sustainability

Article

Enhancing Overland Flow Infiltration through Sustainable Well-Managed Thinning: Contour-Aligned Felled Log Placement in a *Chamaecyparis obtusa* Plantation

Moein Farahnak [1,*], Nobuaki Tanaka [2], Takanori Sato [3], Anand Nainar [4], Mie Gomyo [1], Koichiro Kuraji [5], Toko Suzaki [6], Haruhiko Suzuki [7] and Yoshimasa Nakane [7]

1 Ecohydrology Research Institute, Graduate School of Agriculture and Life Sciences, University of Tokyo, Aichi 489-0031, Japan
2 Graduate School of Agricultural and Life Sciences, The University of Tokyo Hokkaido Forest, Furano 079-1563, Japan
3 Faculty of Regional Environment Science, Tokyo University of Agriculture, Tokyo 156-8502, Japan
4 Faculty of Tropical Forestry, Universiti Malaysia Sabah, Kota Kinabalu 88-400, Malaysia
5 Executive Office, Graduate School of Agricultural and Life Sciences, The University of Tokyo, Tokyo 113-8657, Japan
6 Toyota Yahagi River Institute, Aichi 471-0025, Japan
7 Industrial Affairs Department, Forestry Division, Toyota City 444-2424, Japan
* Correspondence: moein-farahnak@g.ecc.u-tokyo.ac.jp; Tel.: +81-70-9109-1357

Abstract: Contour felling is a restoration method used to decrease overland flow (OF) and soil erosion in the world. However, the impact of thinning and the placement of felled logs on OF remains inconclusive. Low ground cover and soil permeability promote OF in *Chamaecyparis obtusa* (Siebold et Zucc.) Endl plantations, making thinning a method for reducing runoff. We examined the relationship between OF and ground cover in a *C. obtusa* plantation in Japan. Event-based runoff was monitored in three plots from 2016 to 2021, with 40% thinning conducted in 2019. In plot T1, logs were randomly scattered, and, in T2, logs followed contour lines, while control plots stayed the same. After thinning, both treatment plots showed lower OF than the control plot. The ANCOVA test shows a significant slope reduction in treatment plots compared to the control plot from pre-thinning to post-thinning (T1: 0.67 to 0.26, T2: 0.66 to 0.12, $p < 0.001$, Tukey HSD test). However, in plot T2, OF remained stable for two years post-thinning, affirming the enduring effectiveness of contour-aligned log placement. This study backs the notion that aligning fallen logs with contour lines boosts long-term OF infiltration, supporting sustainable forest and soil management.

Keywords: contour felling; Japanese plantations; infiltration; slope runoff; thinning

Citation: Farahnak, M.; Tanaka, N.; Sato, T.; Nainar, A.; Gomyo, M.; Kuraji, K.; Suzaki, T.; Suzuki, H.; Nakane, Y. Enhancing Overland Flow Infiltration through Sustainable Well-Managed Thinning: Contour-Aligned Felled Log Placement in a *Chamaecyparis obtusa* Plantation. *Sustainability* **2023**, *15*, 14124. https://doi.org/10.3390/su151914124

Academic Editor: Jim Lynch

Received: 25 August 2023
Revised: 15 September 2023
Accepted: 22 September 2023
Published: 24 September 2023

1. Introduction

Overland flow (OF) generated on steep mountains leads to sediment transport, landslides, and flooding during intense rainfall over a short period. OF occurs when the following three events occur together [1]: (1) saturation of the entire soil profile during a rainfall event, (2) more rainfall intensity than the infiltration capacity of the soil surface, and (3) delay in water infiltration into the soil because of severe soil water repellency. Vegetation covers, such as forests, reduce OF because they have a high soil water infiltration capacity [1]. However, high OF has been reported even in forestlands in China [2] and in dense *Chamaecyparis obtusa* (Siebold et Zucc.) Endl (*C. obtusa*) plantations in Japan [3,4]. *C. obtusa* is an evergreen coniferous tree with scaly leaves [5] and shallow root systems [6]. Its litterfall occurs between October and November (fall). The scaly leaves of *C. obtusa* are fragile and easily fragmented into small pieces after falling to the ground. Therefore, the litter layer in *C. obtusa* plantations is thin because the fallen fragmented leaves are easily eroded by wind and OF [7].

Most mountainous areas are covered with forests in Japan, accounting for 67%, with *C. obtusa* plantations occupying 10% of the forest areas [8]. Headwater forests play a critical role in regulating water resources in Japan. Previous studies have suggested several reasons for the high OF in *C. obtusa* plantations, such as localized redistributed rainwater (i.e., throughfall and stemflow; [9]), sparse understory due to poor light conditions [10,11], a thin litter layer [7], soil crusting [12], and soil water repellency [13].

Ecohydrological processes in forest ecosystems are driven by various environmental and artificial factors [14], such as forest thinning [15], which affects ecohydrological processes by reducing the leaf area index and canopy interception loss [16–18]. The selective removal of trees, also known as thinning, is a common forest management practice used to improve tree growth [19] and develop understory vegetation [20]. Thinning is performed at different intensities for various purposes [21]. Commercial thinning aims to enhance timber quality, while non-commercial thinning seeks to improve the ecological and hydrological conditions within the forest [14]. In dense Japanese *C. obtusa* plantations, thinning is often conducted non-commercially to improve tree growth and poor light conditions on the forest floor; subsequently, the felled logs are left on the forest floor.

In recent years, the practice of strategically placing felled logs parallel to contour lines in forest plantations has gained prominence in Japan as an innovative approach aimed at promoting sustainability. This method aims to curtail OF and mitigate soil erosion by bolstering ground resistance and augmenting water infiltration into the soil [10,22–24]. Notably, while contour felling has been recognized as a standard rehabilitation technique in European and USA forests following fire events [25–27], as well as in heavily disturbed soils due to machinery operations in Iran [28], its adoption in Japan remains relatively novel, particularly in the context of post-thinning management [22]. Moreover, the outcomes of previous research efforts [10,22–24] concerning the combined impact of thinning practices and the strategic placement of felled logs on OF have yielded inconclusive results.

