Comparison of Human and Computer-based Selective Cleaning

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In silvicultural tending operations like cleaning (pre-commercial thinning), the results are irreversible, so it is important for the decisions to be consistent with the aims for the stand. To enable operational automatic stem selections, a decision support system (DSS) is needed. A previously presented DSS seems to render acceptable cleaning results, but needs further analysis. The aims of the study were to compare the cleaning results of experienced cleaners and DSS simulations when "similar" instructions were given, and to assess the usefulness and robustness of the DSS. Twelve experienced cleaners were engaged to "clean" (mark main stems) six areas; each cleaner "cleaned" two areas. The DSS was used to generate two computer-based cleanings (simulations) of these areas. Four laymen also "cleaned" one of the areas following the DSS. The density results were significantly affected by the areas' location, whereas the proportions of deciduous stems and damaged stems were significantly affected by both the areas' location and method, i.e. manual "cleaning" and general or adjusted simulation. The study showed that the DSS can be adjusted so that the results are comparable with the cleaners' results. Thus, the DSS seems to be useful and flexible. The laymen's results were close to the results of the "general" simulation, implying that the DSS is robust and could be used as a training tool for inexperienced cleaners. The DSS was also acceptable on a single-tree level, as more than 80% of the main-stems selected in the simulations were also selected by at least one cleaner.

Keywords automation, decision support, forestry, practical cleaning, pre-commercial thinning, training-tool

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List of Symbols

A = No. of stems retained in the “OK-Tree-list” at this point (cf. Fig. 4)
B = Total no. of selected stems at this point
C = No. of visited sections (including the current section)
D = No. of undamaged stems in the section’s “Tree-list” (cf. Fig. 4)
mdc = Mean diameter at breast height (dbh) of coniferous stems in the area (mm)
mdt = Mean dbh of all stems in the area (mm)
Cmdc = Mean dbh of coniferous stems selected by the cleaners in each area (mm)
Cmdd = Mean dbh of deciduous stems selected by the cleaners in each area (mm)
P1 = The requested spacing between stems (m)
P2 = The minimum allowed distance between two stems, stem surface to stem surface (m)
P3 = The requested percentage of deciduous stems (%)
T1 = Threshold no. 1, regarding undamaged stems outside the preferred diameter range
T2 = Threshold no. 2, regarding damaged stems
T3 = Threshold no. 3, regarding the final selection of stems
α = Treatment
β = Block
Y_{ij} = The response variable
μ = Grand mean
ε_{ij} = The random error

1 Introduction

Cleaning (pre-commercial thinning) regulates the density in young forest stands. It is primarily done to increase volume growth per stem and to decrease the likelihood of damage (Skogsencyklopedin… 2000). Cleaning can be defined as the thinning of a stand, where the main part of the cut volume originates from stems of less than 10 cm in diameter at breast height (Pettersson and Bäcke 1998). The remaining stems, i.e. main-stems, are chosen individually in selective cleaning. The position and characteristics of a stem determine if it is selected for retention, since the common reasons for individual selections include a desire to improve the stand’s quality and/or influence its species composition (e.g. Berg et al. 1973). Selective cleaning is predominant in e.g. Sweden and Finland, whereas geometrical cleaning is used in e.g. in loblolly pine (*Pinus taeda* L.) stands in USA (Lloyd and Waldrop 1999) and in dense natural generations of beech in Denmark (Möller-Madsen and Petersen 2002). Herbicides are used in some 35% of the treated area in Canada (Ryans and St-Amour 1996, Compendium of Canadian… 2004). In the following text selective cleaning is simply referred to as cleaning.

During the last twenty years in Sweden, the average cost for cleaning has increased compared with logging and regeneration costs (Ligné et al. 2004). Most cleanings are performed motor-manually with brush-saws in Sweden, and there are difficulties in recruiting cleaners for this laborious work (Vestlund 2004). Mechanising, or automating, the cleaning may offer ways to decrease the costs and reduce the laborious working conditions. However, a decision support system (DSS) is needed to enable automatic stem selections in practical cleaning. DSSs are computer-based systems designed to represent and process knowledge in order to support decision-making activities (cf. Holsapple and Whinston 1996).

