Lodgepole pine – stability after thinning

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Supervisors: Eric Agestam, SLU Magnus Andersson, SCA Skog AB

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Master Thesis no. 146
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ABSTRACT

SCA has today almost 300 000 hectares of their forest land planted with lodgepole pine (*Pinus contorta var. latifolia*). Due to initial extensive planting in the 1970ies the area of lodgepole pine forests in the thinning age has grown rapidly from the end of the 1990ies.

During the years 1996-2005 first commercial thinning of lodgepole pine at SCA took place. The goal of the hereby presented study was to investigate the growth and stability in those firstly-thinned lodgepole pine stands a few years after thinning. Furthermore, the objective was to investigate the relationship between stand stability and different stand parameters. Additionally, lodgepole pine stem quality was estimated.

The study is mainly based on the data collected during an inventory project carried out at SCA in 2008. Altogether 91 lodgepole pine stands in northern Sweden were measured after the first thinning. Since the same stands were inventoried in 2004 and 2005, chosen results such as thinning grade, strip-road width and the distance between strip roads were used as additional data in correlation matrix.

It was found that:

- The average volume of dead trees in the inventoried 91 lodgepole pine stands was 3,8 m^3sk/ha being equal to 2,3 % of the standing volume at the time of the inventory.
- In terms of the number of trees, dead trees formed on average 3,9 % of the total number of inventoried lodgepole pine trees.
- No correlation between the volume of dead trees and soil type, soil moisture, stands dominant slope or stands dominant height above sea level was found. The share of the number of dead trees gave similar results. However, a positive and significant correlation between the share of the number of dead trees and soil moisture was found indicating higher risk for damages on wet soils than on dry soils.
- Risk for mortality after thinning increases in stands thinned at larger dominant height, stands with high thinning grade and wide strip-roads.
- No clear relation between types of dead trees and their distance to the closest trip-road centre was found.
- 49 % of measured stems were estimated to have sawn-timber quality. The most frequent defect types were long crook and spike knot.

Keywords: lodgepole pine, quality, stability, wind- and snow damages, thinning

SAMMANFATTNING

Idag äger SCA nästan 300 000 hektar av skogsmark som är planterad med contorta tall (*Pinus contorta var. latifolia*). På grund av omfattande planteringar på 1970-talet har arealen av gallringsmogen contorta skog ökat fort från och med slutet av 1990-talet.

De första contorta bestånden gallrades på SCA mellan 1996 och 2005. Målet med denna studie var att undersöka tillväxt och stabilitet i de förstagallrade contorta bestånden några år efter gallring. Dessutom var målet att undersöka sambandet mellan bestånds stabilitet och olika beståndsparametrar. Förutom det bedömdes kvalitet av kvarvarande stammar.

Studien baserar främst på data som samlades under ett inventeringsprojekt på SCA 2008. Inventeringen omfattade 91 förstagallrade contorta bestånden i norra Sverige. Eftersom samma bestånd inventerades 2004 och 2005 användes vissa resultat som gallringsgrad, stickvägsbredd och stickvägsavstånd som ytterligare data i korrelationsmatrisen.

Resultat:

- Medel avgångsvolym i de inventerade 91 contorta bestånden var 3,8 m^3sk/ha som är lika med 2,3 % av den stående volymen vid inventeringstillfället.
- I relation till antal träd utgjorde avgångsträden 3,9 % av det totala antalet inventerade contorta träden.
- Inget samband mellan avgångsvolym, jordtyp, markfuktighet, beståndens medelterränglutning eller höjd över havet hittades. Proportion av antal avgångsträd från totala antalet träd gav likadant resultat men positiv och signifikant korrelation till markfuktighet hittades som tyder på högre avgångsrisk på fuktiga jordar än på torra jordar.
- Avgångsrisken är större om man gallrar vid högre övre höjd, med större gallringsuttag och breda stickvägar.
- Inget samband mellan avgångsorsak och avstånd mellan avgångsträd och närmaste stickväg hittades.
- 49 % av inventerade contorta stammar bedömdes ha sågtimmerkvalitet. Främsta orsakerna bakom dålig kvalitet var långkrök och spröt.

Nyckelord: contorta tall, stabilitet, kvalitet, vind- och snöskador, gallring

KOKKUVÕTE

1970ndatel aastatel algas SCAs laiaulatuslik metsamaade uuendamine keerdokkalise männiga (*Pinus contorta var. latifolia*). Harvendusraie-ealiste puistute pindala on seetõttu alates 1990ndate aastate lõpust pidevalt suurenenud, praeguseks on keerdokkalist mändi istutatud 300 000 hektarile.

Aastatel 1996-2005 viis SCA istutatud keerdokkalise männi puistutes läbi esimesed harvendusraied. Käesoleva magistritöö eesmärgiks oli hinnata harvendatud puistute suremust tormi- ja lumekahjustuste tõttu mõned aastad pärast harvendusraiet. Lisaks uuriti suremuse ja erinevate kasvuparameetrite suhet, samuti anti hinnang puistus kasvavate puude tüvekvaliteedile.

Lõputöö põhineb peamiselt 2008. aastal SCAs läbiviidud projekti raames kogutud andmestikul ning hõlmab 91 esimesena harvendatud 27 kuni 42aastast keerdokkalise männi puistut Põhja-Rootsis. Samad puistud inventeeriti varasemalt aastatel 2004-2005, seetõttu kasutati käesolevas töös osaliselt eelmisest inventeerimisest saadud andmeid (harvenduskraad, väljaveoteede keskmine laius ja vahemaa väljaveoteede vahel), mis vastandati suremusele peale harvendusraiet korrelatsiooni maatriksis.

Käesoleva töö tulemusena leiti:

- Keskmine suremus peale esimest harvendust oli 91 mõõdetud keerdokkalise männi puistus 3,8 m^3/ha, mis moodustab 2,3 % kasvava metsa mõõtmisteaegsest tagavarast.
- Kogu mõõdetud keerdokkalise männi puude arvust moodustasid surnud puud 3,9 %.
- Surnud puude tagavara, mulla tüübi ja mulla niiskuse, puistu kallaku ega puistu kõrguse vahel merepinnast olulist seost ei leitud. Sarnased tulemused saadi, analüüsides surnud puude arvukuse osakaalu kogu mõõdetud puude arvust. Erinevus ilmnes vaid mulla niiskuse puhul, mis viitab puude suuremale suremuse riskile mulla niiskuse suurenedes.
- Suremuse risk peale esimest harvendusraiet oli suurim puistutes, mis harvendati suurema puude ülemise kõrguse juures, suure harvenduskraadiga ja laiade väljaveoteede puhul.

- Puude suremuse tüübi (seisev surnud puu, kaldus, ümber kukkunud puu, murdunud tüvi, murdunud latv) ja nende kauguse vahel väljaveoteest ei leitud olulist seost.
- 49 % mõõdetud kasvavate keerdokkalise männi tüvedest hinnati olevat saepuidu kvaliteet. Sagedaseimad defektid olid kõveratüvelisus ja tuliokste esinemine.

Võtmesõnad: keerdokkaline mänd, stabiliteet, kvaliteet, tormi- ja lumekahjustused, harvendusraie

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The thesis is based on a project carried out at SCA Skog AB. I am very grateful to Magnus Andersson, my supervisor at SCA, for all his help and ideas concerning methodology of field work and presentation of results.

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Introduction

Pinus contorta

Pinus contorta is a native species of western North America and exceptional for its wide growing range. Contorta's north to south range (figure 1) is from about 37° (31° at one location in Baja California) to about 64° and south-east range from the Pacific Coast to the Black Hills of South Dakota (Koch, 1996). That makes it one of the major timber types of North America occupying about 6 million ha of commercial forest land in the United States of America and about 20 million ha in the western Canada (Koch, 1996). Elevational range of pinus contorta reaches from sea level up to 3900 m above sea level (Segebaden, 1992; Koch, 1996).

Figure 1. Pinus contorta's growing range in North America (Little, 1971).

Pinus contorta has three varieties (table 1) of which subspecies *latifolia* is the dominant resource in North America (Koch, 1996) and has the common name lodgepole pine.

Table 1. Varieties of pinus contorta (Koch, 1996).

Variety	Name in Latin	Range
1) Shore pine	*Pinus contorta* Loud var. *contorta*	Pacific coast
2) Sierra lodgepole pine	*P. contorta* var. *murrayana* Engelm.	Southern Cascades, Sierra Nevada, the mountains of southern Baja California
3) Lodgepole pine	*P. contorta* var. *latifolia* Engelm.	Rocky Mountains and Intermountain regions, northern Cascades in Washington
+ Boulanderi (a shrub)	*P. contorta* var. *boulanderi* (Parl.)	Mendicino White Planes along the northern California coast

Pinus contorta with its fast growth even on poor soils and good survival in hard climate conditions has become of interest to many countries in which it is not a native species. It was introduced in Great Britain in the middle of 19th century and the first experimental plantations in Scandinavia were established in Finland in 1910 (Norgren & Elfving, 1995). There are plantations of pinus contorta in Ireland, Denmark, Island and New Zealand (Elfving et al, 2001). The oldest lodgepole pine stands in Sweden stem from 1928 and until the end of 20th century about 600 000 hectares (Elfving et al, 2001) of lodgepole pine forests were planted in Sweden – the largest area of lodgepole pine plantations in the whole world (Hagner, 2005). Lodgepole pine accounts for approximately 0,6 % of the total growing stock of forest land in Sweden (Skogsstyrelsen, 2007). Experimental plantations on a smaller scale have been established also in other countries, e.g. Estonia where it was for example used to reforestate exhausted oil shale opencast mines (Kuznetsova & Mandre, 2005). Lodgepole pine plantations outside North America are subject to intensive silviculture and are both technically practical and economically efficient while in North America where the species is native the management has typically been very low in intensity or absent (Koch, 1996).

Importance of lodgepole pine - SCA

In Sweden, in the middle of 1950ies, forest companies set their goals to strive for increased growth and production of forests leading to higher incomes. This resulted in a growing interest in introducing fast growing exotic species like lodgepole pine (Hagner, 1983; 2005). One of the leading companies in large-scale lodgepole pine plantation was Swedish Cellulose Company (SCA), founded in 1929 and has since then developed from a pure forest company to a company that also offers personal care products, tissue and packaging. SCA Forest owns totally 2,6 million hectares forest (SCA, 2009). For the company introduction of the exotic species meant also a solution to the problem of timber shortage that was predicted for the beginning of the 21st century (Segebaden, 1992; Hagner, 2005).

