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The effects of ground-based skidding on sapling vitality depending on thinning intensities und skidding technique

Die Auswirkungen von Holzrückung auf Vitalität der Verjüngung abhängig von Durchforstungsintensität und Rücketechnologie

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Keywords: Manual skidding, cable pulling, vitality, sapling damage, Scots pine, *Pinus sylvestris*

Schlüsselbegriffe: Manuelle Bringung, Seilbringung, Rückeschäden, Verjüngung, Waldkiefer, *Pinus sylvestris*

Abstract

Minimizing the negative effects of harvesting activities on natural regeneration is important for sustainable forest management. Various studies have been conducted on the damages of harvesting activities on remaining stands to improve silvicultural management practices, including studies in Türkiye considering thinning intensity. The aim of this study is to determine the effects of different skidding techniques on sapling vitality in thinned stands at different thinning intensities. The study was conducted in Scots pine *(Pinus sylvestris* L.) forests in northeastern Türkiye, with similar ecological characteristics but different thinning intensities. The study was conducted in 18 sample plots with three thinning intensities (low, moderate, high), two skidding techniques (cable pulling and manual skidding) and three replications. After the harvesting activities, the root collar diameters and heights of saplings were measured. The damage type of the damaged saplings and the survival classes of the saplings were determined. 26.0% of the saplings in the areas subject to manual skidding and 22.8% of the saplings in the areas suject to cable pulling were damaged. There was a statistically significant correlation between the thinning intensity and damage types

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(χ^2 = 60.401, df = 3, p < 0.05) and between the thinning intensity and sapling vitality (χ^2 = 18.873, df = 3, p < 0.05).

Zusammenfassung

Für nachhaltige Forstwirtschaft ist es wichtig, die negativen Auswirkungen von Erntemaßnahmen auf die natürliche Entwicklung der Verjüngung zu minimieren. Verschiedene Studien über die Auswirkungen von Erntemaßnahmen auf die verbleibenden Bestände wurden durchgeführt, auch in der Türkei unter Berücksichtigung der Durchforstungsintensität. Ziel dieser Studie war es, die Auswirkungen verschiedener Rücketechniken auf die Vitalität der Jungbäume bei der Durchforstung von Beständen mit unterschiedlicher Durchforstungsintensität zu ermitteln. Die Studie wurde in Waldkiefernwäldern (*Pinus sylvestris* L.) im Nordosten der Türkei mit ähnlichen ökologischen Merkmalen, aber unterschiedlicher Durchforstungsintensität durchgeführt. Die Studie wurde auf insgesamt 18 Probeflächen mit drei Durchforstungsintensitäten (gering, mäßig und hoch), zwei Rücketechniken (Seilzug und manuelle Bringung) und drei Wiederholungen durchgeführt. Nach der Ernte wurden die Wurzelhalsdurchmesser und Pflanzenhöhe der Jungbäume in den Pflegeflächen gemessen. Die Schadensarten der geschädigten Jungbäume und die Überlebensklassen der Jungbäume wurden ermittelt. Das Ergebnis war, dass 26,0 % der Jungbäume in den Gebieten mit manueller Rückung und 22,8 % der Jungbäume in den Gebieten mit Seilzug geschädigt waren. Es bestand ein statistisch signifikanter Zusammenhang zwischen der Durchforstungsintensität und den Schadensarten (χ^2 = 60,401, df = 3, p < 0,05) und zwischen der Durchforstungsintensität und der Vitalität der Jungbäume (χ^2 = 18,873, df = 3, p < 0,05).

1 Introduction

The implementation of sustainable forest management, which has increased in importance in recent years, can be achieved by cultivating productive and stable forests. Sustainable forest management is defined by the United Nations Forest Forum (UNFF) as a dynamic concept that aims to preserve and enhance the economic, social, and environmental functions of forests for the benefit of present and future generations (UNFF, 2009). For this purpose, it is necessary to ensure that the productivity, biodiversity, regeneration capacity, and vitality of forests are not adversely affected (Siry *et al*., 2018). Therefore, forestry activities must be planned by considering both the existence of forests and the continuity of benefiting from the products and services offered by the forest ecosystem. It is known that the damages caused by forestry operations to the forest ecosystem negatively affect sustainable forest management in the long term (Nikooy, 2007; Silva *et al*., 2017). Therefore, one of the most important parameters to be considered in the planning of forestry operations is minimizing the damage to forest ecosystem elements such as forest soil, water resources, wildlife, residual trees, and saplings (Maesano *et al*., 2013; Martin *et al*., 2015). Today, the necessity of ensuring the healthy development of saplings that will create future forests and the wood raw material, which is the main forest product, has gained great importance. The importance of the damages of forestry activities is seen by the fact that this issue is among the priority issues in various international and national procedures, such as "Effective Indicators in the Planning of Wood Production" (FAO, 1987), "Relating to Production Works of Primary Forest Products" communique (GDF, 1996), and "Sustainable Forestry Management Criteria" (GDF, 2007).