In light of these knowledge gaps and the pressing need for sustainable land management strategies, our present study endeavors to shed light on the intricate relationship between thinning practices, the placement of felled logs, and their collective influence on OF dynamics. Our central hypothesis posits that conducting thinning operations while aligning the placement of felled logs parallel to contour lines—a practice akin to well-managed thinning—will yield more effective results in curtailing OF. To rigorously test this hypothesis, we conducted a meticulous comparative analysis, evaluating the OF characteristics of two distinct thinned plots characterized by differing felled log arrangements, in comparison to an adjacent control plot. Furthermore, we delve into the mechanisms underpinning the observed changes in OF subsequent to thinning and the strategic placement of felled logs, thus contributing to a comprehensive understanding of sustainable forest and soil management practices.

2. Materials and Methods

2.1. Study Site

The study was conducted in a *C. obtusa* plantation (catchment area: 1.45 ha) located in the Obora experimental forest site of Toyota City, Aichi Prefecture, Japan (35°16′ N, 137°15′ E; 585 m a.s.l., Figure 1a), from January 2016 to December 2021. The climate of the study area can be characterized by extremely hot and humid summers and moderately cold winters, and it is categorized as wet, warm, and temperate [29]. The climate class is warm temperate and fully humid with hot summers (Cfa), according to the Köppen–Geiger climate classification [30]. The mean annual precipitation and temperature are 1470 mm and 15.3 °C (1991–2020), respectively [31]. Rainfall occurs mainly in May–June (rainy season) and September–October (typhoon season).

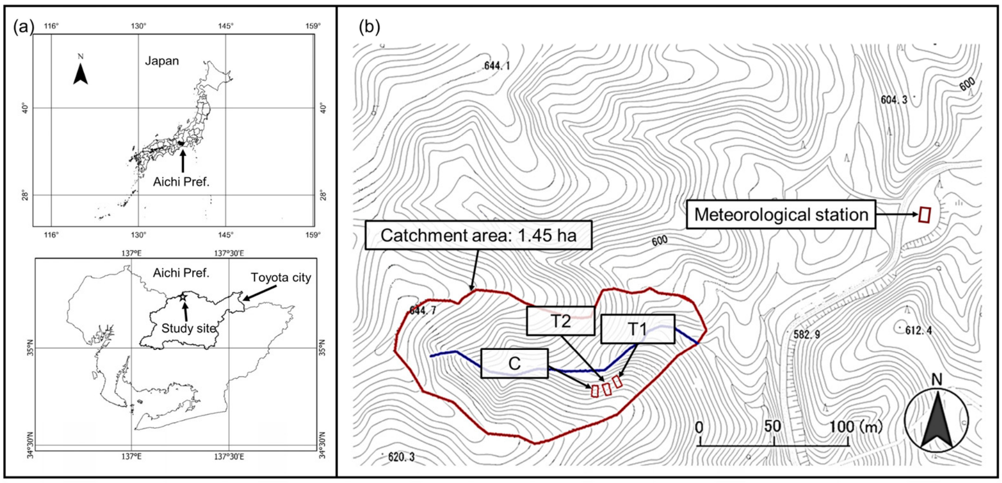

Figure 1. Map of the study site (**a**) and plots (**b**) in the Obora experimental forest site in Toyota City, Aichi Prefecture, Japan.

The *C. obtusa* plantations were established in 1989. The geology of the study area is a Mesozoic late cretaceous layer with granite bedrock [32]. The soil is brown forest soil [33] equivalent to cambisol [34] and covered with almost no understory (Figure 2), a less than 1 cm litter layer, and a ca. 3 cm root mat. A northwest-facing (N5°W) slope (37°) was selected for this study (Figure 1b).

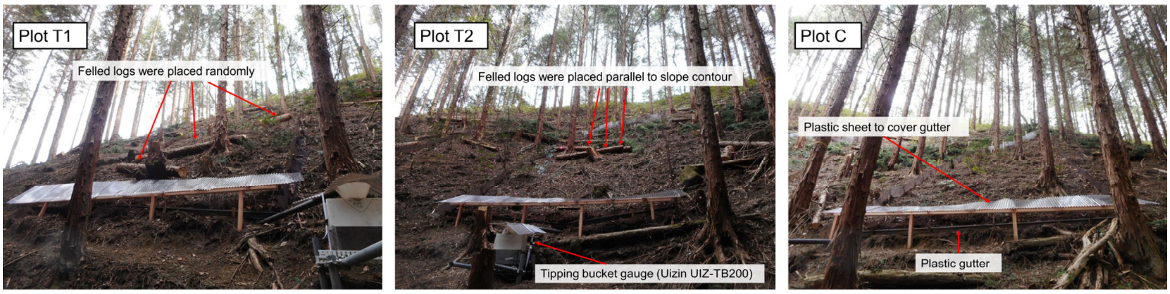

Figure 2. Condition of plot T1: felled logs placed in random directions on the slope; plot T2: felled logs placed parallel to contour lines on the slope; and plot C: control plot after thinning in 2019.

2.2. Experimental Design

Three study plots (each 4 m width, 10 m length) adjacent to each other were deployed along the same slope (Figures 1b and 2). A four-meter buffer zone was placed between each plot. Plots T1 (area: 30.8 m^2) and T2 (area: 31.7 m^2) were established as treatment plots, and plot C (area: 32.1 m^2) as a control (Figures 1b and 2). Each plot was delimited by inserting the plastic sheet into the ground (Figure 2). Overland flow (OF) was guided to a tipping bucket rain gauge (Uizin UIZ-TB200, 200 mm/tip) through a gutter at the bottom boundary of each plot (Figure 2). A plastic sheet was installed on the ground to prevent direct rainfall input to the gutter (Figure 2).