At the early stages of introduction, lodgepole pine was initially planned to be managed without thinning (Persson, 1995). The idea was to minimize rotation period by 25-50 years (Hagner, 1983) compared to Scots pine (*Pinus sylvestris* L.). Lodgepole pine pulpwood can be mixed with Scots pine to produce chemical pulp and with Norway spruce (*Picea abies* (L.) Karst.) to produce paper (Hagner, 2005). Already during the 1970ies studies showed that lodgepole pine timber was similar to Scots pine at sawing and impregnating (Hagner, 2005) which increased the interest of thinning lodgepole pine stands in order to produce sawn timber.

SCA has today according to Persson (2008) almost 300 000 hectares (14%) of their forest land planted with lodgepole pine. Due to initial extensive planting in the 1970ies (Hagner,

2005) the area of lodgepole pine forests in the thinning age has grown rapidly from the end of 1990ies.

Lodgepole pine – growth and yield

Limited knowledge of lodgepole pine silviculture and management has triggered many scientific investigations among which was the selection of proveniences with best survival at the plant stage (Karlman, 1981; Elfving et al, 2001; Hagner, 2005). Studies have shown that lodgepole pine produces 30 – 50 % more volume compared to Scots pine (Martinsson, 1983; Norgren & Elfving, 1995; Elfving et al, 2001; Dermer, 2007; Persson, 2008). The most frequent defects are spike knots and crooks (Dermer, 2007).

Damages

In Sweden the comparisons of lodgepole pine and Scots pine indicate also that the exotic species has up to 50% (Andersson et al, 1999) higher mortality after first thinning mainly due to wind and snow damages (Norgren & Elfving, 1995; Elfving et al, 2001). Lower stability can be caused by the fact that lodgepole pine allocates smaller amount of biomass to the stem than to the crown and the wood of stem and branches is more elastic (Norgren & Elfving, 1995; Rosvall & Ericsson 1998; Elfving et al, 2001). Another factor influencing the species' stability is the establishment method. In naturally regenerated lodgepole pine stands where trees have larger chance to get a symmetric and well-anchored root system they are considered to be much more stable (Eriksson, 1989; Rosvall, 1994). Containerized seedlings with deformed roots in combination with fast juvenile growth lead to unbalance between the root and the stem (Martinsson, 1983; Rosvall, 1998; Elfving et al, 2001). It is found that lodgepole pine plants' stability depends even on soil scarification method (e.g. Matsson & Bergsten, 2003) where plants established on scarified soil are more stabile than plants on unscarified soils (Håkansson & Lindström, 1994). Trees with lower quality (basal crook, double top etc.) and trees growing on fine textured and wet soils are considered to be prone to damage from snow and wind (Rosvall, 1994; Rosvall & Ericsson, 1998; Rune & Mattson, 1998).

There is a number of factors that directly or indirectly affect stand stability such as weather (wind, precipitation, temperature), topography, location, soil (soil type, depth, moisture), stands characteristics (tree species, age, height, number of stems per hectare), silvicultural treatments (choice of species, planting density, pre-commercial thinning, thinning, fertilization, final felling, choice of reforestation method, drainage), time of the year (season), etc. (Persson, 1975; Blomgren, 2006; Valinger et al, 2006).

Thinning of lodgepole pine

Thinning is an important silvicultural treatment that supplies SCA with approximately 15-20% of annual timber consumption (SCA Skog, 2008). Thinning aims towards better economy by increasing dimensions of the remaining trees, avoiding self-thinning, promotion of trees with best quality, affecting tree-species mixture, reducing final-felling costs and giving incomes and timber early at the rotation period (Wallentin, 2007). However, thinning may not favour future growth and can be perceived as a disturbance mainly during the first years after thinning when trees are more sensitive to wind and snow damages before they adjust to new conditions such as more space for roots and crown etc (Persson, 1975; Blomgren, 2006). There is a higher risk for wind and snow damage after every thinning operation and the risk increases with higher thinning grade especially in stands with larger dominant height (Persson, 1975). Strip-road system might increase the risk for wind and snow damages by creating openings in the stand (Persson, 1975; Blomgren, 2006). The susceptibility to wind and snow damages is higher in thinning of stands with large density (Whitehead, 2001).

Forest owners believe that heavy storms have become more frequent throughout the years. This observation can be explained by the fact that the standing volume and forest area have lately increased and therefore the risk for wind damages has become higher (Petersen, 2006).

The overall scope of this study

During the years 1996-2005 first commercial thinning of lodgepole pine at SCA took place. The goal of the hereby presented study was to investigate the growth and stability in those firstly thinned lodgepole pine stands a few years after thinning. Furthermore, the objective was to investigate the relationship between stand stability and different stand parameters. Additionally, lodgepole pine stem quality was estimated.

The study is mainly based on the data collected during an inventory project carried out at SCA in 2008. Altogether 91 firstly-thinned lodgepole pine stands were measured. Since the same stands were inventoried in 2004 and 2005, chosen results such as thinning grade, strip-road width and the distance between strip roads were used as additional data in correlation matrix.

In the study following hypotheses were tested:

- lodgepole pine stands growing on moist fine-textured soils, steep slopes and located higher up above sea level have lower stability than lodgepole pine stands growing on dry core-textured soils, plain terrain and on lower heights above sea level;
- stands thinned at larger dominant height, stands with higher thinning grade, wider strip roads and shorter distance between the strip roads run a higher risk of damage than stands with parameters of opposite values;
- trees located closer to the strip-road edges are more vulnerable than trees growing further from the strip-roads;
- considerable share of lodgepole pine trees have defects and cannot be used as sawn timber.

Materials and methods

Data collected in 2008

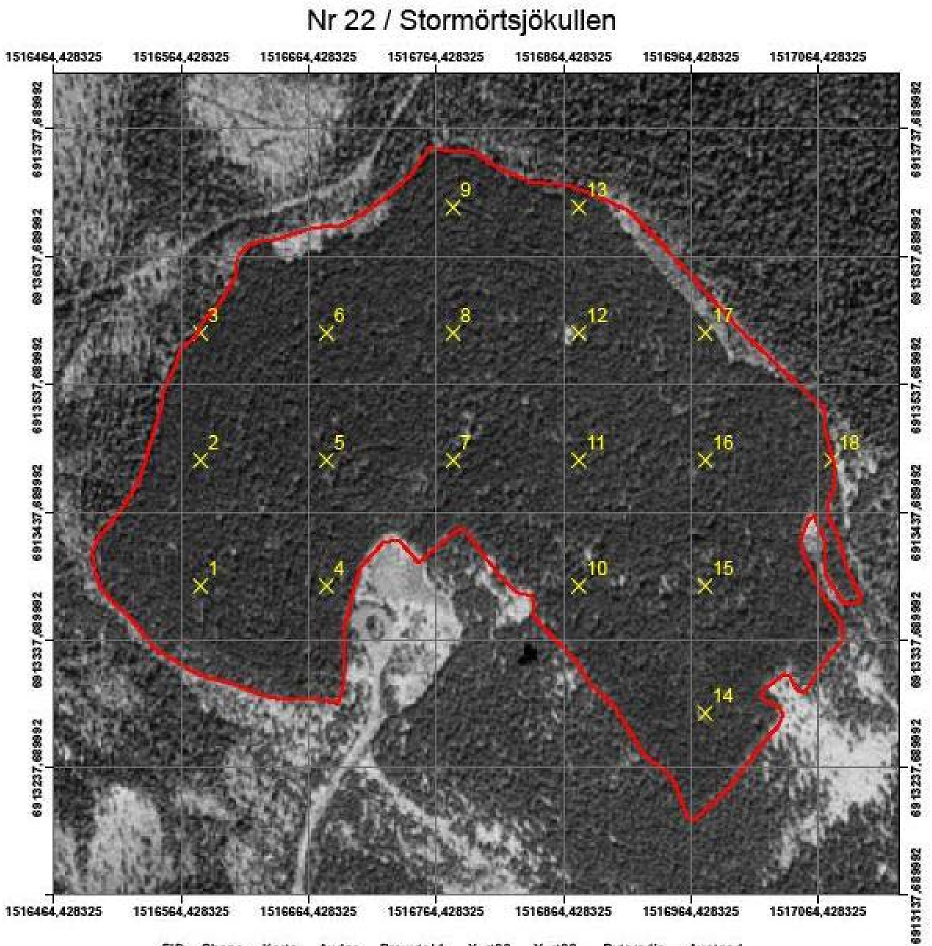
The thesis is based on a project carried out at SCA Skog AB in northern Sweden. Altogether 91 lodgepole pine stands were inventoried after the first thinning. The stands were thinned during a period 1996-2005. 60 of the objects are located in Medelpad, 28 in Jämtland and 3 in Ångermanland forest district. Division of the inventoried stands between different thinning years is given in table 2.

Table 2. Thinning year and the number of years between thinning and inventory of the inventoried lodgepole pine stands.

Thinning year	Number of years between thinning and inventory	Number of stands
1996	12	1
1997	11	1
1999	9	2
2000	8	1
2001	7	5
2002	6	4
2003	5	22
2004	4	45
2005	3	10
		Total: 91

Data collection was based on circular sample plots which were laid out systematically with a randomly chosen start point. An application to ArcGIS was used in order to create a map with sample plot layout and coordinates for each object (figure 2).

A GPS-receiver and a navigation tool in the digital calliper were used in order to locate the centre of sample plots, based on the coordinates from the field map.



FID	Shape	Karta	Avdnr	Provyteld	X_rt90	Y_rt90	Pyteradie	Avstand
0	Punkt	1	1	1	6913379	1516580	7,98	99
1	Punkt	1	1	2	6913478	1516580	7,98	99
2	Punkt	1	1	3	6913577	1516580	7,98	99
3	Punkt	1	1	4	6913379	1516679	7,98	99
4	Punkt	1	1	5	6913478	1516679	7,98	99
5	Punkt	1	1	6	6913577	1516679	7,98	99
6	Punkt	1	1	7	6913478	1516778	7,98	99
7	Punkt	1	1	8	6913577	1516778	7,98	99
8	Punkt	1	1	9	6913676	1516778	7,98	99
9	Punkt	1	1	10	6913379	1516877	7,98	99
10	Punkt	1	1	11	6913478	1516877	7,98	99
11	Punkt	1	1	12	6913577	1516877	7,98	99
12	Punkt	1	1	13	6913676	1516877	7,98	99
13	Punkt	1	1	14	6913280	1516976	7,98	99
14	Punkt	1	1	15	6913379	1516976	7,98	99
15	Punkt	1	1	16	6913478	1516976	7,98	99
16	Punkt	1	1	17	6913577	1516976	7,98	99
17	Punkt	1	1	18	6913478	1517075	7,98	99

Figure 2. Example of a field map with sample plots and coordinates.

