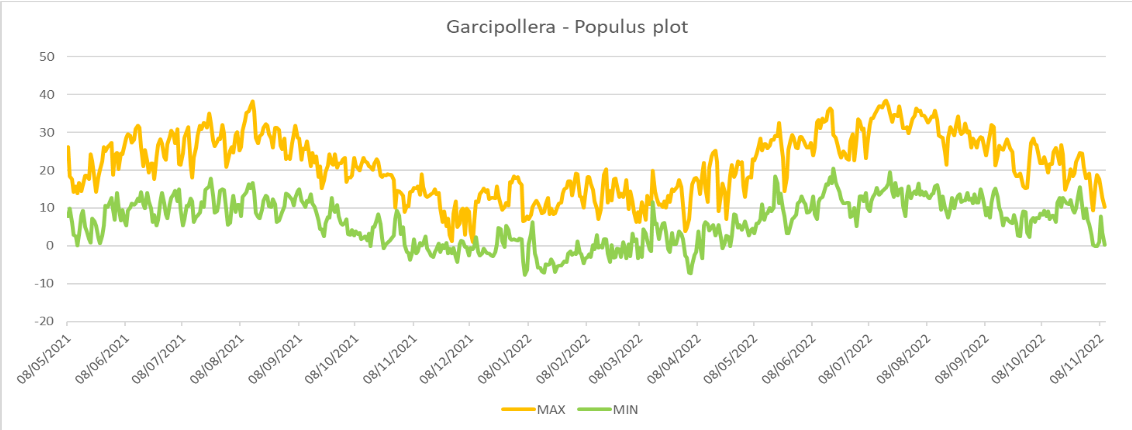


Figure 25. Daily average of minimum and maximum temperature in the Populus plots.

	Pinus plot		Populus plot	
	Tmax	Tmin	Tmax	Tmin
Max	37.6	20.9	38.5	20.4
Min	-1.6	-12.4	1	-7.7
Mean	19.2	5.7	21.5	6.4

Table 15. Mean minimum and maximum temperature in the Pinus nigra and Populus plots.

Figure 26 is a climogram showing monthly averages of maximum temperature, minimum temperature and mean monthly precipitation for the period. As in the case of *Pinus* plots, the low rainfall in March is striking. 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.

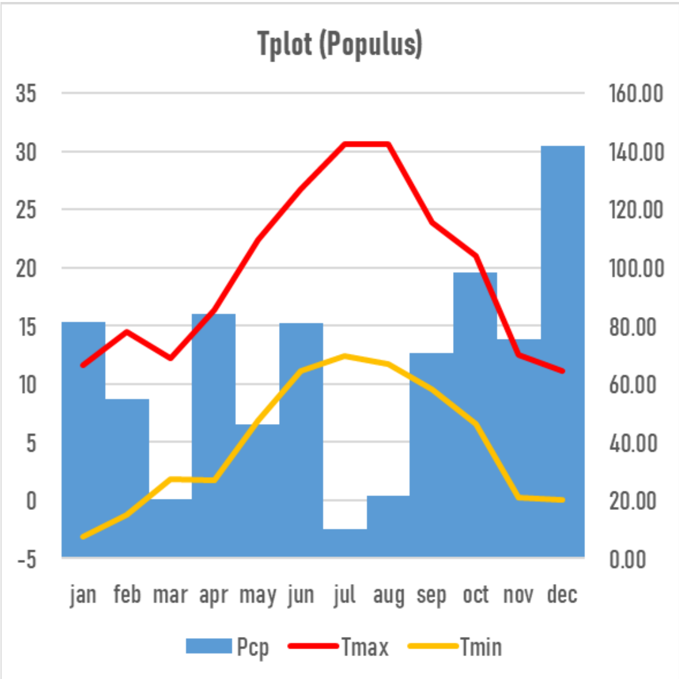


Figure 26. Climogram in the Populus plot.

5. Results of the 1st and 2nd 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) and (Pascual, et al., 2022b).

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 27).

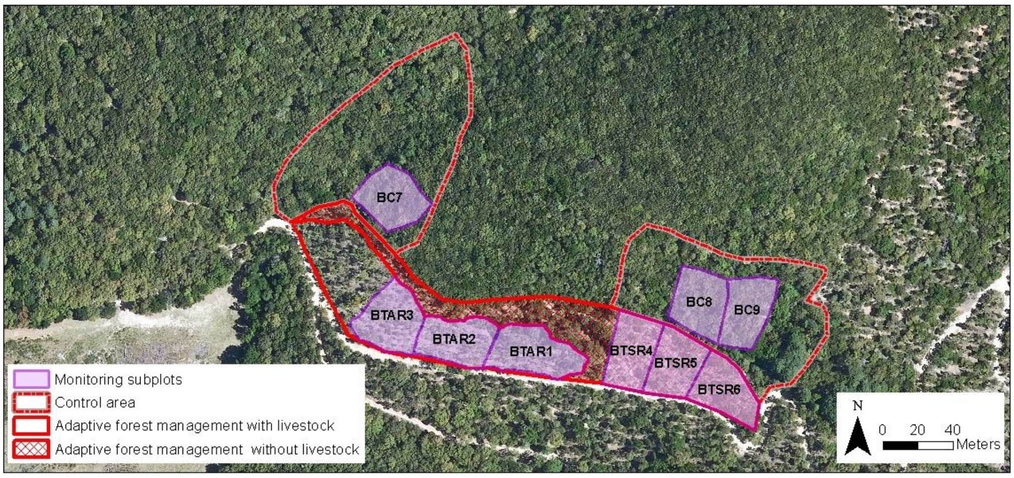


Figure 27. Location of the monitoring plots and replicates of the experimental design.