Rainfall data were recorded via a tipping bucket rain gauge (Ota Keiki OW-34-BP, 0.5 mm/tip) at a nearby weather station (ca. 500 m from the studied plots, Figure 1b). A rain event was divided into 6 h of the rain-free period with a minimum 5.5 mm amount of rainfall (i.e., the minimum amount of rainfall that generated OF in all three studied plots). The tipping times of OF and rainfall data were recorded using the same type of data logger (Onset HOBO Pendant® Event Data Logger UA-003-64). The area of plots T1 and T2 was thinned (ca. 40% tree ha^{-1}) in early 2019, and plot C remained intact as a control plot. Thinning was performed using a chainsaw, minimizing any disruption to the soil surface within each treatment plot. As a result, the stand density of studied plots changed from 2018 to 2020 as follows: plot T1 changed from 1623 tree ha^{-1} to

974 tree ha^{-1}, plot T2 changed from 1299 tree ha^{-1} to 649 tree ha^{-1}, and the control plot remained unchanged (974 tree ha^{-1}) (Table 1). In addition, five felled logs (ca. 2 m in length and 30 cm in diameter) were left randomly on the slope (i.e., not parallel to contour lines) in plot T1, and another five felled logs were placed parallel to contour lines in plot T2 (Figure 2). Felled logs covered 5% of the ground in each treatment plot.

Table 1. General statistics of plots T1, T2, and C in pre- and post-thinning periods at the Obora experimental forest site.

Parameter	Pre-Thinning (2016–2018)			Post-Thinning (2019–2021)		
	T1	T2	C	T1	T2	C
[1] Tree height (m)	14.2	14.2	14.3	13.7	14.4	14.3
[1] Diameter at breast height (cm)	18.1	20.5	21.8	17.2	21.9	21.8
[1] Tree density (tree ha^{-1})	1623	1299	974	974	649	974
Number of trees	5	4	3	3	2	3
Total rainfall, P (mm)		4147			4757	
Total surface runoff, OF (mm)	44.1	51.6	68.6	48.1	17.5	160.2
OF ratio	0.011	0.012	0.017	0.010	0.004	0.034
Number of rainfall vents (*n*)		96			107	
OF min (mm)	0.006	0.006	0.006	0.006	0.006	0.006
OF mean (mm)	0.460	0.538	0.715	0.449	0.163	1.497
OF max (mm)	5.649	4.379	7.327	2.390	1.338	9.913
[2] OF SD (mm)	0.748	0.757	1.059	0.540	0.250	1.954
$Freq.OF_{T1}$:$Freq.OF_C$		0.727			0.531	
$Freq.OF_{T2}$:$Freq.OF_C$		0.941			0.490	

[1] Field survey for tree height, DBH, and stand density was conducted in 2018 (pre-thinning) and 2020 (post-thinning). [2] OF and SD denote overland flow and standard deviation, respectively.

2.3. Statistical Analyses

Only OFs that were generated in all three studied plots were included in the data analyses. In this way, we can compare the event-based OF of treatment plots with the control plot. The data loss of OF during the thinning operation was excluded from the analyses (Figure 3). The relationship between the event-based OF and rainfall characteristics was investigated by performing a Pearson's correlation (r) analysis to understand the OF generation mechanism in each plot in the pre- and post-thinning periods. Rainfall amount, intensity, duration, and antecedent precipitation index or soil moisture conditions were selected as rainfall characteristics.

Antecedent precipitation index (API) was calculated for the rain events to understand the surrogate antecedent soil moisture conditions of the studied site prior to each OF event during the study period (Figure S1). We defined the API for a particular day as follows:

$$API_d = k \times API_{d-1} + P_d \tag{1}$$

where API_d is the antecedent precipitation index for the day d, k is an empirical decay factor less than one, and P_d is rainfall for the day d. k is usually between 0.85 and 0.98. A constant value of 0.95 was recommended by Hill et al. [35]. In this study, we used the API for the 7th and 14th days before each OF event. We used these data for Pearson's correlation (r) analysis. Further, API7 and API14 represented the soil surface and subsurface moisture conditions, respectively.

We performed analysis of covariance (ANCOVA) to detect differences in even-based OF between the thinned and control plots in the pre- and post-thinning periods. Post hoc comparisons with Tukey's honestly significant difference (HSD) tests were performed to determine whether the slopes of the regression lines differed between years (in the pre- and post-thinning periods). Finally, the slopes of the regression lines were compared to detect differences between the thinned and control plots. The ANCOVA results showed the impact of thinning and felled logs on OF in the thinned plots compared with the control plot. The R software ver. 3.4.2 (R Development Core Team, Vienna, Austria) was used for the statistical analyses.

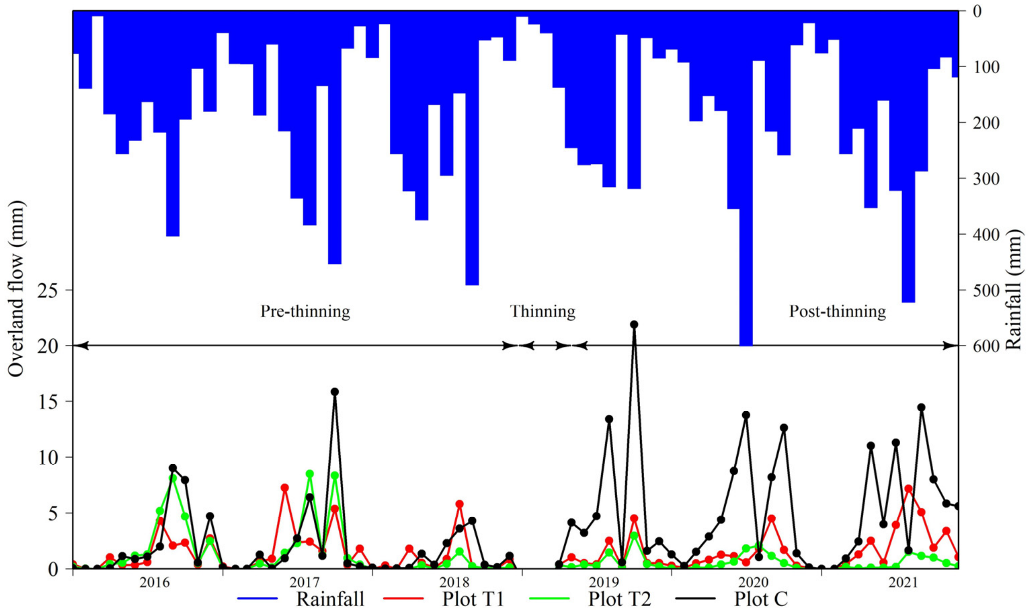

Figure 3. Monthly precipitation and overland flow (OF) in plots T1, T2, and C in the pre- and post-thinning periods.