Sample plots were circular with a radius of 7,98 m (200 m^2). Sample plots located on impediments, openings, close to stand borders and in unthinned parts of the stand were mirrored. Mirroring was done at a right angle or reverse to the walking direction towards a plot. In some cases mirroring was not possible due to large unthinned areas, narrow stand patches or large openings and in those cases the sample plots were skipped.

Number of sample plots and the distance between them was correlated with stand area and ranged from 6 to 19 per stand (table 3).

Table 3. Relationship between stand area, number of sample plots and spacing.

Area (ha)	No of plots	Spacing (m)
≤2	6	≤60
4	8	70
6	10	80
8	12	80
10	14	80
12	15	90
14	16	90
16	17	100
18	18	100
≥20	19	≥100

Digital calliper (Digitech Professional) was used to measure stand parameters and register the data on each plot. Values for the different stand parameters on stand level were calculated as the average from plots. At each plot following parameters were measured and calculated:

- Basal area (standing at the time of inventory) – based on measured diameters at breast height. Dead trees and trees assumed to die in the short run were not included (e.g. broken or heavily leaning trees). Trees that had breast height diameter <8 cm were not measured.
- Basal area removed at thinning – based on measured stump diameters 10 cm over ground as follows:

Diameter at breast height (**Dbh**) was calculated with a method from the Swedish National Forest Inventory (Westerlund, personal comment):

Dbh = **A** + **B***__sDia__ + **C***__sDia__*__sDia__ + **D***log(**sDia**) + **E** + **F**

sDia – stump diameter, cm

A = 51.880901;

B = 1.019230;

C = -0.000108;

D = -25.024839;

E = 0.064956*Latitude;

F = -0.011649*Distance to the coast.

- Basal area of dead trees after thinning – dead trees were defined as trees that died or trees that were assumed to fall out in the short run (assumption was subjective and based on the damage grade such as leaning angle or the amount of vital crown). Diameters of dead trees at stump height (10 cm over ground) were measured. The calliper estimated diameters at breast height and calculated basal area as above.
- Volume for all trees was calculated. First height was calculated. On each plot heights were measured for two systematically sampled trees per plot – two last measured trees on the plot. Heights for all trees (also those only callipered) were calculated from the relation between diameters with a method by Bergstrand (1980).

Height = (**K1** + **K2*****LOG**(**D**) + **K4*****H25** + **K3*****H25*****LOG**(**D**))

where:

H25 = Hbw - (K1 + K2*LOG(Dbh) / (K3*LOG(Dbh) + K4)

H25 - height of a tree with Dbh of 25cm, m

Dbh – mean diameter at breast height of sample trees, cm

Hbw– basal-area-weighted average height of sample trees (Loreys mean height)

D – diameter of trees without height, cm

K1 = 1,518;

K2 = -1,086;

K3 = 1,086;

K4 = -0,518;

LOG – logarithm with base 10.

- Volumes[1] of trees remaining after thinning (at the time of inventory), removed at thinning and dead trees were calculated based on the measured basal area and sample-tree heights. Functions for individual trees by Brandel (1990) were used.

$$\mathbf{Vol = 10^{a} * Dbh^{b} * (Dbh + 20.0)^{c} * H^{d} * (H - 1.3)^{e}}$$

[1] All volumes are given in "m^3sk" which stands for forest cubic meter standing volume (stem volume from stump to top, including bark).

Dbh – measured or calculated diameter at breast height, cm

H – Tree height, m

a = -1.20914;

b = 1.94740;

c = -0.05947;

d = 1.40958;

e = -0.45810.

- Type and cause of damage were assessed and registered for every dead tree. Since in two stands wind-damaged trees had been removed after thinning but before the inventory took place, stump diameters of these trees were registered as 'post-thinning cuttings'. Different damage types used were as follows:
    - damaged but not dead (heavily-damaged tree assumed to die in the short term, e.g. dying standing tree with heavy defoliation)
    - dead standing tree
    - heavily leaning (tree assumed to fall over in the short run due to large leaning angle, based on subjective assumption)
    - overturned
    - broken top
    - broken stem
    - post-thinning cuttings

Additionally damage cause was assessed and registered for every dead tree:

- wind
- snow
- unknown (dead tree for which the cause of damage was hard to determine)

- Distance from every dead tree to the centre of the nearest strip road was measured.
- Dominant height (Hdom) – average height of two trees with largest diameter measured with Vertex IV hypsometer and registered in the calliper. Dominant height at the time of thinning was calculated with the help of height development curves (Scots pine height development curves adjusted to lodgepole pine) (Elfving & Kiviste, 1997) using dominant height of trees at the time of thinning, site index and total age (age at breast height plus 7 years).

- Age at breast height – measured by breast-height coring of one of the dominant height trees. Number of annual rings was counted and registered in the calliper.
- Site index (SI) – calculated with the help of height development curves (Elfving& Kiviste, 1997) based on the measured dominant height and total age (age at breast height plus 7 years).
- Direction of slope – based on subjective estimation. Using a compass the elevation was determined as Northern (N), North-Western (NW), Western (W), etc.
- Soil type and moisture were determined by extracting soil samples and comparing them with the instructions by Hägglund & Lundmark, 1987.
- Stem quality of lodgepole pine trees - estimation was done on 5-meter stem height from the base of the tree. Based on the evaluated stem quality every tree was registered as either having sawn-timber or non-sawn-timber quality. Trees with non-sawn timber quality were assigned to one of the following defect category:
    - basal crook (tree with a crook on the base of the stem)
    - long crook (tree with a stem crook at least 1 m long)
    - point crook (tree with a sharp and short stem crook)
    - fork (tree with a double top or double stem higher up from the stump height)
    - double stem (tree with a double stem starting from the stump height)
    - spike knot (tree with a thick branch growing at a sharp angle)
    - bark damage (tree with a bark damage caused by bark stripping or thinning damage)

Dominant height above sea level and dominant slope in degrees for every inventoried stand were obtained from the SCA's ArcGIS database.

Additional data

The stands were also inventoried 2004 and 2005. From this inventories data about thinning grade and striproads was used.

Thinning grade – proportion of removed basal area (Ba removed/Ba before thinning). Basal area after thinning was measured with relascope and basal area removed by measuring diameter of stumps and transforming the measured diameter to breast height diameter with the method described above.

Strip-road width was measured on a 10m stretch between two trees located nearest to the strip-road edge (figure 3).

Distance between strip roads was measured between the centres of two adjacent strip roads.

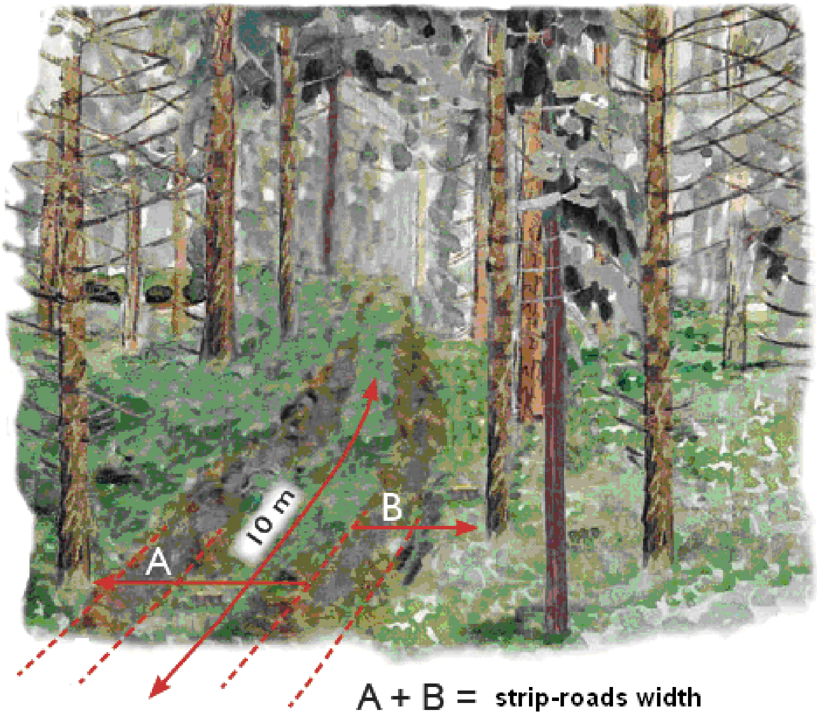


Figure 3. Strip-road width measurement in inventories done in 2004 and 2005 (SCA Skog, 2007)

Result compilation

In order to investigate the relation between the volume of dead trees, share of number of dead trees and stand parameters a correlation matrix was done using statistical program "Statistica". Significance level was set to 95% (p-value <0,05). Following variables were included in correlation matrix:

a. on the stand level: dominant slope, dominant height above sea level, time after thinning, thinning removal (basal area, volume) and dominant height of trees at the time of thinning;

b. on plot level: direction of slope, soil type and moisture;

a. 2004/05 year data on stand level: thinning grade, strip-road width and distance between the centres of strip roads.

Results

Lodgepole pine growth

All measured parameters present values 3-12 years after thinning (at the time of inventory). The main parameters describing characteristics of the inventoried stands are given in table 4.

Table 4. Mean values for different stand parameters at the time of the inventory in the 91 inventoried lodgepole pine stands. Dead trees after thinning were not included.

Stand parameter	Min	Max	Average	Unit
• dominant height	13,2	19,9	15,6	m
• age at breast height	20	35	26	years
• site index	C28	C32	C30	H100,m
• basal area after thinning	12,0	37,8	20,5	m^2/ha
• basal area removed at thinning	2,9	14,4	8,9	m^2/ha
• standing volume after thinning	89,0	359,0	152,1	m^3sk/ha
• volume removed at thinning	22,0	101,0	59,7	m^3sk/ha

Large variation in total production in the inventoried lodgepole pine stands (figure 4) is partly due to varying total age of stands ranging from 27 to 42 years (average 33 years).

