forests

Article

Small-Scale Effect of Pine Stand Pruning on Snowpack Distribution in the Pyrenees Observed with a Terrestrial Laser Scanner

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Abstract: Forests in snow-dominated areas have substantial effects on the snowpack and its evolution over time. Such interactions have significant consequences for the hydrological response of mountain rivers. Thus, the impact of forest management actions on the snow distribution, and hence the storage of water in the form of snow during winter and spring, is a major concern. The results of this study provide the first detailed comparison of the small-scale effect of forest characteristics on the snowpack distribution, assessed prior to and following major modification of the structure of the canopy by pruning of the lower branches of the trees to 3 m above the ground. This is a common management practice aimed at reducing the spread of forest fires. The snowpack distribution was determined using terrestrial laser scanning (LiDAR technology) at a high spatial resolution (0.25 m) over a 1000 m^2 study area during 23 survey dates over three snow seasons in a small study area in the central Pyrenees. The pruning was conducted during summer following the snow season in the second year of the study (i.e., the study duration encompassed two seasons prior to canopy pruning and one following). Principal component analysis (PCA) was used to identify recurring spatial patterns of snow distribution. The results showed that pruning reduced the average radius of the canopy of trees by 1.2 m, and increased the clearance around the trunks, as all the branches that formerly contacted the ground were removed. However, the impact on the snowpack was moderate. The PCA revealed that the spatial configuration of the snowpack did not change significantly, as the principal components included survey days from different periods of the snow season, and did not discriminate days surveyed prior to and following pruning. Nevertheless, removal of the lower branches reduced the area beneath the canopy by 36%, and led to an average increase in total snow depth of approximately 14%.

Keywords: snow distribution; canopy pruning; terrestrial laser scanner (TLS); Pyrenees

1. Introduction

Snow accumulation in mountain areas has major effects on a wide variety of environmental processes including plant survival and phenology [1] soil temperature and moisture [2], and the hydrological response of mountain areas [3]. Snow accumulation plays a major role in water supply in many areas worldwide [4]. In Mediterranean and semiarid environments, the hydrology is particularly dependent on snow, and therefore understanding factors affecting snow accumulation is required [5].

The Pyrenees provide a clear example of the significance of the snowpack to water reservoir areas downstream, as snow accounts for approximately 40% of the spring runoff [6]. In this mountain range, substantial accumulation of snow that largely persists over time typically occurs 1600 m above sea level (a.s.l.), which is the average 0 °C isotherm elevation between November and April [7]. The tree line in the Pyrenees ranges east-west from 1900 to 2300 m a.s.l. [8]. Consequently, extensive snow-covered areas interact with forest cover, and this has been the basis of various studies investigating snowpack dynamics in Pyrenean forested areas [9–11]. Furthermore, since the middle of the 20th century there has been an increase in forest cover at all elevations in the Pyrenees, as a consequence of decreased human pressure [12,13]; the elevation of the tree line is shifting upwards because of decreasing grazing pressure in conjunction with warmer temperatures [14–16]. Thus, increased knowledge on the interactions between the snowpack and forest is necessary to clarify the recent evolution, and most likely future scenarios, of water availability in the region [5].

Much effort has been made to improve understanding of how the forest canopy affects snow interception, sublimation, and the various energy fluxes involved in metamorphosis and melting of the snowpack [17–21]. The total accumulation of snow in open areas and areas beneath the forest canopy varies among mountain ranges, depending on the characteristics of the forest (tree species and distribution) and the climate [22,23]. Thus, previous studies comparing open and canopy areas in the Pyrenees have reported average differences of 49% [11] and 40% [9,10] (i.e., 40%–49% shallower snowpack under canopy areas). However, these values have been associated with large spatial, seasonal, and interannual variability, depending on the canopy characteristics (canopy type and density) and the dominant meteorological conditions.

Forested areas are typically managed with the aim of preserving their environmental value, while at the same time reducing the risk of fire and the spread of forest pests and diseases [24]. This increases the economic return from forest harvesting, facilitating movement and accessibility within the forest areas [25], and to a lesser extent optimizing the snow storage capacity. Some studies have focused on understanding how a reduction in forest density or the creation of clear-fell areas can enhance snow accumulation and the generation of runoff [26,27]. A common practice in fire risk control is to prune the trees up to a certain height, to reduce the possibility of fire spread [28]. This can significantly change the structure of individual trees, and alters the area beneath the crown because the longest branches are removed. Many studies have analyzed the effects of various changes to forested areas on snow dynamics from insect disturbance [29–31], and fire disturbance [32] to other forest disturbance and management actions [26,33,34]. However, the effect of tree pruning—aimed at fire risk prevention—on snow accumulation and its temporal evolution has not been previously investigated.

The main objective of this study was to undertake the first small-scale investigation of the impact of moderate fire control branch pruning (increasing the distance between the lower branches and the ground by an average of 2.5 m) on snowpack accumulation and melting dynamics. The study period included three snow seasons, during which high spatial resolution information on the snowpack distribution was obtained using a terrestrial laser scanner (TLS) on 23 survey dates. This enabled sub-meter topographies to be developed, including for snow-covered areas and areas under the forest canopy [35–38]. Pruning of the forest stand was conducted following two years of TLS monitoring (2011–2012 and 2012–2013). This process facilitated assessment, at fine spatial detail, of the effect of the pruning changes to forest structure on total snowpack accumulation, and its evolution during the subsequent snow season (2013–2014).