3. Results

3.1. Overall OF

In total, 203 rainfall storms resulted in OF. In the pre-thinning period, 96 rainfall storms occurred (36, 35, and 25 in 2016, 2017, and 2018, respectively), and 107 occurred during the post-thinning period (27, 45, and 35 in 2019, 2020, and 2021, respectively). During the pre-thinning period, 41%, 32%, and 27% of the rainfall event amounts were <25, 25–50 mm, and >50 mm, respectively. In the post-thinning period, 36%, 36%, and 28% of the rainfall event amounts were <25, 25–50, and >50 mm, respectively. During the pre-thinning period, the monthly OF was almost identical among the three plots (Figure 3). Contrastingly, in the post-thinning periods, the monthly OF in plot C was higher than that in plots T1 and T2 (Figure 3). Plot T2 had the lowest monthly and total OF in the post-thinning period compared to plots T1 and C (Figure 3 and Table 1). The OF frequency also reduced from the pre- to post-thinning periods in both thinned plots (Table 1).

Figure 4 illustrates the general trend in OF changes across three study plots from the pre-thinning to the post-thinning periods. During the pre-thinning period, all studied plots had similar flow–duration curves (FDCs, Figure 4, total, 2016, 2017). However, in the first year after thinning (2019), the FDC of plot C was higher than that of plots T1 and T2 (Figure 4, 2019). The FDCs were distinctly separated in the second year after thinning (2020), with plots T2, T1, and C having the lowest, moderate, and the highest FDCs, respectively (Figure 4, 2020). In the third year after thinning (2021), the FDC of plot T2 remained the lowest, whereas that of plot T1 shifted to plot C (Figure 4, 2021).

3.2. Relationship between OF and Rainfall Characteristics

3.2.1. Pre-Thinning Period

The rainfall amount was positively correlated with OF in all plots (Table 2). Additionally, rainfall duration was positively correlated with OF in plot C (Table 2). Contrastingly, API7 and API14 were negatively correlated with OF in plot T1 (Table 2 and Figure S1).

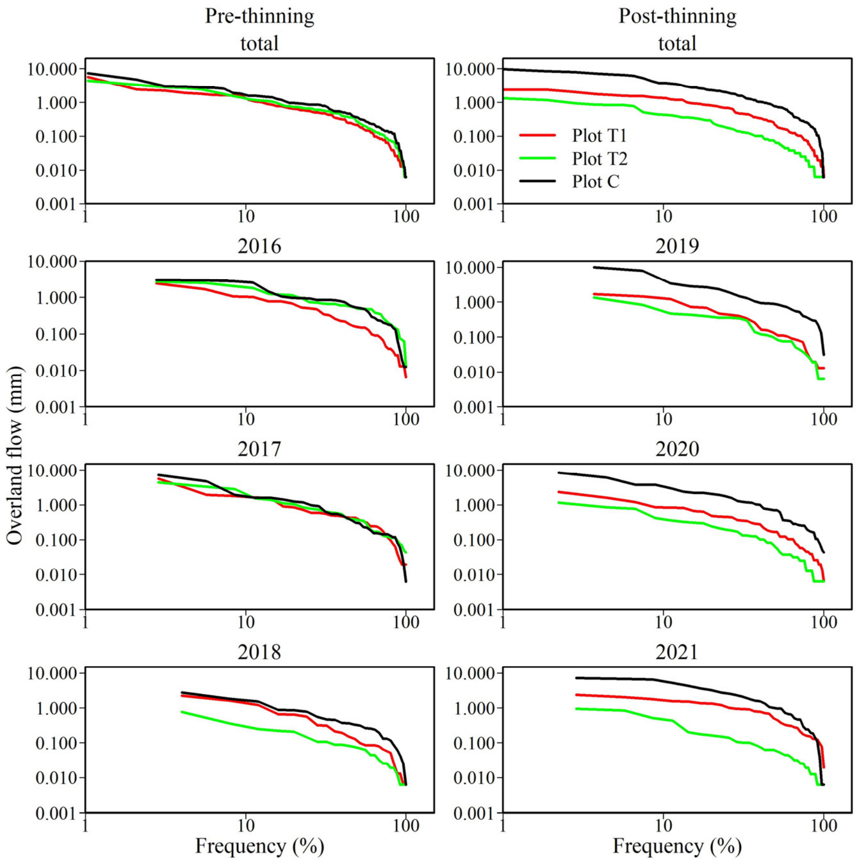

Figure 4. Flow–duration curve for plots T1, T2, and C in the pre- and post-thinning periods.

Table 2. Results of Pearson's correlation (r) analysis between event-based OF and rainfall characteristics in plots T1, T2, and C in the pre-and post-thinning periods at the Obora experimental forest site.

	Pre-Thinning		**Post-Thinning**	
	Correlation Coefficient	***p*-Value**	**Correlation Coefficient**	***p*-Value**
Plot T1				
Rainfall amount	0.23	0.03	0.45	0.00
Rainfall intensity	0.10	0.36	0.06	0.54
Rainfall duration	0.13	0.21	0.15	0.13
API7	−0.27	0.01	0.02	0.81
API14	−0.21	0.04	−0.02	0.79
Plot T2				
Rainfall amount	0.35	0.00	0.38	0.00
Rainfall intensity	0.18	0.08	0.27	0.01
Rainfall duration	0.18	0.09	0.05	0.62
API7	0.08	0.41	−0.01	0.95
API14	−0.01	0.95	0.04	0.67
Plot C				
Rainfall amount	0.49	0.00	0.55	0.00
Rainfall intensity	−0.03	0.80	0.00	1.00
Rainfall duration	0.47	0.00	0.32	0.00
API7	0.04	0.72	−0.12	0.22
API14	−0.02	0.82	−0.05	0.60

Significant correlations at a 95% confidence level.

3.2.2. Post-Thinning Period

During the post-thinning period, the rainfall amount was positively correlated with OF in all plots, with a higher correlation coefficient (r) value than in the pre-thinning period (Table 2). Further, in this period, APIs and OF were not correlated in plot T1 (Table 2). Additionally, rainfall intensity was positively correlated with OF in plot T2 (Table 2). Further, the relationship between rainfall characteristics and OF remained unchanged in plot C in this period compared to that in the pre-thinning period (Table 2).