5.1. Monitoring results of the Soil

5.1.1. Soil characteristics

The first soil samplings were carried out in June 2020. The results of the initial sampling were presented in Deliverable 14 (Pascual, et al., 2021). In Requesens, no intermediate samples are taken, and the soil characteristics will be evaluated again at the end of the project, to compare the initial conditions with the final ones. For this reason, soil characteristics has not been monitored in the 2nd monitoring campaign and results are not shown here.

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 28).

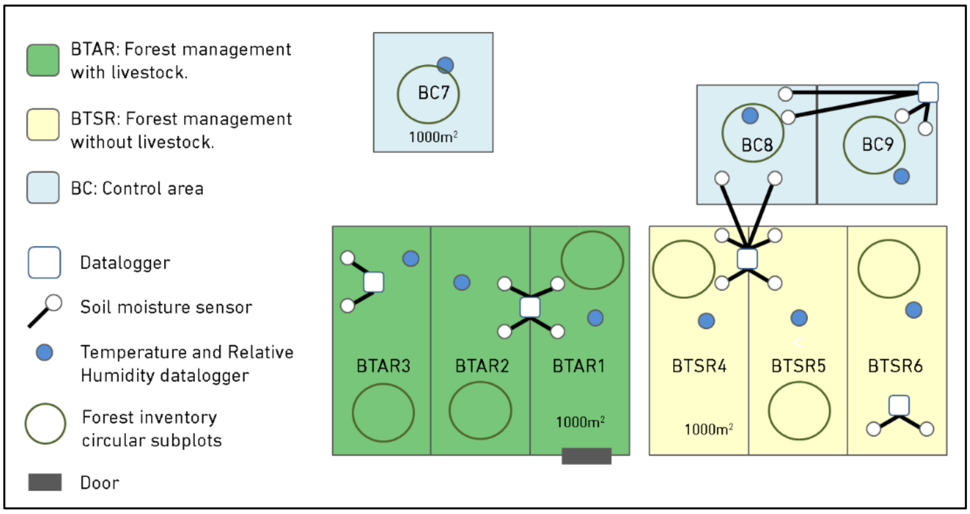


Figure 28. Diagram of the livestock and monitoring subplots.

Figure 29 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. Initial results show that the soil moisture is significantly higher in managed plots than in control plots, indicating a higher water availability for vegetation in managed areas under water stress situation. Besides, soil moisture is higher in managed areas with livestock than in areas without livestock, indicating the favourable role of livestock to maintain the scrubland under control.

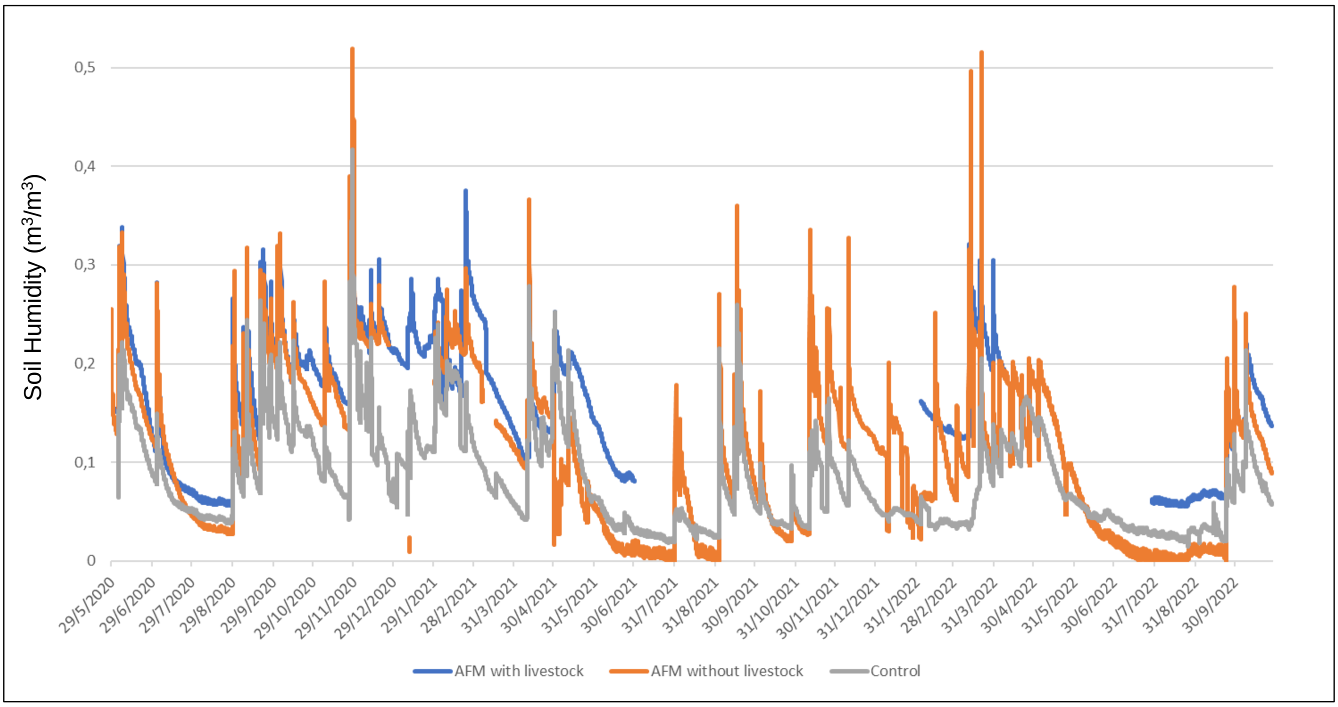


Figure 29. Soil humidity and precipitation in the Holm oak experimental plot (Requesens).

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 30).