2. Experimental Section

2.1. Study Site and Period

The study was conducted in the Balneario de Panticosa forest in the central Spanish Pyrenees (Figure 1a), and was based on data obtained during three snow seasons (2011–2012, 2012–2013, and 2013–2014). The study site is located at 1700 m a.s.l. (42°45′ N, 0°04′ W), and has an approximate area of 1000 m^2. The flat topography and the small area of the study site enabled assessment of the snow-trees' interaction with only negligible influences of topography and climate variability. The experimental area comprises 17 *Pinus sylvestris* individuals of differing heights (average 9.4 m, maximum 14 m) and crown radius. *P. sylvestris* is the dominant species from 1200 to 1700 m a.s.l., and currently occupies 24% of the forested surface in the central western Pyrenees [39]. The Balneario de Panticosa area provides a good example of the reforestation that took place in the Pyrenees during the 20th century, so the forest stand used in the study comprises relatively young trees. Figure 2 shows images of the area taken 100 years apart, in 1906 and 2006.

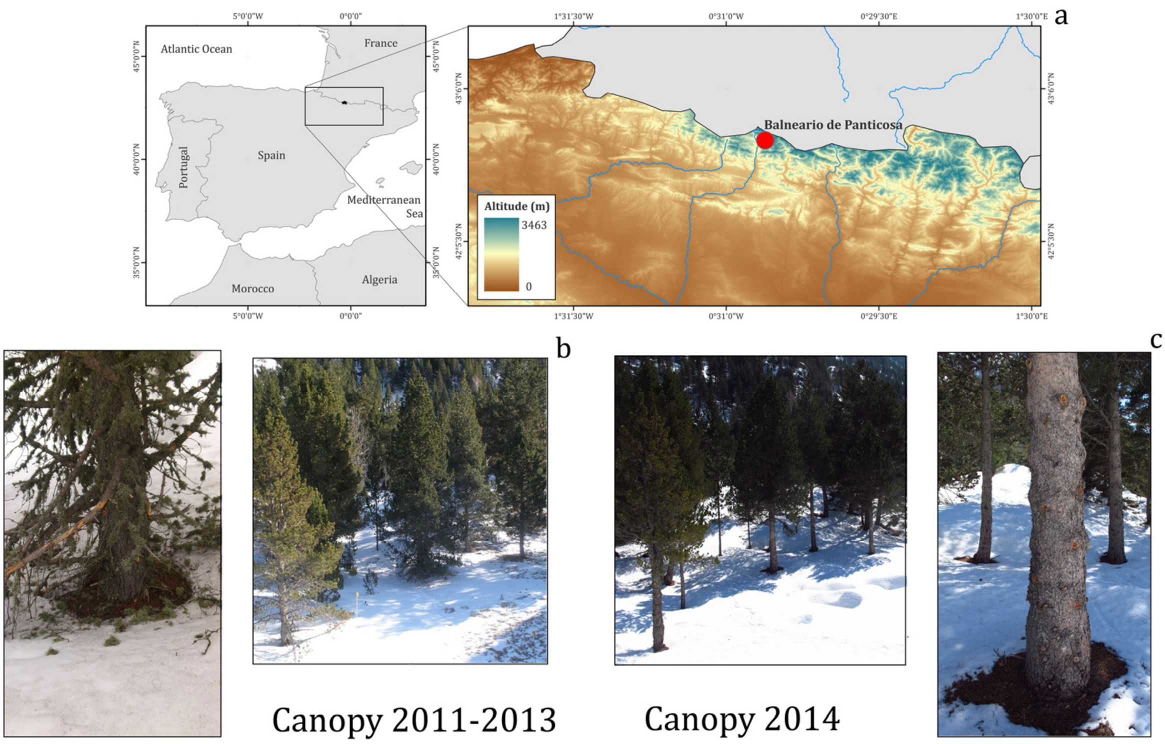

Figure 1. The Balneario de Panticosa study area (**a**) and crown-trunks comparisons prior to (**b**) and following (**c**) branch pruning.

The Pyrenees are characterized by marked interannual variability in terms of snow accumulation, with some years having very low levels of snow accumulation and others having high levels [40]. This climatic characteristic was evident during the first two snow seasons considered in this study. In the 2011–2012 snow season, very shallow snow depths were observed, while in the 2012–2013 season deep snow accumulation occurred (Figure 3). During the 2013–2014 snow season the snow depth at the nearest meteorological station (700 m from the study site) commenced with values between the 25th and 75th percentiles of the historical data, but in the last half of the snow season these values exceeded the 75th percentile.

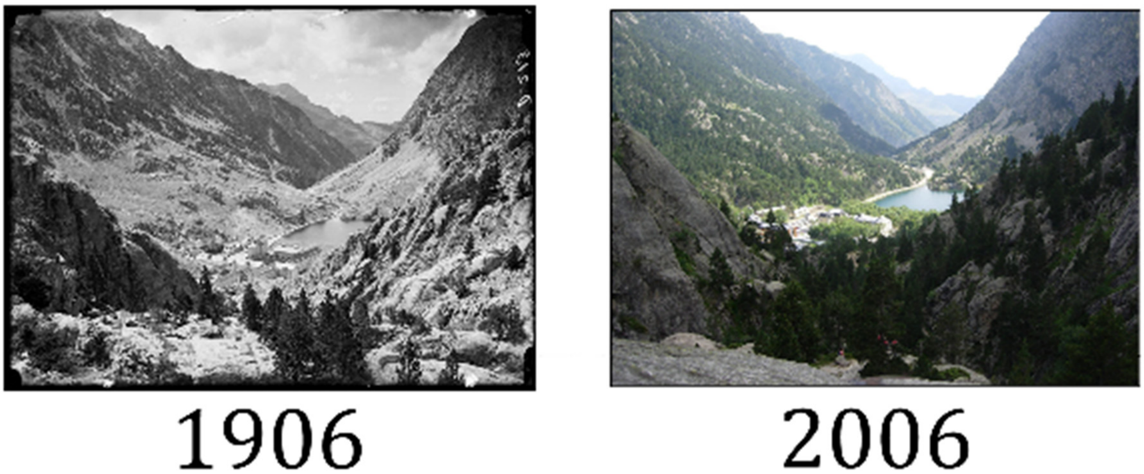

Figure 2. The study area and surroundings in 1906 and 2006, showing the reforestation that has occurred in the Pyrenees.

