LIFE MIDMACC

Mid-mountain adaptation to climate change

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Report with the 3rd 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 third year of the monitoring in 2023. 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, second and third monitoring campaigns were realized in 2021, 2022 and 2023 respectively, between May and November.

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 ones (DL14. Report with the 1st year monitoring results of the implementation action C2 and DL19. Report with the 2nd 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, second and third monitoring campaigns, in both sites of Aragon and Catalonia. Finally, the sixth section summarizes the main outcomes found in the monitoring campaigns.

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 third 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 2023, 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 implementation (2020) Final (2023)
	Forest fuel continuity	Crown fire hazard Fuel type cover (%) Fuel height (m) Distance betw. fuel types (m) Understorey biovolume	Fuel identification and classification Strip biomass transects	Initial (2020) After implementation (2020) Annual survey (2021-22-23)
	Forest health status	Forest decline (%) Tree mortality (%) Defoliation (%) Decolouration (%)	Forest health sampling	Initial (2020) After implementation (2020) Annual survey (2021-22-23)
	Fuel moisture	Relative water content (RWC)	Forest fuel sampling	Nine measures per year during summer (4 years, 2020-21-22-23).

	Variable	Measured variables	Methodology	Periodicity
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 implementation (2020) Annual simulations (2020-2021-2022-2023)
Site meteorological conditions	**Precipitation**	Precipitation	Pluviometers (only in La Garcipollera)	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, 2nd and 3rd 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 2023 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).

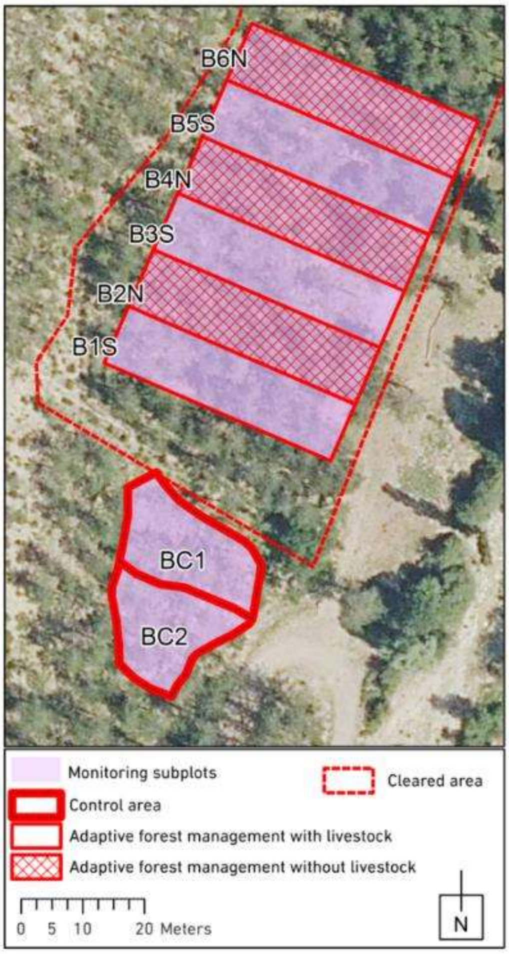


Figure 1. Location of the monitoring plots and replicates of the experimental design.

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, when a complete analysis of soil characteristics was developed. Later on, two annual monitoring campaigns were performed in 2021 and 2022, once the animals entered three times in the experimental plots. In this annual campaign, samples were taken only for the superficial soil (0-10 cm) and the analysis were centred in carbon and nitrogen stocks. Finally, the final sampling of the monitoring variables has been carried out in November 2023, taking sample for different depths, and performing analysis of all the soil variables, but the results of this sampling are not yet available. The objective is to compare with the initial conditions, to find trends and changes in the 4 years of monitoring.

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). It should be noted, that during this year the calculation to determine Corg, SOC and N stocks have been slightly modified, and consequently some data may differ from previous deliverables.

The following tables present the mean values at the initial conditions, and after the first and second years of monitoring and the change occurred in percentage for the main variables (0-10 cm) measured in the experimental plots during the 2021 and 2022 monitoring campaign in La Garcipollera Research Station. Statistical results did not show significant differences between the management plots and the control plots at the third year of monitoring, neither between the initial conditions and the 2021 and 2022 values. Some changes could be highlighted. Related to SOC values (Table 2 and Figure 2) (i) higher SOC stocks are observed after the first and second monitoring year, except in the no livestock plots; (ii) the higher increase in SOC stock is observed in the control plot, and higher values are observed in the livestock plots. Related to N stocks (Table 3 and Figure 3): (i) an increase in N stocks is observed in all the plots during the second year, with similar values in all the plots. 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 lower values are recorded during the second year; and (ii) the highest ratio is observed in the livestock plot.

SOC Mg ha^{-1} (10 cm)	YEAR 0	YEAR 1	YEAR 2	Change 1 %	Change 2 %
Livestock	49.4	67.4	54.5	*+ 36.6*	*+ 10.3*
No livestock	56.3	53.3	54.1	*- 5.3*	*- 4.0*
CONTROL	44.4	48.5	53.9	*+ 9.1*	*+ 21.3*

Table 2. Soil organic carbon (SOC) stocks of soil samples for the initial conditions and first and second 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	YEAR 2	Change 1 %	Change 2 %
Livestock	3.7	4.1	4.2	*+ 10.2*	*+ 14.4*
No livestock	4.2	2.4	4.3	*- 43.0*	*+ 0.8*
CONTROL	2.9	1.7	4.3	*- 44.2*	*+ 48.8*

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	YEAR 2	Change 1 %	Change 2 %
Livestock	13.2	17.1	13.1	+ 29.7	- 0.7
No livestock	13.2	21.9	12.9	+ 65.9	- 2.5
CONTROL	14.8	28.9	12.2	+ 95.5	- 17.5

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).

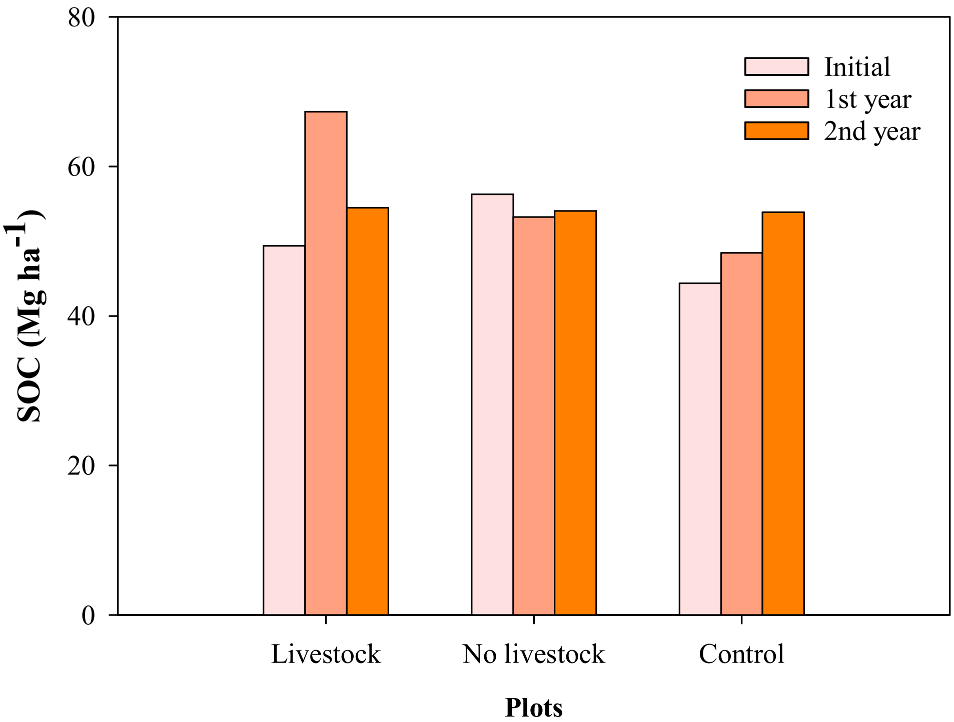


Figure 2. Soil organic carbon (SOC) stocks of soil samples for the initial conditions and first and second year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

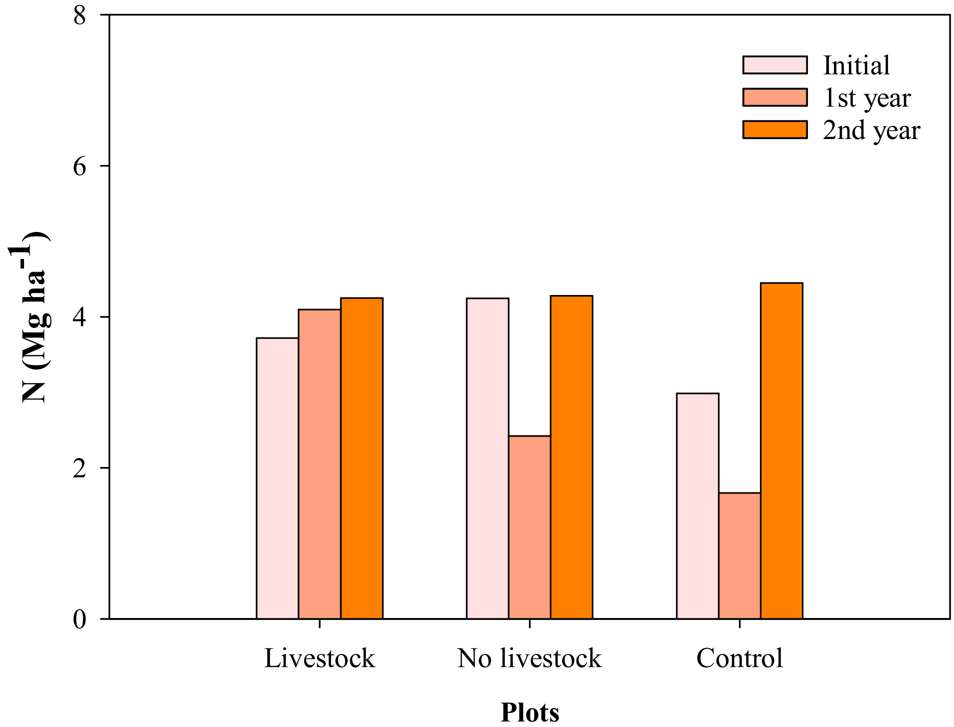


Figure 3. Nitrogen (N) stocks of soil samples for the initial conditions and first and second year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

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 of two 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 4).

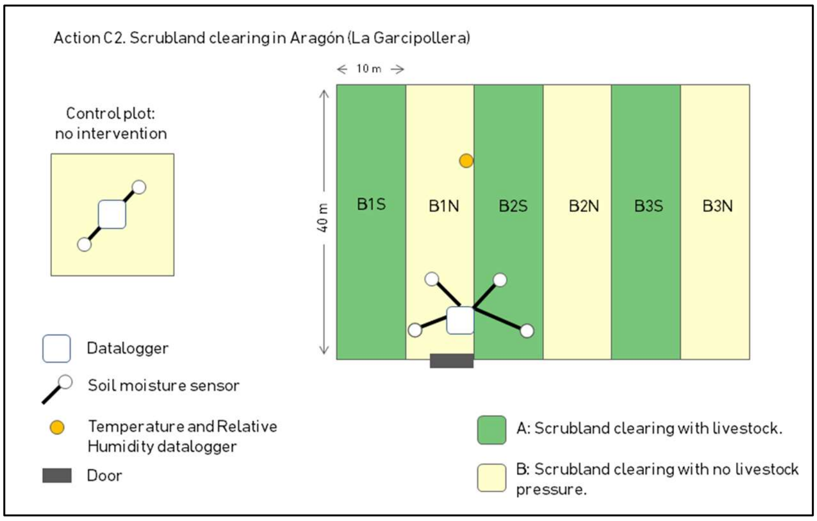


Figure 4. Final diagram of the soil moisture instrumentation.

Figure 5 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 is updated until 15th of November 2023. The results show the good response of the sensors to the recorded rainfall events, as expected higher values were observed after rainfall events. Almost at the end of the project it can be said that the plots with livestock show lower soil moisture levels than the plots without livestock and the control. In the next deliverable the relevant analysis of the results of the last 4 years will be made, trying to explain the evolution. Figure 6 shows the results grouped by season and the graphic shows how the moisture response in the plots without livestock is very similar to that of the control plot. Perhaps this is due to the ability of the vegetation to fix moisture in the soil. The seasonal pattern is similar in the three plot types.

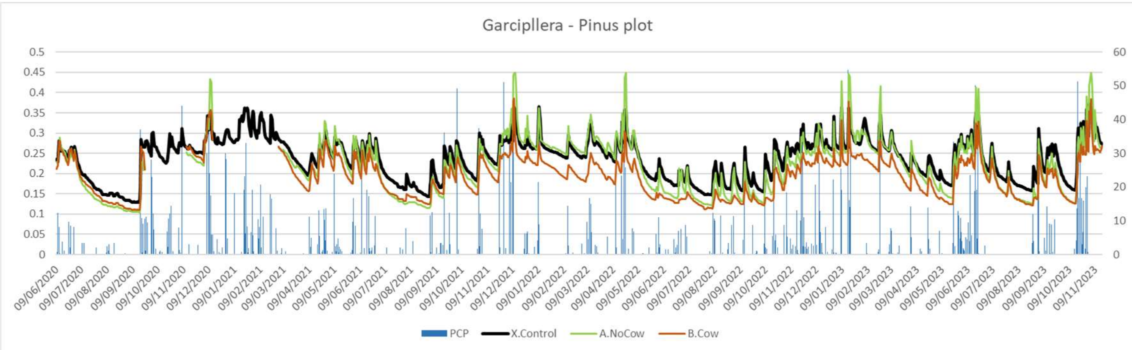


Figure 5. Soil humidity and precipitation in the Pinus nigra experimental plot (La Garcipollera).

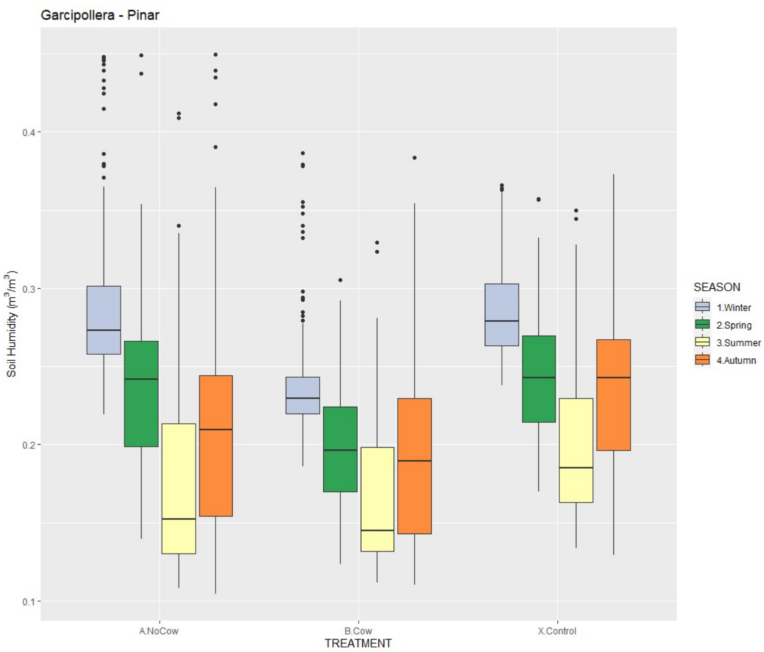


Figure 6. Soil humidity distribution per season and treatment in the Pinus nigra experimental plot (La Garcipollera).