3.3. Impact of Thinning and Placement of Felled Logs on OF

The relationship between OF in thinned plots and pre- and post-thinning in plot C is shown in Figure 5. The ANCOVA results showed that in both thinned plots, the slope of the regression line in the post-thinning period and in the first year after thinning (2019) was lower than that in the pre-thinning period (Figure 5c,d and Table 3). Differences in OF between the thinned plots began in the second year after thinning (Figure 5c,d and Table 3). The regression line for the second year post-thinning (2020) was higher than that for the first year post-thinning (2019) in plot T1, and remained unchanged from the second to the third year post-thinning (Figure 5c and Table 3). Contrastingly, in plot T2, the slope of the regression lines remained unchanged from the first year post-thinning until the end of the study period (Figure 5d and Table 3).

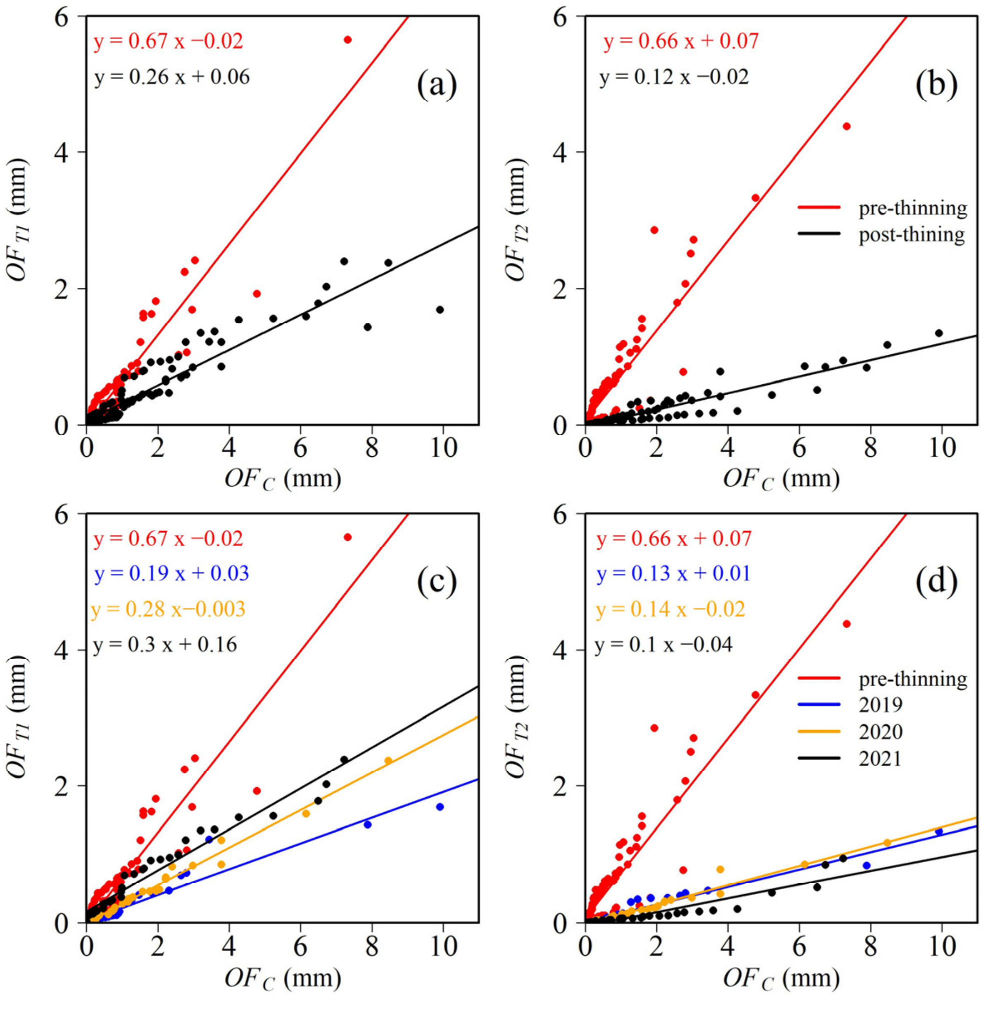

Figure 5. OF in plot T1 vs. plot C (OF_{T1} vs. OF_C) (**a**), plot T2 vs. plot C (OF_{T2} vs. OF_C) (**b**) in the pre-and post-thinning periods and OF_{T1} vs. OF_C (**c**) and OF_{T2} vs. OF_C (**d**) in pre-thinning and the years 2019, 2020, and 2021.

Table 3. Results of covariance (ANCOVA [1]) analysis between the slope of regression lines of studied plots in pre-thinning and post-thinning periods.

Plot	Pre-Thinning to Post-Thinning	Pre-Thinning to 2019	2019 to 2020	2020 to 2021
	p-Value	*p*-Value	*p*-Value	*p*-Value
OF_{T1} vs. OF_C	<0.001	<0.001	0.002	0.711
OF_{T2} vs. OF_C	<0.001	<0.001	0.948	0.387

[1] ANCOVA comparison test (Tukey HSD) was applied to assess the statistical significance of the slope of regression lines.

4. Discussion

The study findings showed that OF was affected by the thinning and placement of felled logs. Previous studies have demonstrated the importance of ground cover in increasing ground resistance and reducing OF in forests [36,37]. Their results indicated that OF increased with the removal of ground litter layers [36,37]. Furthermore, dos Santos et al. [38] observed that after thinning a native dry tropical forest in Brazil, a well-developed herbaceous layer acted as a barrier, reducing surface runoff. Wagenbrenner et al. [26] reported the effectiveness of contour felling in reducing the peak runoff rates in a post-fire rehabilitation treatment in the Colorado Front Range. Our results showed that in the thinned *C. obtusa* plantations with low ground cover, the remaining felled logs played a vital role in maintaining low OF by increasing water residence time and providing an opportunity for the generated OF to infiltrate the soil.

Furthermore, differences in microtopography could have caused differences in the OF generation mechanism in each plot during the pre-thinning period (Table 2). Sato et al. [39] experimented with small traps (for sediment, litter, and OF measurements) in the same *C. obtusa* catchment, and suggested that the high OF variability in a *C. obtusa* plantation could be affected by the microtopography or internal heterogeneity between the studied plots.