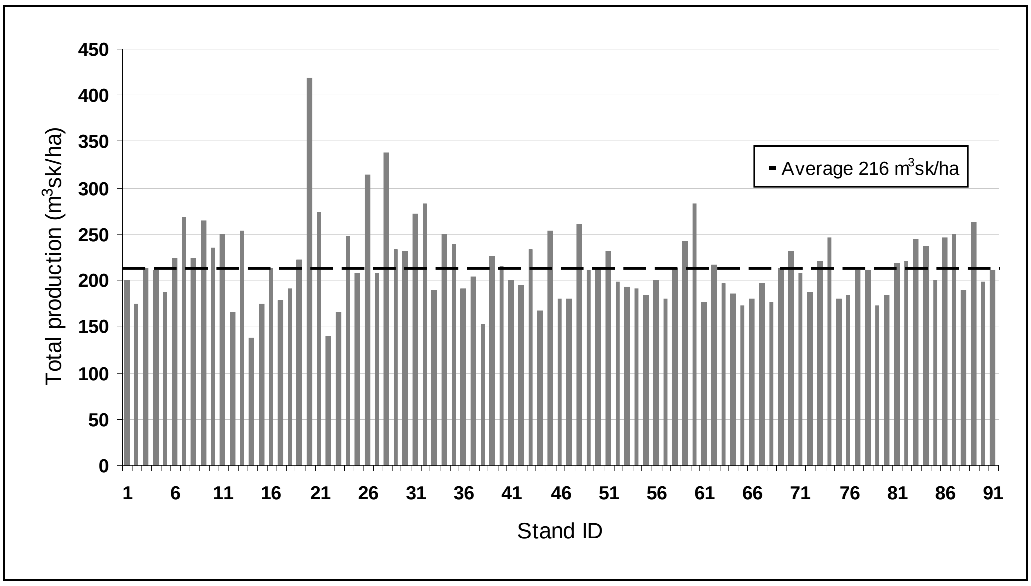


Figure 4. Total production in the inventoried lodgepole pine stands (sum of standing volume at the time of inventory, volume of trees taken out at thinning and volume of dead trees).

Mean annual increment equalled 6 m^3sk/ha/year and a large variation between stands can be seen (figure 5).

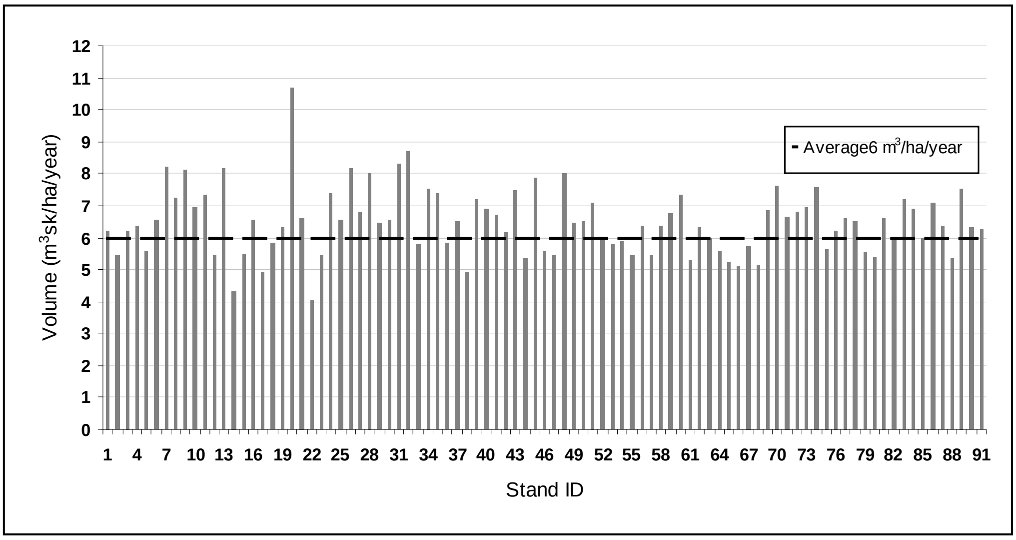


Figure 5. Mean annual increment in the inventoried lodgepole pine stands (calculated as the total production divided by the total age).

Mean annual increment in different age classes in inventoried stands is presented in figure 6.

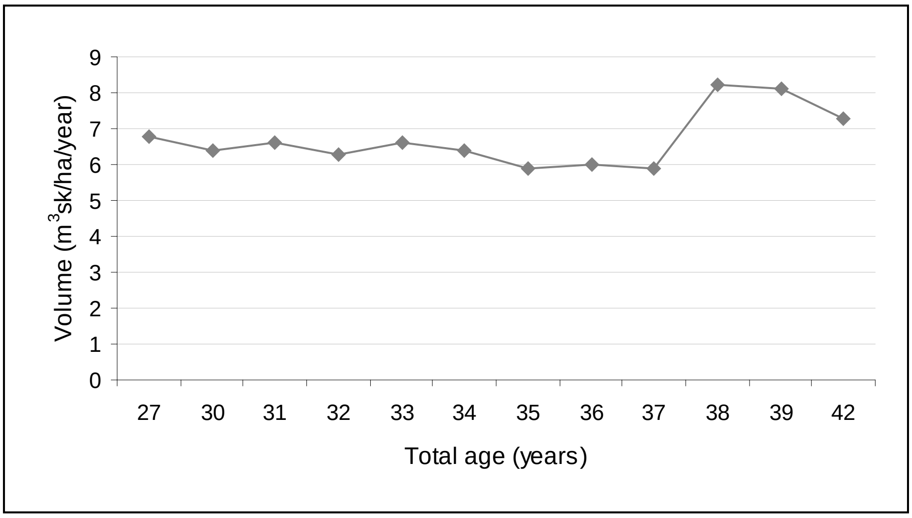


Figure 6. Mean annual increment in the inventoried lodgepole pine stands per age class.

Stability after thinning

Amount of damages

Average share of the number of dead trees from the average number of measured lodgepole pine trees per hectare in each inventoried stand is presented on figure 7. The average share of number of dead trees for all stands was 3,9 %.

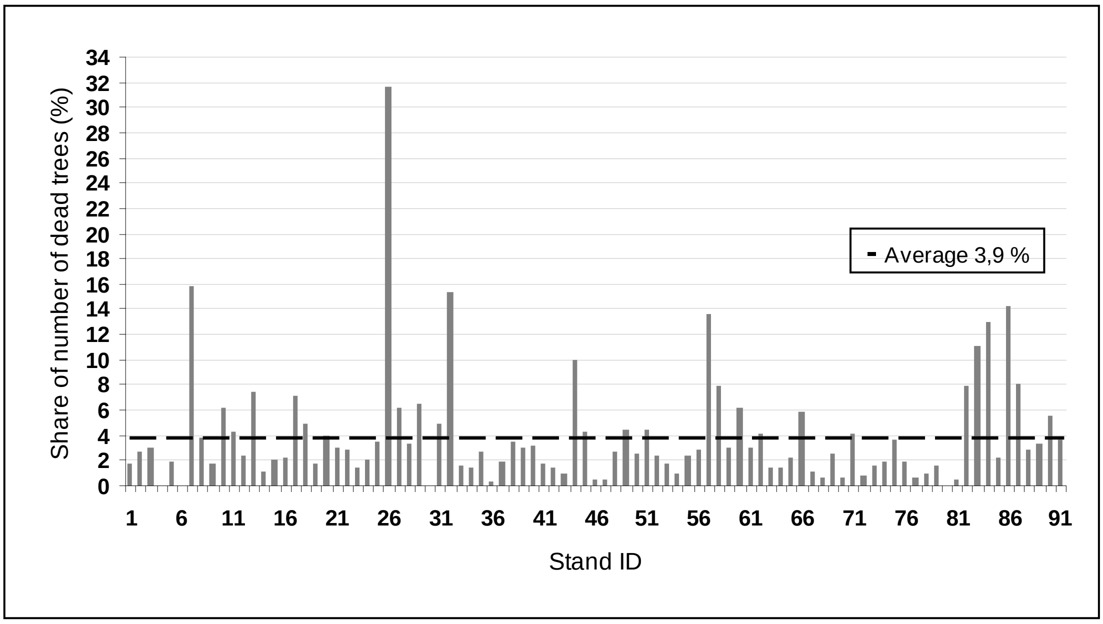


Figure 7. Share of number of dead trees of the total number of inventoried lodgepole pine trees per hectare.

Average standing volume after thinning in the inventoried lodgepole pine stands at the time of inventory was 152,1 m^3sk/ha and the average volume of dead trees 3,8 m^3sk/ha (2,5%). Volume of dead trees on the stand level is given in figure 8.

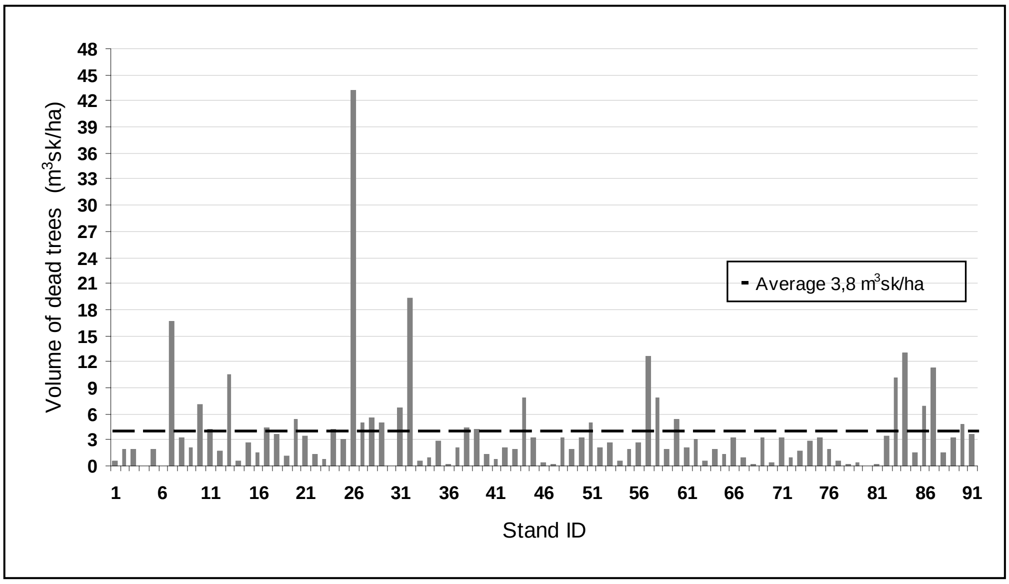


Figure 8. Volume of dead trees per hectare on the stand level.