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 in June 2020, with the objective to set the initial conditions of the forest stand, to follow up its evolution on time. The following inventories were performed between May and November of 2021, 2022 and 2023. In 2023, the final forest inventory was carried out to compare with the initial conditions. The results of the four years of monitoring 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 has been evaluated again at the end of the project, to compare the initial conditions with the final ones. The inventories have been developed in November 2023 and data is currently in analysis. The results will be shown in Deliverable 31 (Report with the final monitoring results of the implementation action C2) due to in March 2024.

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. Annual inventories were performed in October-November 2021, 2022, and 2023.

Table 5 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the three 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		Annual campaign 2023	
	Forest fuel continuity model	Crown fire hazard	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	B13	Moderate
BC2	C12	Low	C12	Low	B13	Moderate	B14	Moderate
B1S	A5	High	A5	High	C9	Low	C12	Low
B3S	C12	Low	A5	High	C12	Low	C12	Low
B5S			C12	Low	C12	Low	C10	Low
B2N	A5	High	A5	High	C12	Low	C12	Low
B4N	C12	Low	B13	Moderate	C10	Low	C12	Low
B6N	B13	Moderate	B13	Moderate	C10	Low	C12	Low

Table 5. Crown fire hazard after implementing the forest management (2020) and in the monitoring campaigns. 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. Annual inventories were performed in October-November 2021, 2022 and 2023.

Table 6 shows the forest decay after the implementation of the forest management and after the monitoring campaigns. The results of the four inventories show a slow decrease in forest decay with forest management but not significant yet (Figure 7, left) between treatments and control. This fact can be explained because in the pine forest, forest management affected only the undergrowth without intervention at the tree level. Despite this, a positive effect of livestock in decay reduction is observed comparing managed plots. The differences of forest decay among years are notable starting from a mean forest decay of about 8.1% in 2020, to a mean value of about 31.1% in 2021, 9.1% in 2022 and 43.8% in 2023 (Figure 7, right). The percentage of affection in 2020 and 2022 are significantly lower than the affection in 2021 and 2023. The values in 2023 can be due to the strong drought that affected the area in the summer of 2022, because in the conifers this effect is observable a year after the dry conditions.

Forest inventory subplot	After implementation 2020			Annual campaign 2021			Annual campaign 2022			Annual campaign 2023		
	TD	LD	MFD	TD	LD	MFD	TD	LD	MFD	TD	LD	MFD
BC1	0.0	4.5	**4.5**	23.0	6.0	**29.0**	1.0	5.0	**6.0**	14.0	12.0	**26.0**
BC2	0.0	5.0	**5.0**	28.0	2.5	**30.5**	0.5	7.0	**7.5**	6.5	15.5	**22.0**
B1S	1.5	4.0	**5.5**	19.5	7.0	**26.5**	1.0	6.5	**7.5**	9.0	41.0	**50.0**
B2N	0.0	9.5	**9.5**	29.5	3.5	**33.0**	1.0	8.5	**9.5**	14.5	41.0	**55.5**
B3S	0.0	12.0	**12.0**	35.0	1.5	**36.5**	0.0	11.0	**11.0**	9.5	38.0	**47.5**
B4N	1.5	7.0	**8.5**	35.0	1.5	**36.5**	0.5	7.5	**8.0**	12.5	39.0	**51.5**
BS5	0.5	8.5	**9.0**	24.0	1.0	**25.0**	0.0	13.5	**13.5**	10.5	38.0	**48.5**
B6N	2.0	9.0	**11.0**	25.5	6.0	**31.5**	0.0	9.5	**9.5**	17.5	31.5	**49.0**

Table 6. Forest decay per forest inventory subplots measured in July 2020, November 2021, October 2022 and November 2023. TD: Tree defoliation (%), LD: Leaf discoloration (%), MFD: Mean forest decay (%).

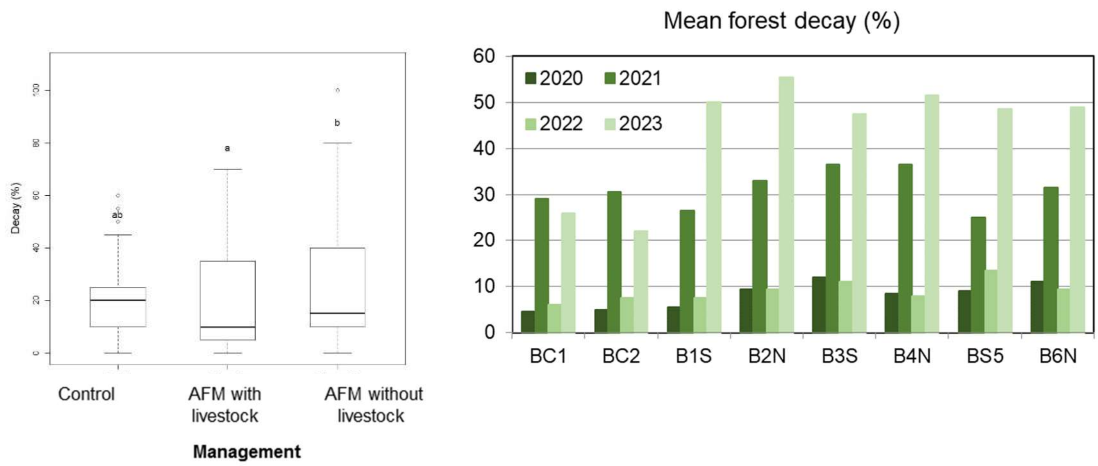


Figure 7. Left: Treatment effect on forest decay (%) in 2020-21-22-23. Right: Differences in forest decay (%) between 2020, 2021, 2022 and 2023 among forest inventory subplots.

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 8 shows the effect of the adaptive forest management on vegetation water content in the four years of monitoring (2020-2021-2022-2023). Water content is higher in the treated plots, both with and without livestock, although differences among the plots are only significant between control and management without livestock for both species.

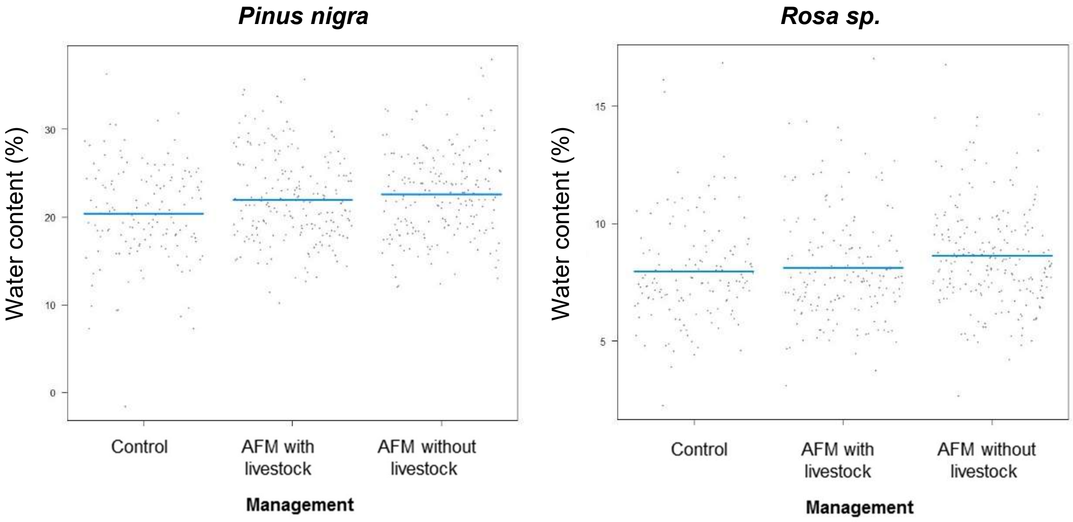


Figure 8. Treatment effect on vegetation water content in the Pinus nigra forest, La Garcipollera.

3.3. Monitoring results of the Pastures

The objective is to assess the effect of forest management and cow grazing on pasture service in terms of biodiversity, biomass production and nutritive quality. We hypothesize that forest management interacting with cow grazing will help maintain biodiverse, productive, and highly nutritive herbaceous pastures. While species rich pastures will contribute to their natural value and global biodiversity, the maintenance of their productivity and nutritive quality will enable to support extensive livestock activities in these areas, thus enhancing socio-economic development. Moreover, forest management and subsequent grazing by cow will also restrain scrub encroachment, therefore diminishing the fire risk in these areas.

3.3.1. Biodiversity

Vegetation surveys were arranged within four subplots (1 m^2) at each of the three replicate plots per treatment: control area not managed without livestock, managed area without livestock and managed area with livestock. Vegetation sampling was carried out once a year (between late spring and early summer) for three years to observe the evolution of the vegetation in the plots from the initial to the final stage (also evaluating the intermediate stage). The first sampling was done in June 2020 to record the initial stage of the pasture in the experimental plots prior to any livestock entry. Intermediate stage of the vegetation in the experimental plots was recorded in June 2022 (after having entered cows two years in a row). Final stage of the pasture was recorded June 2023 (after having entered cows three years in a row).

To assess the effects of forest management and cow grazing on pasture biodiversity, the data evaluated were the cover and richness of herbaceous and woody species separately. We also assessed the effect of those factors on the bare soil cover. Regarding the forest management factor, we expected to find a positive effect of woody plant removal in the herbaceous pasture cover and richness in the first sampling because of the elimination of woody competitors for light, space, nutrients, and water. We expected this effect to be maintained over the years. On the other hand, regarding the cow grazing we expected not to find any effect of livestock in the first year since vegetation surveys were set prior to cow entry in the plots. But we expected to find a positive effect of cow grazing by promoting the growth of herbaceous species (both in cover and richness) and controlling the growth of woody species along the subsequent years (2022 and 2023).

As we expected, in the first monitoring year, we found significant differences between the managed and not managed area in all the cover variables considered, the bare soil cover and the herbaceous and woody species cover, and this effect was maintained in the second-year monitoring (Figure 9). Specifically, we found a larger bare soil cover and woody species cover and a lower herbaceous species cover in the control plots (not managed) than in the managed plots. Also, we found higher herbaceous species richness in plots submitted to forest management than in non-managed plots, but these differences disappeared in the intermediate and final monitoring dates (Figure 10). Regarding the effect of the livestock, in the first year we did not find any significant difference 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 year (intermediate status) we found significantly higher bare ground cover and lower woody species cover in the grazed than in the ungrazed treatments, and these differences maintained in the final stage monitoring (Figure 9). The grazing treatment did not affect the woody species richness through the whole experiment, but significantly increased the herbaceous species richness from the intermediate monitoring stage (Figure 10).

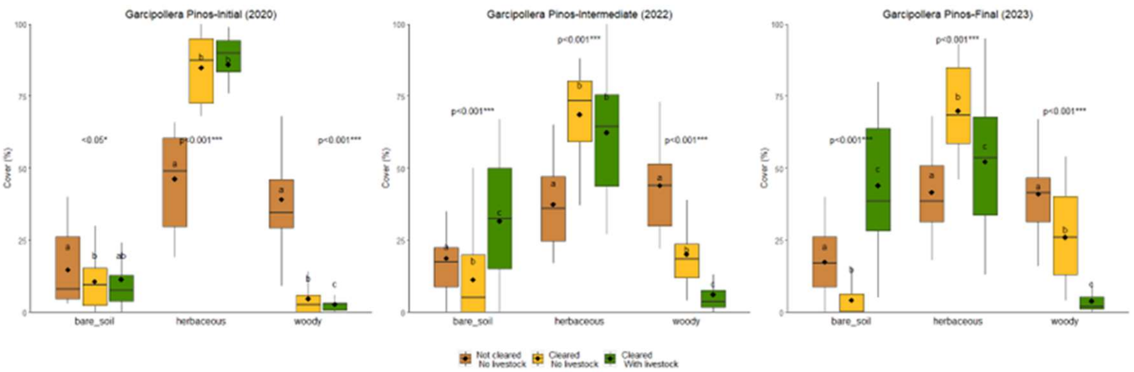


Figure 9. Boxplots showing mean cover and data variability of the bare soil, herbaceous species, and woody species separately in each treatment (not managed without livestock, managed without livestock, managed with livestock). Initial, intermediate, and final stages of the experimental plots are shown.

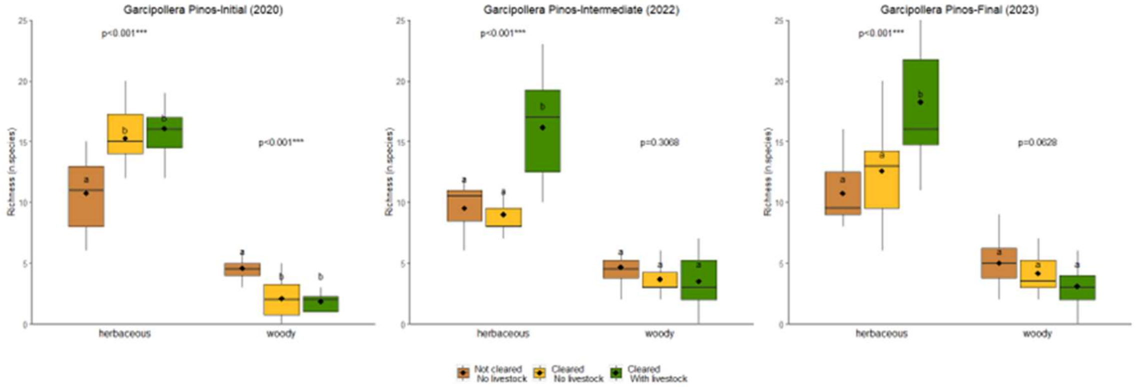


Figure 10. Boxplots showing mean species richness for herbaceous species and woody species separately in each treatment (not managed without livestock, managed without livestock, managed with livestock). Initial, intermediate, and final stages of the experimental plots are shown.

3.3.2. Pasture production and quality

To assess pasture production and nutritive quality we harvested the plants growing within four subplots (0.25 m^2) at each of the three replicate plots per treatment: control area not managed without livestock, managed area without livestock and managed area with livestock. Samples were collected between late spring and early summer (matching the vegetation growth peak) at the initial and final stage of the experiment. The first sampling was done in June 2020 to record the initial stage of the pasture in the experimental plots prior to any livestock entry and second sampling was done in June 2023 to record the final stage of the pasture after having entered cows three years in a row. We considered that recording the intermediate stage of the pastures in terms of production and quality was not relevant because it is a short period of time to achieve significant results.

To assess the effects of forest management and cow grazing on pasture production, we considered dry biomass (kg/ha) of the gathered herbaceous plants. The nutritive quality of pastures was evaluated in terms of the content of digestible fibers (Relative Feed Value) and crude protein (estimated in laboratory from the dry matter derived from the collected herbaceous samples).

Regarding the forest management factor, we expected to find a positive effect of woody plant removal in the herbaceous plants' biomass and quality because of the elimination of woody competitors for light, space, nutrients, and water. We expected to find this effect both in the first and final samplings. On the other hand, regarding the cow grazing, we expected not to find any effect of the livestock in the first year since samples were collected before the cows' entrance into the plots. But we expected to find a positive effect of cow grazing by promoting the growth and nutritive quality of herbaceous species in the final stage.