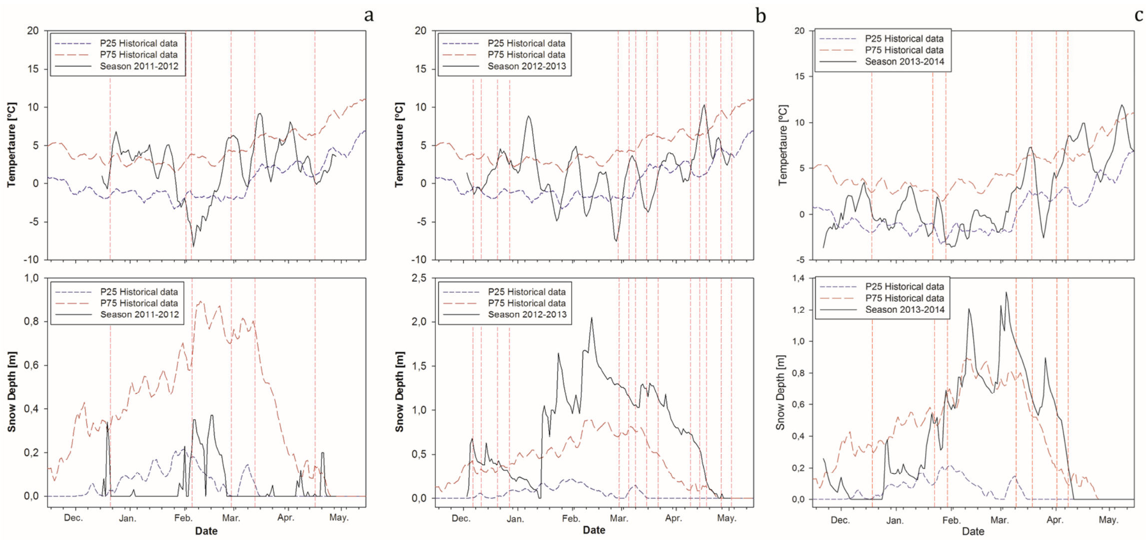

Figure 3. Temperature (up) and snow depth (down) for the 2011–2012 (**a**); 2012–2013 (**b**) and 2013–2014 (**c**) snow seasons. The red vertical dashed lines show the TLS acquisition dates.

2.2. Methods

High spatial resolution information on the distribution of the snowpack on different days was obtained using a TLS (that uses LiDAR technology for measuring distances); these devices have been used extensively for monitoring snow evolution [36,37,41,42] recently reported the use of a TLS (RIEGL LPM-321) for analysis of snowpack dynamics in the same study area as was used in this study. Following the pruning that occurred in summer 2013, the snowpack distribution was assessed on seven additional dates using the same data acquisition protocol [11]; this enabled direct comparison with the data collected under pre-pruning conditions. Based on results presented in this study, we decided to not include data from four TLS surveys collected during the 2011–2012 snow season, as the snow distribution was clearly driven by an anomalous wind redistribution event, and was not comparable to conditions observed during the snow season following pruning. The results were based on data from a total of 23 experimental TLS surveys undertaken in 2011–2012 (2 TLS acquisitions), 2012–2013 (14 TLS acquisitions), and 2013–2014 (7 TLS acquisitions). The products obtained using the method referred to above were 0.25 m $\times$ 0.25 m grid cell maps of the snow depth distribution. For each TLS survey date, more than 11,000 grid cells having the observed snow depth were obtained. Examples of the snow depth maps based on the TLS data are shown in Figure 4 (all snow depths maps are provided in the supplementary material of the article).