The thinned plots responded to OF reduction by changing the relationship between rainfall characteristics and OF from the pre-thinning to the post-thinning period (Table 2). Nevertheless, the limited correlation observed between rainfall characteristics and OF suggests the presence of additional factors influencing OF generation within the treatment plots (Table 2). In plot T1, the random placement of felled logs significantly affected the OF generation mechanism by eliminating the impact of API7 and API14 in the post-thinning period (Table 2). These results indicated that soil moisture was an influential factor in generating OF in plot T1 prior to thinning. Contrastingly, the OF generation mechanism changed when the felled logs were randomly placed on the ground during the post-thinning period. In plot T2, rainfall intensity was a new parameter influencing OF during the post-thinning period (Table 2), thus supporting our hypothesis that the parallel placement of felled logs on contour lines changes the OF generation mechanism in the post-thinning period (Table 2). Kuraji et al. [24] also mentioned that the parallel placement of felled logs decreased the peak OF and increased subsurface runoff after the thinning of a *C. obtusa* stand compared to that in a grassland area. In our study, thinning and placing felled logs decreased OF in the treatment plots compared to the control plot with no thinning. Cheng et al. [40] reported that surface runoff in a heavily thinned *Larix principisrupprechtii* forest in China depended on the rainfall amount and intensity and litter interception. In plot C, the ground cover remained unchanged from the pre-thinning to post-thinning periods (Figure 2); therefore, the OF generation mechanism in this plot was similar during the post-thinning period (Table 2).

The FDCs and ANCOVA results showed the effectiveness of thinning in reducing OF following thinning in 2019 (Figures 4 and 5, and Table 3). The FDCs demonstrated the changes in the flow frequency (i.e., OF occurrences) of thinned plots compared to that of plot C from the pre-thinning to post-thinning periods (Figure 4, total). Additionally, a shift in FDC in plot T1 toward plot C in the second year after thinning suggested that the impact of thinning was longer in plot T2, with the felled logs placed parallel to the contour lines in the post-thinning periods (Figure 4, 2020). The differences in the FDCs between plots T1 and T2 were related to the direction of the felled log. Placing felled logs (or any barrier) on a slope helps to infiltrate water into the soil and stop sediments from being carried by OF [41]. In the first year after thinning, felled logs in both thinned plots caused sediment deposits on the upper sides of the felled logs. The sediment deposited from parallel-felled logs in plot T2 enhanced OF infiltration into the soil. In plot T1, the random placement of felled logs negatively impacted OF reduction from the second year after thinning because the deposited sediments directed the OF downslope rather than infiltrating into the soil. Jourgholami et al. [28] reported a decrease in runoff and sediment yield when felled logs were aligned with contour lines in a natural broad-leaved forest in northern Iran disturbed by a heavy operating machine. In contrast, Fernández and Vega [25] observed that erosion barriers (i.e., contour felling with a trench on its upslope) were effective for a relatively short period (a few months) in controlling sediment and OF after severe wildfires in Spain. The discrepancy between these results and our results could be related to the high level of disturbance after the wildfire compared to the well-managed thinning in our study.

The ANCOVA results also showed that OF remained low in plot T2 in the second and third years after thinning, whereas in plot T1, OF increased in the second year after thinning (Figure 5c,d). Kubota et al. [42] also reported an increase in runoff in the second year after the 50% thinning of a small catchment of *C. obtusa*, where felled logs were left randomly.

Our findings underscore the effectiveness of well-managed thinning coupled with the strategic placement of felled logs parallel to contour lines in controlling OF within plantations, particularly in the context of *C. obtusa* where the understory is underdeveloped. By interrupting the movement of water across the soil surface, this approach demonstrated its capacity to efficiently manage OF dynamics. Furthermore, the sustained alteration of soil surface hydrology, achieved through the parallel arrangement of felled logs following thinning, highlights the potential for enduring impacts on water movement patterns.

While our study provides compelling support for the positive outcomes of thinning and felled log placement in reducing OF, it is imperative to acknowledge the long-term considerations inherent in sustainable land management. For a comprehensive grasp of the broader implications, it is recommended that future research delves into the influence of decomposing felled logs on soil hydraulic properties, and their role in rainfall–runoff processes over extended periods. Additionally, there exists a valuable opportunity to disentangle the distinct impacts of thinning practices and felled log placement by incorporating a thinned plot devoid of felled log interventions. Such multifaceted investigations will contribute to refining our understanding of sustainable forestry practices aimed at minimizing overland flow.

5. Conclusions

This study investigated the effects of the thinning and placement of felled logs on OF generation in a *C. obtusa* plantation in Japan. This study is the first to compare the impact of thinning on OF by considering the placement direction of felled logs (i.e., parallel versus random). We hypothesized that the thinning and parallel placement of felled logs would efficiently reduce OF. The results showed lower total and monthly and event-based OF and runoff frequency in the plot with a parallel placement of felled logs than in the plot with a random placement of felled logs in the post-thinning period, thus supporting our hypothesis. Our findings showed the importance of ground cover (i.e., felled logs) and its direction (i.e., random placement or parallel placement to the contour line) in controlling OF by altering soil surface hydrology after thinning a *C. obtusa* plantation. However, future research is necessary to improve the OF reduction mechanism using parallel-felled log placement. In the future, the impacts of thinning and felled logs on OF could be separately assessed by comparing the OF between thinned plots with and without felled logs. Sustainable forestry practices, like the ones examined in this study, can play a pivotal role in preventing soil erosion and maintaining soil health. Discussing the role of felled logs in reducing surface runoff can underscore the importance of such practices for long-term sustainability. Additionally, future research should include a comprehensive economic analysis of aligning felled logs along contours, particularly in areas where favorable rainfall conditions promote rapid tree growth and natural recovery, while also exploring the implications of sediment transport for enhanced land management practices.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/su151914124/s1, Figure S1: Daily rainfall, antecedent precipitation index (API), and overland flow in plots T1, T2, and C in the pre- and post-thinning periods.