Viewing the amount of dead trees as the share of standing volume at the time of inventory, the average proportion of dead trees was found to be 2,3 % (figure 9).

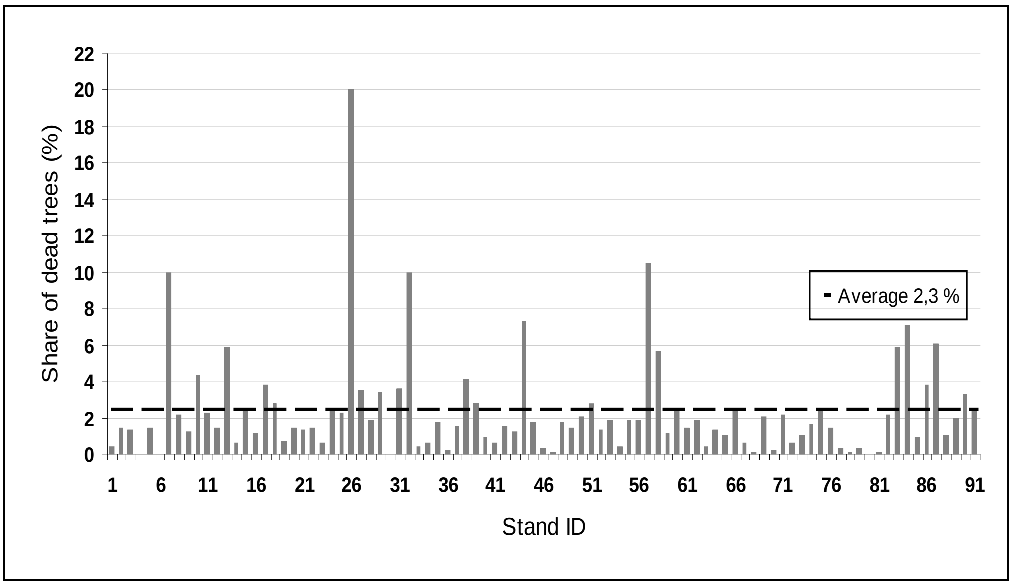


Figure 9. Volume of dead trees as a share of standing volume at the time of inventory.

Average share of dead trees as the percent of total production equalled 1,6 % (figure 10).

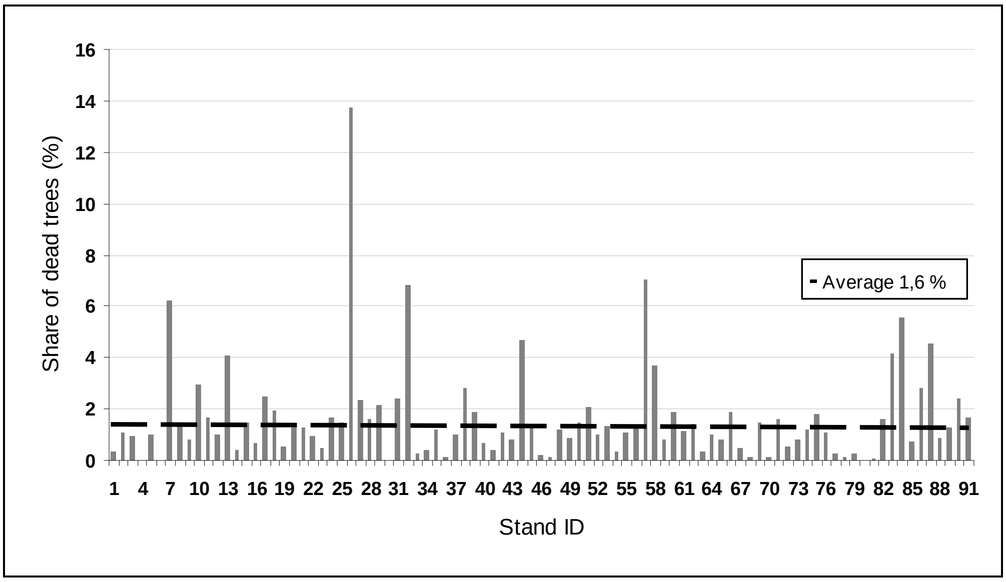


Figure 10. Volume of dead trees as a share of total production.

Size of dead trees

Volume of dead trees (per tree) varied from 0,013 m^3sk to 0,550 m^3sk and the average equalled 0,114 m^3sk. The average volume of dead trees per se in relation to different damage types varied as well (figure 11).

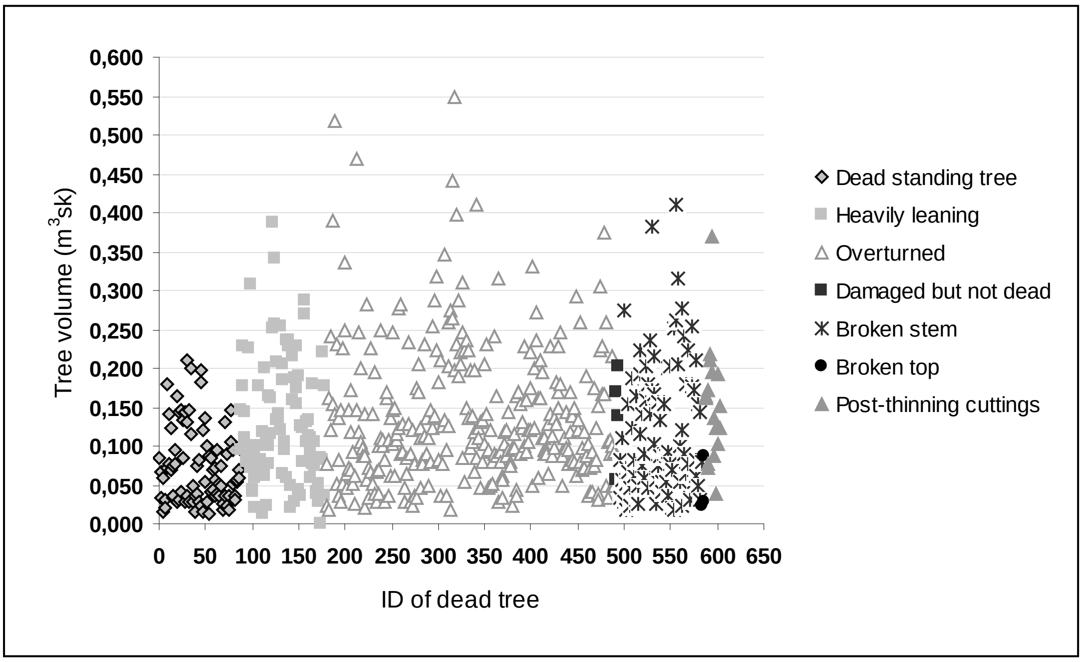


Figure 11. Damage types in relation to the dead tree volume.

Largest average tree size in volume (m^3sk/tree) had dead trees removed after thinning (0,152 m^3sk), damaged but not dead trees (0,141 m^3sk), overturned trees (0,135 m^3sk), heavily leaning trees (0,129 m^3sk) and trees with a broken stem (0,121 m^3sk). Lowest average volume had trees with a broken top (0,046 m^3sk) and dead standing trees (0,073 m^3sk).

No clear pattern between the damage types and trees distance to the centre of the nearest strip road was found (figure 12). The distance varied from 1,1 m to 26,1 m and the average distance for all measured dead trees was 6,4 m.

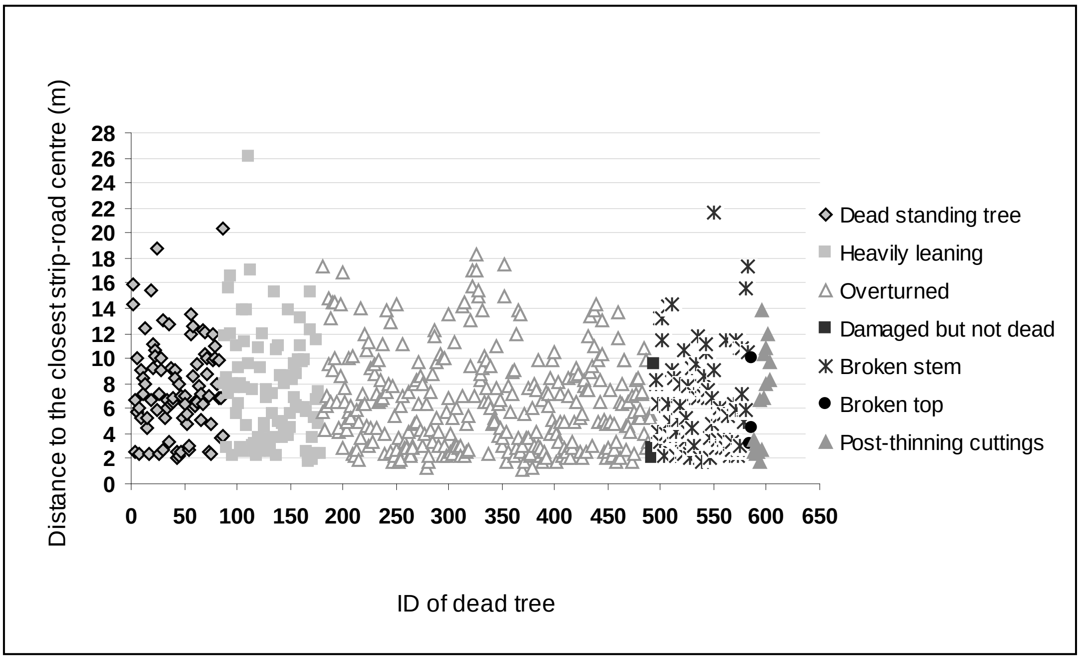


Figure 12. Damage types in relation to distance to the closest strip-road centre.

Investigating the distribution of the measured dead trees in relation to distance to the closest strip road, it was found that the largest number of trees was in zones 3,1-6 m and 6,1-9 m – 156 trees in both (table 5). All stands were thinned with the same strip-road system – one harvester road between strip-roads. The distance between strip roads was usually between 25 and 30 meters.

Table 5. Distribution of the measured dead trees in relation to distance to the closest strip road.

Distance to the closest strip-road centre (m)	No. of trees
0 – 3	132
3,1 – 6	156
6,1 – 9	156
9,1 – 12	95
12,1 – 15	42
15,1 – 18	16
18,1 – 21	3
21,1 – 24	1
24,1 – 27	1
Total	**602**

Types of damages

In terms of the stem number - overturned dead trees accounted for 51,6 % and were most common (table 6). The least frequent damage types were damaged but not dead and trees with broken top – 0,6 % and 0,5 % respectively.