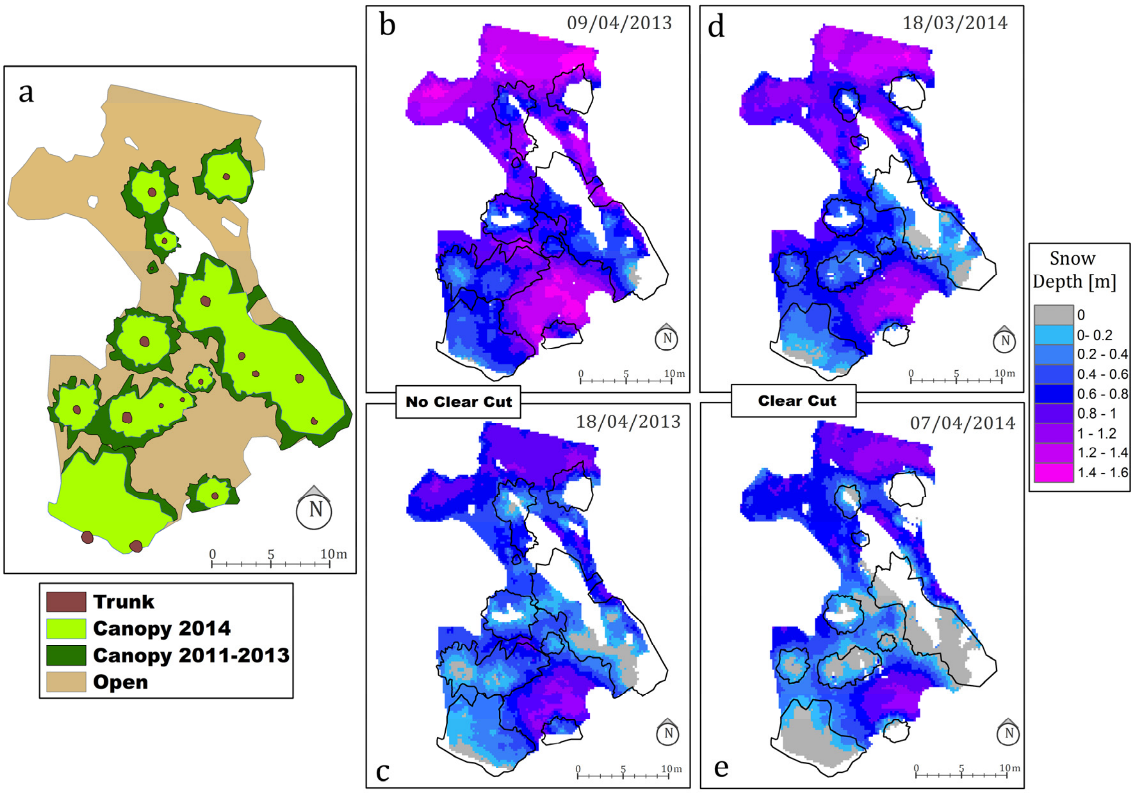

Figure 4. Canopy mask comparisons (**a**) prior to (2011–2013) and following (2014) tree branch pruning. The (**b**,**c**) and (**d**,**e**) maps show examples of four snow depth distribution maps obtained during the study period. The central maps were obtained prior to pruning and the right maps following pruning. Each map shows the canopy limit on each acquisition date.

Discrimination between canopy and open areas, and the change in branch height with pruning, was determined using TLS data of the canopies prior to and following pruning, under snow-free conditions. The change in canopy structure caused by pruning is shown in the bottom panels of Figure 1. The lower branches of the trees within the study area were removed, resulting in a reduction in the average crown radius from 3.1 m (2011–2012 and 2012–2013) to 1.9 m (2013–2014). This difference in radius produced a 36% reduction in the total canopy area at the study site. Pruning of the lower branches also resulted in an increase in the distance from the crown base to the ground, from 0.67 m (2011–2012 and 2012–2013) to 2.97 m (2013–2014).

The difference between both canopy configurations (difference between canopy presence masks) is shown in Figure 4. In the following analysis, snow depths were classified as Canopy or Open, considering the canopy mask corresponding to each acquisition date. A transition zone between Open and Canopy areas of 0.25 m was established and data within this transition was discarded.

The snow depth distribution maps derived for each TLS survey date were classified using a T-mode principal component analysis (PCA) [43–45] in which the grid cells were the cases, and the snow depths measured during each survey were the variables (analysis performed with IBM SPSS Statistics 21, Armonk, New York, NY, USA). This facilitated identification of the groups of days having contrasting snow depth distribution configurations. The number of components selected in the PCA was based on the percentage of explained variance [46]; components having an explained variance exceeding 10% were retained for further analysis. Varimax rotation [47,48] was applied to distinguish components having physically consistent patterns. The PCA analysis was applied to the dataset of

11,000 grid cells of snow depth distribution data for each of the 23 TLS survey days. With this analysis, the survey dates were classified in the different components considering the highest correlation with the components.

In addition to the PCA analysis, for each survey day the average snow depth in the Open and Canopy areas was computed, and the difference in average snow depth between these two areas was also determined. The average snow depth values for grid cells representing different distances from the trunk (from 0.25 to 5.75 m, at intervals of 0.25 m) were also calculated for the various survey dates.

3. Results

The PCA analysis discriminated three components that grouped the 23 survey dates and explained 87.5% of the total variance. Component 1 (C1) explained 39.5% of the variance, component 2 (C2) explained 34%, and component 3 (C3) explained 13%. Table 1 shows the survey dates classified into each of the three PCA components, the average snow depths for the Open and Canopy areas, and the difference between them. Dates classified in C1 had deep snow, with accumulations in Open areas exceeding 0.8 m for almost all dates, and an average snow accumulation of 1.5 m. Thus, C1 represented the expected snow depth distribution for days having the greatest snow depths during the study period. Dates classified in C2 had Open area snow depth values < 0.5 m. Thus, survey days included in C2 represented those characterized by shallow snow depths. Dates classified in C3 were those at the end of the snow season, when the snowpack was subject to long melt periods. For further discussion of the observed distributions, see [11].

Although the 2013 summer pruning caused major crown disturbance, there was no associated significant change in the snow distribution pattern. This was evident because surveys carried out in 2013–2014 were classified in principal components that included the snow depth distributions observed prior to pruning.

Table 1. Survey dates classified into the three principal component analysis (PCA) components. For each date the mean values for the Open and Canopy areas, and the difference between them, are provided. Survey dates and data following pruning are shown in italics.

PCA Component	Exp. Campaign Date	Snow Season	Open Average SD (m)	Canopy Average SD (m)	Difference Open-Canopy (%)
C1	27 February 2013	2012/13	1.53	1.11	28
	4 March 2013	2012/13	1.45	1.04	28
	8 March 2013	2012/13	1.29	0.90	30
	15 March 2013	2012/13	1.53	1.04	32
	21 March 2013	2012/13	1.45	0.98	33
	9 April 2013	2012/13	1.14	0.67	41
	14 April 2013	2012/13	0.96	0.51	46
	18 April 2013	2012/13	0.73	0.29	60
	22 January 2014	*2013/14*	*0.70*	*0.32*	*54*
	31 January 14	*2013/14*	*0.78*	*0.39*	*50*
	11 March 14	*2013/14*	*1.18*	*0.74*	*36*
	18 March 14	*2013/14*	*0.91*	*0.51*	*44*
	1 April 14	*2013/14*	*0.84*	*0.39*	*54*
C2	20 December 2011	2011/12	0.16	0.08	52
	2 December 2012	2011/12	0.15	0.05	69
	6 December 2012	2011/12	0.49	0.32	36
	11 December 2012	2011/12	0.30	0.19	37
	20 December 2012	2011/12	0.30	0.15	51
	27 December 2012	2011/12	0.22	0.07	70
	18 December 2013	*2013/14*	*0.16*	*0.08*	*53*
C3	26 April 2013	2012/13	0.41	0.10	76
	2 May 2013	2012/13	0.30	0.06	80
	7 April 14	*2013/14*	*0.64*	*0.17*	*74*

The first TLS acquisition in the 2013–2014 snow season (18 December) was included in C2; it showed an average snow depth of 0.16 m, with a 53% reduction observed in Canopy areas. The average Open-Canopy difference observed for the other TLS dates in this component was 52%. Thus, the snow depth distribution observed for 18 December 2013, and the average Open-Canopy difference, were both similar to that observed prior to canopy disturbance. Therefore, the distribution of shallow snow depths (0.15–0.49 m) observed during the early part of the snow season did not show significant differences, despite the pruning procedure.