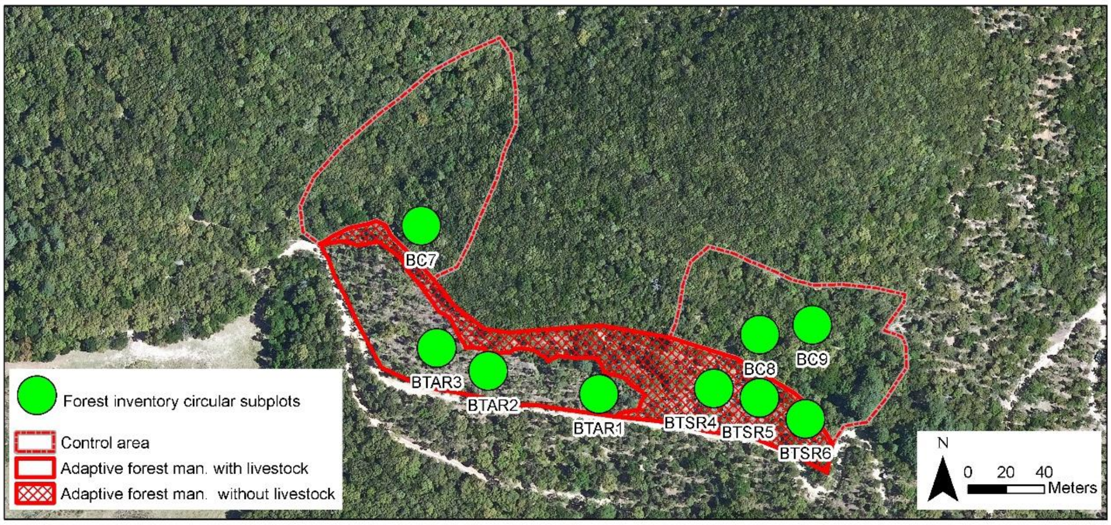


Figure 30. Location of the circular inventory subplots in Catalonia.

The initial forest inventory was carried out on May 2020, with the objective to set the initial conditions of the forest stand. The second inventory was performed between May and November 2021, corresponding to the first monitoring campaign. The third inventory has been performed between May and November 2022, corresponding to the second monitoring campaign, which results are shown following.

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 2nd 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, the initial and after implementation inventories were coincident in May 2020. The annual inventory was performed in October 2022 during the second monitoring campaign.

Table 16 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the 1st and 2nd monitoring campaigns. 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. In this sense, these first results are in consonance with the expected impact of the action implemented.

Forest inventory subplot	After implementation 2020		Annual campaign 2021		Annual campaign 2022	
	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard
BC7	B9	Moderate	B9	Moderate	B9	Moderate
BC8	B9	Moderate	B9	Moderate	B9	Moderate
BC9	B9	Moderate	B9	Moderate	B9	Moderate
BTAR1	B16	Moderate	C16	Low	C16	Low
BTAR2	B16	Moderate	C16	Low	C16	Low
BTAR3	B16	Moderate	C16	Low	C16	Low
BTSR4	B16	Moderate	B16	Moderate	B16	Moderate
BTSR5	B16	Moderate	B16	Moderate	B16	Moderate
BTSR6	B16	Moderate	B16	Moderate	B16	Moderate

Table 16. Crown fire hazard after implementing the forest management (2020) and in the 1st and 2nd monitoring campaigns.

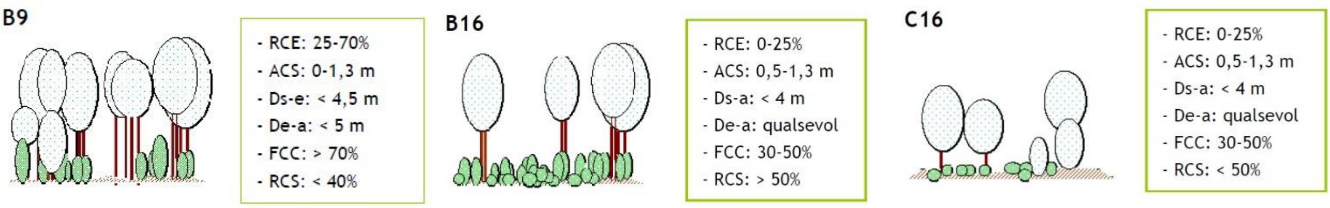


Figure 31. Description of the structure type B9, B16 and C13 with moderate and low crown fire hazard following Piqué et al. 2011.

5.2.3. Forest health status

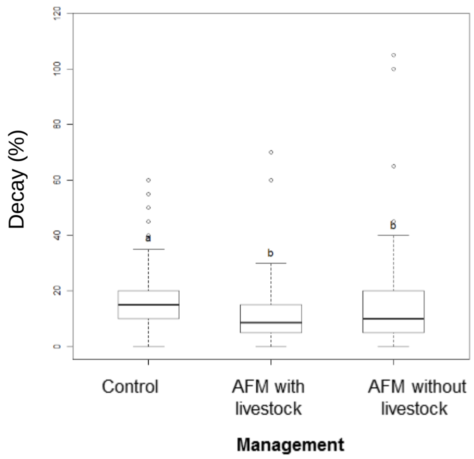
Forest health refers to the status of the forest decline due to climate change effects (mainly droughts) or other related threatens (plagues, diseases …). Forest decline is defined by the degree of defoliation, decolouration or mortality of the individuals of the forest.

Forest health status is assessed initially, after implementing the forest management, annually (in autumn) and at the end of the project. In this case, the initial and after implementation inventories were coincident in May 2020. The annual inventory was performed in October 2022 during the second monitoring campaign.