Table 6. Share of dead trees in relation to damage type (calculated in relation to the number of stems).

Types of dead trees	Share of total (%)
• overturned	51,6
• heavily leaning	15,3
• broken stem	14,8
• dead standing trees	14,4
• post-thinning removal	2,8
• dead but not damaged	0,6
• broken top	0,5

The most frequent damage cause registered was wind which accounted for 52%. For 40% of measured dead trees it was not possible to determine the cause of damage. Only 8% of trees were estimated as snow-damaged.

Damages and site characteristics

Figure 13 presents various parameters on plot level, such as direction of slope, soil type and moisture in relation to share of number of dead trees per hectare and volume of dead trees per hectare.

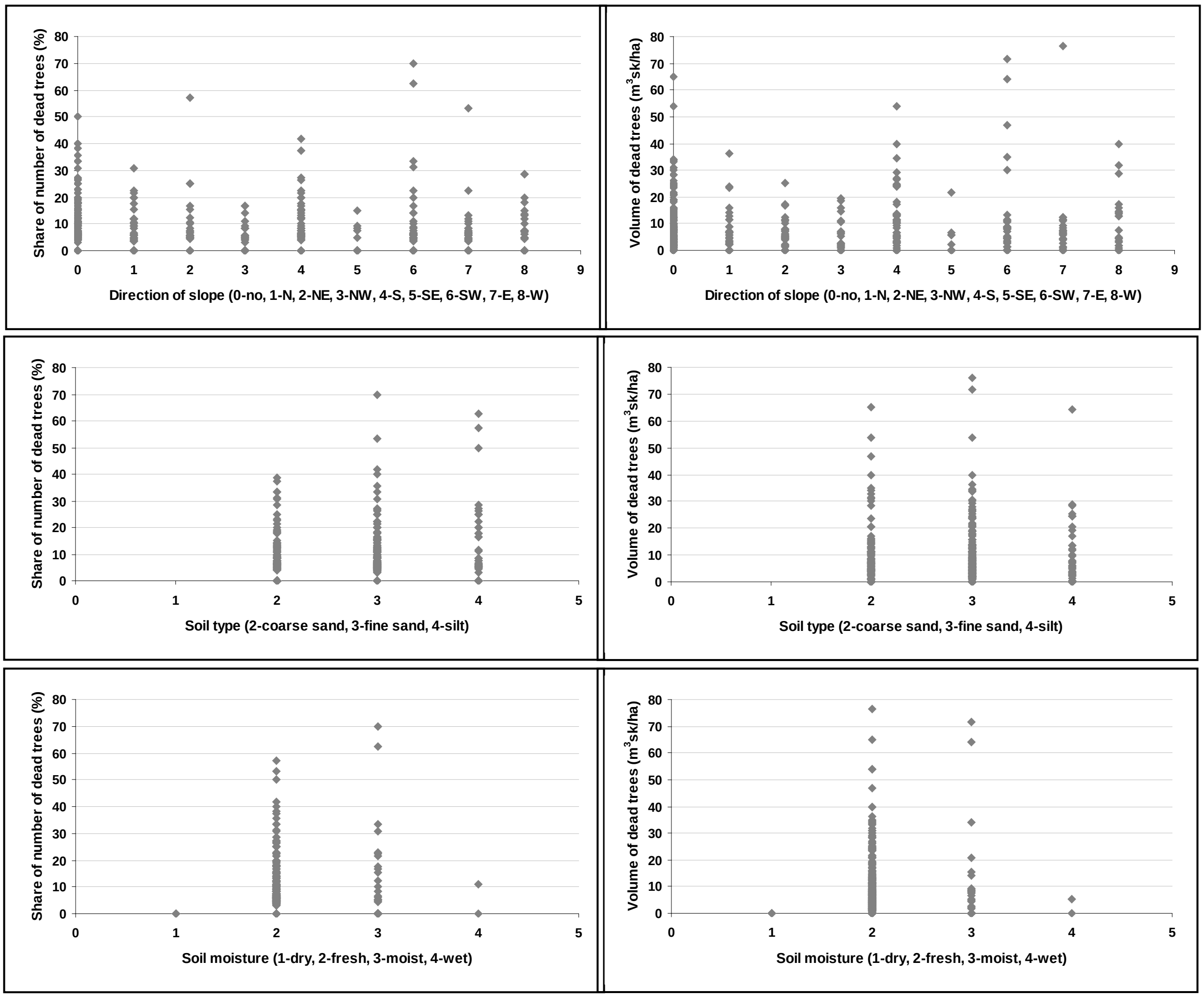


Figure 13. Relationship between **the share of number of dead trees** and direction of slope, soil type and soil moisture and relationship between **the volume of dead trees** and direction of slope, soil type and soil moisture **on plot level**.

Figure 14 presents various parameters on stand level, such as dominant slope, dominant height above sea level and time after thinning in relation to share of number of dead trees per hectare and volume of dead trees per hectare.

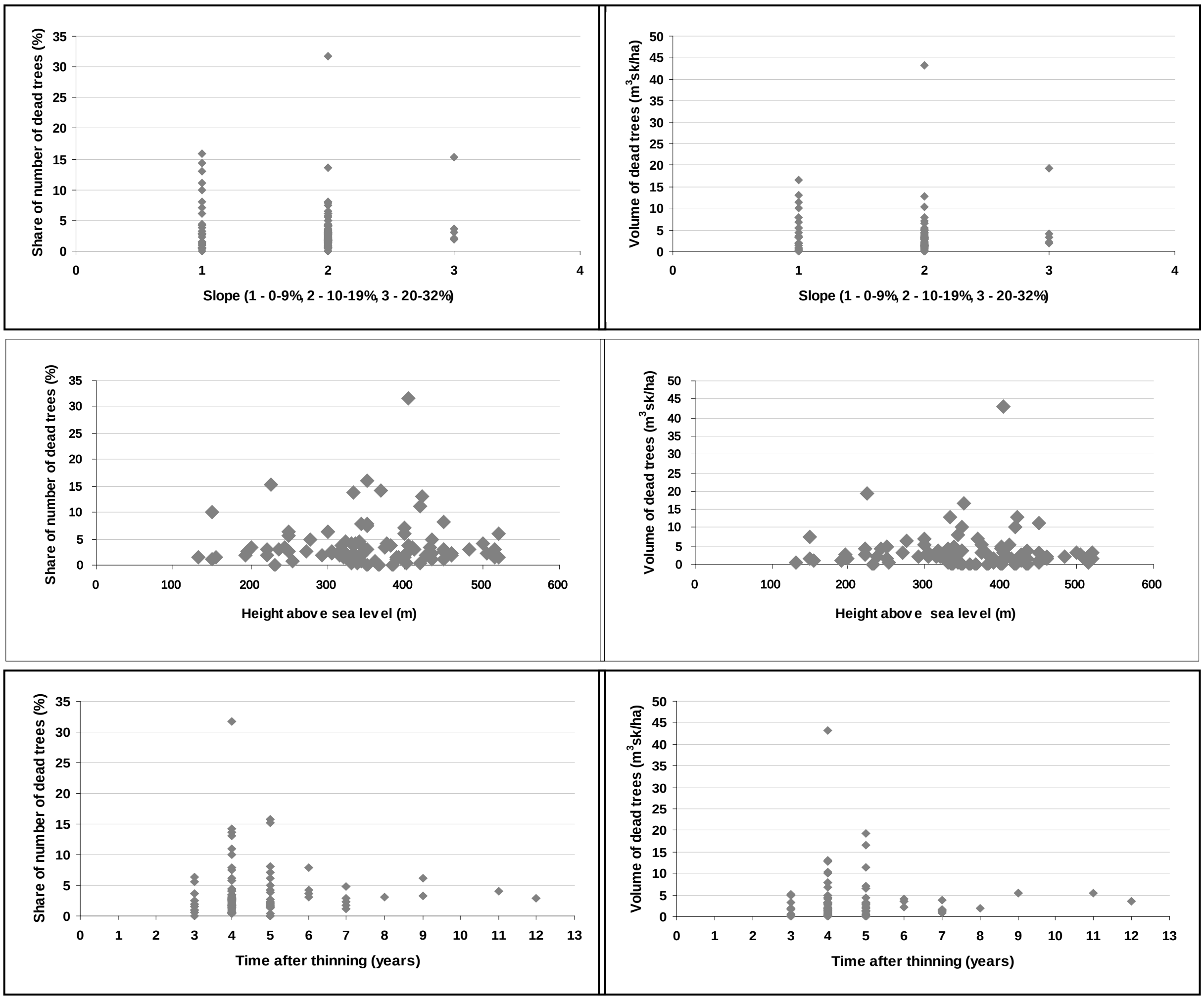


Figure 14. Relationship between **the share of number of dead trees** and stands dominant slope, height above sea level and time after thinning and relationship between **the volume of dead trees** and stands dominant slope, height above sea level and time after thinning **on stand level**.

Damages and thinning

Figure 15 shows thinning removal – basal area, volume and thinning grade in relation to share of number of dead trees per hectare and the volume of dead trees per hectare on stand level.