Similarly, for C1 dates the Open-Canopy differences following pruning (average 47% for the 2013–2014 surveys) were similar to those observed for TLS surveys conducted prior to pruning (43% in 2012–2013), with snow depth values in Open areas ranging from 0.7 to 1.2 m and 0.7 to 1.5 m, respectively. Thus, the days classified in C1 showed similar average snow depths and differences between Open and Canopy areas prior to and following canopy pruning.

The medians of the Open-Canopy differences are: 41% for C1, 52% for C2, and 76% for C3. The different medians obtained at pre-pruning and post-pruning surveys are: C1 pre-pruning surveys 36%, C1 post-pruning surveys 50%, and C2 pre-pruning surveys 52%. Rather similar medians are found for C1 post-pruning and C2 surveys of pre-pruning conditions, which may come from the height increase of the lower branches after the pruning. This creates a distance increase between the snow surface and the lower branches that could produce a different snowpack evolution. It is worth noting that the Open average snow depths are smaller than those observed for C1 pre-pruning surveys, and this creates greater Open-Canopy differences. However, it is difficult to quantify the effect of the distance increase between the snow surface and the lower branches with the available data.

The three survey dates included in C3 (two in 2012–2013 and one in 2013–2014) also showed comparable snow depth values in Open areas, with differences beneath the canopy ranging from 74% to 80%. Thus, the TLS surveys included in C3, which were undertaken following periods dominated by melting (see the temperature increase in Figure 3), also showed similar differences in Open and Canopy areas with both canopy distributions (prior to and following pruning). The 2012–2013 differences were 76% and 80%, with 0.41 m and 0.30 m average snow depths (in Open areas), respectively. Similarly, for the 2013–2014 survey included in C3 (7 April 2014) there was a 74% Open-Canopy difference, with an average accumulation of 0.64 m in Open areas.

Figure 5 shows the percentage differences between Open and Canopy areas as a function of the Open area average snow depth observed for the various survey dates. This figure includes linear trends lines obtained in the TLS surveys prior to pruning and after the pruning. One of these trend lines was obtained for dates involving shallow snow accumulation (C2 survey dates), while the other linear trend lines were obtained for days having deep snow accumulation (C1 survey dates and C3 dates at the end of melting period; note that the latter represented an evolution from C1 survey days associated with the melting period) with pre/post pruning data. For the trend line obtained for the 2013–2014 snow season (following canopy pruning), it was evident that despite the increase in the slope of the trend line (from $m_{C1\text{–}3pre} = -43\ \text{m}^{-1}$ in the pre-pruning trend line to $m_{C1\text{–}3post} = -57\ \text{m}^{-1}$ in the post-pruning), the C1/C3 trend lines are more similar to each other than the C2 trend line ($m_{C2} = -88\ \text{m}^{-1}$). In view of the small number of data points and the complexity and heterogeneity of the study area, the difference between both C1/C3 trend lines (before (continuous line in Figure 5) and after pruning (dotted line in Figure 5) is relatively negligible, indicating that both sets of days represent a not dissimilar temporal evolution of the Open-Canopy difference. This shows that despite differences, the temporal evolution of the snow depth distribution was controlled more by total snow accumulation than by differences in canopy structure.