As expected, we found significantly higher herbaceous biomass production under the forest management treatment than in the unmanaged forest through the whole experiment (Figure 11). Unexpectedly, in the first monitoring date (before the entry of the cattle), the plots intended for grazing treatment showed significantly less herbaceous biomass than the plots without grazing, and these differences were maintained in the final monitoring stage.

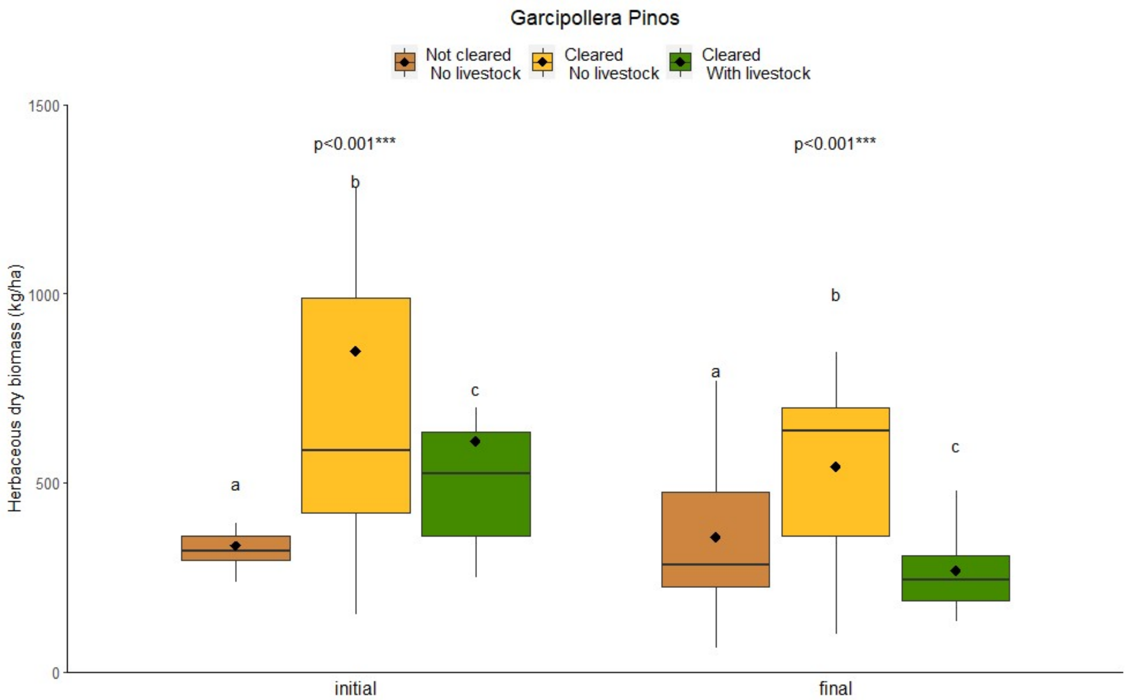


Figure 11. Boxplots showing mean herbaceous dry biomass in each treatment (not managed *without livestock, managed without livestock, managed with livestock). Initial and final stages of the experimental plots are shown*.

The nutritional quality of the grass harvested this June 2023 is currently under analysis in the laboratory. As we only have available the data from the initial stage, the comparison among nutritional quality of the grass at the initial and the final experiment stages is not shown.

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), second (2021) and third (2022) 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 managed plots without livestock showed very limited hydrological and sedimentological response. Note that among the experiments in the control plot only one produced runoff and sediment. The response was higher in the managed plot with livestock, although the production of runoff and sediments was moderate, with mean RC=0.06, SC=0.37 g/l and SP=0.7 g/m^2. Accordingly, the rate of infiltration was lowest in the managed plot with livestock.

Site	Land management	Slope (%)	RI (mm h^{-1})	INF (mm h^{-1})	RC (-)	SC (g L^{-1})	SP (g m^{-2})
Pinus nigra	Control	20	47.1	28.2	0.02	0.07	0.24
	AFM with livestock (BS)	17	45.5	25.4	0.06	0.37	0.70
	AFM without livestock (BN)	14	46.2	32.3	0.00	0.00	0.00

Table 7. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in Garcipollera Pinus nigra (2020, 2021, 2022). RI: rainfall intensity (mm h^{-1}), INF: infiltration rate (mm h^{-1}), RC: Runoff coefficient (mm mm^{-1}), SC: Sediment concentration (g l^{-1}), SP: Sediment production or erosion rate (g m^{-2}).

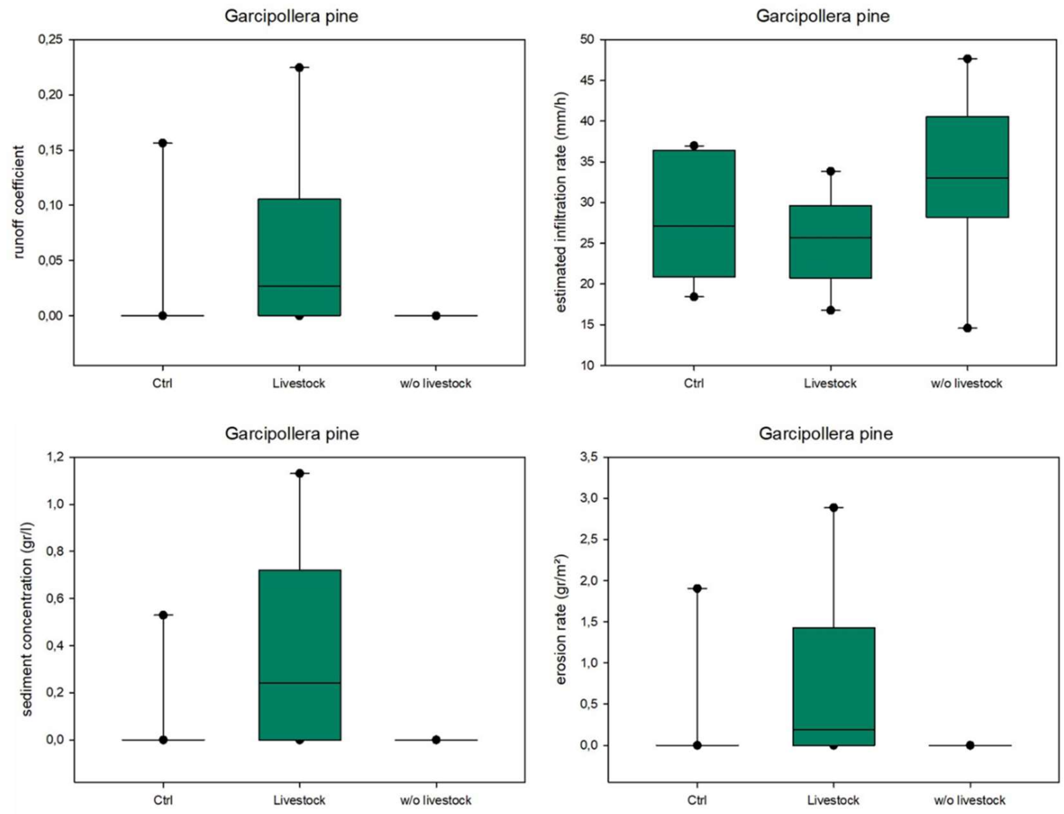


Figure 12. Runoff coefficient (mm mm^{-1}), Infiltration rate (mm h^{-1}), Sediment concentration (g l^{-1}) and erosion rate (g/m^2) in La Garcipollera P. nigra (2020, 2021, 2022).

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 13. In this period, until 15-11-2023, the maximum temperature has been 37.5 ºC and the minimum -12.4 (Table 8). The data are continuous (no gaps) and clearly show the annual cycle of temperatures. Trend lines have been added as a prelude to the trend analysis to be carried out for the final deliverable, and a positive trend can already be seen in the temperatures of the last 3 years.

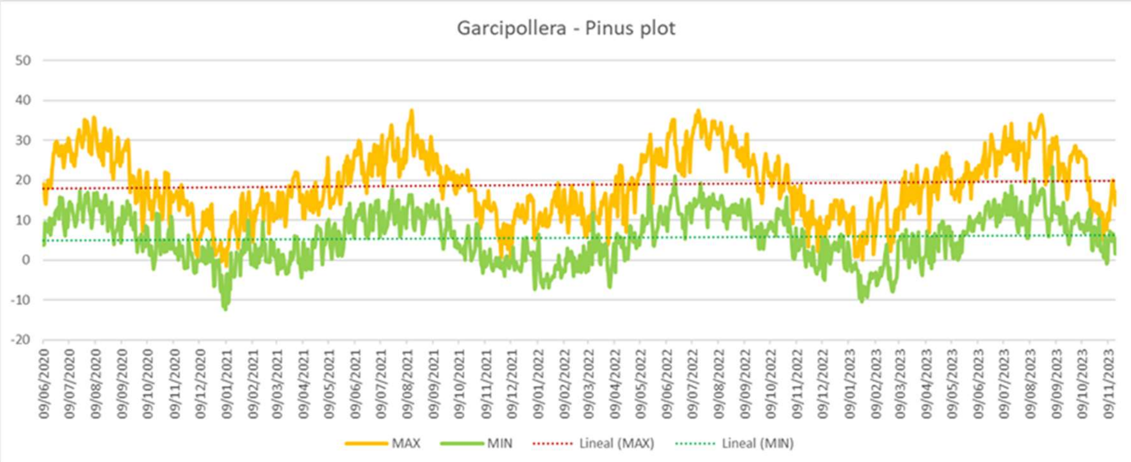


Figure 13. Daily average of minimum and maximum temperature in the Pinus nigra plots.

	Pinus plot	
	Tmax	Tmin
Max	37.5	20.9
Min	-1.5	-12.4
Mean	18.9	5.7

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

Figure 14 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, to contextualise our results.

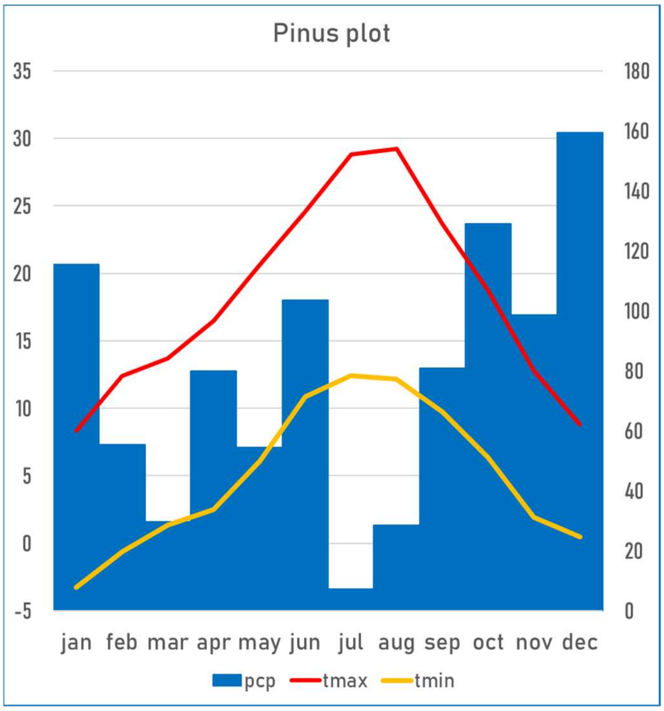


Figure 14. Climogram in the Pinus nigra plot.

4. Results of the 1st, 2nd, and 3rd monitoring campaign in the *Populus* forest, Aragon

This chapter includes the results of the 2021-2022-2023 campaigns 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 15).

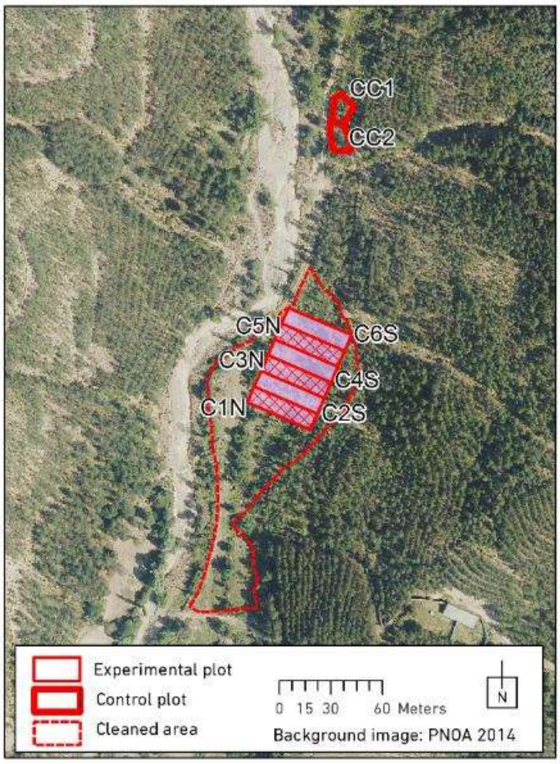


Figure 15. Location of the monitoring plots and replicates of the experimental design.

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 and 2022, superficial soil samples (0-10 cm) were taken to assess carbon and nitrogen concentration. Finally, the final sampling of the monitoring variables has been carried out in November 2023, taking sample for different depths, and performing analysis of all the soil variables. The objective is to compare with the initial conditions, to find trends and changes in the 4 years of monitoring.

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 ($CaCO_3$), organic carbon (Corg), soil organic carbon (SOC) and nitrogen (TN) stocks, organic matter (OM) and Corg/N ratio. It should be noted, that during this year the calculation to determine Corg, SOC and N stocks have been slightly modified, and consequently some data may differ from previous deliverables.

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 and second year of monitoring (autumn 2021 and 2022) 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 and second years of monitoring, neither between the initial conditions and the present values. Some changes could be highlighted. Related to SOC values (Table 9 and Figure 16) (i) lower SOC stocks are observed after the first and second monitoring year (almost no changes in the no livestock plot); (ii) higher values are observed in the no livestock plots. Related to N stocks (Table 10 and Figure 17): (i) a decrease in N stocks is observed in all the plots after the second year of monitoring; and (ii) the no livestock plots show higher N stocks. Related to the Corg/N ratio (Table 11): (i) higher values are observed after the first and second monitoring year; and (ii) the highest ratio is observed in the control plot.

SOC Mg ha^{-1} (10 cm)	YEAR 0	YEAR 1	YEAR 2	Change 1 %	Change 2 %
Livestock	61.6	49.9	40.1	*- 18.9*	*- 34.8*
No livestock	65.8	52.9	65.0	*- 19.6*	*- 1.2*
CONTROL	65.7	44.3	59.0	*- 32.5*	*- 10.1*

Table 9. Soil organic carbon (SOC) stocks of soil samples for the initial conditions and first and second 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	YEAR 2	Change 1 %	Change 2 %
Livestock	5.4	3.4	2.6	- 36.8	- 50.9
No livestock	5.8	3.6	3.7	- 38.3	- 36.8
CONTROL	4.9	2.6	2.6	- 46.6	- 47.0

Table 10. Nitrogen (N) stocks of soil samples for the initial conditions and first and second 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	YEAR 2	Change 1 %	Change 2 %
Livestock	11.2	14.8	17.3	+ 31.9	+ 54.4
No livestock	11.5	14.8	15.1	+ 28.1	+ 31.5
CONTROL	9.2	18.7	22.8	+ 103.7	+ 149.3

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).