Table 17 shows the forest decay after the implementation of the forest management and after the 1st and 2nd monitoring campaigns. 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 15.9% in 2021 and 15.5% in 2022. However, we observe a significant difference between control and both treatments plots, with higher decay in control plots (Figure 32). Figure 33 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			Annual campaign 2022		
	Tree defoliation (%)	Leaf discoloration (%)	Mean forest decay (%)	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	0.0	20.0	20.0
BC8	12.5	2.0	14.5	6	16.5	22.5	0.5	20.0	20.5
BC9	10.0	0.5	10.5	5.5	14.5	20	0.5	17.5	18.0
BTAR1	0.5	4.0	4.5	3	7.5	10.5	1.5	8.5	10.0
BTAR2	0.5	4.7	5.2	1.9	5.5	7.4	1.5	11.0	12.5
BTAR3	8.5	14.5	23.0	1.7	6.5	8.2	0.5	7.0	7.5
BTSR4	10.5	1.5	12.0	4	13	17	3.0	12.0	15.0
BTSR5	8.0	1.5	9.5	4	8.5	12.5	1.5	11.5	13.0
BTSR6	18.5	1.0	19.5	4	19.5	23.5	2.0	21.0	23.0

Table 17. Forest decay per forest inventory subplots measured on May 2020, November 2021 and October 2022.



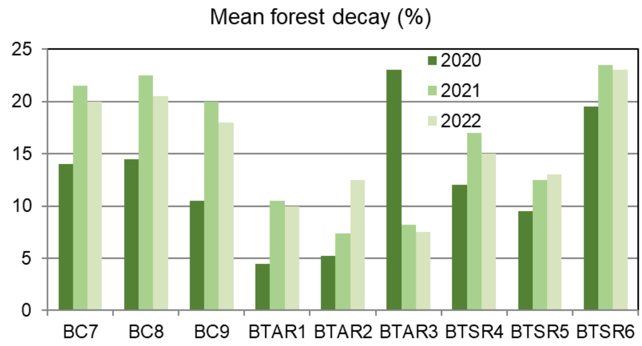


Figure 32. Left: Treatment effect on forest decay (%) in 2020-21-22. Right: Differences in forest decay (%) between 2020, 2021 and 2022 among forest inventory subplots.

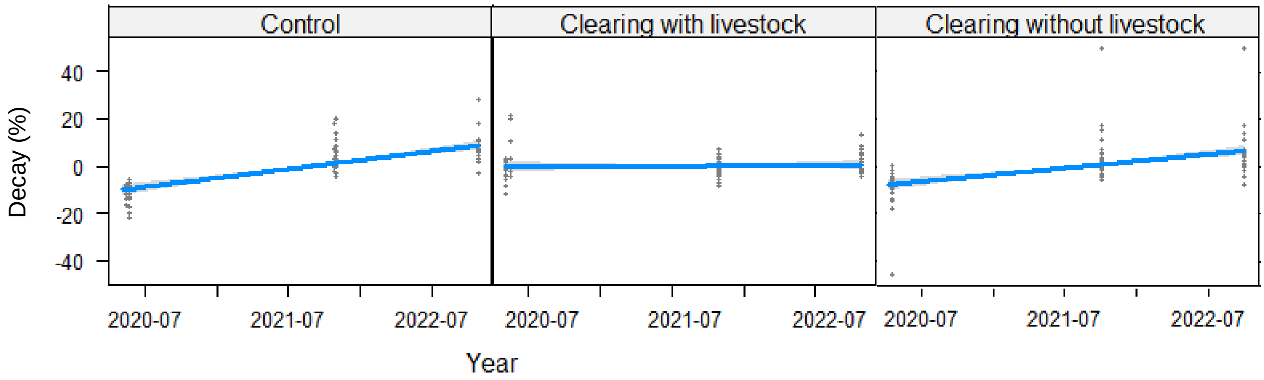


Figure 33. Treatment effect on Holm oak decay in Requesens, from 2020 to 2022.

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 34 shows the effect of the adaptive forest management on vegetation water content in the three years of monitoring. Fire risk has been reduced in the treated plots, both with and without livestock, and the differences among the three years are significant. Although data for more year are needed, the results of the 2022 show the expected trend.

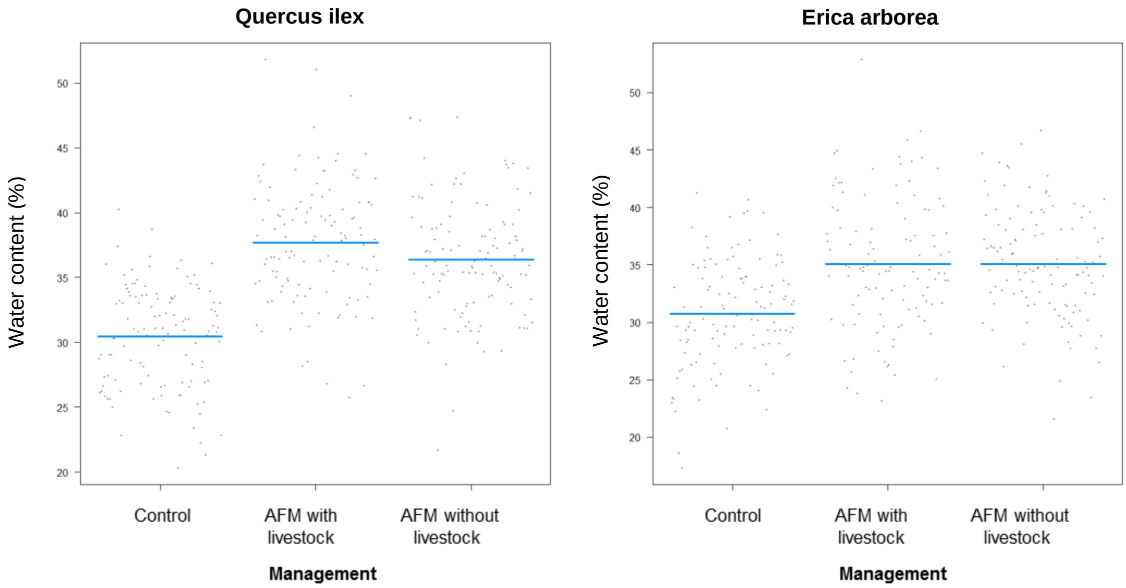


Figure 34. Treatment effect on vegetation water content in Requesens.