The damages caused by forest operations to saplings cause a decrease both in the quantity and quality of trees that will constitute the value of future stands (Bobik, 2008; Adekunle and Olagoke, 2010). Thus, it will be possible to grow healthy individuals with minimal damage to the saplings during silvicultural interventions and harvesting activities (Picchio *et al*., 2020). The main factors affecting the damage to saplings in forestry operations can be listed as; silvicultural intervention type (Hartley, 2003), harvesting technique (Martin *et al*., 2015; Tavankar *et al*., 2017), equipment type (Cudzik *et al*., 2017), ground conditions (Stampfer and Seinmuller, 2004), forest characteristics, operational characteristics, and workers' education level (FAO, 2004; Kizha *et al*., 2021).

Silvicultural interventions are the main priorities of sustainable forest management in regulating the products and services that forests provide (Bhandari and Lamichhane, 2020). One of the most important types of silvicultural intervention applied in terms of increasing the future yield and durability of the stands is forest maintenance activities. Making the necessary maintenance interventions to the stands according to their developmental age is of great importance in ensuring the future of the forest (Yücesan *et al*., 2015). It was emphasized in many studies that the most damage to saplings occurred during ground-based skidding where selective, shelterwood, and thinning interventions were applied (Kuramoto *et al*., 2008; Ünver and Acar, 2009; Mousavi Mirkala, 2017; Ünver-Okan, 2018). Thinning activities can also affect stand productivity depending on tree species, planting density, thinning intensity, site conditions, and stand structure (Fortier *et al*., 2022; Li *et al*., 2020; Thiffault, 2020).

There is no study about the damage to saplings of thinning regardless of thinning intensities in Türkiye. In addition, although the damage types and severity of ground-based skidding to saplings were evaluated in these studies, no assessments were made on sapling vitality (Ünver and Oktan, 2023). This study is unique in considering thinning intensities and determining the effects of ground-based skidding and both downhill and uphill cable pulling on sapling vitality.

Vitality is commonly defined as life force, liveliness, or resilience. Zlobin (1970) demonstrated that vitality in plants can be determined in various ways based on the physiological, biochemical, phenological, and morphological characteristics of the plants. In addition, Schulz and Hartling (2003) suggested that vitality can also be determined based on the plant's ability to host nutrients. The method of calculating plant vitality based on visual data and physical characteristics of the plant is preferred over other methods because it is more practical (Dobbertin, 2005; Percival and Keary, 2008; Martinez-Trinidad *et al*., 2009). However, it was emphasized that there may be some disadvantages to the use of this method in young stands where the crowns of trees are not fully formed in some studies (Szymura, 2005; Polak *et al*., 2006). In addition, Johnstone *et al*. (2013) stated that since the vitality of plants is not a feature that can be measured directly, it would be more reliable to evaluate it by considering several methods instead of a single method.

It is known that the number, size, quality, and spatial distribution of surviving saplings post-harvest is of great importance to the development process of the stand (Surakka *et al*., 2011). For this reason, determining the vitality of saplings in the post-harvest area and making plans to take these into account will be important for ensuring the healthy development of the forest. This study aims to determine the effects of downhill manual skidding and uphill cable pulling on sapling vitality and sapling damage in maintenance areas by applying three different thinning intensities; weak, moderate, and strong.

2 Material and methods

The study was conducted in the pure Scots pine (*Pinus sylvestris* L.) forests in the Torul district of Gümüşhane province, located between 40°21'-40°48' north latitudes and 38°52'-39°19' east longitudes in the northeastern part of Türkiye (Figure 1).