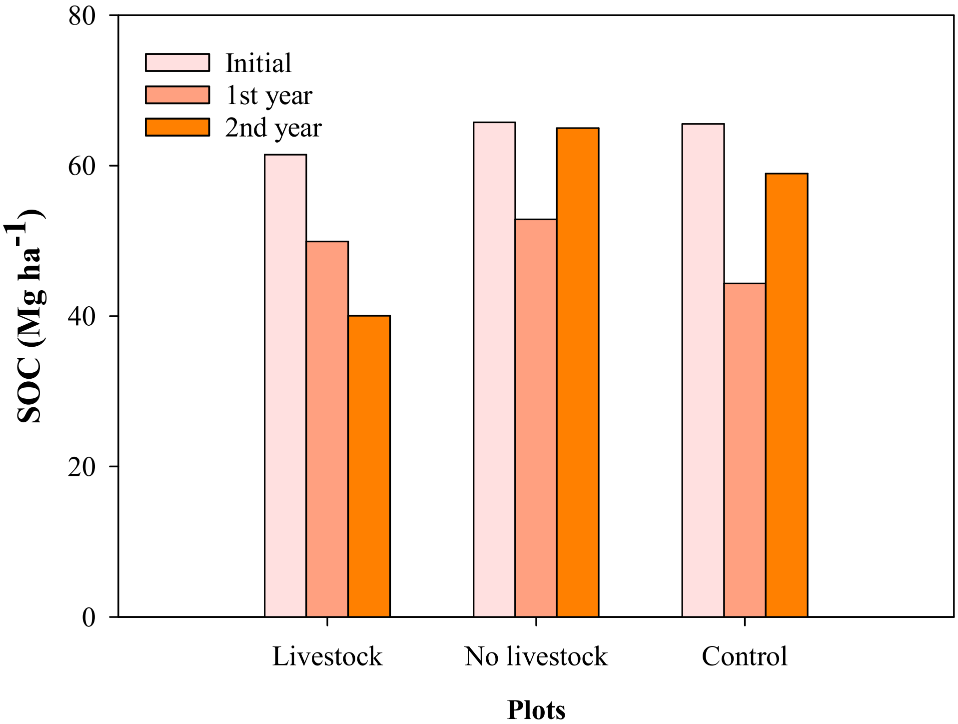


Figure 16. Soil organic carbon (SOC) stocks of soil samples for the initial conditions and first and second year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control plots).

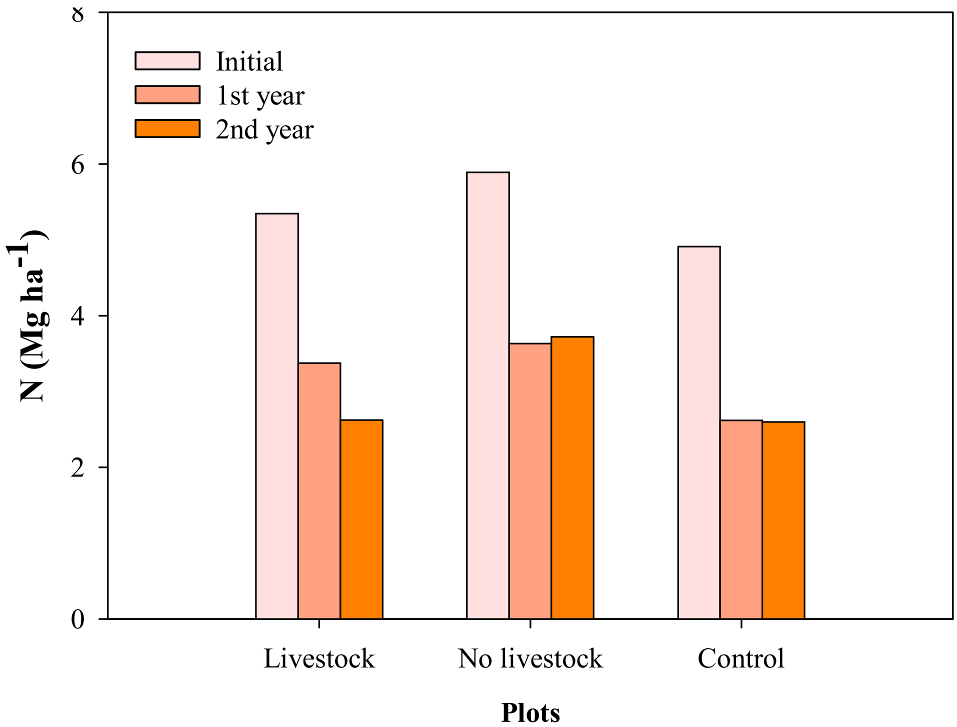


Figure 17. Nitrogen (N) stocks of soil samples for the initial conditions and 1st and 2nd year of monitoring (at depth of 0-10 cm) and in the different plots (livestock, no livestock and control).

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. The network consists of two 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 18).

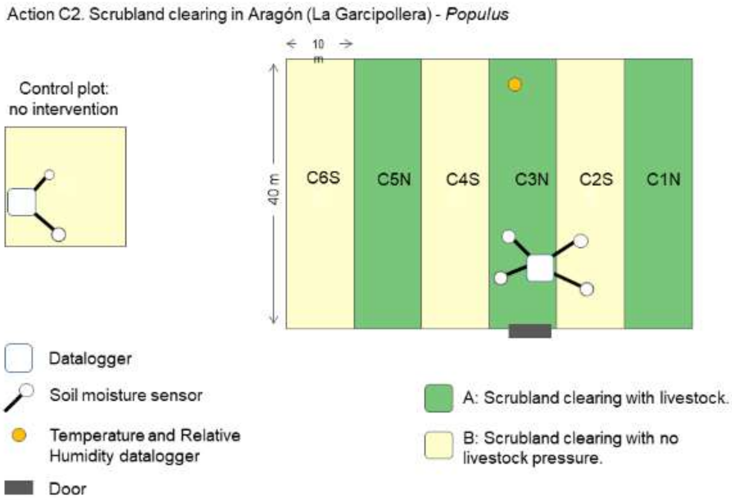


Figure 18. Diagram of the soil moisture instrumentation.

Figure 19 shows the daily soil moisture data recorded 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 at the beginning of the period and in spring 2023. The figure shows the good response of the sensors to the recorded rainfall events, as expected higher values were observed after rainfall events. Although more results are needed to start extracting conclusions when comparing among treatments and with the control subplots, the plots with livestock have, in this case, a higher capacity to hold water in the soil, a fact that is also shown in Figure 20 where the results are grouped by season.

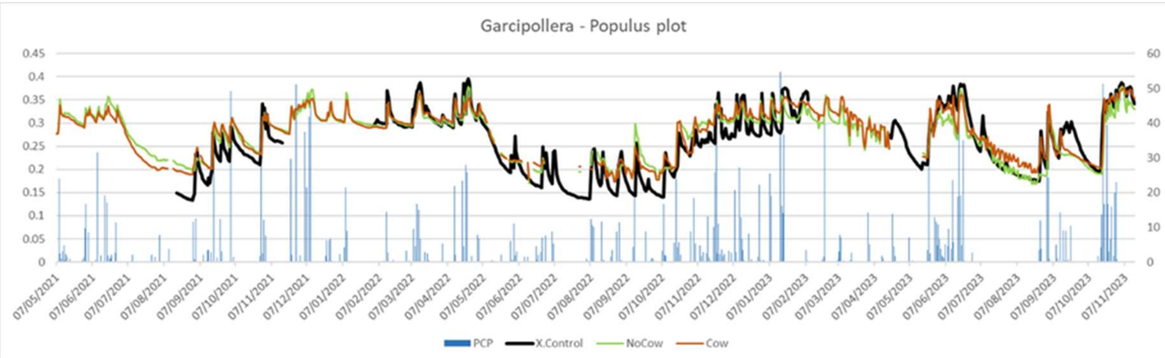


Figure 19. Soil humidity and precipitation in the Populus experimental plot (La Garcipollera).

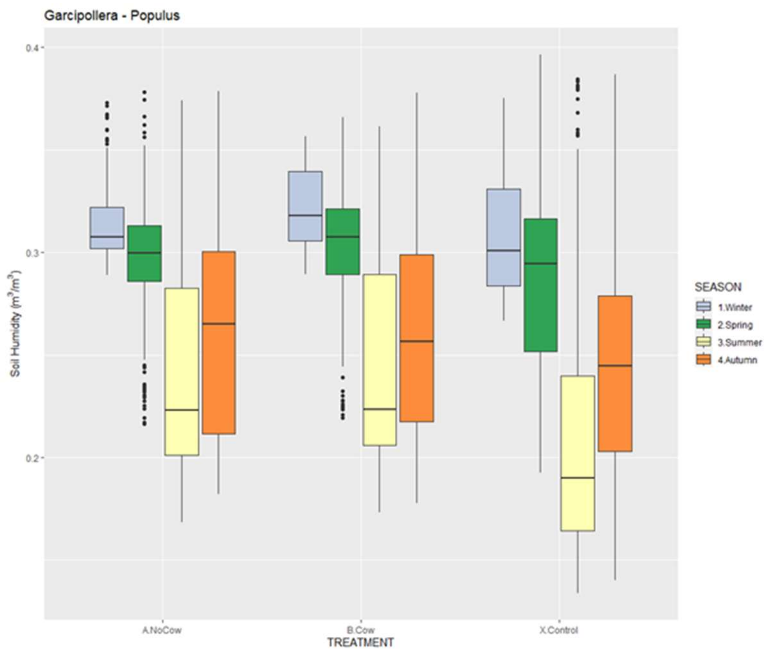


Figure 20. Soil humidity distribution per season and treatment in the Populus experimental plot (La Garcipollera).

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 15). 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 in May 2021, with the objective to set the initial conditions of the forest stand, to follow up its evolution on time. The following inventories were performed between May and November of 2021, 2022 and 2023. In 2023, the final forest inventory was carried out to compare with the initial conditions. The results of the four years of monitoring 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 has been evaluated again at the end of the project, to compare the initial conditions with the final ones. The inventories have been developed in November 2023 and data is currently in analysis. The results will be shown in Deliverable 31 (Report with the final monitoring results of the implementation action C2) due to in March 2024.

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. Annual inventories were performed in October-November 2022 and 2023.

Table 12 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the two monitoring campaigns. 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		Annual campaign 2023	
	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard	Forest fuel continuity model	Crown fire hazard
CC1	B16	Moderate	B16	Moderate	B16	Moderate
CC2	B16	Moderate	B16	Moderate	B16	Moderate
C2S	C13	Low	C13	Low	C16	Low
C4S	B16	Moderate	C13	Low	C16	Low
C6S	C13	Low	C13	Low	C16	Low
C1N	C13	Low	C13	Low	C16	Low
C3N	C13	Low	C13	Low	C16	Low
C5N	C13	Low	C13	Low	C16	Low

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

4.2.3. Forest health status

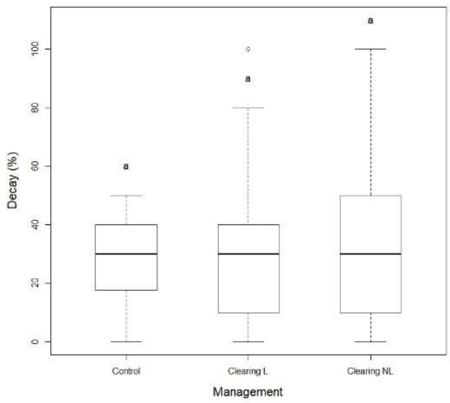
Forest health refers to the status of the forest decline due to climate change effects (mainly droughts) or other related threatens (plagues, diseases …). Forest decline is defined by the degree of defoliation, decolouration, or mortality of the individuals of the forest.

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. Annual inventories were performed in October-November 2021, 2022, and 2023.

Table 13 shows the forest decay after the implementation of the forest management and after the monitoring campaigns. The results of the inventories show not significant differences among treatments, so there is not a positive effect of forest management in the reduction of forest decay (Figure 21, 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 22.0% in 2021 to a mean value of about 45.7% in 2022 and 40.7% in 2022 (Figure 21, right). The extreme dry summer and year 2022 and 2023 had a direct effect on populous decay.

Forest inventory subplot	After implementation 2021			Annual campaign 2022			Annual campaign 2023		
	TD	LD	MFD	TD	LD	MFD	TD	LD	MFD
CC1	18.3	0.0	**18.3**	20.0	20.0	**40.0**	10.0	28.3	**38.3**
CC2	24.0	0.0	**24.0**	21.3	21.3	**42.5**	11.7	16.7	**28.3**
C1N	27.0	0.0	**27.0**	27.5	40.0	**67.5**	10.0	30.0	**40.0**
C2S	39.2	0.0	**39.2**	23.8	11.3	**35.0**	6.3	30.0	**36.3**
C3N	20.7	0.0	**20.7**	31.4	20.7	**52.1**	10.8	41.7	**52.5**
C4S	13.8	0.0	**13.8**	20.0	14.4	**34.4**	10.0	37.5	**47.5**
C5N	16.7	0.0	**16.7**	36.7	16.7	**53.3**	7.5	35.0	**42.5**
C6S	16.4	0.0	**16.4**	25.0	15.8	**40.8**	12.5	27.5	**40.0**

Table 13. Forest decay per forest inventory subplots measured on May 2021, October 2022 and November 2023. TD: Tree defoliation (%), LD: Leaf discoloration (%), MFD: Mean forest decay (%).



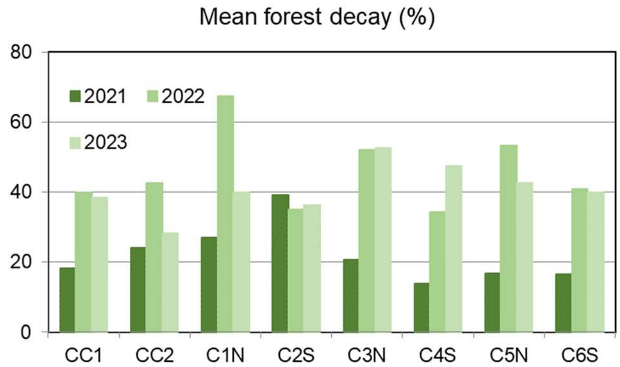


Figure 21. Left: Treatment effect on forest decay *(%) in 2021, 2022 and 2023. Right: Differences in forest decay (%) between 2021, 2022 and 2023 among forest inventory subplots.*

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 22 shows the effect of the adaptive forest management on vegetation water content in the three years of monitoring (2021-2022-2023). 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.