5.3. Monitoring results of the Pastures

The objective is to assess the effect of the adaptive forest management 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 thinning and scrubland clearing interacting with cow grazing will help maintain biodiverse, productive and highly nutritive herbaceous pastures. Pasture's 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.

5.3.1. Biodiversity

Vegetation surveys are arranged inside four subplots (1 m^2) at each replicate plot per typology/treatment: control area not cleared without livestock (BC), cleared without livestock (BTSR), cleared with livestock and seeded with a commercial seed mixture (BTAR), and cleared without livestock and also seeded (Bpasto). Vegetation surveys are carried out in late spring or early summer, matching with the vegetation growth peak, in favour of recording the maximum number of species. The first sampling was done in early July 2020 in order to record the initial status of the pasture in the experimental plots. The second monitoring campaign was made in late April 2022 in order to record the intermediate status of the pastures two years after the livestock entrance. A final vegetation survey will be done in May 2023 to study potential effects of the livestock activity over a longer period of time (after three years of grazing).

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, which we would observe in both the intermediate and final samplings too. On the other hand, we expected not to find any effect of the livestock treatments in the first year (2020) since vegetation surveys were set previous to cows' entry in the plots, but to find a positive effect of the livestock in the pasture biodiversity along the subsequent years (2022 and 2023). In general, we expect to find a higher species cover and richness in seeded plots than in the other treatments.

As we expected, in the first year monitoring, we found significant differences between the cleared and not cleared area in all the bare soil cover and the herbaceous and woody species cover (Figure 35). Specifically, we found a larger bare soil cover and a lower herbaceous species cover in the control plots (not cleared) than in the cleared plots, but for woody species cover, significant differences between the control and the cleared plots were found only in those plots submitted to livestock activity (the lowest woody species cover). In the second monitoring, we found significant differences in bare soil cover between the control plots and the cleared plots not submitted to livestock, but not between the control and the cleared plots submitted to livestock. Regarding herbaceous species, significant differences were found between the plots without seeding and the seeded plots, with no effect of livestock. For woody species, we found the highest cover in cleared plots not submitted to livestock nor seeding, followed by the cleared plots not submitted to livestock and seeded (Figure 35).

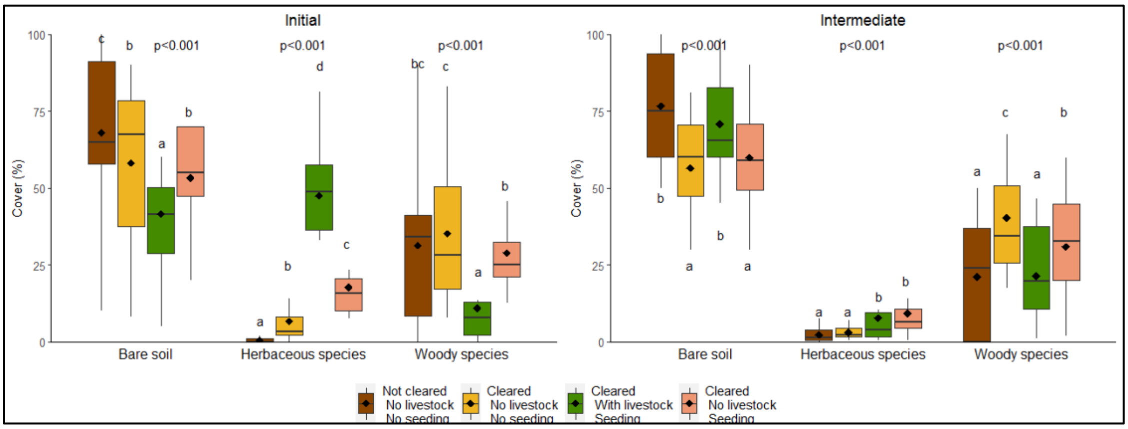


Figure 35. Boxplots showing mean cover (and data variability) of the bare soil, herbaceous species and woody species for each treatment: not cleared without livestock (BC), cleared without livestock (BTSR), cleared with livestock and seeded (BTAR), cleared without livestock and seeded (Bpasto). Initial status (first monitoring, 2020) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

In terms of total species richness, we found significant differences between the cleared plots and the control plots, being lower in the latter for both the initial and intermediate status (Figure 36). We did not find an effect of the livestock activity in total species richness for neither the initial nor the intermediate status. In the initial status, species richness was significantly higher in the seeded plots not submitted to livestock (Bpasto) than in the rest of the treatments. In the intermediate status, significant differences were found only between the control plots and the cleared ones, with no significant differences in species richness between cleared plots themselves.