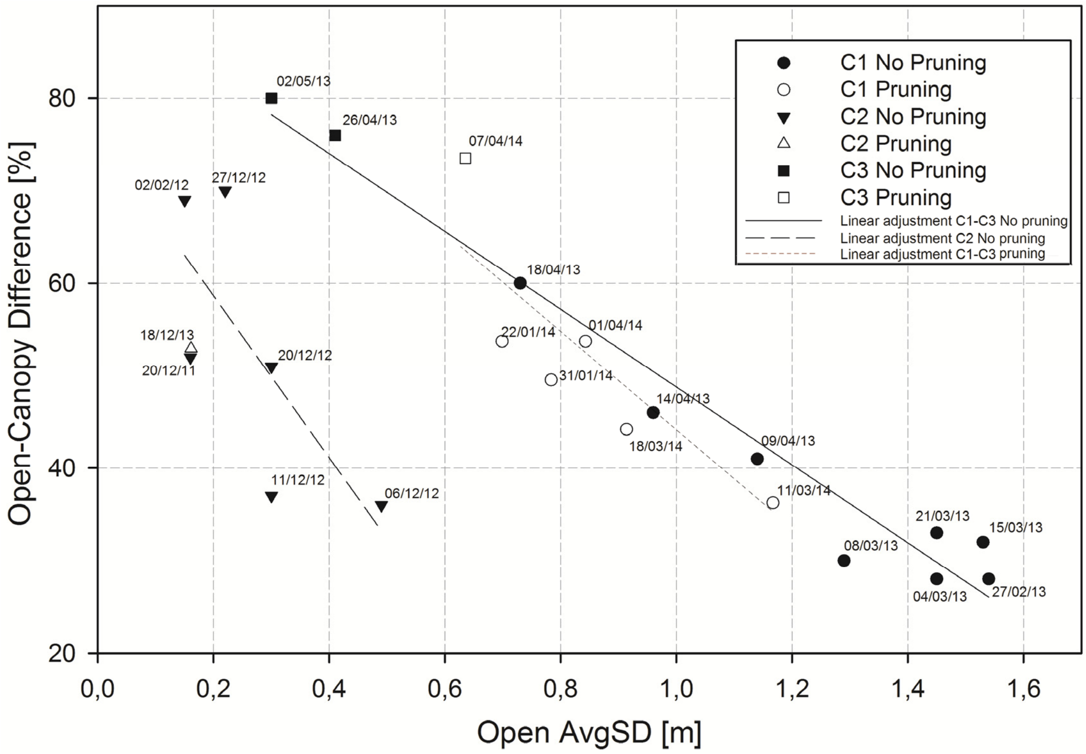

Figure 5. Open-Canopy differences plotted as a function of the average snow depth for the survey dates associated with each PCA component. The continuous black line shows the linear trend obtained for the C1–C3 survey dates (prior to pruning), the dashed black line shows the linear trend for the C2 survey dates prior to pruning and the dotted line shows the linear trend of C1/C3 surveys after pruning.

Figure 6 shows the sum of the observed snow depth values (sum of all grid cell values within the study area) and the average snow depth in Open areas for all survey dates. This analysis enabled assessment of the overall impact of pruning on snow accumulation at the stand scale. The figure presents two series and two trend lines, one obtained based on observations prior to canopy pruning, and the other following pruning. Despite the limited number of observations, there was an evident increase in snow accumulation at the stand scale following pruning, with an average increase of approximately 14%, based on the values obtained from each linear trend. For example, based on the linear trends, when the average snow depth in Open areas was 0.7 m, the total accumulation in the forest stand was 489 m under pre-pruning conditions, and 560 m following pruning (13.7% difference). When the snow depth in Open areas increased to 1.5 m, the total accumulation in the stand was 1107 m under pre-pruning conditions, and 1245 m following pruning (12.8% difference).

Figure 7 shows the average snow depth values determined at various distances from the tree trunks. For easier interpretation and visualization, the upper plot in Figure 7 shows data from C1 surveys (in these, the Open-Canopy transition is easily observed) prior to pruning, and the bottom plot from C1 surveys following pruning. Prior to pruning (upper plot) the TLS surveys show a progressive increase in the snow depth with distance from the tree trunk, to a distance of 4–4.3 m; this marks the accumulation area associated with the canopy branches. Beyond this point the snow depth decreased to a constant depth at greater distances. Following canopy pruning (lower plot) the snow depth increased to only 2.3–2.6 m from trunk, beyond which there was a decrease in snow depth to a constant depth at greater distances. Thus, the graphs show that there were shallower snow depths close to the trunks, associated with faster melting of snow in these areas. Additionally, for both canopy structures (prior to and following pruning) the snow depth for distances under that of peak accumulation show a constant, and in almost all surveys there was a linear increase from shallow depths close to the trunk to the maximum snow depth. Following pruning, the peak snow depth was approximately 1.5 m closer to the tree trunks than before pruning.

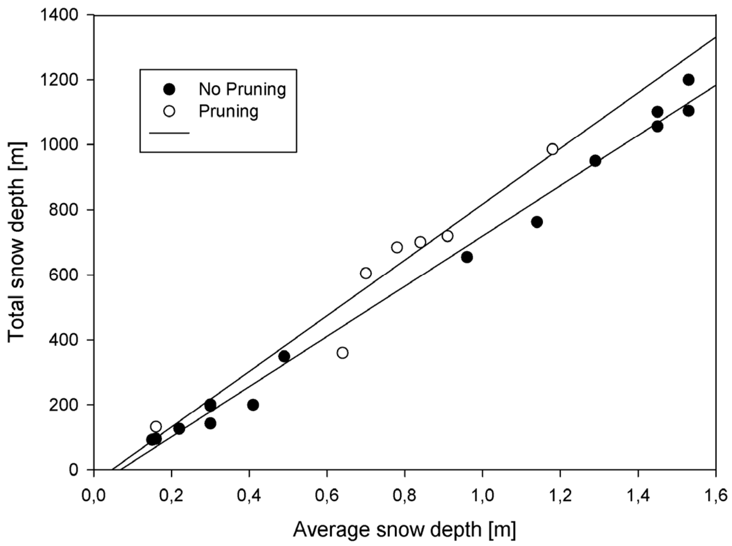

Figure 6. Total snow depth within the study area for the various survey dates, plotted as a function of the average snow depth in Open areas. The data obtained prior to and following canopy pruning are plotted as two data series and two linear adjustments.