The results of cleaning are irreversible so it is important for the decisions to be consistent with the aims for the stand. Current cleaning instructions are quite general, and mainly concern the results regarding number of stems per hectare, species composition, and percentage of stems with damage (Vestlund 2004). Written instructions, i.e. cleaning manuals (cf. Brunberg 1990, Röjning… 1999), give more details, but the way in which the desired results should be attained is left, to a large degree, to the cleaners who use their experience, subconsciously, to select stems (Vestlund 2004). Furthermore, cleaners do not always follow these general instructions in practise. This causes variations in the results, which although are usually deemed to be acceptable by the assigners (Vestlund 2004). Thus, the relationship between instructions and results are vague, and the individual cleaner influence the results.

A DSS, on the other hand, does not give intuitive advice. DSSs aid the decision analysis process and can explain the basis for the given recommendations (Giarratano and Riley 1998, Daume and Robertson 2000a). DSSs can either be deployed in a machine or used as a training-tool for humans. Vestlund et al. (2005) presented a DSS for operational automatic selective cleaning that was designed to generate acceptable cleaning results in conventional Swedish cleaning stands (cf. Brunberg 1990, Varmola and Salminen 2004, Vestlund 2004, Ligné et al. 2004) comparable to those obtained by human cleaners. This DSS was used to run six computer-based cleaning scenarios, i.e. simulations, of 17 stands with varying density, species composition, damage frequency and diameter. The simulations' results were evaluated according to the same criteria as used in a standard cleaning follow-up (i.e. stems per hectare, species composition, and percentage of damaged stems), and the results seemed to be within acceptable limits (Vestlund et al. 2005). However, these results should also be compared with the results of experienced cleaners that can exemplify and mirror human decisions (cf. Daume and Robertson 2000a).

The aims of this study were to compare the cleaning results of experienced cleaners and DSS simulations when "similar" instructions were given, and to assess the usefulness and robustness of the DSS.

2 Material and Methods

To ascertain the usefulness and robustness of the DSS, twelve experienced cleaners were engaged to "clean", i.e. mark trees in six areas. Their results were compared with those of a general simulation and provided the basis for an adjusted simulation. The adjusted simulation was run to assess the flexibility of the DSS. Finally, to further test the robustness and practicability of the system, four persons with little or no forestry knowledge were engaged to "clean" an area following the recommendations of the DSS. The laymen functioned as substitutes for actual cleaning robots.

A field inventory was conducted in the summers of 2002 and 2003 (Fig. 1). The selected stands (Table 1), four dominated by Scots pine (*Pinus sylvestris* L.) and two by Norway spruce (*Picea*

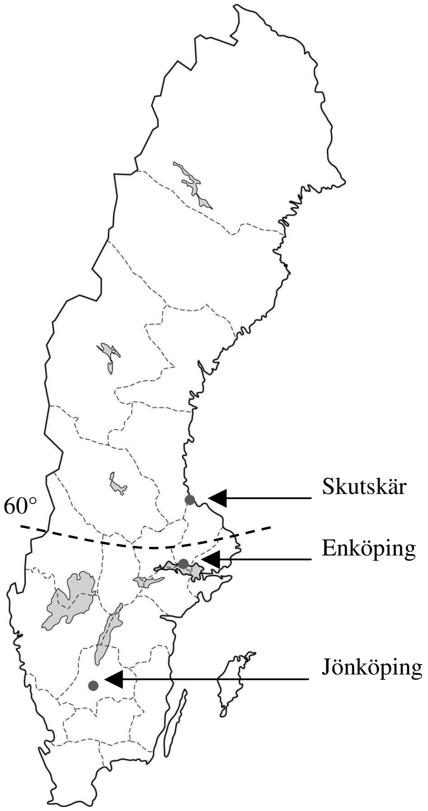

Fig. 1. Sweden, location of the field inventory areas (Skutskär, Enköping, and Jönköping). The position of the 60th parallel is roughly marked.