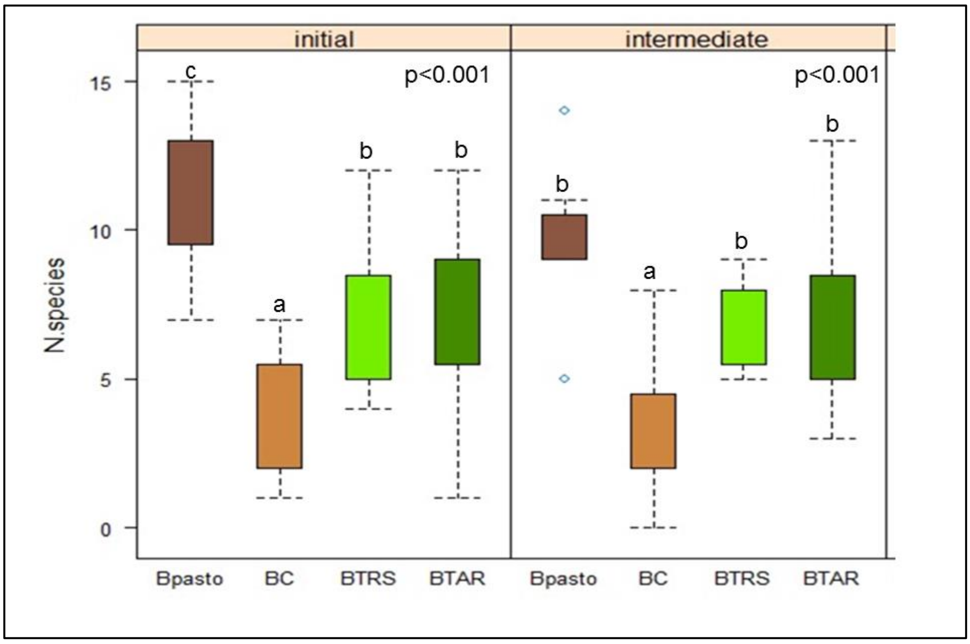


Figure 36. Boxplots showing mean species richness (and data variability) for each treatment: not cleared without livestock (BC), cleared without livestock (BTSR), cleared with livestock and seeded (BTAR), cleared without livestock and seeded (Bpasto). Initial status (first monitoring, 2020) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

Looking at the effects of forest management on species composition (specifically by differentiating the species into functional groups: grasses, legumes and other families), in the initial conditions, we found a significantly lower cover of grasses in control plots than in cleared plots with and without livestock (Figure 37). In the intermediate conditions, we found significant differences in grasses cover between the control plots and the cleared plots submitted to seeding (both with livestock and without livestock). Regarding legumes, in the initial status, we found the significant highest cover in cleared plots not submitted to livestock but seeded. In the intermediate status, we found a significantly lower cover of legumes in the plots not submitted to seeding than in those submitted to seeding.

For other families, in the initial conditions we found the lowest cover in plots submitted to livestock, and among plots without livestock, we found a significant lower cover in seeded plots than in the plots not submitted to seeding (Figure 37). In the intermediate conditions, we found the highest cover of other families in the cleared plots not submitted to livestock nor seeded, followed by the cleared plots not submitted to livestock and seeded.

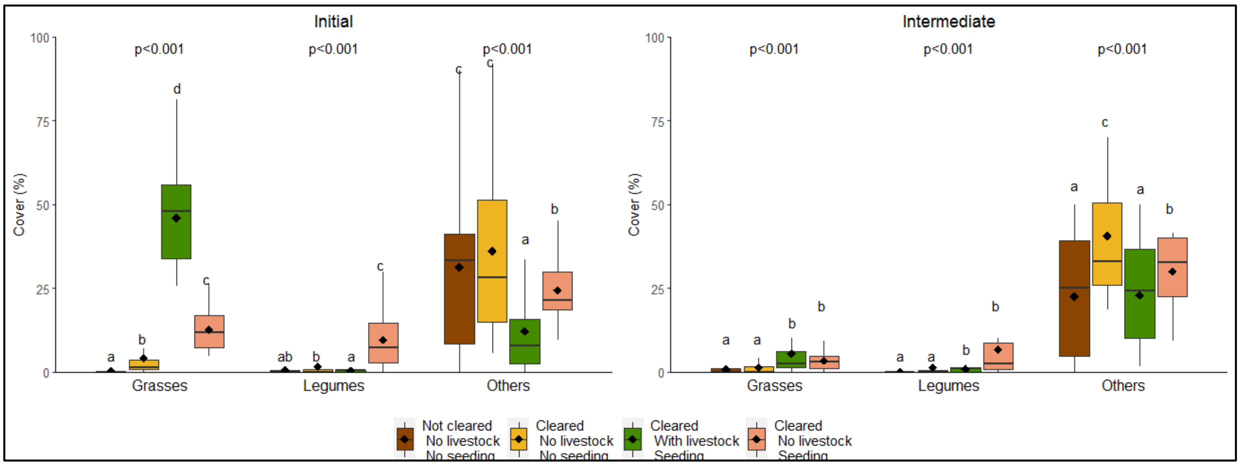


Figure 37. Boxplots showing mean cover (and data variability) of grasses, legumes and other families for each treatment: not cleared without livestock (BC), cleared without livestock (BTSR), cleared with livestock and seeded (BTAR), cleared without livestock and seeded (Bpasto). Initial status (first monitoring, 2020) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

5.3.2. Pasture production and quality

Pasture production and quality samplings are carried out in late spring or early summer (May-June), as well as the biodiversity surveys. 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 made in the 3rd monitoring campaign in June 2023 in order to record the final status of the pastures. We considered that recording the intermediate status of the pastures in terms of production and quality was not relevant because it is a short period of time to achieve significant results. Therefore, vegetation samples were not gathered in the 2nd monitoring campaign and consequently, no results are shown in this report. Results of the initial status of the pasture production and quality are available in the first monitoring report.

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. Here we present the results of the first (2020) and second (2021) year of monitoring. The experiments were always carried out in autumn. The hydrogeomorphological response was higher in the cleared plots without livestock (BTRS), with a RC of 0.39 and SP of 12.9 g/m^2, followed by the control plot with a RC of 0.28 and a SP of 9.3 g/m^2. The cleared plot with livestock (BTAR) showed a lower hydrological response (RC = 0.16) and low sediment response (SP=1.4 g/m^2). These contrasting results between the two managed plots are most probably due to their differences in the herbaceous vegetation, with 65-100% cover in the BTAR plots and a lack of herbaceous cover and large surface of bare ground in the BTRS plots.