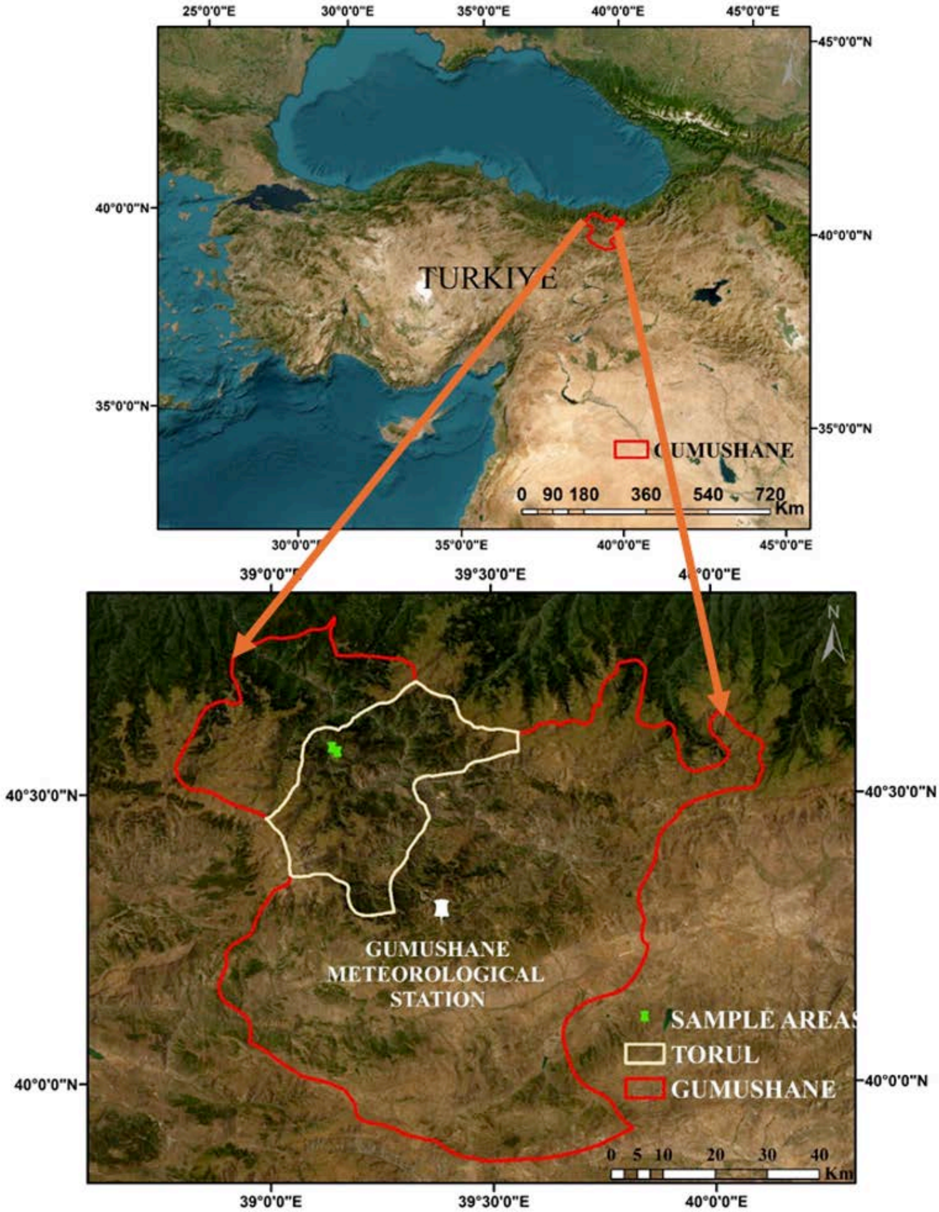

Figure 1: The geographical location of the research area in the Gümüşhane forests (URL-1, 2023).

Abbildung 1: Die Lage des Untersuchungsgebietes im Gümüşhane (URL-1, 2023).

The average slope and elevation of the Gümüşhane forests are 40% and between 190 m and 3350 m, respectively. According to Gümüşhane Meteorological Station data, while the highest temperature in the region in August is 28.6 °C (monthly average), the lowest temperature observed in January is -5.9 °C (monthly average). The annual average temperature and precipitation amounts were determined as 9.5 °C and 415 mm, respectively (Turkish State Meteorological Service, 2023). The distance between Gümüşhane Meteorological Station and sample areas is approximately 35 km.

The study area is a natural forest with the status of even-aged forests, between 100-110 years old, managed with a wood production function. The main purpose of the thinning activities applied in pure Scots pine forests is regeneration. The experimental design consists of 18 sample areas (20 m x 50 m) which have similar ecological characteristics from 20.4 ha and include three thinning intensities (weak, moderate, and strong), and two extraction techniques (cable pulling and manual skidding) with three replications for each. Half of the sample areas (9 areas) were extracted using manual skidding and for the other half (9 areas) cable pulling was used (Table 1).