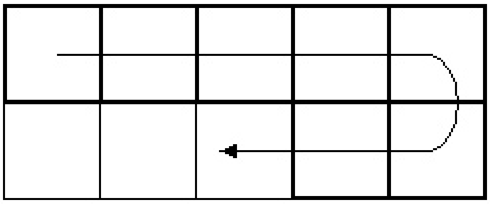

Fig. 2. General layout of the measured area and its sections. The arrow shows the sequence in which data for each of the sections was added in the simulations.

abies (L.) H. Karst.), were selected to represent conventional Swedish cleaning stands (cf. Brunberg 1990, Varmola and Salminen 2004, Vestlund 2004, Ligné et al. 2004). The stands were in need of cleaning according to cleaning manuals (cf. Röjning… 1999) and according to the assigners. The studied area at each location was 160 m^2 (20 m × 8 m), except in the JönköpingPine area, where it was 224 m^2 (28 m × 8 m).

The studied areas were separated from the surrounding stand with "marking tape" and each area was divided into smaller parts, here called sections (Fig. 2). The size of a section was the squared double-spacing, i.e. the targeted spacing. The general instruction to cleaners is to leave 2500 stems per hectare after cleaning (Vestlund 2004), so the spacing was set to 2 m, i.e. each section was 4 m × 4 m, in the inventory.

Retrieved attributes in the inventory were: diameter, position, species, and damage; in accordance with the findings in Vestlund (2004). All stems over one cm in diameter at breast height (dbh) were callipered with mm precision. The centre positions of the stems were measured in the X and Y planes at breast height with cm precision. The stems were categorised as Scots pine, Norway spruce, juniper (*Juniperus communis* L.), birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.; species not separated), or "other deciduous". There are a number of damage types (cf. Brunberg 1990, Röjning… 1999, Vestlund 2004), and in this study four types considered automatically measurable were chosen to define damage (Fig. 3). For 34 stems other types of damage were observed, and noted as "undefined damage". The average tree age for each area was provided by

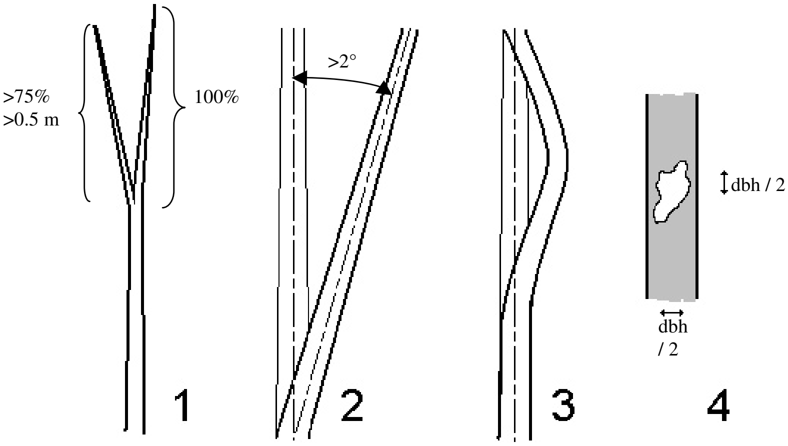

Fig. 3. The defined types of damage: 1) Double top, where the height of the shorter top was at least 0.5 m and at least 75% of the height of the taller top, 2) Leaning stems, i.e. stems having a mean inclination angle larger than 2° from root to top, 3) Stems with crooks, where it was not possible to join the centres of each end with a straight line without crossing the outer edges of the stem at some point, and 4) Stem damage with an area larger than the squared radius (r^2) at breast height of the stem.

Table 1. Stand data from the field inventory. All stems over 1 cm in diameter at breast height (dbh) were counted and measured.