Site	Land management	Slope (%)	RI (mm h^{-1})	RC (-)	TR (min)	WF (cm)	SC (g L^{-1})	SP (g m^{-2})
Quercus ilex	Control	22	64.3	0.28	6.7	8.6	2.15	9.3
	BTSR (AFM without livestock)	18	69.9	0.39	5.1	6.1	1.07	12.9
	BTAR (AFM with livestock)	17	67.4	0.16	6.0	7.5	2.66	1.4

Table 18. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in Requesens in the first (2020) and second (2021) year of monitoring. RI: rainfall intensity (mm h-1), 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 or erosion rate (g m^{-2}).

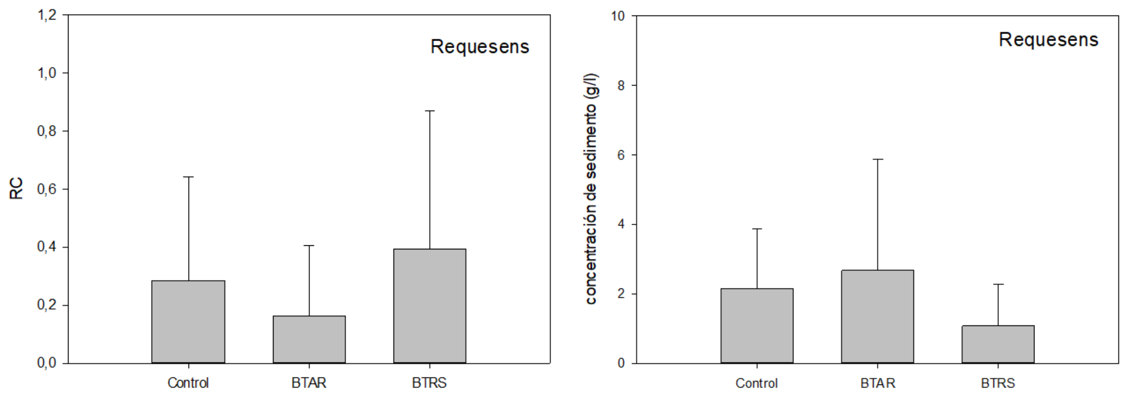


Figure 38. Mean runoff coefficient (RC) and sediment concentration for each treatment: not cleared without livestock (control), cleared without livestock (BTSR), and cleared with livestock (BTAR) in Requesens.

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 39).

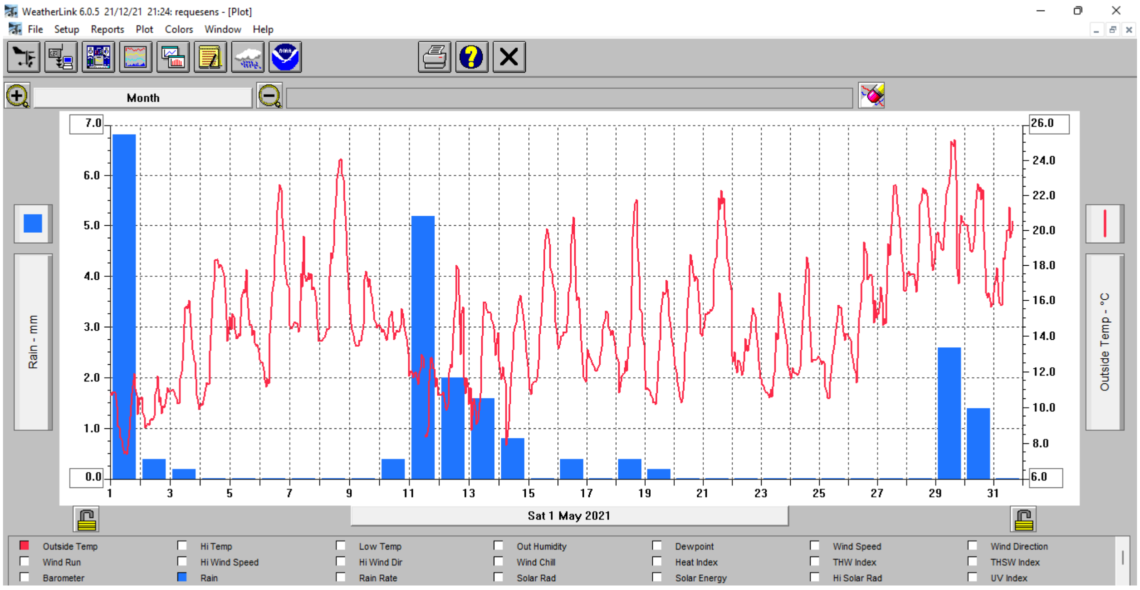


Figure 39. Detailed outputs of the weather station located in Requesens pilot area.

6. Conclusions

The main objective of this deliverable is to present the **results of the second monitoring campaign developed in 2022** of the action C.2.