Table 1: Selected site and stand characteristics of sample areas.

Tabelle 1: Ausgewählte Standorts und Bestandesmerkmale der Probeflächen.

Extraction Method	Parameters					
	Sample Point	Slope (%)	Aspect	Elevation (m)	Canopy cover (%)	Thinning Intensities
Manual Skidding	M-1	52.2	NE	1865	48	Weak
	M-2	41.4	NE	1910	21	Weak
	M-3	36.7	E	1900	46	Weak
	M-4	45.2	E	1880	56	Moderate
	M-5	40.2	NE	1920	54	Moderate
	M-6	38.3	NE	1871	53	Moderate
	M-7	46.1	NE	1860	42	Strong
	M-8	37.1	NE	1910	41	Strong
	M-9	64.3	NE	1906	62	Strong
Cable Pulling	C-1	75.0	NE	1840	27	Weak
	C-2	64.0	NE	1810	38	Weak
	C-3	45.2	NE	1847	16	Weak
	C-4	53.0	NE	1820	24	Moderate
	C-5	46.9	NE	1838	44	Moderate
	C-6	40.1	NE	1846	57	Moderate
	C-7	31.8	NE	1844	58	Strong
	C-8	30.9	NE	1835	31	Strong
	C-9	31.8	NE	1850	63	Strong

Where, E-East; NE-North East.

The average slope, elevation, and canopy of the sample areas used for manual skidding were 44.61%, 1891.33 m, and 47.00%, respectively, and those of the sample areas used for cable pulling were 46.52%, 1836.67 m, and 39.78%, respectively. A total of 131 m³ of logs was produced in the study areas, with a 90 m³ planned yield and a 41 m³ extraordinary yield (Table 1). While the skidding distance for manual skidding is 210 m downhill, it is 125 m uphill for cable pulling.

In the study, the regeneration density in the sample areas was between 52% and 84%. The damages to saplings and effects on sapling vitality of manual skidding and cable pulling by tractor extraction methods were investigated. Manual skidding was carried out by pushing/pulling movements applied directly to the logs by the workers using their hands or simple hand tools. With this method, skidding was not carried out on a fixed site but was carried out dispersedly in the forest (Figure 2a). In all sample areas, skidding operations were carried out by the same team consisting of a chainsaw operator and three forestry workers.

The cable pulling was carried out with a tractor (Figure 2b). In this method, the cable wrapped around the drum was taken by a worker to the logs located downhill and tied to the log. Then, the cable was pulled up to the side of the road, wrapping it around the drum using the tractor's engine power. Each cable pulling operation pulled one or two logs at a time. The cable pulling activities were performed by the same team consisting of a machine operator and two forest workers.

Figure 2: Manual skidding (a) and cable pulling (b) techniques.

Abbildung 2: Manuelle Rückung (a) und Rückung mit Seilzug (b).

All individuals with a stem diameter less than 8 cm were considered saplings, and the root collar diameters and lengths of the saplings were measured. All saplings in the study areas were examined, and the damage types on saplings, such as stem broken, uprooted, fallen, and broken crowns, were identified. The vitality assessment class table, which was created by Oktan (2015) by adapting the assessment scales used by Hindar *et al*. (2003), Dobbertin (2005), Martinez-Trinidad *et al*. (2010) and Rutishauser *et al*. (2011), was used for the assessment of the sapling vitality (Table 2). Saplings were divided into five vitality classes according to current status, damage rate, leaf density, leaves/needles, and crown length/height ratio in this classification. The damage levels of vitality classes, which reveal the vitality and quality of the saplings, were determined according to a scale including five damage levels ranging from very slightly damaged (1) to dead (5) individuals.

Table 2: Sapling vitality assessment classes.

Tabelle 2: Vitalitätsklassen der Jungbäume.

Parameters	Vitality Classes				
	Very slightly (1)	Slightly (2)	Moderately (3)	Severely (4)	Dead (5)
Current Status	Standing	Standing	Standing	Inclined	Dead tree
Damage Rate (%)	No Damage	< 10	10-30	> 30	Fallen
Leaf Density (%)	> 70	50-70	30-50	10-30	-
Leaves/Needles	Dark Green	Dark Green	Light Green	Light Green	-
Crown Length/Height Ratio	< 1/3	1/3 - 1/2	< 1/2	> 1/2	-

The statistical analysis of the data was performed using the SPSS 23.0 (SPSS Inc. Chicago, IL, USA) software package. The chi-square (χ^2) test was used to determine the relationship between the severity of damage and the vitality of the saplings with the applied thinning intensities, and the t-test was used to determine the relationship between the thinning intensities and the extraction technique. The existence of a statistically significant relationship between the damage types occurring on saplings and their vitality was determined using the one-way ANOVA test and the Duncan post hoc test (α=0,05).