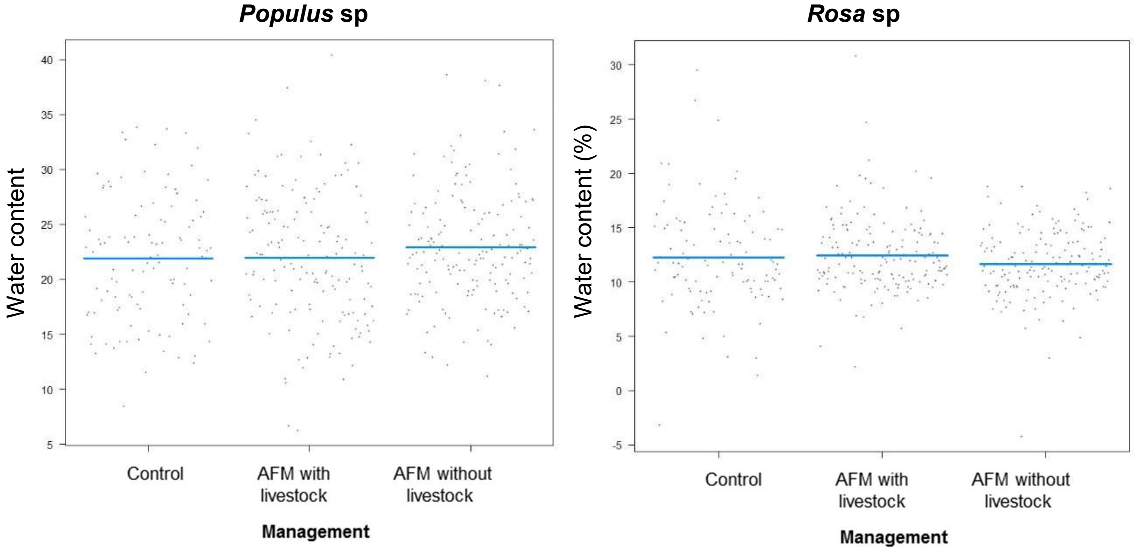


Figure 22. Treatment effect on vegetation water content in the Populus forest, La Garcipollera.

4.3. Monitoring results of the Pastures

The objective is to assess the effect of forest management and cow grazing on pasture services in terms of biodiversity, biomass production and nutritive quality. We hypothesize that forest management interacting with cow grazing will help maintain biodiverse, productive, and highly nutritive herbaceous pastures. While species rich pastures will contribute to their natural value and global biodiversity, the maintenance of their productivity and nutritive quality will enable to support extensive livestock activities in these areas, thus enhancing socio-economic development. Moreover, forest management and subsequent cow grazing will also restrain scrub encroachment, therefore diminishing the fire risk in these areas.

4.3.1. Biodiversity

Vegetation surveys were arranged within four subplots (1 m^2) at each of the three replicate plots per treatment: control area not managed without livestock, managed area without livestock and managed area with livestock. Vegetation sampling was carried out once a year (between late spring and early summer) for three years to observe the evolution of the vegetation in the plots from the initial to the final stage (also evaluating the intermediate stage). The first sampling was done in June 2021 to record the initial stage of the pasture in the experimental plots prior to any livestock entry. Intermediate stage of the vegetation in the experimental plots was recorded in June 2022 (after having entered cows two years in a row). Final stage of the pasture was recorded June 2023 (after having entered cows three years in a row).

To assess the effects of forest management and cow grazing on pasture biodiversity, the data evaluated was the cover and richness of herbaceous and woody species separately. We also assessed the effect of those factors on the bare soil cover. Regarding the forest management, we expected to find a positive effect of woody plant removal in the herbaceous pasture cover and richness in the first sampling because of the elimination of woody competitors for light, space, nutrients, and water. We expected this effect to be maintained over the years. On the other hand, regarding the cow grazing we did not expect to find any effect of livestock in the first year since vegetation surveys were set prior to cow entry in the plots. But we expected to find a positive effect of cow grazing by promoting the growth of herbaceous species (both in cover and richness) and controlling the growth of woody species along the subsequent years (2022 and 2023).

As we expected, in the first-year monitoring, we found significant differences between the managed and not managed area for all the bare soil cover and the herbaceous and woody species cover (Figure 23). Specifically, we found a larger bare soil cover and woody species cover and a lower herbaceous species cover in the not managed plots than in the managed plots. This effect was maintained through the whole experiment. Regarding the effect of the livestock, in the first year we did not find differences between the treatments (livestock versus no livestock) for the herbaceous and woody species cover, but we found significantly more bare ground cover in the plots the grazing treatment prior to the entry of the cattle than in the ungrazed treatment plots, which was maintained through the experiment. The woody species cover showed not significant differences between grazing treatments, either in the second nor in the final monitoring stages.

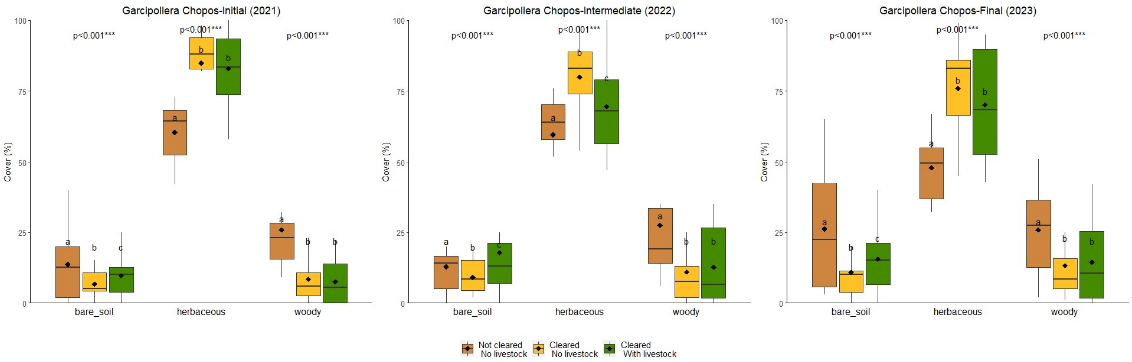


Figure 23. Boxplots showing mean cover and data variability of the bare soil, herbaceous species, and woody species separately in each treatment (not managed without livestock, managed without livestock, managed with livestock). Initial, intermediate, and final stages of the experimental plots are shown.

In terms of species richness in the initial monitoring year, we found significantly higher number of herbaceous species in the managed treatment than in the control without forest management, this effect of management maintained through the whole experiment. However, management treatment did not affect the number of woody species. Grazing did not affect the herbaceous nor the woody species richness during the two years of experiment (Figure 24).

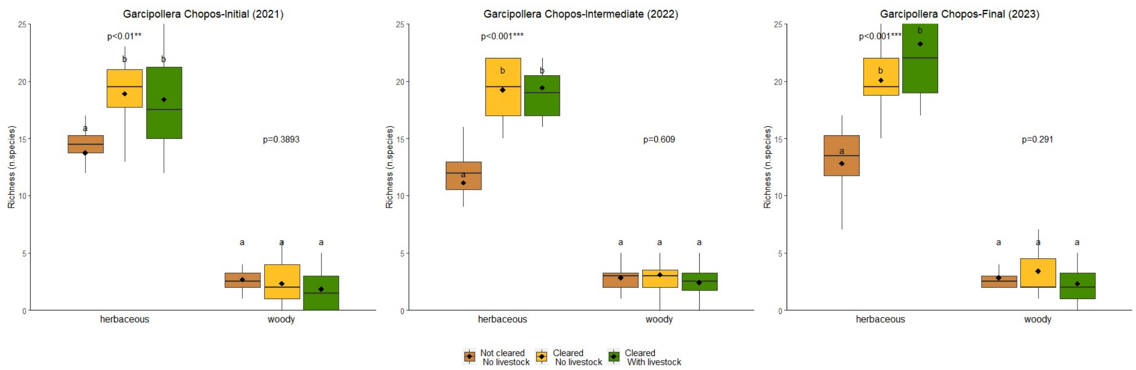


Figure 24. Boxplots showing mean species richness for herbaceous species and woody species separately in each treatment (not managed without livestock, managed without livestock, managed with livestock). Initial, intermediate, and final stages of the experimental plots are shown.

4.3.2. Pasture production and quality

To assess pasture production and nutritive quality we harvested the plants growing within four subplots (0.25 m^2) at each of the three replicate plots per treatment: control area not managed without livestock, managed area without livestock and managed area with livestock. Samples were collected between late spring and early summer (matching the vegetation growth peak) at the initial and final stage of the experiment. The first sampling was done in June 2020 to record the initial stage of the pasture in the experimental plots prior to any livestock entry and second sampling was done in June 2023 to record the final stage of the pasture after having entered cows three years in a row. We considered that recording the intermediate stage of the pastures in terms of production and quality was not relevant because it is a short period of time to achieve significant results.

To assess the effects of forest management and cow grazing on pasture production, we considered dry biomass (kg/ha) of the gathered herbaceous plants. The nutritive quality of pastures was evaluated in terms of the content of digestible fibers (Relative Feed Value) and crude protein (estimated in laboratory from the dry matter derived from the collected herbaceous samples).

Regarding the forest management factor, we expected to find a positive effect of woody plant removal in the herbaceous plants' biomass and quality because of the elimination of woody competitors for light, space, nutrients, and water. We expected to find this effect both in the first and final samplings. On the other hand, regarding the cow grazing, we expected not to find any effect of the livestock in the first year since samples were collected prior to cows' entry in the plots. But we expected to find a positive effect of cow grazing by promoting the growth and nutritive quality of herbaceous species in the final stage.

Management treatment affected the herbaceous biomass, which was significantly higher under the managed treatment than in the control without forest management, being this effect maintained in the final monitoring. Herbaceous biomass was significantly lower in the plots intended for grazing treatment prior to the entry of the cattle than in the ungrazed treatment plots, being this effect maintained in the final monitoring (Figure 25).

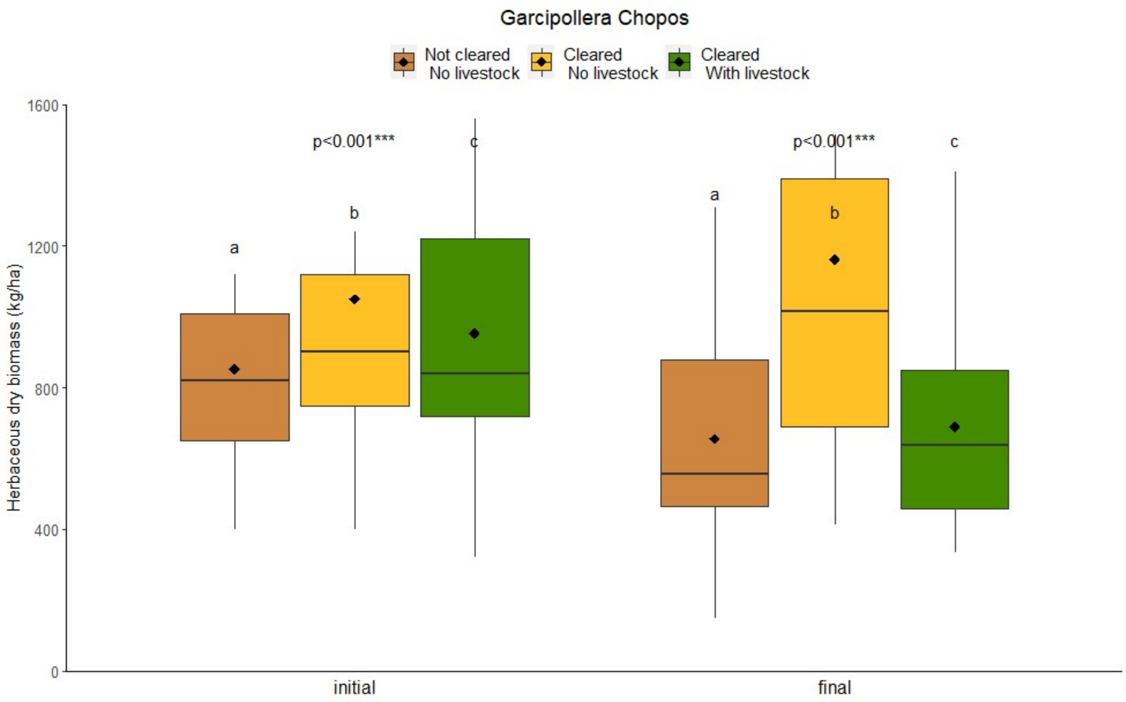


Figure 25. Boxplots showing mean cover (and data variability) of grasses, legumes, and other families for each treatment: not managed without livestock (SD), managed without livestock (A) and managed with livestock (B). Initial status (first monitoring, 2021) and Intermediate status (second monitoring, 2022) of the experimental plots are shown.

The nutritional quality of the grass harvested this June 2023 is in the process of laboratory analysis, having available only the data of the initial stage, so these data are not shown.

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, we present the results of the first (2021) and second (2022) monitoring campaign.

The managed plot with livestock recorded the highest hydrological response (mean RC=0.23). However, the sediment response was higher in the control plots, with mean SC=0.96 g/l and SP=2.10 g/m^2. As already observed in the Pinus nigra forest, the hydro-sedimentological response in the managed plot without livestock was the lowest and the infiltrated water the highest.

Site	Land management	Slope (%)	RI (mm h^{-1})	INF (mm h^{-1})	RC (-)	SC (g L^{-1})	SP (g m^{-2})
Populus	Control	22	48.5	25.4	0.14	0.96	2.10
	AFM with livestock (BS)	12	57.9	11.4	0.23	0.37	1.82
	AFM without livestock (BN)	10	56.0	28.2	0.01	0.35	0.27

Table 14. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in La Garcipollera Populus (2021, 2022). RI: rainfall intensity (mm h^{-1}), INF: infiltration rate (mm h^{-1}), RC: Runoff coefficient (mm mm^{-1}), SC: Sediment concentration (g l^{-1}), SP: Sediment production or erosion rate (g m^{-2}).

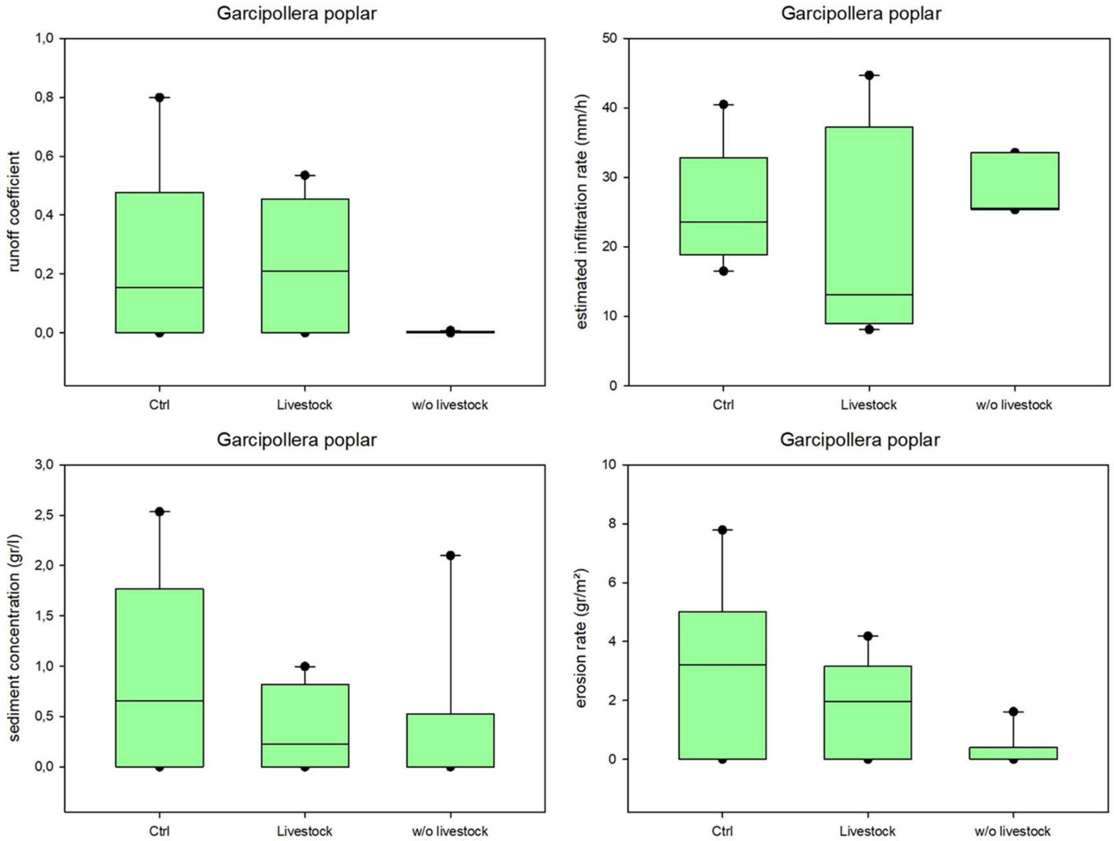


Figure 26. Runoff coefficient (mm mm^{-1}), Infiltration rate (mm h^{-1}), Sediment concentration (g l^{-1}) and erosion rate (g/m^2) in La Garcipollera Populus (2021, 2022).