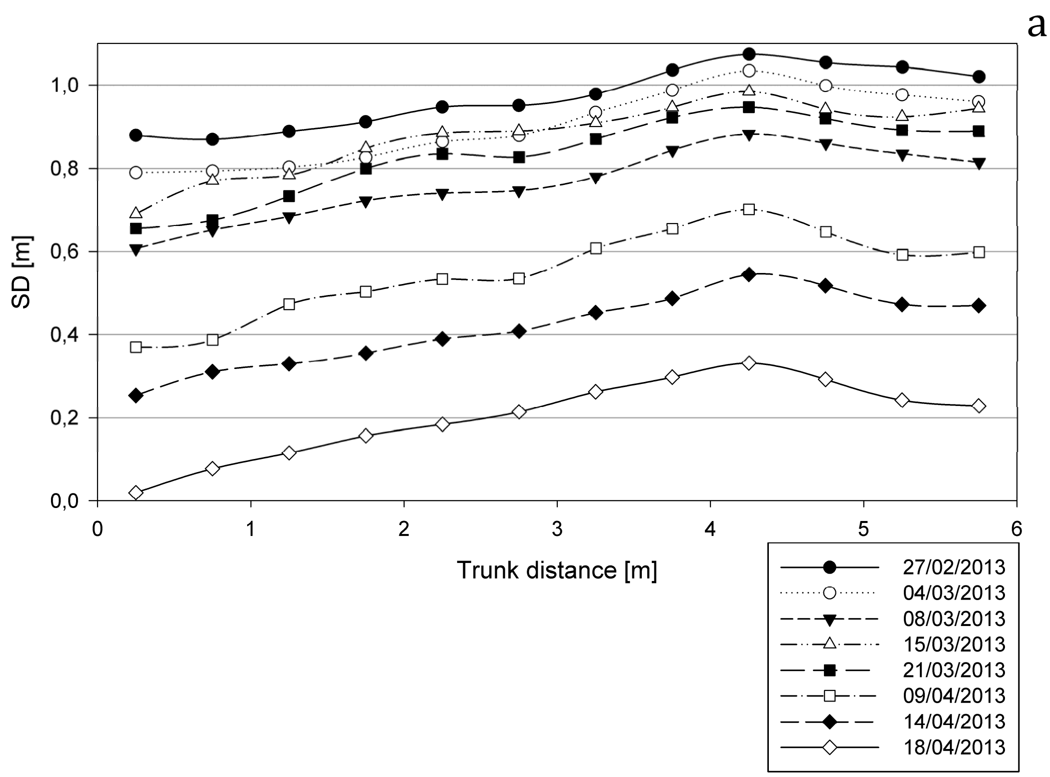

Figure 7. *Cont.*

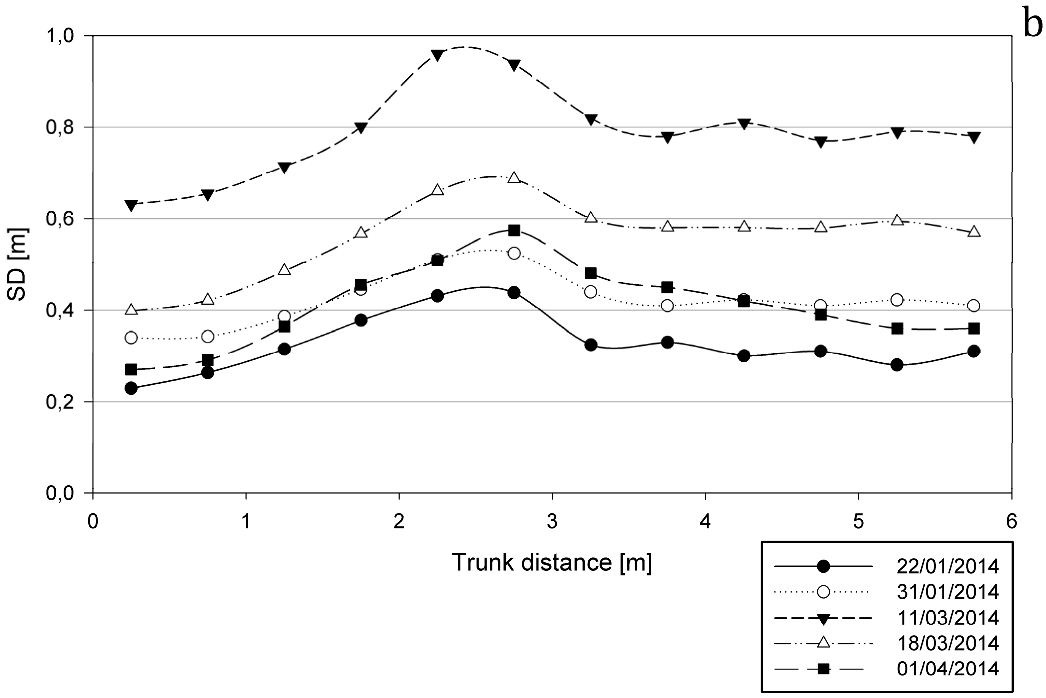

Figure 7. Average snow depths as a function of distance from the tree trunk, for PCA component C1 prior to (**a**) and following canopy pruning (**b**).

4. Discussion

In this study we made the first evaluation of the impact of pruning of the lower crown branches of trees in a small *Pinus sylvestris* stand in the central Spanish Pyrenees on the accumulation and melting dynamics of the snowpack. The snow depth was measured at a very high spatial resolution (0.25 m) using a TLS. The study period comprised three snow seasons. The type of canopy pruning performed at the Balneario de Panticosa study site is a widespread procedure used at forested sites to prevent the spread of fire; its purpose is to increase the distance between the ground and the base of the canopy to 3–3.5 m [25]. The pruning in this study was undertaken prior to the third year in which snowpack depth measurements were made. The acquisition of high spatial resolution data on snow depth at a single study site having varying canopy characteristics enabled direct assessment of the small-scale snowpack dynamics in a forested site following a typical forest management action.

Previous studies have suggested the greater sensitivity to meteorological variations than to the spatial variations in vegetation cover as modeled in the sensitivity test conducted by [49]. Other studies have also shown reduced interception efficiency with increasing snowfall [50]. The Pyrenees has high interannual variability in temperature and precipitation, leading to substantial uncertainty in annual snow accumulation [51]. The data from our study enabled analysis of the importance of forest cover disturbance in relation to climate variability; the first snow season (2011–2012) involved particularly low levels of snow accumulation, while the 2012–2013 and 2013–2014 seasons were associated with high levels of snow accumulation. We found that a 36% reduction in the canopy area (as a result of pruning) affected snow accumulation at the scale of the forest stand, but to a much lesser extent than that resulting from meteorological forcing.