***Pinus nigra* forest in Aragon**		
Soil	Soil characteristics	Results of soil samples in a depth of 0-10 cm are shown, comparing initial conditions (2020) and after the 1st year of monitoring (2021). Statistical results did not show significant differences between the management plots and the control plots. Changes to be highlighted: higher SOC (soil organic carbon) stocks are observed in 2021, except in the no livestock plots; a higher increase in SOC stock and higher values are observed in the livestock plots; an increase in N stocks is observed in the livestock plot compared with a decrease in N stocks in the no livestock and control plots; higher values of Corg/N ratio are observed in 2021, being significant in the control plots; and the highest ratio is observed in the control plot. Results show an increase of SOC and N stocks after one year of livestock grazing.
	Soil moisture	A sensor network is installed since 2020. Soil moisture data shows a good response of the sensors to the recorded rainfall events
Forest	Forest struct.	There is not annual monitoring of this variable.
	Forest fuel continuity	Crown fire hazard has reduced from a moderate-high risk in 2020 and 2021 campaigns to a low risk in 2022 in the forest-managed plots with and without livestock, due to the reduction of vertical and horizontal fuel continuity.
	Forest health status	Forest decay did not show significant differences among treatments in 2022, similar to 2020 and 2021, so there is not yet a positive effect of forest management in the reduction of forest decay. Forest decline has improved in all subplots, from a mean of about 8% in 2020, to a 31% in 2021 and a 9% in 2022.
	Fuel moisture	Fuel moisture was higher in the *Pinus* managed plots, both with and without livestock, although differences among the plots were not yet significant.
Pastures	Biodiversity	Forest management had a positive significant effect in all the bare soil cover and the herbaceous species cover, and a negative significant effect in woody species cover, and this effect maintains in the second year of monitoring. Regarding the effect of the livestock, the managed with livestock plots showed higher bare soil and lower woody species than the managed without livestock plots, and not differences were observed for the herbaceous species cover. Regarding total species richness, the managed with livestock plots showed higher species richness than the plots without livestock.
	Pasture prod. and quality	There is not annual monitoring of this variable.
Rainfall simulations		The control plots and managed without livestock plots showed limited hydrological and sedimentological response. However, the response was clearly higher in the managed plot with livestock, for both runoff and soil erosion.
Site meteorological conditions		Maximum, minimum temperature and relative humidity are recorded continuously from June 2020.

***Populus* forest in Aragon**		
Soil	Soil characteristics	Results of soil samples in a depth of 0-10 cm are shown, comparing initial conditions (may 2021) and after the 1st year of monitoring (autumn 2021). Statistical results did not show significant differences between the management plots and the control plots. Changes to be highlighted: lower SOC (soil organic carbon) stocks are observed in autumn; higher SOC stock values are observed in the livestock and no livestock plots; a decrease in N stocks is observed in all the plots; the livestock and no livestock plots show higher N stocks; higher values of Corg/N ratio are observed in autumn, and the highest ratio is observed in the control plot. Results show a decrease of SOC and N stocks in all plots but an increase in Corg/N ratio in all, higher in the control plots.
	Soil moisture	A sensor network is installed since 2021. Soil moisture data shows a good response of the sensors to the recorded rainfall events
Forest	Forest struct.	There is not annual monitoring of this variable
	Forest fuel continuity	Crown fire hazard has maintained as low in all managed plots, and has been reduced from moderate to low risk in one of the managed plots.
	Forest health status	Forest decay did not show significant differences among treatments in 2022, similar to 2021, so there is not yet a positive effect of forest management in the reduction of forest decay. Forest decline has worsened in all subplots, from a mean value about 22% in 2021 to a 46% in 2022. The extreme dry summer and year 2022 had a direct effect on populous decay
	Fuel moisture	Fuel moisture was higher in the *Populus* managed plots, both with and without livestock, although differences among the plots were not yet significant.
Pastures	Biodiversity	Forest management had a positive significant effect in all the bare soil cover and the herbaceous species cover, and a negative significant effect in woody species cover, and this effect maintains in the first year of monitoring. Regarding the effect of the livestock, the managed with livestock plots showed higher bare soil than the managed without livestock plots, and not differences were observed for the herbaceous and woody species cover. Regarding total species richness, higher species richness were observed in managed and control plots, without significant differences between the plots with and without livestock activity.
	Pasture prod. and quality	There is not annual monitoring of this variable.
Rainfall simulations		The hydrological and sedimentological response in the control plot was higher, probably due to the high slope gradient. The managed plot with livestock produced slightly more water and more sediment than the one without livestock.
Site meteorological conditions		Maximum, minimum temperature and relative humidity are recorded continuously from May 2021.

***Quercus ilex* forest in Catalonia**		
Soil	Soil characteristics	There is not annual monitoring of this variable.
	Soil moisture	A sensor network is installed since 2020. Soil moisture data shows a good response of the sensors to the recorded rainfall events
Forest	Forest struct.	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.
	Forest health status	Forest decline has significantly decrease in managed plots, compared with control plots. Results also show that the application of forest management together with livestock management is able to reverse the decay trend, although the differences with the plots without livestock are not yet significant. Forest decline has slightly worsened, starting from a mean value of about 12.5% in 2020 to 15.9% in 2021 and 15.5% in 2022.
	Fuel moisture	The evolution of fuel moisture (2020-21-22) showed that fire risk has been reduced in the managed plots, both with and without livestock, and the differences among the three years are significant.
Pastures	Biodiversity	The effects of forest management were not so clearly shown in the second monitoring, when significant differences between the managed plots and not managed plots are only found for herbaceous species in plots submitted to livestock and woody species in plots not submitted to livestock. Regarding the effect of the livestock, the managed with livestock plots showed higher bare soil and herbaceous species and lower woody species than the managed without livestock plots. Regarding total species richness, higher species richness were observed in managed plots compared with plots, without significant differences between the plots with and without livestock activity.
	Pasture prod. and quality	There is not annual monitoring of this variable
Rainfall simulations		The hydrogeomorphological response was higher in the managed plots without livestock, followed by the control plot. The managed plot with livestock showed a lower hydrological response and low sediment response. These contrasting results between the managed plots are most probably due to their differences in the herbaceous vegetation, with 65-100% cover in the livestock plots and a lack of herbaceous cover and large surface of bare ground in plots without livestock.
Site meteorological conditions		Maximum, minimum temperature, and relative humidity are recorded continuously from May 2021. Besides, meteorological variables are continuously recorded since May 2018.

Mid-mountain adaptation to climate change

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