3 Results and Discussion

We found that 157 of the 656 saplings in the study areas were stem broken, uprooted, fallen, or had broken crowns as determined by Türk and Gümüş (2015). 57.96% of the saplings damaged in all the study areas occurred, where manual skidding was used, and 42.04% in the areas, where cable pulling was used. The manual skidding of the logs was carried scattered throughout the forest, whereas the logs in cable pulling were pulled on two fixed skidding roads. This may be one reason for more sapling damage for manual skidding than that of cable pulling.

26.0% of the saplings were damaged in the areas, where manual skidding was used, and 22.76% of the saplings were damaged in the areas where cable pulling was used. Similarly, Öztürk (2009), Naghdi *et al*. (2009), and Bektaş (2011) found that the damage of ground-based skidding to saplings with machine power was 26.2%, 23.3%, and 23.0%, respectively. Mousavi Mirkala (2017) found that only 12.7% of saplings were damaged during skidding with a winch. The proportional distribution of damage types was calculated as manual skidding and cable pulling (Figure 3) used in the study.

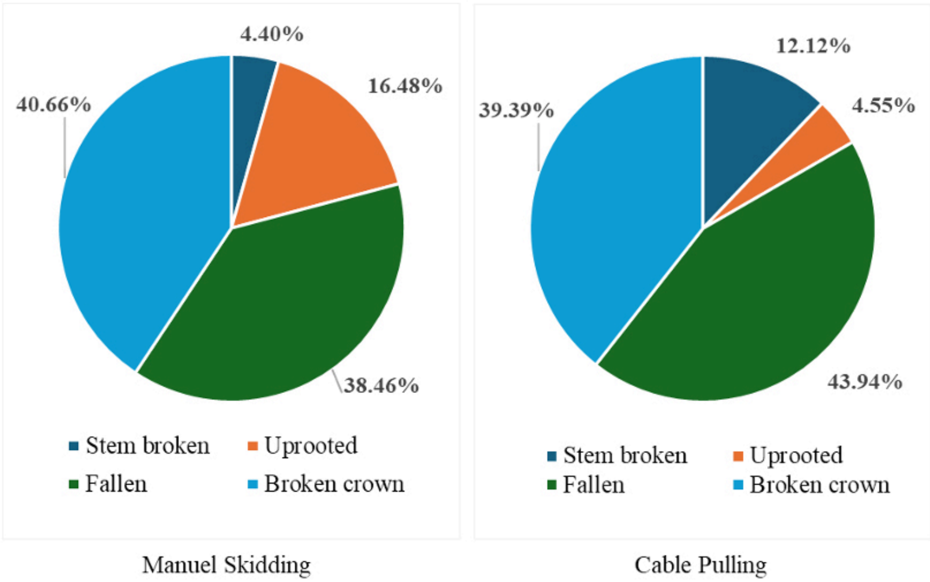

Figure 3: The proportional distributions of damage types, according to skidding techniques.

Abbildung 3: Die Anteile der Schadenstypen, unterteilt nach Rücketechnik.

Uprooted and broken crowns occurred more frequently in manual skidding activities, while stem broken and fallen saplings occurred more frequently in cable pulling activities.

Ünver-Okan (2018) determined the damages of downhill manual uncontrolled skidding activities on saplings in the spruce (*Picea orientalis*) and eastern beech (*Fagus orientalis*) forests in Trabzon region by having only strong thinning. It was determined that during manual skidding, the saplings suffered from fallen (44.0%), uprooted (21.0%), stem broken (20.0%), and broken crowns (15.0%).

The proportional distribution of damaged saplings according to the extraction techniques and thinning intensities is given in Figure 4.