The classification of survey dates based on PCA analysis supported the hypothesis that the snowpack is more sensitive to meteorological variations than to what occurs in the canopy following pruning. Thus, the PCA groups were based on the observed snow depth distributions, but no separate PCA component involved TLS surveys that were conducted following canopy pruning. Thus, surveys involving high levels of snow accumulation both prior to and following tree pruning were included in the same component, and a similar finding occurred for surveys involving low levels of snow accumulation.

When the ratio between Open and Canopy areas was related to the average snow accumulation in open areas, most of the observations made following pruning showed smaller reductions in the level of snow accumulation, indicating that the canopy had reduced influence on the spatial distribution of the snowpack. This was probably because of a decrease in interception capacity, and the easier penetration of snow beneath the crown following removal of the branches closest to the ground. It is noteworthy that interception capacity of forests is highly variable (reported to be 10%–55%), depending on factors including the type of forest, the geometry of the canopy, and the vertical structure of the trees [10,18,52].

Besides, other effects may have an important role when comparing the snow depth distribution before and after the pruning. This is the case with light transmission, long wave radiation, and forest temperature [19]. The snowpack distribution in forested areas is governed by snow interception processes and also by changes in the energy balance. [53] implemented a canopy radiation transfer model that accounts of absorption and multiple scattering of radiation using the leaf area index [54] as the key parameter. Since this index presents some controversies [55] and the intention of this work was neither to derive this variable from LiDAR data nor to use an energy balance snowmelt model, the analysis of the consequences of the canopy reduction on light transmission has not been assessed. Nevertheless, pruning the lower branches has reduced the leaf area index in the study site (the index is defined as leaf area/ground area) and increased the distance between the lower canopy branches and the snowpack surface, markedly affecting the transfer of radiation. Similarly, trees' shadows may have had an important modification after the pruning.

The PCA results also showed that pruning did not significantly affect the spatial patterns of snow distribution in the forest stand. Thus, TLS survey dates prior to and following pruning were represented in PCA groups discriminated according to the snow depth in the forest stand, or the different periods along the snow season (i.e., long melting periods). This indicates that despite differences in canopy area and geometry, snow depth differences in Open and Canopy areas are mainly controlled by meteorological characteristics (snow accumulation). Changes in the snow depth distribution following pruning should depend on the new geometry of canopies as it is discussed in the following paragraph. Therefore, once the main characteristics of a study area have been determined, the snow depth distribution can be estimated from the average snow depth in open areas [10] combined with information about the distribution of forest canopy.

The reduction of approximately 1.5 m in the peak snow depth-to-trunk distance was consistent with the reduction in the average crown radius (from 3.1 m to 1.9 m). The relationship between the reduction of crown radius and the snowpack area affected by the canopy shows that pruning reduced the effect of the canopy on the snowpack. In combination, the smaller area covered by the pruned canopy, the increased height of the canopy around the trunks, and the reduced interception capacity of the remaining canopy increase the snow storage at the stand scale. Thus, at the Balneario de Panticosa study site we found an average increase of approximately 14% in the total snow depth. This is consistent with the 49% average difference between open and canopy areas reported for the same study area by [10], linked with the 36% reduction of canopy area extension after the pruning.

It is noteworthy that this does not imply the same increase in total water storage (e.g., we did not consider the snowpack density in our study), but it is clear that the total snow accumulation is higher (Figure 6). Thus, a water storage increase could be expected in forested areas following canopy pruning. Studies of forest cover disturbance and the sensitivity of the hydrological response have shown that increased stream flow volumes are directly related to increased snow accumulation because of reduced interception by trees [26]. However, the effect of vegetation changes in downstream areas and the time period to reach a new equilibrium depends on the combination of many effects (vegetation type, regrowth, afforestation, the climatic conditions of the area, etc.) [56]. Therefore, changes in stream flow dynamics must be analyzed in relation to the specific characteristic of the study site and the mountain range involved. In a comprehensive study in the Canadian Rocky Mountains [25], modeled snowmelt associated with forest gap-thinning, and showed an increase of spring snowmelt, but noted differences in the timing of runoff associated with other slope orientations, which resulted in a substantial extension of the spring melt period. Such a delay in melting dynamics should also be expected in the Balneario de Panticosa study area, because of the reduced the Canopy area effect.

López-Moreno's study [10] showed the longer persistence of snow in open areas at Balneario de Pantsicosa study site, as its December-February-January average temperature is above −1 °C (which was identified by [21] as a threshold above which snow persists longer in the open and below which snow persists longer under the canopy). At this site, the longer snow persistence in open areas and the open area increase after the pruning suggest that tree pruning may delay melt. However, in general, assessment of changes in forest structure and their consequences for evolution of the snowpack must take the climatic characteristics of the study area into account.

5. Conclusions

In forested areas the snowpack distribution and its temporal evolution is markedly influenced by canopy extension and proximity to the trunk. The results of this study show that standard forest management practices, in this case aimed at reducing fire risk, may not have a marked impact on the snowpack distribution (similar snow depth distribution patterns despite radial distance decrease in accordance to canopy reduction) but could increase the water storage within forest stands. The major findings of the study were:

- the snow depth accumulation in open areas is the most suitable variable to describe the classification of the observed snowpack distribution during the three years of measurements, despite the fact that the canopy structure was modified just before the beginning of the last year;
- the change in canopy structure led to an average increase in snow accumulation of 14%, relative to the accumulation of snow in open areas prior to pruning. This change was mainly a result of the reduction (36%) in canopy area, and the previously observed average reduction in snow accumulation under canopies (49%).

The results indicate that changes in canopy structure such as those caused by pruning may increase the total water storage in forested areas. Since the temperate climate of the Pyrenees favours longer persistence of snow in open areas compared with canopy areas, the pruning of trees may delay snowmelt.

Supplementary Materials: The following are available online at www.mdpi.com/1999-4907/7/8/166/s1, Figure S1: Snow depth maps obtained during the study period at Balneario de Panticosa experimental site.

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