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 27. In this period, until 15-11-2023, the maximum temperature has been 38.5 ºC and the minimum -12.2 (Table 15).

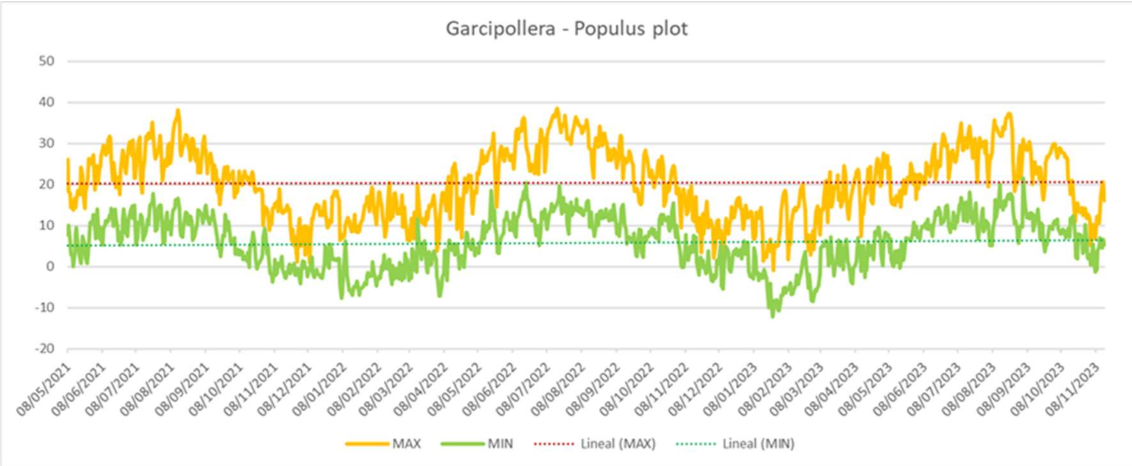


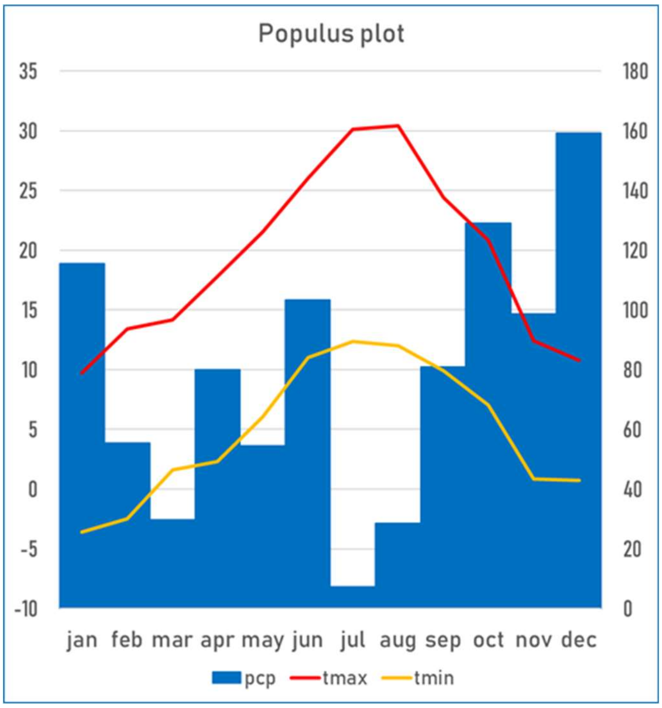
Figure 27. Daily average of minimum and maximum temperature in the Populus plots.

	Populus plot	
	Tmax	Tmin
Max	38.5	21.5
Min	-0.9	-12.2
Mean	20.5	5.8

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

Figure 28 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, to contextualise our results.

Figure 28. Climogram in the Populus plot.



5. Results of the 1st, 2nd and 3rd monitoring campaign in the *Quercus ilex* forest, 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 29).

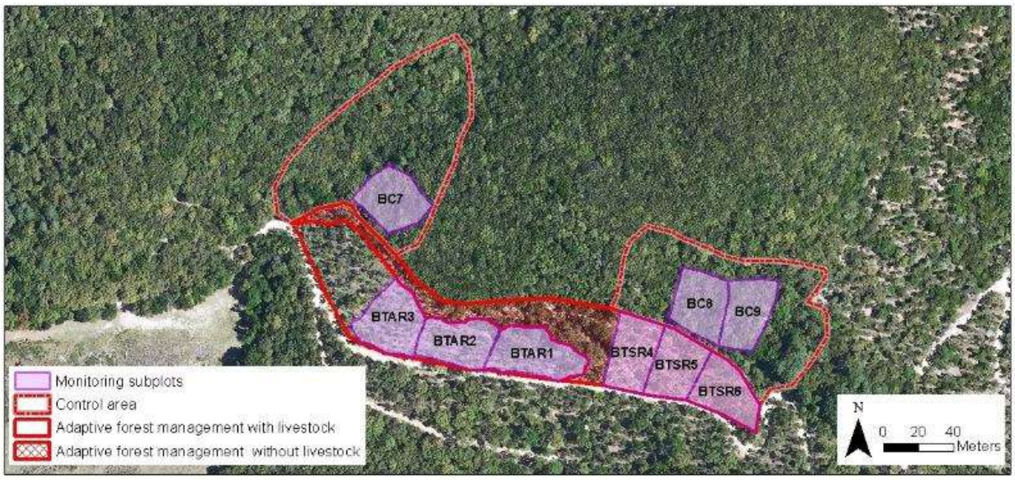


Figure 29. Location of the monitoring plots and replicates of the experimental design.

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 annual carbon sampling was taking. The final soil samplings were carried out in October 2023. Samples are being analysed on the laboratory and the results will be presented in the final deliverable in March 2024.

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 of 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 30).

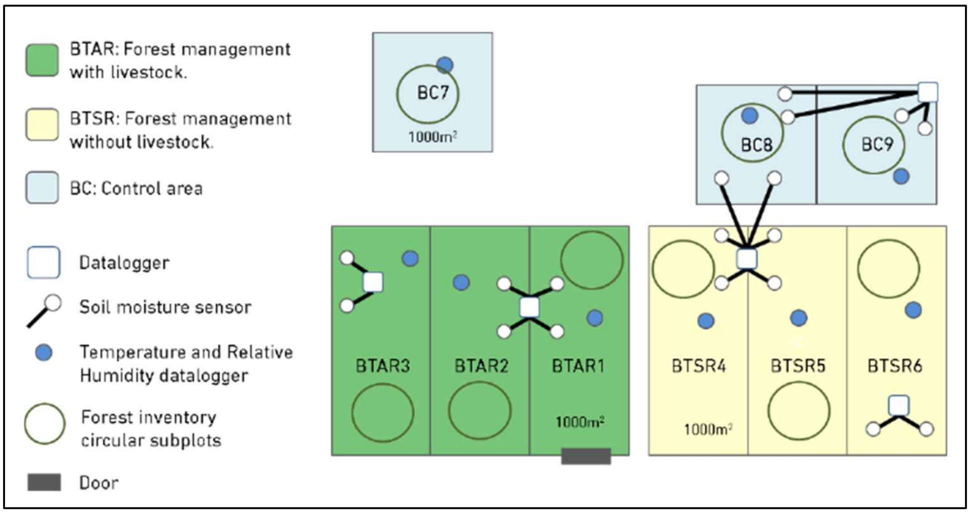


Figure 30. Diagram of the livestock and monitoring subplots.

Figure 31 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. 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.

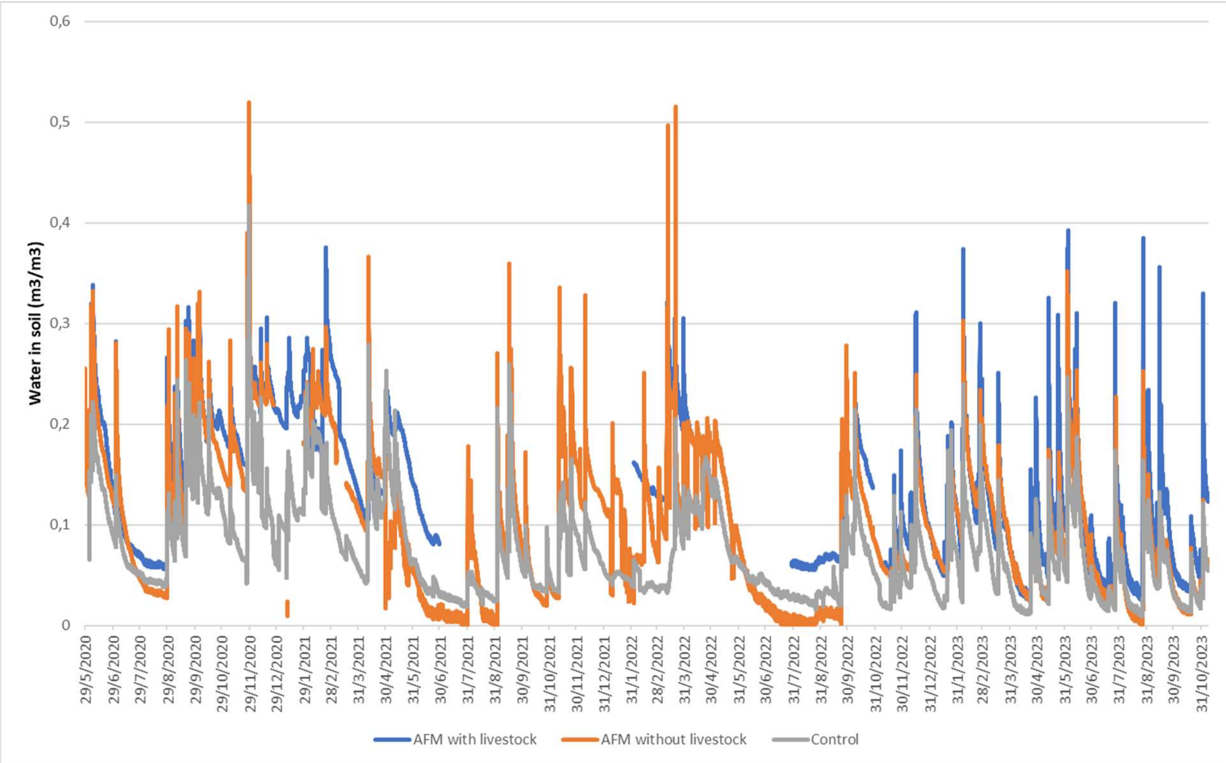


Figure 31. Soil humidity in the Holm oak experimental plot (Requesens).

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 32).

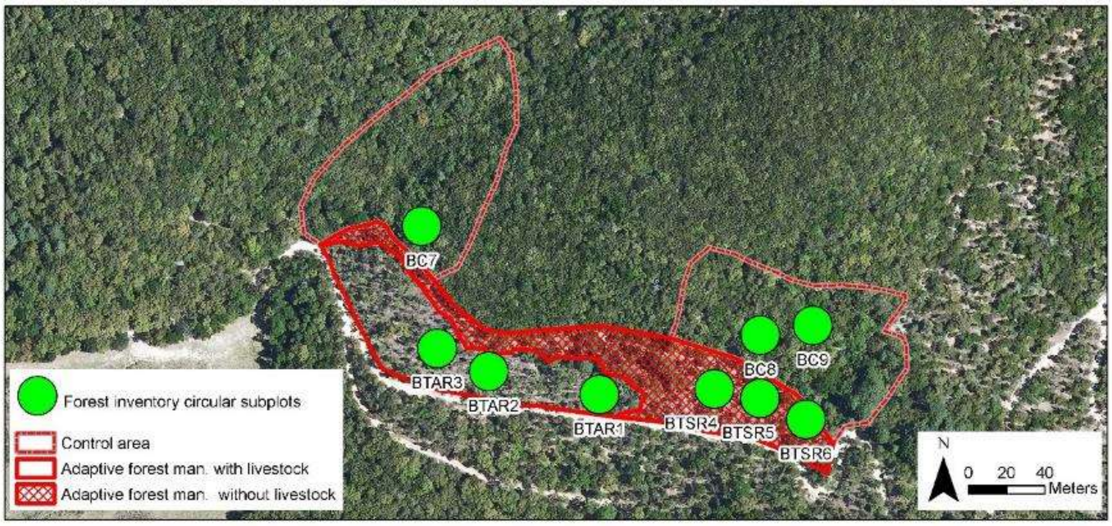


Figure 32. Location of the circular inventory subplots in Catalonia.

The initial forest inventory was carried out in May 2020, with the objective to set the initial conditions of the forest stand. The following inventories were performed between May and November of 2021, 2022 and 2023. In 2023, the final forest inventory was carried out to compare with the initial conditions. The results of the four years of monitoring 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 has been evaluated again at the end of the project, to compare the initial conditions with the final ones. The inventories have been developed in November 2023 and data is currently in analysis. The results will be shown in Deliverable 31 (Report with the final monitoring results of the implementation action C2) due to in March 2024.

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. Annual inventories were performed in October-November 2021, 2022, and 2023.

Table 16 shows the forest fuel continuity model and the crown fire hazard after the implementation of the forest management and after the three 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.

Forest inventory subplot	After implementation 2020		Annual campaign 2021		Annual campaign 2022		Annual campaign 2023	
	Forest fuel continuity model	Crown fire hazard	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	B9	Moderate
BC8	B9	Moderate	B9	Moderate	B9	Moderate	B9	Moderate
BC9	B9	Moderate	B9	Moderate	B9	Moderate	B9	Moderate
BTAR1	B16	Moderate	C16	Low	C16	Low	C16	Low
BTAR2	B16	Moderate	C16	Low	C16	Low	C16	Low
BTAR3	B16	Moderate	C16	Low	C16	Low	C16	Low
BTSR4	B16	Moderate	B16	Moderate	B16	Moderate	B16	Moderate
BTSR5	B16	Moderate	B16	Moderate	B16	Moderate	B16	Moderate
BTSR6	B16	Moderate	B16	Moderate	B16	Moderate	B16	Moderate

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

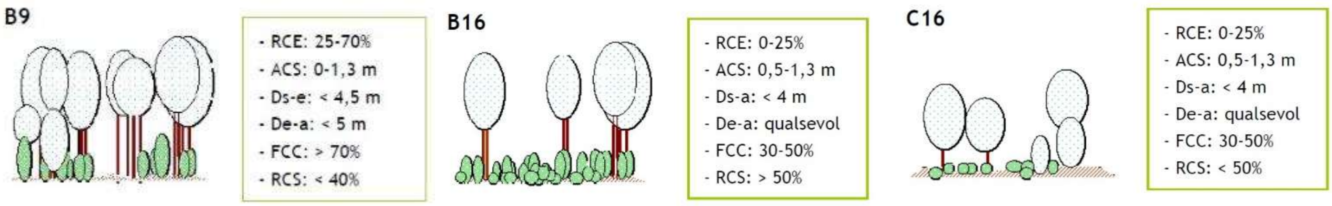


Figure 33. Description of the structure type B9, B16 and C13 with moderate and low crown fire hazard following Piqué et al. 2011.