Stand data	Location (cf. Fig. 1)					
	Enköping Pine1	Enköping Pine2	Jönköping Pine	Jönköping Spruce	Skutskär Pine	Skutskär Spruce
Density (stems per ha)	10000	9875	5893	5500	6188	6938
Proportion of birch stems (%)	51.9	32.9	59.1	8.0	2.0	18.9
Proportion of "other deciduous" stems (%)	3.8	1.3	0.0	0.0	2.0	36.0
Mean dbh, total (mm)	29.7	28.6	40.4	46.4	68.6	35.6
Mean dbh, coniferous (mm)	42.3	33.5	72.4	46.8	70.2	49.6
Mean dbh, deciduous (mm)	19.7	19.1	18.2	41.3	29.5	24.0
Proportion of stems with damage (%)	57.5	41.1	65.2	15.9	14.1	60.4
Proportion of stems with "undefined damage" (%)	4.4	0.6	7.6	6.8	5.1	4.5
Age (years)	15	15	15	12	24	17
Site index	T 22	T 22	T 25	G 28	T 24	G 26

the landowners (Table 1).

Twelve professional forestry workers were engaged to "clean" the six areas. The names of cleaning entrepreneurs and cleaners were obtained from forest companies, which were asked to appoint cleaners known for producing acceptable results. The cleaners, all men, worked in southern and central Sweden (Table 2). It was difficult for the cleaners to define how much time they had spent on cleaning, but it ranged from one to 36 years/working-seasons. Cleaning is not usually done when there is snow on the ground.

The cleaners were given brief instructions about how they were supposed to clean and they made their "cleaning" on site. They walked through the stand one by one and made their choices of main-stems by indicating on a map, revealing the areas' stems and section borders, which stems they decided to leave. The cleaners were instructed to select the remaining stems, as in an actual cleaning, considering the desired targets:

- 2500 stems per hectare
- 10% deciduous stems, "other deciduous" stems should be favoured to increase diversity
- at least 0.5 metres between each remaining stem
- avoid selecting damaged stems

Each cleaner "cleaned" two areas and four cleaners "cleaned" each area, in order to perceive the personal and interpersonal reliability. Cleaners were instructed to select their stems without regarding any of the borders. This field study was performed in the spring and summer of 2003.

Table 2. Information about the twelve cleaners.

	Mean	Median	Min.	Max.
Age (years)	51.8	44.5	23	56
Time worked professionally in forestry on various tasks (years)	30.8	23	1	40

A DSS for automation of individual stem selections in practical cleaning was developed by Vestlund et al. (2005). It is presented here as an algorithm (Fig. 4), and it was used for the computer-based cleanings, i.e. simulations. The DSS includes, in order to be simple and operational, only a few attributes, which were considered automatically measurable (Vestlund et al. 2005). The DSS uses three parameters, three thresholds and a "quality criteria" definition, i.e. simulation-specific restrictions regarding species, diameter, and damage, for selecting remaining main-stems.

The first parameter is the requested spacing [P1], and concerns the density target and maxi-