Author Contributions: Conceptualization, M.F.; formal analysis, M.F. and T.S. (Takanori Sato); funding acquisition, K.K. and H.S.; investigation, M.G. and K.K.; methodology, M.F. and N.T.; project administration, K.K. and Y.N.; resources, T.S. (Toko Suzaki), H.S. and Y.N.; software, M.F.; supervision, N.T. and K.K.; visualization, M.F.; writing—original draft, M.F.; writing—review and editing, M.F., N.T. and A.N. All authors have read and agreed to the published version of the manuscript.

Funding: This work was partially supported by monitoring the water conservation function of Toyota City Hall.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available within the article or its Supplementary Material.

Acknowledgments: We gratefully acknowledge the involvement of everyone in this project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sidle, R.C.; Ziegler, A.D.; Negishi, J.N.; Nik, A.R.; Siew, R.; Turkelboom, F. Erosion processes in steep terrain—Truths, myths, and uncertainties related to forest management in Southeast Asia. *For. Ecol. Manag.* **2006**, *224*, 199–225. [CrossRef]
2. El Kateb, H.; Zhang, H.; Zhang, P.; Mosandl, R. Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China. *Catena* **2013**, *105*, 1–10. [CrossRef]
3. Sidle, R.C.; Hirano, T.; Gomi, T.; Terajima, T. Hortonian overland flow from Japanese forest plantations—An aberration, the real thing, or something in between? *Hydrol. Process.* **2007**, *21*, 3237–3247. [CrossRef]
4. Miyata, S.; Kosugi, K.I.; Nishi, Y.; Gomi, T.; Sidle, R.C.; Mizuyama, T. Spatial pattern of infiltration rate and its effect on hydrological processes in a small headwater catchment. *Hydrol. Process.* **2010**, *24*, 535–549. [CrossRef]
5. Osone, Y.; Hashimoto, S.; Kenzo, T.; Araki, M.G.; Inoue, Y.; Shichi, K.; Toriyama, J.; Yamashita, N.; Tsuruta, K.; Ishizuka, S.; et al. Plant trait database for *Cryptomeria japonica* and *Chamaecyparis obtusa* (SugiHinoki DB): Their physiology, morphology, anatomy and biochemistry. *Ecol. Res.* **2020**, *35*, 274–275. [CrossRef]
6. Karizumi, N. The mechanism and function of tree root in the process of forest production. I. Method of investigation and estimation of the root biomass. *Bull. Gov. For. Exp. Stn.* **1974**, *259*, 1–99.
7. Takahashi, T.; Toda, H.; Haibara, K. Changes in soil chemical and physical characteristics in Japanese cypress (*Chamaecyparis obtusa* Endl.) stands by mixture of deciduous broad-leaved trees in the northern Kanto region of Japan. *J. For. Res.* **1999**, *4*, 223–228. [CrossRef]
8. Japan Forestry Agency. Annual Report on Forest and Forestry in Japan, Fiscal Year 2020 (Summary). 2020. Available online: https://www.maff.go.jp/e/data/publish/index.html (accessed on 18 May 2022).
9. Jeong, S.; Otsuki, K. Effects of tree mortality on the estimation of stemflow yield in a self-thinning coniferous plantation. *Ecohydrology* **2021**, *14*, e2327. [CrossRef]
10. Gomi, T.; Sidle, R.C.; Ueno, M.; Miyata, S.; Kosugi, K.I. Characteristics of overland flow generation on steep forested hillslopes of central Japan. *J. Hydrol.* **2008**, *361*, 275–290. [CrossRef]
11. Katsuyama, M.; Ohte, N.; Kosugi, Y.; Tani, M. The Kiru experimental watershed: 50-years of rainfall-runoff data for a forest catchment in central Japan. *Hydrol. Process.* **2021**, *35*, e14104. [CrossRef]
12. Mizugaki, S.; Nanko, K.; Onda, Y. The effect of slope angle on splash detachment in an unmanaged Japanese cypress plantation forest. *Hydrol. Process.* **2010**, *24*, 576–587. [CrossRef]
13. Ide, J.I.; Haga, H.; Chiwa, M.; Otsuki, K. Effects of antecedent rain history on particulate phosphorus loss from a small forested watershed of Japanese cypress (*Chamaecyparis obtusa*). *J. Hydrol.* **2008**, *352*, 322–335. [CrossRef]