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. Annual inventories were performed in October-November 2021, 2022, and 2023.

Table 17 shows the forest decay after the implementation of the forest management and after the three 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 15.9% (2021), 15.5% (2022) and 19.6% (2023). However, we observe a significant difference between control and management without livestock treatment plots, with higher decay in control plots (Figure 34). Figure 35 shows that the application of forest management together with livestock management can 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			Annual campaign 2023		
	TD	LD	MFD	TD	LD	MFD	TD	LD	MFD	TD	LD	MFD
BC7	13.0	1.0	**14.0**	6	15.5	**21.5**	0.0	20.0	**20.0**	1.0	18.5	**19.5**
BC8	12.5	2.0	**14.5**	6	16.5	**22.5**	0.5	20.0	**20.5**	7.5	25.5	**33.0**
BC9	10.0	0.5	**10.5**	5.5	14.5	**20**	0.5	17.5	**18.0**	5.0	18.0	**23.0**
BTAR1	0.5	4.0	**4.5**	3	7.5	**10.5**	1.5	8.5	**10.0**	4.5	11.5	**16.0**
BTAR2	0.5	4.7	**5.2**	1.9	5.5	**7.4**	1.5	11.0	**12.5**	4.0	10.0	**14.0**
BTAR3	8.5	14.5	**23.0**	1.7	6.5	**8.2**	0.5	7.0	**7.5**	1.0	7.0	**8.0**
BTSR4	10.5	1.5	**12.0**	4	13	**17**	3.0	12.0	**15.0**	8.0	17.0	**25.0**
BTSR5	8.0	1.5	**9.5**	4	8.5	**12.5**	1.5	11.5	**13.0**	4.5	11.5	**16.0**
BTSR6	18.5	1.0	**19.5**	4	19.5	**23.5**	2.0	21.0	**23.0**	3.5	18.5	**22.0**

Table 17. Forest decay per forest inventory subplots measured in May 2020, November 2021, October 2022 and November 2023. TD: Tree defoliation (%), LD: Leaf discoloration (%), MFD: Mean forest decay (%).

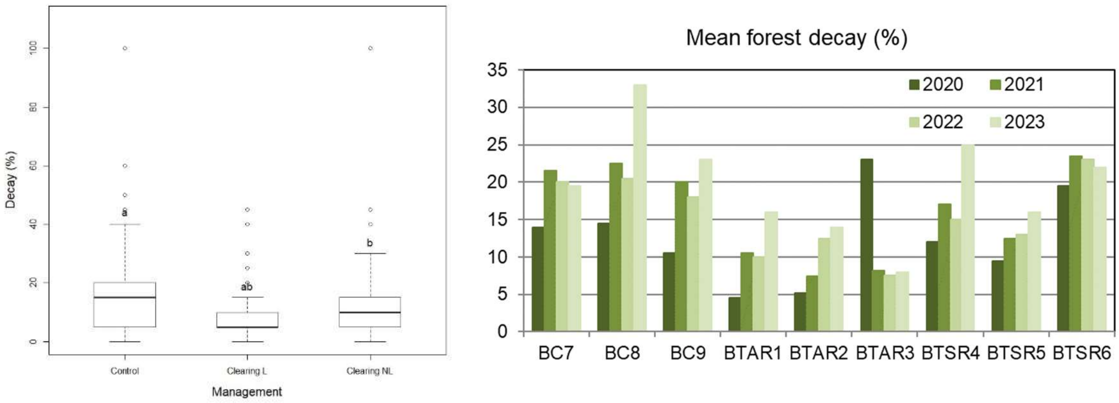


Figure 34. Left: Treatment effect on forest decay (%) in 2020-21-22-23. Right: Differences in forest decay (%) between 2020, 2021, 2022 and 2023 among forest inventory subplots.

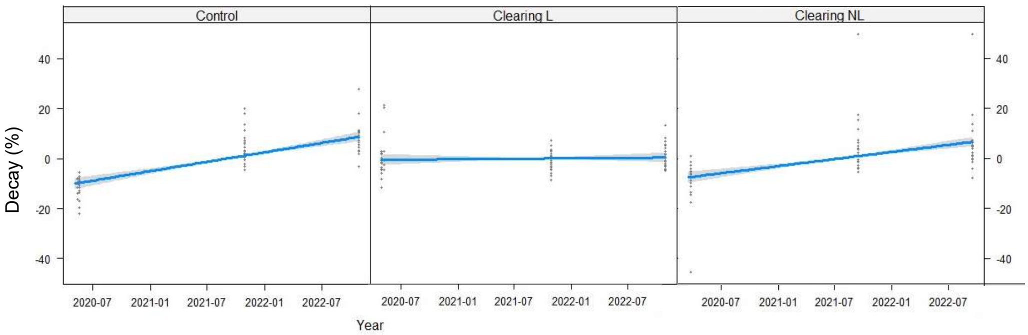


Figure 35. Treatment effect on Holm oak decay in Requesens, from 2020 to 2023.

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 36 shows the effect of the adaptive forest management on vegetation water content in the four years of monitoring (2020-2021-2022-2023). 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 2023 show the expected trend.

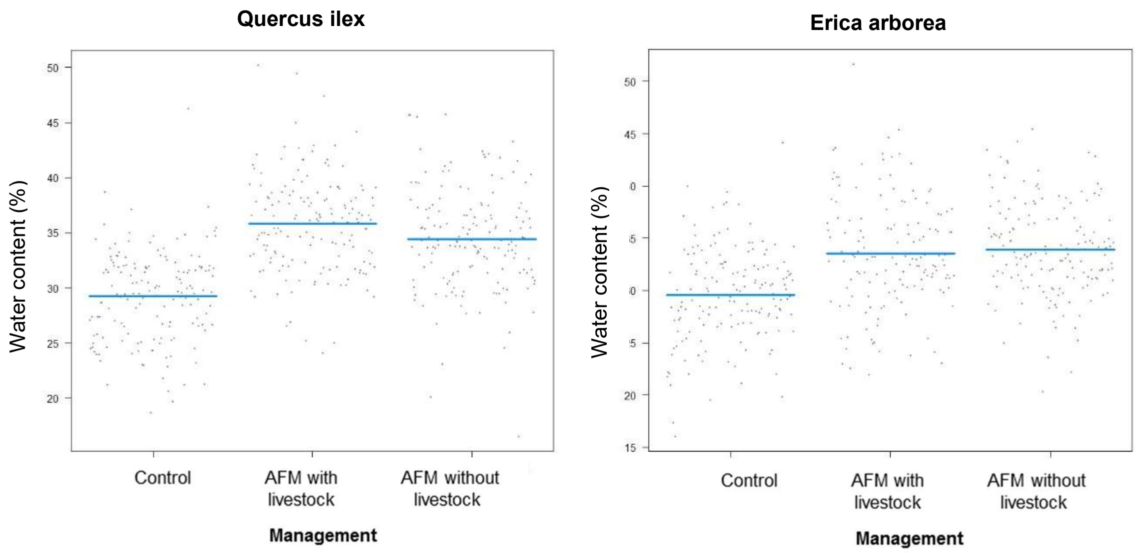


Figure 36. Treatment effect on vegetation water content in Requesens.

5.3. Monitoring results of the Pastures

The objective is to assess the effect of forest management and cow grazing on pasture service in terms of biodiversity, biomass production and nutritive quality. We hypothesize that forest management interacting with cow grazing will help maintain biodiversity, productivity, and nutritive value of herbaceous pastures. While species rich pastures will contribute to their natural value and global biodiversity, the maintenance of their productivity and nutritive quality will enable to support extensive livestock activities in these areas, thus enhancing socio-economic development. Moreover, forest management and subsequent grazing by cow will also restrain scrub encroachment, therefore diminishing the fire risk in these areas.

5.3.1. Biodiversity

Vegetation surveys were arranged within four subplots (1 m^2) at each of the three replicate plots per treatment: control area not managed without livestock and seeds, not managed without livestock and without seeds, managed without livestock and without seeds, managed with livestock and seeds. Vegetation sampling was carried out once a year (between late spring and early summer) for three years to observe the evolution of the vegetation in the plots from the initial to the final stage (also evaluating the intermediate stage). The first sampling was done in May 2020 to record the initial stage of the pasture in the experimental plots prior to any livestock entry. Intermediate stage of the vegetation in the experimental plots was recorded in May 2022 (after having entered cows two years in a row). Final stage of the pasture was recorded May 2023 (after having entered cows three years in a row).

To assess the effects of forest management and cow grazing on pasture biodiversity, the data evaluated were the cover and richness of herbaceous and woody species separately. We also assessed the effect of those factors on the bare soil cover. Regarding the forest management factor, we expected to find a positive effect of woody plant removal in the herbaceous pasture cover and richness in the first sampling because of the elimination of woody competitors for light, space, nutrients, and water. We expected this effect to be maintained over the years. On the other hand, regarding the cow grazing we expected not to find any effect of livestock in the first year since vegetation surveys were set prior to cow entry in the plots. But we expected to find a positive effect of cow grazing by promoting the herbaceous species (both in cover and richness) and controlling the woody species along the subsequent years (2022 and 2023).

Forest management effects on the bare ground, herbaceous and woody cover, and species richness.

Forest management significantly decreased the bare ground cover from the initial monitoring and along the whole experiment (Figure 37). This treatment also significantly increased the cover of herbaceous and woody species in all the monitoring stages (except for herbaceous species in the intermediate monitoring, which was not different from the non-managed treatment). Finally, forest management significantly increased the herbaceous species richness in the initial and final monitoring stages and woody species richness in the intermediate and final monitoring stages (Figure 38).

Combined effects of grazing and seeding in previously managed plots on the bare ground, herbaceous and woody cover, and species richness.

The grazing treatment increased the bare ground cover in the intermediate and final monitoring, despite these plots had been seeded (Figure 37). Woody species cover was significantly lower in the grazed&seeded treatment than in the non-grazed&non-seeded treatment along the whole experiment. Unexpectedly, this effect was also evident in the plots intended for grazing prior to the entry of the cattle (initial monitoring). Herbaceous and woody richness species were not affected by the grazing&seeding treatment except in the final monitoring stage, where herbaceous richness was significantly lower in the grazed-seeded treatment (Figure 38).

Seeding effects in non-managed and managed forest plots on the bare ground cover

In the non-managed forest plots, bare ground cover was significantly lower in the seeded than in the non-seeded treatment all along the monitoring stages (Figure 37).

In the managed plots prior to the entry of the cattle (initial monitoring stage), bare ground cover was significantly lower in the seeded treatments than in the non-seeded plots (Figure 37).

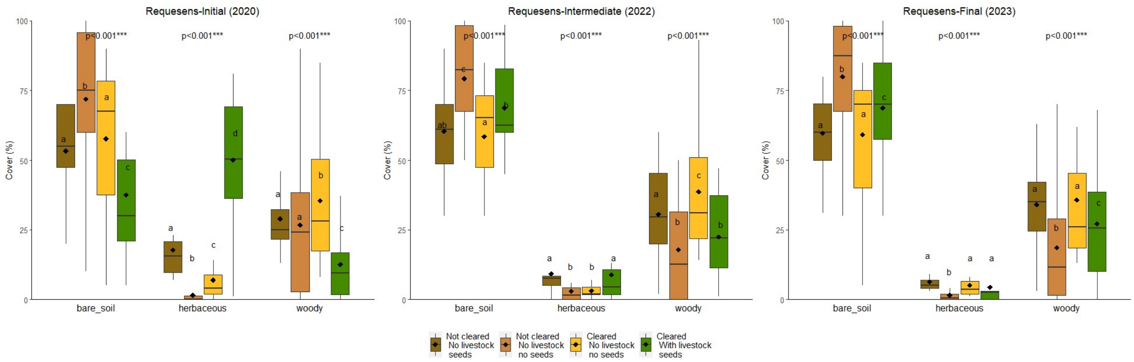


Figure 37. Boxplots showing mean cover and data variability of the bare soil, herbaceous species, and woody species separately in each treatment (not managed without livestock and seeds, not managed without livestock and without seeds, managed without livestock and without seeds, managed with livestock and seeds). Initial, intermediate, and final stages of the experimental plots are shown.

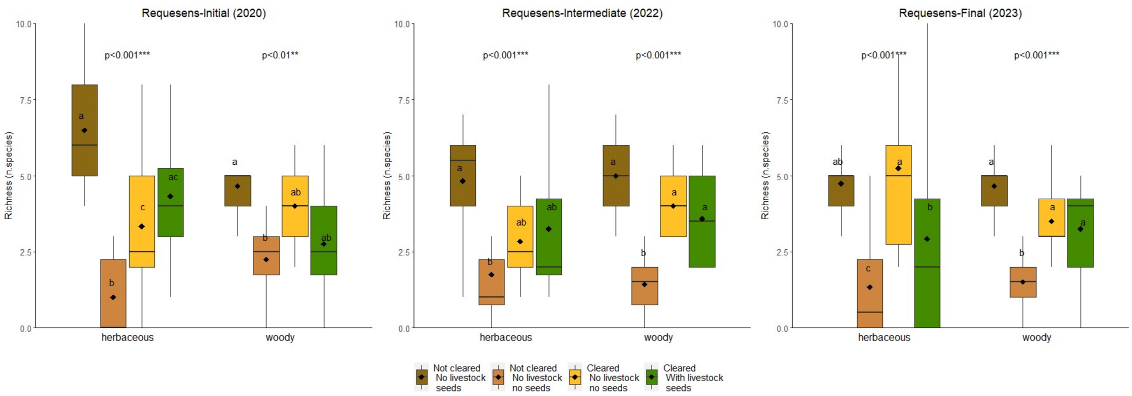


Figure 38. Boxplots showing mean species richness for herbaceous species and woody species separately in each treatment (not managed *without livestock and seeds, not* managed *without livestock and without seeds,* managed *without livestock and without seeds,* managed *with livestock and seeds). Initial, intermediate, and final stages of the experimental plots are shown.*

5.3.2. Pasture production and quality

To assess pasture production and nutritive quality we harvested the plants growing within four subplots (0.25 m^2) at each of the three replicate plots per treatment: control area not managed without livestock, managed area without livestock and managed area with livestock. Samples were collected between late spring and early summer (matching the vegetation growth peak) at the initial and final stage of the experiment. The first sampling was done in May 2020 to record the initial stage of the pasture in the experimental plots prior to any livestock entry and second sampling was done in May 2023 to record the final stage of the pasture after having entered cows three years in a row. We considered that recording the intermediate stage of the pastures in terms of production and quality was not relevant because it is a short period of time to achieve significant results.

To assess the effects of forest management and cow grazing on pasture production, we considered dry biomass (kg/ha) of the gathered herbaceous plants. The nutritive quality of pastures was evaluated in terms of the content of digestible fibers (Relative Feed Value) and crude protein (estimated in laboratory from the dry matter derived from the collected herbaceous samples).