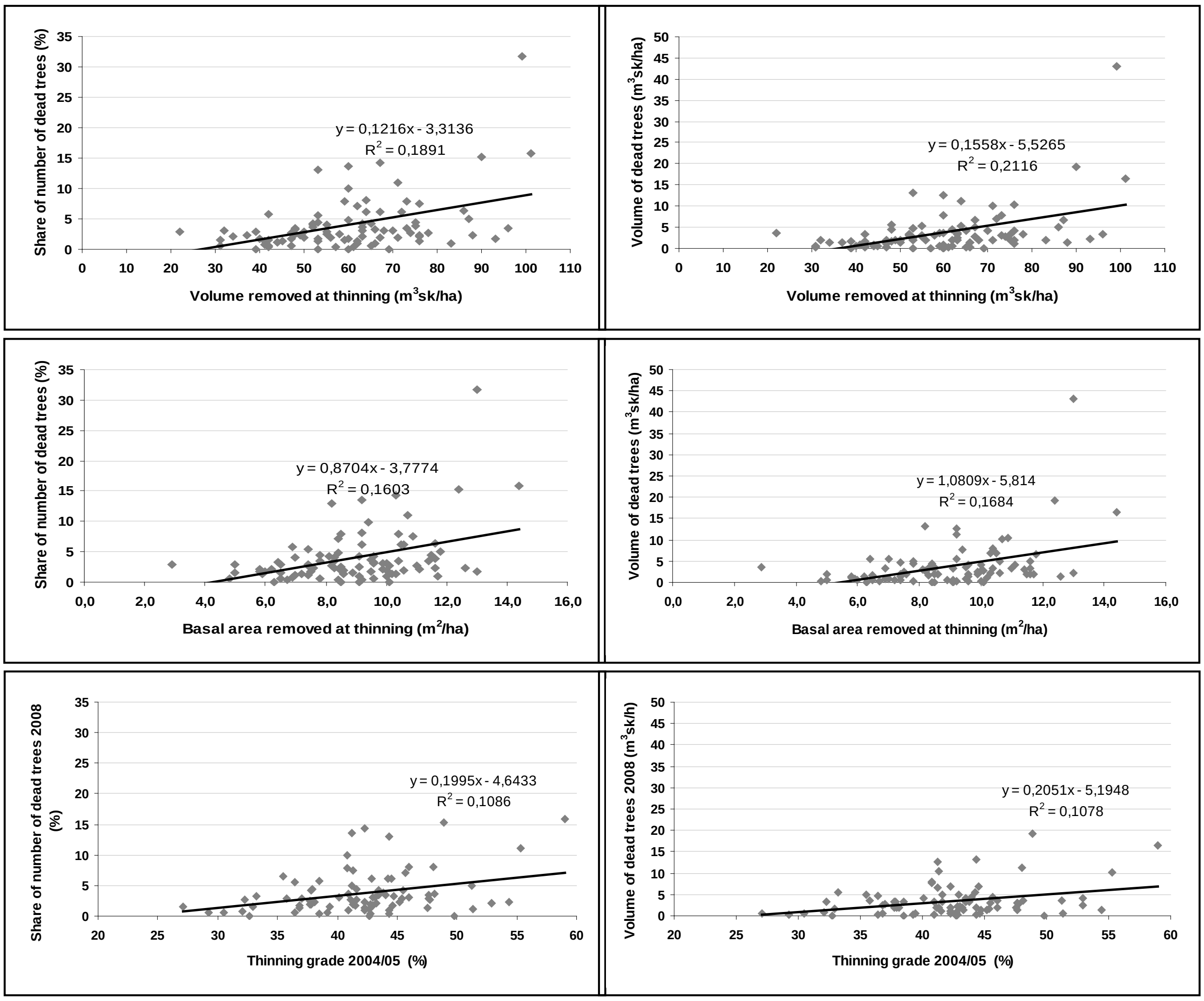


Figure 15. Relationship between **the share of number of dead trees** and thinning removal – basal area, volume, thinning grade and relationship between **the volume of dead trees** and thinning removal – basal area, volume, thinning grade **on stand level**.

Damages and stand characteristics

Figure 16 shows dominant height of trees at the time of thinning, strip-road width and distance between the centres of strip roads in relation to share of number of dead trees per hectare and the volume of dead trees per hectare on stand level.

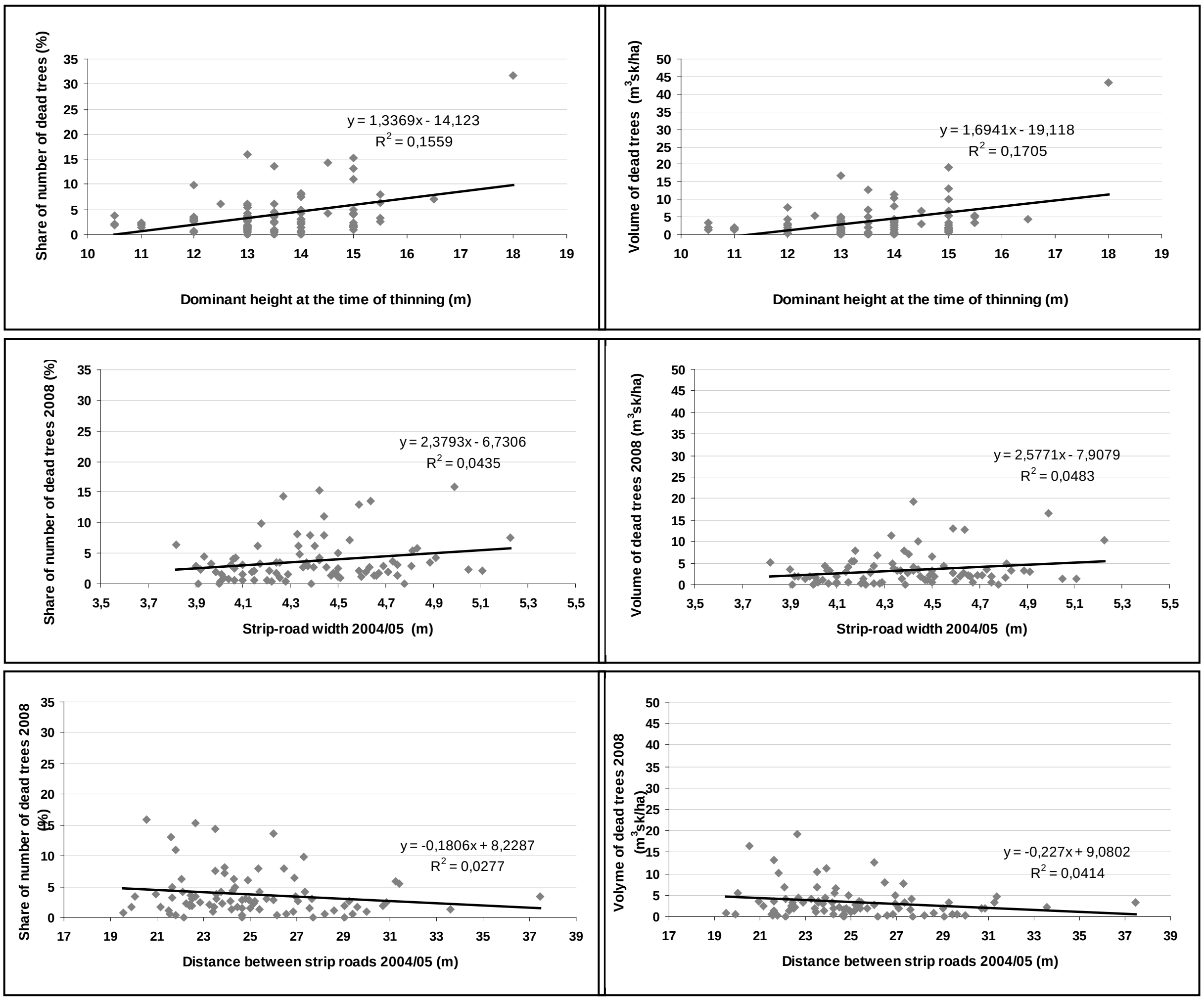


Figure 16. Relationship between **the share of number of dead trees** and dominant height of trees at the time of thinning, strip-road width and distance between the centres of strip roads and relationship between **the volume of dead trees** and dominant height of trees at the time of thinning, strip-road width and distance between the centres of strip roads **on stand level.**

Following parameters were found to be statistically significant and positively correlated to the volume of dead trees after thinning (table 7):

- thinning removal (basal area, volume and thinning grade);
- dominant height at the time of thinning;
- strip-road width.

Following parameters were found to be statistically significant and positively correlated to the share of number of dead trees (table 7):

- thinning removal (basal area, volume and thinning grade);
- dominant height at the time of thinning;
- strip-road width;
- soil moisture.

Table 7. Correlation matrix. Marked correlations are significant at $p < 0,05000$ (Casewise deletion of missing data)

STAND LEVEL (N= 91)	Volume of dead trees (m^3sk/ha)	Share of dead trees (%)
Slope (%)	0,0333 p=0,745	-0,0276 p=0,795
Height above sea level (m)	-0,0125 p=0,906	-0,0029 p=0,978
Time after thinning (years)	0,0125 p=0,906	0,0029 p=0,978
Volume removed at thinning (m^3sk/ha)	**0,4600** **p=0,000**	**0,4349** **p=0,000**
Basal area removed at thinning (m^2/ha)	**0,4103** **p=0,000**	**0,4004** **p=0,000**
Dominant height at the time of thinning (m)	**0,4129** **p=0,000**	**0,3948** **p=0,000**

PLOT LEVEL (N= 1056)	Volume of dead trees(m^3sk/ha)	Share of dead trees (%)
Direction of slope	0,0430 p=0,163	0,0176 p=0,568
Soil type	0,0012 p=0,969	0,0404 p=0,190
Soil moisture	0,0463 p=0,133	0,0885 p=0,004

2004/05 YEAR DATA (N= 82)	Volume of dead trees (m^3sk/ha)	Share of dead trees (%)
Thinning grade 2004/05 (%)	**0,3295** **p=0,003**	**0,3303** **p=0,002**
Strip-roads width (m)	0,2430 p=0,028	0,2372 p=0,032
Distance between centres of strip roads (m)	-0,2026 p=0,068	-0,1546 p=0,166

Quality evaluation

The share of lodgepole pine trees estimated as having sawn-timber quality and non-sawn-timber quality equalled on average 49% and 51% respectively. The share of trees with different defect types on the stand level is given in figure 17.