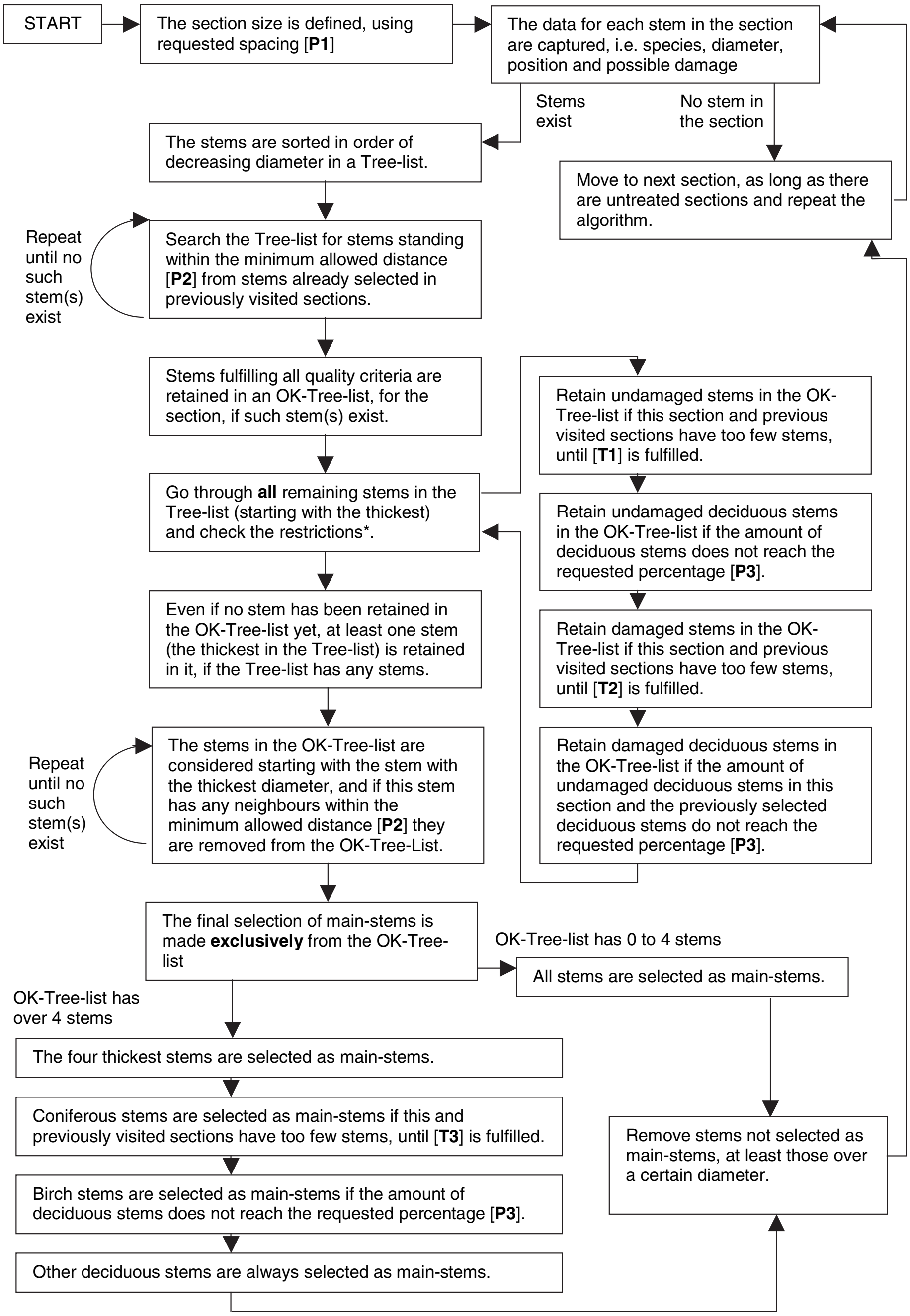

Fig. 4. The DSS for selective cleaning by Vestlund et al. (2005), presented as an algorithm. The parameters [P1–3] depend on the purpose of the cleaning and the thresholds [T1–3] (Eqs. 1–3) influence the number of selectable and selected stems in each section. See also List of symbols. The “quality criteria” vary in the simulations, but are concerned with species, diameter, and damage. * = Each stem is compared with the restrictions, in the presented order, and if the stem fulfils a condition it is retained and the comparing-procedure starts once again with the next stem in the “tree-list” if such stem(s) exist, as no stem is retained more than once.

mum distance restriction. To meet the density target each section should have, on average, four remaining stems after cleaning. However, to prevent gaps at least one stem should remain in each section, if possible. The second parameter is the minimum allowed distance between two stems [P2], stem surface to stem surface. This parameter causes the DSS to reject stems, regardless of their quality, if they are situated within this distance from an already selected stem. The last parameter is the requested percentage of deciduous stems [P3], which influences the final selection of remaining stems.