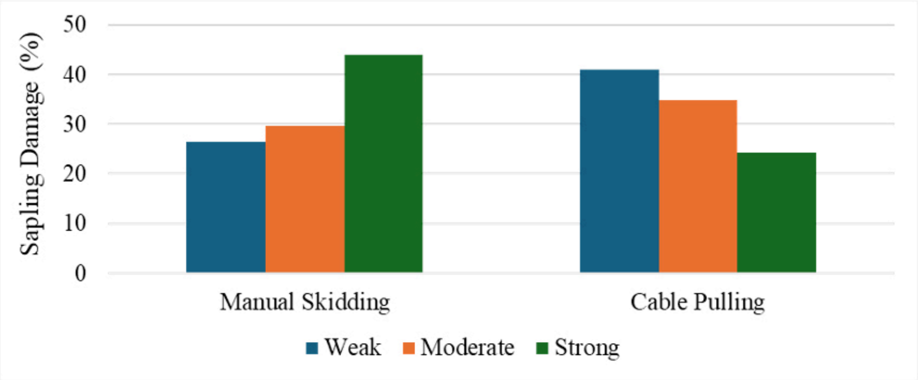

Figure 4: The distribution of sapling damage according to skidding techniques and thinning intensities.

Abbildung 4: Verteilung der Schäden an Jungbäumen, unterteilt nach Rücketechnik und Durchforstungsintensität.

While the most damage to saplings occurred in strong thinning (43.96%) in the manual skidding method, it occurred in weak thinning in cable pulling (40.91%). The lowest sapling damage in manual skidding and cable pulling methods occurred in weak thinning (26.37%) and strong thinning (24.24%) applications. The high damage to saplings may be due to the harvesting of large-scale dead or dying individuals in weak thinning, while in strong thinning it may be caused by the transportation of a large number of individuals in the stand that is now in the regeneration section.

The proportional distributions of the damage types in saplings were determined based on the thinning intensities applied in maintenance areas where manual skidding was used and where cable pulling was used (Figure 5).

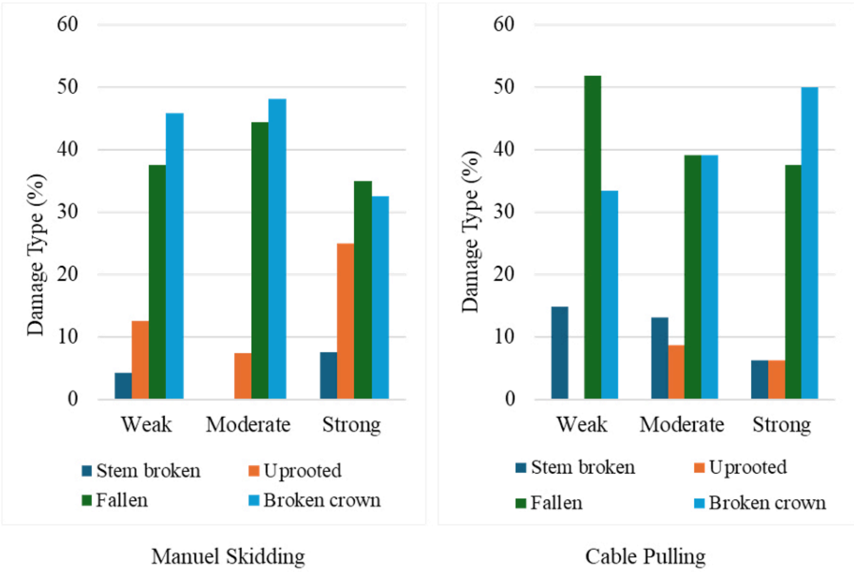

Figure 5: The distribution of damage type in areas using manual skidding and cable pulling according to thinning intensity.

Abbildung 5: Verteilung der Anteile der Schadenstypen, unterteilt nach Rücketechnik und Durchforstungsintensität.

As seen in Figure 5a, the damage to the saplings occurred during manual skidding at similar rates in weak (26.37%) and moderate (29.67%) thinning, and higher in strong thinning (43.96%). The most common damage types in saplings were observed in weak (48.15%) and moderate (37.50%) thinning, as broken crowns and fallen (35.00%) in strong thinning. The least damage occurred as stem broken (4.17%, 0.0%, and 7.50%) in all three thinning intensities.

Using cable pulling, the amount of damage to the saplings in maintenance areas where weak, moderate, and strong thinning was applied was 40.91%, 34.85%, and 24.24%, respectively (Figure 5b). The most common damage types on saplings in weak, moderate, and strong thinning were determined to be fallen (51.85%), broken crown and fallen (39.13%), and broken crown (50.00%), respectively. In addition, the lowest rate of damage was determined in uprooted at all thinning intensities. The thinning intensities determined uprooted damage rates as 6.25%, 8.70%, and 0.00%, respectively.

A total of 656 saplings were identified in the sample areas. A graph of the distribution of root collar diameters and sapling heights of damaged saplings was drawn according to their viability classes (Figure 6).