14. del Campo, A.D.; Otsuki, K.; Serengil, Y.; Blanco, J.A.; Yousefpour, R.; Wei, X. A global synthesis on the effects of thinning on hydrological processes: Implications for forest management. *For. Ecol. Manag.* **2022**, *519*, 120324. [CrossRef]
15. Crampe, E.A.; Segura, C.; Jones, J.A. Fifty years of runoff response to conversion of old-growth forest to planted forest in the HJ Andrews Forest, Oregon, USA. *Hydrol. Process.* **2021**, *35*, e14168. [CrossRef]
16. Sadeghi, S.M.M.; Gordon, D.A.; Van Stan, J.T., II. A global synthesis of throughfall and stemflow hydrometeorology. In *Precipitation Partitioning by Vegetation*; Springer: Cham, Switzerland, 2020; pp. 49–70. [CrossRef]
17. Hakimi, L.; Sadeghi, S.M.M.; Van Stan, J.T.; Pypker, T.G.; Khosropour, E. Management of pomegranate (*Punica granatum*) orchards alters the supply and pathway of rain water reaching soils in an arid agricultural landscape. *Agric. Ecosyst. Environ.* **2018**, *259*, 77–85. [CrossRef]
18. Shinohara, Y.; Levia, D.F.; Komatsu, H.; Nogata, M.; Otsuki, K. Comparative modeling of the effects of intensive thinning on canopy interception loss in a Japanese cedar (*Cryptomeria japonica* D. Don) forest of western Japan. *Agric. For. Meteorol.* **2015**, *214*, 148–156. [CrossRef]
19. Benedetti-Ruiz, S.; Loewe-Muñoz, V.; Del Río, R.; Delard, C.; Barrales, L.; Balzarini, M. Effect of thinning on growth and shape of *Castanea sativa* adult tree plantations for timber production in Chile. *For. Ecol. Manag.* **2023**, *530*, 120762. [CrossRef]
20. Trentini, C.P.; Campanello, P.I.; Villagra, M.; Ritter, L.; Ares, A.; Goldstein, G. Thinning of loblolly pine plantations in subtropical Argentina: Impact on microclimate and understory vegetation. *For. Ecol. Manag.* **2017**, *384*, 236–247. [CrossRef]
21. Lõhmus, A. Silviculture as a disturbance regime: The effects of clear-cutting, planting and thinning on polypore communities in mixed forests. *J. For. Res.* **2011**, *16*, 194–202. [CrossRef]
22. Yamase, K.; Tochimoto, D.; Sekioka, H.; Todo, C. Inhibition of forest soil runoff by horizontal step works using thinning logs. *J. Jpn. Soc. Reveget. Tech.* **2010**, *36*, 9–14. [CrossRef]
23. Dung, B.X.; Miyata, S.; Gomi, T. Effect of forest thinning on overland flow generation on hillslopes covered by Japanese cypress. *Ecohydrology* **2011**, *4*, 367–378. [CrossRef]
24. Kuraji, K.; Gomyo, M.; Nainar, A. Thinning of cypress forest increases subsurface runoff but reduces peak storm-runoff: A lysimeter observation. *Hydrol. Res. Lett.* **2019**, *13*, 49–54. [CrossRef]
25. Fernández, C.; Vega, J.A. Are erosion barriers and straw mulching effective for controlling soil erosion after a high severity wildfire in NW Spain? *Ecol. Eng.* **2016**, *87*, 132–138. [CrossRef]
26. Wagenbrenner, J.W.; MacDonald, L.H.; Rough, D. Effectiveness of three post-fire rehabilitation treatments in the Colorado Front Range. *Hydrol. Process.* **2006**, *20*, 2989–3006. [CrossRef]
27. Robichaud, P.R.; Wagenbrenner, J.W.; Brown, R.E.; Wohlgemuth, P.M.; Beyers, J.L. Evaluating the effectiveness of contour-felled log erosion barriers as a post-fire runoff and erosion mitigation treatment in the western United States. *Int. J. Wildland Fire* **2008**, *17*, 255–273. [CrossRef]
28. Jourgholami, M.; Ahmadi, M.; Tavankar, F.; Picchio, R. Effectiveness of three post-harvest rehabilitation treatments for runoff and sediment reduction on skid trails in the Hyrcanian forests. *Croat. J. For. Eng. J. Theory Appl. For. Eng.* **2020**, *41*, 309–324. [CrossRef]
29. JMA (Japan Meteorological Agency). The Normal Value of Toyota City, Aichi Prefecture. 2020. Available online: http://www.data.jma.go.jp/obd/stats/etrn/view/nml_amd_ym.php?prec_no=51&block_no=0464&year=&month=&day=&view= (accessed on 6 February 2020). (In Japanese).
30. Kottek, M.; Grieser, J.; Beck, C.; Rudolf, B.; Rubel, F. World map of the Köppen-Geiger climate classification updated. *Meteorol. Z.* **2006**, *15*, 259–263. [CrossRef]
31. JMA (Japan Meteorological Agency). Climate of Tokai District. 2020. Available online: https://www.data.jma.go.jp/gmd/cpd/longfcst/en/tourist/file/Tokai.html (accessed on 6 February 2020).
32. Tobe, H.; Chigira, M.; Doshida, S. Comparisons of landslide densities between rock types in weathered granitoid in Obara village, Aichi prefecture. *J. Jpn. Soc. Eng. Geol.* **2007**, *48*, 66–79. (In Japanese with English abstract) [CrossRef]
33. Forest Soil Division. Classification of forest soil in Japan (1975). *Bull. Gov. For. Exp. Stn.* **1976**, *280*, 1–28. (In Japanese with English summary)
34. IUSS Working Group WRB. World reference base for soil resources 2014, update 2015: International soil classification system for naming soils and creating legends for soil maps. *World Soil Sci. Res.* **2015**, *106*, 192.
35. Hill, P.; Zhang, J.; Nathan, R. *Australian Rainfall and Runoff Revision Project 6: Loss Models for Catchment Simulation*; Commonwealth of Australia: Canberra, Australia, 2016.
36. Nainar, A.; Kishimoto, K.; Takahashi, K.; Gomyo, M.; Kuraji, K. How do ground litter and canopy regulate surface runoff?—A paired-Plot investigation after 80 years of broadleaf forest regeneration. *Water* **2021**, *13*, 1205. [CrossRef]
37. Gomyo, M.; Kuraji, K. Effect of the litter layer on runoff and evapotranspiration using the paired watershed method. *J. For. Res.* **2016**, *21*, 306–313. [CrossRef]
38. dos Santos, J.C.N.; de Andrade, E.M.; Medeiros, P.H.A.; Guerreiro, M.J.S.; de Queiroz Palácio, H.A. Effect of Rainfall Characteristics on Runoff and Water Erosion for Different Land Uses in a Tropical Semiarid Region. *Water Resour. Manag.* **2017**, *31*, 173–185. [CrossRef]
39. Sato, T.; Tanaka, N.; Nainar, A.; Kuraji, K.; Gomyo, M.; Suzuki, H. Soil erosion and overland flow in Japanese cypress plantations: Spatio-temporal variations and a sampling strategy. *Hydrol. Sci. J.* **2020**, *65*, 2322–2335. [CrossRef]
40. Cheng, X.; Bai, Y.; Zhu, J.; Han, H. Effects of forest thinning on interception and surface runoff in *Larix principisrupprechtii* plantation during the growing season. *J. Arid. Environ.* **2022**, *181*, 104222. [CrossRef]

41. Badía, D.; Sánchez, C.; Aznar, J.M.; Martí, C. Post-fire hillslope log debris dams for runoff and erosion mitigation in the semiarid Ebro Basin. *Geoderma* **2015**, *237*, 298–307. [CrossRef]
42. Kubota, T.; Tsuboyama, Y.; Nobuhiro, T. Effects of thinning on canopy interception loss, evapotranspiration, and runoff in a small headwater *Chamaecyparis obtusa* catchment in Hitachi Ohta Experimental Watershed in Japan. *Bull. For. For. Prod. Res. Inst.* **2018**, *17*, 63–73. [CrossRef]