In areas where there are too few stems that fulfil the "quality criteria" to meet the targeted density, more stems can be selectable according to two thresholds. The first threshold [T1] sets how many undamaged stems outside the diameter range can be retained in the "OK-Tree-list" with selectable stems (Eq. 1). The second threshold [T2] does likewise but for damaged stems (Eq. 2). The last threshold [T3] influences the final selection of remaining stems (Eq. 3).

$$\frac{(A+B)}{C} < \text{valueUndamaged [T1]} \tag{1}$$

where *A* is the number of stems retained in the "OK-Tree-list" at this point (cf. Fig. 4), *B* the total number of selected stems at this point, and *C* the number of visited sections (including current section).

$$\frac{(A+B+D)}{C} < \text{valueDamaged [T2]} \tag{2}$$

where *D* is the number of damaged stems in the section's "Tree-list" (cf. Fig. 4).

$$\frac{B}{C} < \text{valueDefinitive [T3]} \tag{3}$$

Within the allowed diameter range thicker stems are preferred. When stems outside the diameter range must be selected, thicker stems are preferred. If an "other deciduous" stem has been retained in the "OK-Tree-list" it is always selected. The DSS does not regard stems outside the marked-off areas and it only considers the predefined types of damage. Note that Scots pine and Norway spruce are considered equal in the DSS.

The first simulation used general settings for the DSS correlated to the instructions to the cleaners, but allowing variances in the results that should be similar to cleaners' variations. The underlying idea was that cleaners select more stems when more undamaged stems are present and vice versa (cf. Vestlund 2004). Subsequently, an adjusted simulation was made, based on the results of the cleaners. When the restrictions were set, the selection process, which was made section by section (Fig. 2), started.

To fulfil the "quality criteria" in the "general" simulation, stems had to be undamaged (cf. Fig. 3), of preferred species, and within the preferred diameter range. Since the dbh of all stems was known from the inventory, the coniferous and total mean dbh values (mdc and mdt) were calculated and used to select preferred diameter ranges (Eqs. 4–5). The constants used for the ranges were selected with the intention to increase the mean dbh, but to reject stems with very large dbh. The threshold and parameter values are presented in Table 3.

$$(0.66 \times \text{mdc}) \le \text{coniferousdiameterscope} \le (1.66 \times \text{mdc}) \tag{4}$$

$$(0.66 \times \text{mdt}) \le \text{deciduousdiameterscope} \le (1.66 \times \text{mdt}) \tag{5}$$

In the "adjusted" simulation the "quality criteria" were altered. To fulfil the "quality criteria" coniferous stems were to be undamaged and within the preferred diameter range (as in the "general" simulation). However, both undamaged and damaged deciduous stems within the preferred dbh range were regarded as fulfilling the "quality criteria" in the "adjusted" simulation. The density [P1], species mix [P3], and preferred dbh range (Eqs. 6–7) were changed in accordance with the mean results of the cleaners, i.e. the dbh ranges were calculated from the cleaners' coniferous and deciduous mean dbh values (Cmdc and Cmdd). The constants used for the ranges were altered so as to reach similar mean diameters to those obtained by the cleaners. To improve the possibility of reaching the targeted density, the "valueDefinitive" [T3] was decreased (Table 3).

$$\left(0.5 \times \mathrm{Cmdc}\right) \leq \mathrm{coniferousdiameterscope} \leq \left(1.5 \times \mathrm{Cmdc}\right) \tag{6}$$

$$\left(0.5 \times \mathrm{Cmdd}\right) \leq \mathrm{deciduousdiameterscope} \leq \left(1.5 \times \mathrm{Cmdd}\right) \tag{7}$$

As shown in Table 3, P1 for the adjusted simulation was 2.32 m in one area, SkutskärPine. The size of this area was 28 m x 8 m, and in order to be able to make 2 × 12 sections an area of 9.28 m × 27.84 m was needed. Therefore, an accustomed area was created by replicating a strip from 0 to 1.28 m, as a strip from 8 to 9.28 m. P1 in the other areas was less than 2 m, i.e. the utilised areas in these "adjusted" simulations were smaller than the inventoried 160 m^2.