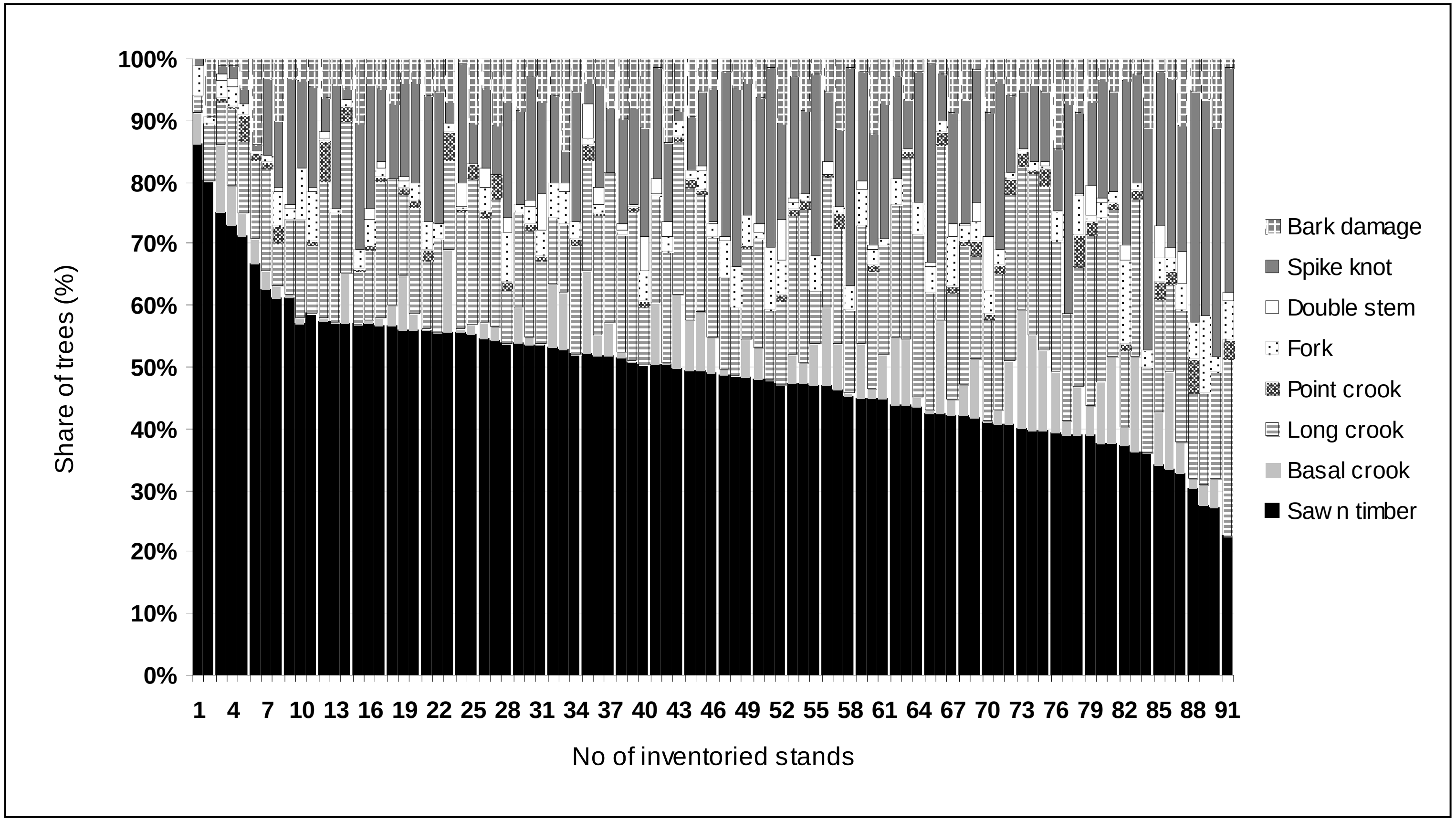


Figure 17. Share of lodgepole pine trees having sawn-timber and non-sawn-timber quality and different defect types.

The most frequent defect types were long crook and spike knot which amounted on average to 18% and 17% respectively (table 8). Double stem and point crook were found to be the least frequent defects and amounted to 1% each.

Table 8. Share of defect types in the inventoried 91 lodgepole pine stands after thinning as an average per stand (calculated as the percent of the total number lodgepole pine trees).

Defect type	Share %		
	Min	**Max**	**Average**
• long crook	2,9	29,5	17,8
• spike knot	0	37,7	16,8
• bark damage	0	15,0	5,9
• basal crook	0	19,3	5,3
• fork	0	13,5	3,1
• double stem	0	8,6	1,1
• point crook	0	6,4	1,0
Total (%)			**51**

Discussion

“Lodgepole pine is and will remain a foreign tree species for a long time in Sweden. This means that the knowledge and experiences with this species are more restricted than with our indigenous species.” (Martinsson, 1983)

Relatively low thinning removal which equalled on average 8,9 m^2/ha can be explained by the fact that some stumps may have been missed at the inventory (overgrown by mosses and vegetation or covered with branches) and not included in the measurement. Therefore data from 2004 and 2005 inventories concerning thinning grade in the inventoried lodgepole pine stands, which indicated rather high thinning removals, was included in the calculations. Measurements of the basal area before thinning would have given more accurate data on thinning removal than the stump measurement.

It was not possible to obtain data on basal area or standing volume of lodgepole pine stands right before or right after thinning. An important factor that hampered data analyses was that the inventoried stands were not thinned at the same time but 6-13 years before the inventory took place.

In order to investigate the relation between mortality and stand parameters, a share of the number of dead trees after thinning was calculated. However, it was not possible to calculate the share of volumes of dead trees since the existing formulas would give rather estimations than precise volumes. Presenting just average volumes of dead trees per hectare might be misleading since the volumes of trees vary depending on the tree species, site index, age, etc. For comparison both share of number of dead trees and volume of dead trees were tested in correlation matrix and gave similar results.

Results concerning dead tree volumes per tree showed that dead standing trees and trees with broken top had on average 2-3 times smaller volumes than trees with broken stem, overturned trees or heavily leaning trees. This is to some extent confirmed in Perssons (1975) findings where trees with smaller diameters were reported to be more prone to snow damages while larger trees to wind damages. Determination of damage cause was often complicated.

However, looking at the types of damages, about 84,5% of the dead trees were most likely wind-damaged and only 0,5% snow-damaged. Since it was not possible to separate dead trees that were damaged by other factors than snow or wind the total amount of damaged trees was used in the calculations.

No relation between damage types and distance to the closest strip-road centre was found. The average distance from a dead tree to the closest strip-road centre was 6,4 meters. Looking at the number of dead trees, 74% of the measured dead trees were located 0-9 m from the centre of the closest strip road. There is, however, no data indicating how large share of plots were located 0-9 m from the centre of the closest strip road. Blomgren (2006) reported in south-western Sweden that risk for wind damages was largest on the strip-road edges. Highest frequency of snow and wind damages on trees closest to the strip road (0-8 m) was also found by Persson (1995).

Andersson et al (1999) reported that lodgepole pine stands run twice as high risk for natural mortality after first thinning than Scots pine, mainly due to wind and snow damages. The average volume of dead trees in the inventoried lodgepole pine stands was 3,8 m^3sk/ha which accounted for approximately 2,3 % of the average standing volume at the time of inventory. Even if the share of the number of dead trees was much higher on some of the measured plots, the share on the stand level was evened out by plots with no dead trees whatsoever.

No correlation between volume of dead trees and dominant slope, direction of slope, soil type or soil moisture was found and these results do not confirm the hypothesis. Share of the number of dead trees was similarly not correlated to the afore-mentioned parameters. However, the correlation matrix indicated a positive and significant correlation between the share of the number of dead trees and soil moisture – higher risk for damages on wet soils than on dry soils. Eriksson (1989) reported lower stability for lodgepole pine trees that grow on plain soils with high ground water level and for stands that were located on fine-textured soils. Additionally, Persson (1975) and Rosvall (1994) found lower stability in thinned stands located on fine-textured and wet soils. It is difficult to determine if the selection of stands subject to thinning was done in relation to soil conditions. The relation between the volume of dead trees and soil conditions could have been hard to show if mainly stands located on suitable soils (not too moist or fine-textured) were thinned.

Relation between the volume of dead trees and stands' height above sea level was found insignificant. The same result was found for the share of the number of dead trees. Slope measurements on the plot level or evaluation of stands' exposure to the main wind directions could have given more precise results.

It was difficult to compare volume of dead trees or share of number of dead trees and the time after thinning because the number of stands thinned at each year was not the same. Higher volumes of dead trees occurred in stands that were thinned 4 and 5 years ago and earlier thinned stands had rather low volumes of dead trees, but the largest number of stands was also thinned in 2004 and 2003 and for example only one stand was thinned in 1996. It is said that the longer time after thinning the more stable trees become (Persson, 1975), however, the weather conditions and wind strength vary between years and are also of importance.

Positive and significant correlation between the volume of dead trees, share of number of dead trees and stand dominant height at the time of thinning indicates that there is a higher risk of damage with increasing dominant height. Persson (1975) and Rosvall (1994) reported similar conclusions.

It was planned to investigate if there is a correlation between mortality and thinning grade according to 2008 inventory data but it was difficult to calculate basal area directly after thinning due to the fact that the existing formulas give rather estimations than precise result. It is also unknown when exactly the dead trees had died after thinning (how much they had grown after thinning) and even in the same stand trees could have died in different years. In addition the time of thinning varied in the inventoried stands between 1996 and 2005.

The risk of damage after thinning increases with increased thinning grade according to the result of this study. Norgren & Efving (1995) reported that lodgepole pine stands should be thinned at the right time and not too hard. The difficulty in applying the right thinning grade might be caused by the fact that there is a large number of low-quality trees in lodgepole pine stands and it is difficult for the machine drivers to make the right selection.

Blomgren (2006) has reported positive correlation between wind damages in thinned stands and increasing amount of strip roads. Result of this study is similar and shows that the wider the strip road the higher the risk for damages.

49% of the measured lodgepole pine trees had sawn-timber quality. Most frequent defect types were long crook and spike knot which accounted for 18% and 17% respectively. Dermer (2007) found that lodgepole pine trees had relatively good quality compared to Scots pine and that spike knots and crooks were the main lodgepole pine defects. Persson (2008) reported that 21% of potential final felling trees in lodgepole pine stands were straight and without spike knots, compared to 30% in Scots pine stands.

It is difficult to consider all factors that can affect the stability of lodgepole pine stands after thinning and damages might appear in an unpredictable way. However, by planting on suitable soils, thinning early and light and by applying a well-planned strip-road system the risk of mortality after thinning can be reduced.

Conclusions

- Mortality after thinning was on average low – the mean volume of dead trees in the inventoried 91 lodgepole pine stands was 3,8 m^3sk/ha being equal to 2,3% of the standing volume at the time of the inventory.
- In terms of number of trees, dead trees formed on average 3,9% of the total number of inventoried lodgepole pine trees.
- No correlation between the volume of dead trees and soil type, soil moisture, stands dominant slope or stands dominant height above sea level was found. The share of the number of dead trees gave similar results. However, a positive and significant correlation between the share of the number of dead trees and soil moisture was found indicating higher risk for damages on wet soils than on dry soils.
- Risk for mortality after thinning increases in stands thinned at larger dominant height, stands with high thinning grade and wide strip-roads.
- No clear relation between types of dead trees and their distance to the closest trip-road centre was found.
- 49 % of measured stems were estimated to have sawn-timber quality. The most frequent defect types were long crook and spike knot.

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