Regarding the forest management factor, we expected to find a positive effect of woody plant removal in the herbaceous plants' biomass and quality because of the elimination of woody competitors for light, space, nutrients, and water. We expected to find this effect both in the first and final samplings. On the other hand, regarding the cow grazing, we expected not to find any effect of the livestock in the first year since samples were collected prior to cows' entry in the plots. But we expected to find a positive effect of cow grazing by promoting the growth and nutritive quality of herbaceous species in the final stage.

Forest management effects on herbaceous biomass.

Forest management increased significantly the herbaceous biomass in the initial monitoring. This effect maintained in the final monitoring (Figure 39).

Combined effects of grazing Grazing&seeding in previously managed plots: on the herbaceous biomass

Prior to the entry of the cattle (initial monitoring), herbaceous biomass was higher in the seeded plots, which were intended for grazing along the experiment. The effect was the opposite in the final monitoring, i.e., herbaceous biomass was lower in the grazing&seeded treatment than in the non-grazed&non-seeded treatment (Figure 39).

Seeding effects in non-managed and managed forest plots on herbaceous biomass.

In the non-managed forest plots, herbaceous biomass was significantly higher in the seeded than in the non-seeded treatments, either in the initial and the final monitoring (Figure 39). In the managed plots prior to the entry of the cattle (initial monitoring stage), herbaceous biomass was significantly higher in the seeded treatments than in the non-seeded plots (Figure 39).

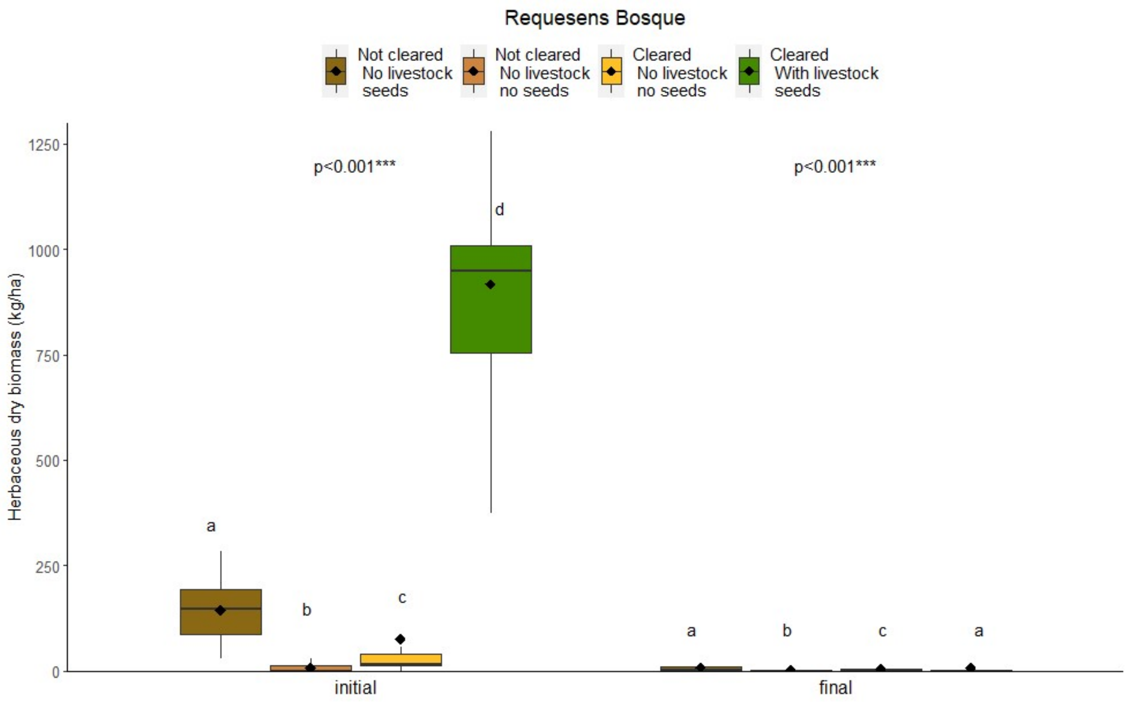


Figure 39. Boxplots showing mean herbaceous dry biomass in each treatment (not managed without livestock and seeds, not managed without livestock and without seeds, managed without livestock and without seeds, managed with livestock and seeds). Initial and final stages of the experimental plots are shown.

The nutritional quality of the grass harvested this May 2023 is in the process of laboratory analysis, having available only the data of the initial stage, so these data are not shown.

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 whole monitoring period (2020, 2021, 2022, 2023). The experiments were always carried out in autumn.

The hydro-sedimentological response was higher in the control plots due to two experiments that produced very high runoff (RC > 0.50), otherwise the response was low. In the *Quercus ilex* forest, the hydrological response was slightly higher in the managed plots with livestock than in those without livestock (trend already observed in La Garcipollera). However, the sediment production was lower in the grazed plot, probably because of the denser herbaceous cover. Accordingly, the infiltrated water was lower in the managed and grazed plot than in the plot without livestock.

Site	Land management	Slope (%)	RI (mm h^{-1})	INF (mm h^{-1})	RC (-)	SC (g L^{-1})	SP (g m^{-2})
Quercus ilex	Control	18	54.0	29.6	0.14	1.36	4.32
	AFM with livestock (BTAR)	15	48.4	25.9	0.10	1.59	0.83
	AFM without livestock (BTRS)	15	53.8	32.1	0.08	0.44	1.15

Table 18. Mean hydrogeological and sedimentological variables extracted from rainfall simulations in Requesens (2020, 2021, 2022, 2023). RI: rainfall intensity (mm h^{-1}), INF: infiltration rate (mm h^{-1}), RC: Runoff coefficient (mm mm^{-1}), SC: Sediment concentration (g l^{-1}), SP: Sediment production or erosion rate (g m^{-2}).

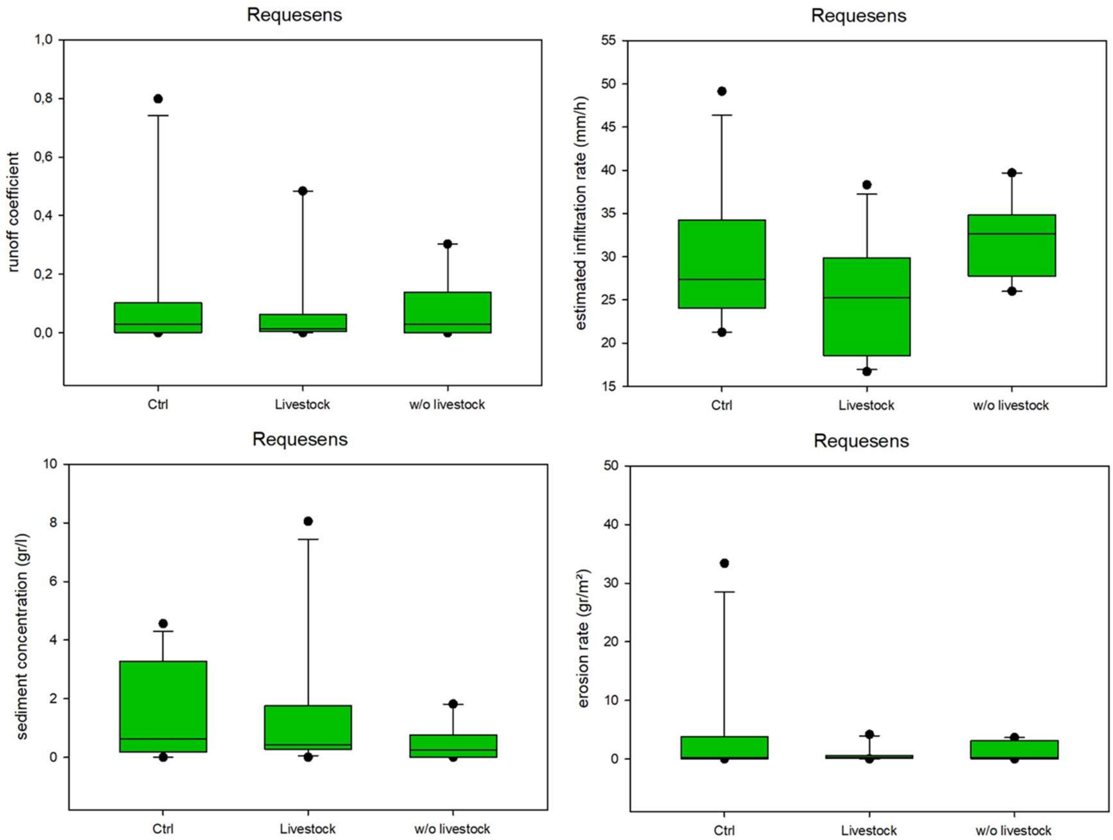


Figure 40. Runoff coefficient (mm mm^{-1}), Infiltration rate (mm h^{-1}), Sediment concentration (g l^{-1}) and erosion rate (g/m^2) in Requesens (2020, 2021, 2022, 2023).

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).

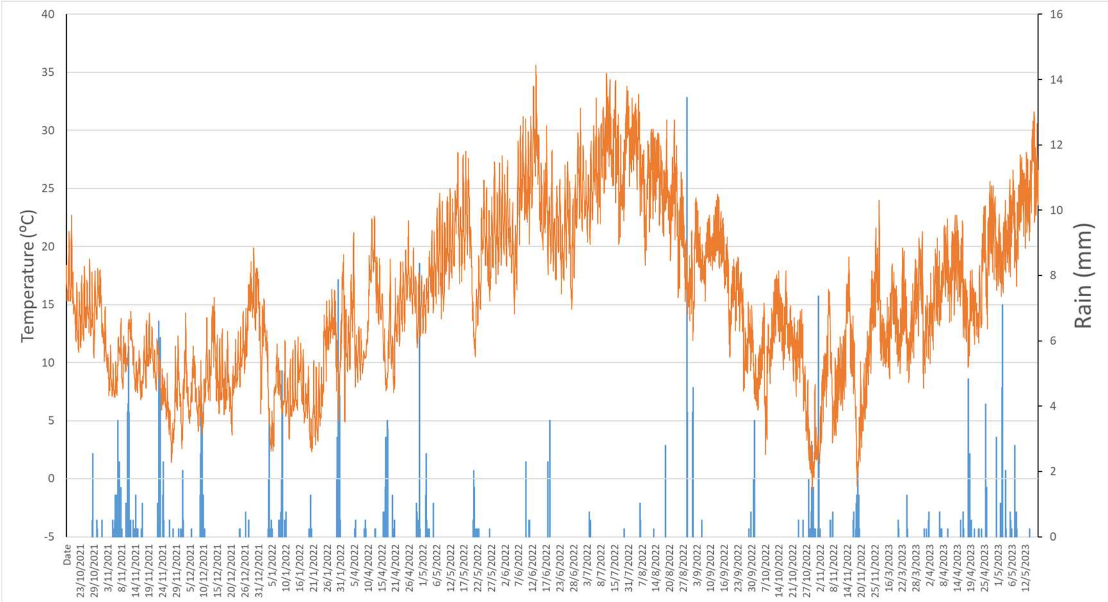


Figure 41. Detailed outputs of the weather station located in Requesens pilot area.

6. Conclusions

The main objective of this deliverable is to present the **results of the third monitoring campaign developed in 2023** 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 and 2nd years of monitoring (2021 and 2022). Statistical results did not show significant differences between the management plots and the control plots.
	Soil moisture	A sensor network was installed in 2020. Soil moisture data shows a good response of the sensors to the recorded rainfall events
Forest	Forest struct.	The final inventories have been developed but data is still not analysed. The results will be shown in the final deliverable.
	Forest fuel continuity	Crown fire hazard has reduced from a moderate-high risk in 2020 and 2021 campaigns to a low risk in 2022 and 2023 in the forest-managed plots with and without livestock, due to the reduction of vertical and horizontal fuel continuity.
	Forest health status	Forest decay showed a slow decrease in forest decay with forest management but not significant yet between treatments and control. This fact can be explained because in the pine forest, forest management affected only the undergrowth without intervention at the tree level. Despite this, a positive effect of livestock in decay reduction is observed comparing managed plots.
	Fuel moisture	Fuel moisture was higher in the treated plots, both with and without livestock, although differences among the plots are only significant between control and management without livestock for both species.
Pastures	Biodiversity	Forest management significantly increased herbaceous species cover and decreased bare ground and woody species cover through the whole experimentation. In plots managed, cattle grazing significantly decreased the woody species cover through the whole 3-year experimentation and increased the bare ground cover and herbaceous species richness from the intermediate monitoring.
	Pasture prod. and quality	Forest management significantly increased the herbaceous biomass along the whole experimentation. Cattle grazing effects on grassland production and nutritional quality are currently under analysis.
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, although the production of runoff and sediments was moderate.
Site meteorological conditions		Maximum, minimum temperature and relative humidity are recorded continuously from June 2020 to November 2023.

***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 and 2nd year of monitoring (autumn 2021 and 2022). Statistical results did not show significant differences between the management plots and the control plots.
	Soil moisture	A sensor network is installed since 2021 with some problems that are being solved. Soil moisture data shows a good response of the sensors to the recorded rainfall events
Forest	Forest struct.	The final inventories have been developed but data is still not analysed. The results will be shown in the final deliverable.
	Forest fuel continuity	Crown fire hazard has maintained low in all managed plots, compared with control plots where the hazard is moderate.
	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 22.0% in 2021 to a 45.7% in 2022 and 40.7% in 2023. The extreme dry summer and year 2022 and 2023 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 significantly increased herbaceous species cover and richness, and decreased bare ground and woody species cover through the whole experimentation. In plots managed, cattle grazing did not decrease the woody species cover nor affected the herbaceous or woody species richness within the 2 years of experimentation.
	Pasture prod. and quality	Forest management significantly increased the herbaceous biomass along the whole experimentation. Cattle grazing effects on grassland production and nutritional quality are currently under analysis.
Rainfall simulations		The managed plot with livestock recorded the highest hydrological response and slightly higher erosion than the managed plot without livestock.
Site meteorological conditions		Maximum, minimum temperature and relative humidity are recorded continuously from May 2021 to November 2023.

***Quercus ilex* forest in Catalonia**		
Soil	Soil characteristics	There is not annual monitoring of this variable. The final soil samplings were carried out in October 2023. Samples are being analysed on the laboratory and the results will be presented in the final deliverable in March 2024
	Soil moisture	A sensor network is installed since 2020. Soil moisture data shows a good response of the sensors to the recorded rainfall events. 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
Forest	Forest struct.	The final inventories have been developed but data is still not analysed. The results will be shown in the final deliverable.
	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, 15.5% in 2022 and 19.6% in 2023.
	Fuel moisture	The evolution of fuel moisture (2020-21-22-23) 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	Forest management significantly increased woody species cover and decreased bare ground cover through the whole experimentation, while increased significantly herbaceous cover in most of the monitoring dates. Moreover, forest management increased the herbaceous and woody species richness in most of the monitoring dates. In plots managed, cattle grazing&seeding significantly decreased the woody species cover through the whole experimentation and increased the bare ground cover from the intermediate monitoring date.
	Pasture prod. and quality	Forest management significantly increased the herbaceous biomass along the whole experimentation. Cattle grazing and forage species seeding effects on grassland production and nutritional quality are currently under analysis
Rainfall simulations		The hydrological response was slightly higher in the managed plots with livestock than in those without livestock. However, the sediment production was lower in the grazed plot, probably because of the denser herbaceous cover.
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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