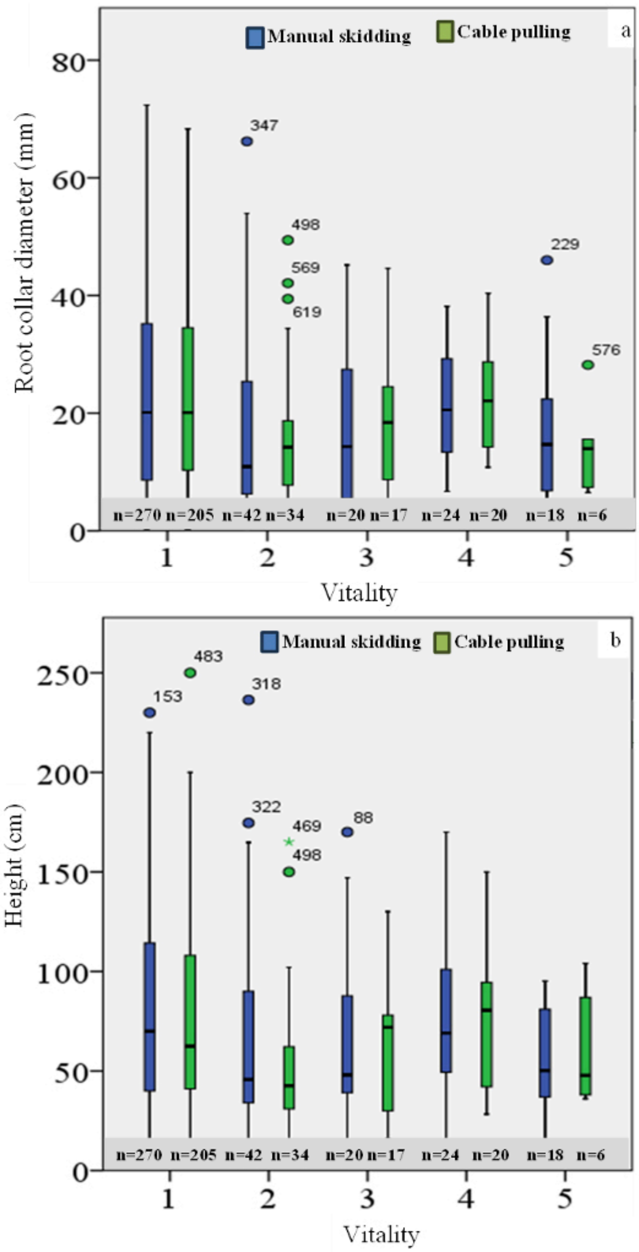

Figure 6: The distribution of sapling vitality according to root collar diameter (a) and height (b) of saplings.

Abbildung 6: Verteilung der Jungbaumvitalität, abhängig von Wurzelhalsdurchmesser (a) und Höhe (b) der Jungbäume.

As seen in Figure 6, the root collar diameters of the saplings in the sample areas range from 0.30 mm to 72.36 mm ($\bar{x}$ = 21.66, σ = 15.60) and their heights range from 5 cm to 250 cm ($\bar{x}$ = 76.16, σ = 49.37). In the study, the vitality classes of saplings in maintenance areas ranged from 1 to 5 ($\bar{x}$ = 1.56, σ = 1.06). Vitality class-1, which represents healthy saplings in this classification, was not taken into account in the evaluation of the vitality of damaged saplings. The proportional distributions of sapling vitality classes according to the thinning intensities in maintenance areas where manual skidding was used and where cable pulling was used are given in Figure 7.

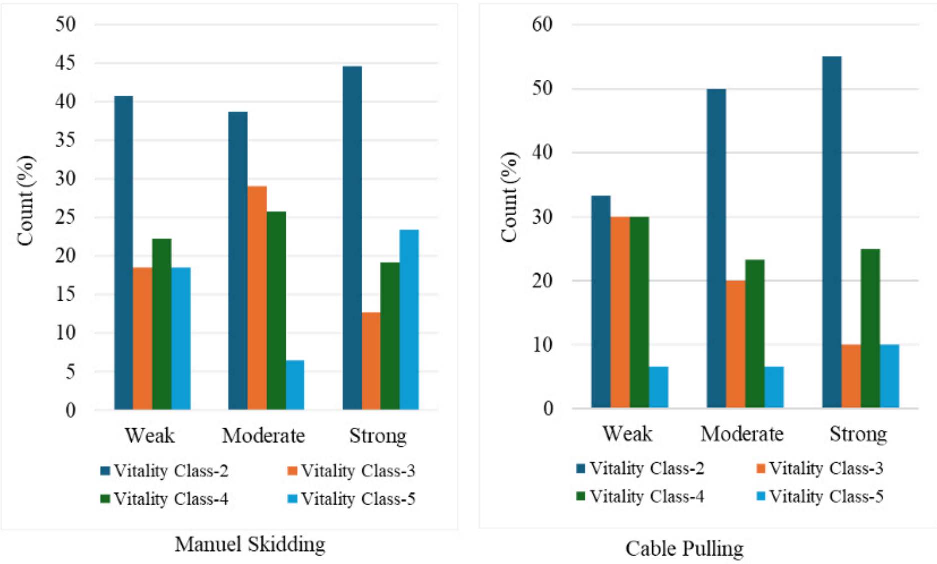

Figure 7: The distribution of sapling vitality classes according to thinning intensities in areas using manual skidding and cable pulling.

Abbildung 7: Verteilung der Jungbaumvitaltität, unterteilt nach Durchforstungsintensität und Rücketechniken.

As seen in Figure 6a, the majority of saplings were in vitality class 2 at all thinning intensities in areas where manual skidding was used. The least number of saplings was determined in vitality class 3 for weak and strong thinning, while it was determined in vitality class 5 for moderate thinning.

As seen in Figure 6b, the majority of saplings were in vitality class-2 in all thinning intensities in areas where cable pulling was used, while the least number of saplings were in vitality class-5 in weak and moderate thinning, and in vitality class-3 in strong thinning.

4 Statistical Analyses

As a result of the Chi-square (χ^2) test, it was found that there were significant relationships between thinning intensities and damage types (χ^2 = 60401, df = 3, $p < 0.05$), and between thinning intensities and sapling vitality (χ^2 = 18.873, df = 3, $p < 0.05$). Cross tables were created to identify the reasons for the statistical relationships between thinning intensities and damage types and between thinning intensities and sapling vitality (Table 3, Table 4).

Table 3: Cross table for thinning intensities and damage types.

Tabelle 3: Kreuztabelle der Durchforstungsintensität und Schadentypen.

Thinning Intensities	Damage Types			
	Stem Broken	Uprooted	Fallen	Broken Crown
Weak	5	3	23	20
Moderate	3	4	21	22
Strong	4	11	20	21
Total	12	19	64	64

As seen in Table 3, 81.50% of the damage to the saplings according to the thinning intensities occurred in the form of fallen and broken crowns. Additionally, it was determined that these damage types had a homogeneous distribution based on thinning intensities (Table 4).

Table 4: Cross table for thinning intensities and sapling vitalities.

Tabelle 4: Kreuztabelle der Durchforstungsintensität und Jungbaumvitalität.

Thinning Intensities	Sapling Vitalities			
	2	3	4	5
Weak	17	13	15	6
Moderate	20	13	13	4
Strong	22	7	15	12
Total	59	33	43	22

Table 4 showed that 64.78% of the saplings were in vitality classes 2 and 4 according to the thinning intensity, and these vitality classes were homogeneously distributed.

As a result of the one-way ANOVA test, it was determined that there was a significant relationship between damage types and sapling vitality (df = 3, F = 33.909, $p < 0.05$). Duncan's post-hoc test was used to reveal the reason for this result (Table 5).

Table 5: Duncan's post-hoc test result.

Tabelle 5: Duncans Post-hoc-Testergebnisse.

Vitalities	Unit (N)	Damage Types		
		1	2	3
2	59			3.644
3	33		3.273	
4	43		2.954	
5	22	1.909		

As a result of the Duncan post-test, it was determined that the stem broken and fallen damages were similar in terms of sapling vitality, while the broken crown and uprooted damages were different. As a result of the applied t-test, it was determined that there was a statistically significant relationship between the thinning intensities and the extraction techniques (t = 35.940, df =156, $p < 0.05$).

Regardless of thinning intensities, manual skidding techniques should be avoided in equal-aged, normally closed, pure Scots pine stands where the number of saplings is less than 1 per square meter. Instead, tractors should be used when the skidding distance is suitable, and if the skidding distance is high, aerial systems should be used.

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Authors' Contributions

Saliha Unver: Conceptualisation, Methodology, Data curation, Formal analysis, Investigation, Writing – original draft, Project administration, Supervision. Ercan Oktan: Conceptualisation, Methodology, Data curation, Investigation, Writing – review & editing.

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