Four persons, three men and a woman, aged 24 to 25, with little or no forestry knowledge, herein called laymen, were given a printed version of the DSS. The laymen were directed to follow the system's recommendations and "cleaned" one area, SkutskärPine. The laymen were given the same damage definitions as the computer, but were allowed to decide for themselves which of the stems were damaged. They made their selections in accordance with the general settings for the DSS (Table 3), without considering stems outside the marked-off area. They indicated the stems they selected with the aid of the DSS on a map revealing the areas' stems and section borders. They also indicated the reasons for their selections on this map.

Treatment effects were analysed with analysis of variance (ANOVA), using the univariate procedure in SPSS for Windows (release 11.0.0). The experiment was analysed as a randomised block design, with method of cleaning as treatment (α) and area as block (β) (Eq. 8).

$$Y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij} \tag{8}$$

where Y_{ij} is the response variable, μ the grand mean and ε_{ij} the random error.

The three treatments, i.e. cleaning methods, were manual cleaning and the "general" and "adjusted" simulations. In all analyses, there were five degrees of freedom for block, two for treatment, and 10 for error. Treatment means were compared using "two-sample" t-tests with Bonferroni corrections for multiple comparisons. Results were considered significant if $p < 0.05$. The assumption of normal variance for the residuals was violated for the proportion of deciduous stems, proportion of damaged stems, and proportion of stems with undefined damage, which made it necessary to transform the data before ANOVA. Logarithmic transformation was used for this purpose, as it resulted in a good distribution of the residuals. Correction for logarithmic bias was performed according to Finney (1941), when values were retransformed.

Table 3. Target settings for the two simulations. P1 is spacing, P2 the minimum allowed distance between stems, and P3 the requested proportion of deciduous stems. The threshold values "valueUndamaged" [T1], "valueDamaged" [T2], and "valueDefinitive" [T3] are described in Eqs. 1–3.

Simulation	Settings					
	P1 (m)	P2 (m)	P3 (%)	T1	T2	T3
General	2	0.5	10	4	3	5.5
Adjusted	1.75–2.32 [a)]	0.5	4.0–36.7 [a)]	4	3	4.5

[a)] Area-specific

The mean results and confidence intervals at 95% certainty (CI_{95}) were calculated for the cleaners' (four in each area) and the laymen's (four in one area) results regarding density, diameter, proportion of deciduous stems, and proportion of damaged stems (cf. Everitt 2002).

3 Results

Although the density target of 2500 stems per hectare remained identical for all areas, the cleaners' mean results for the areas varied from –636 to +750 stems per hectare from this target. The "general" simulations rendered similar variations; –491 to +1000 stems per hectare in the different areas. The "adjusted" simulations differed from –122 to +393 stems per hectare from their targets, which were area-specific. The density results were significantly affected by location according to the ANOVA, but not by method (Tables 4–5).

Table 4. Mean results for the three methods for each response variable. Values within the same row followed by different letters were significantly different ($p < 0.05$).

Variable	Method / Treatment Manual-cleaning	 "General" simulation	 "Adjusted" simulation
Density (stems/ha)	2735a	2710a	2891a
Proportion of deciduous stems (%)	17.3a	9.4b	19.6a
Mean dbh* total (mm)	57.2a	58.6a	54.8a
Mean dbh* coniferous (mm)	64.2a	59.7a	62.6a
Mean dbh* deciduous (mm)	29.0a	41.6a	28.4a
Proportion of stems with damage (%)	22.0a	8.2b	15.9ab
Proportion of stems with "undefined damage" (%)	4.4a	7.9a	7.7a

* Diameter at breast height, stems over 1 cm.

Table 5. Results of ANOVA of mean results for methods and blocks for each response variable; there were five degrees of freedom for block, two for treatment, and 10 for error in each case.

Variable	Method / Treatment p-value	Location / Block p-value	Adjusted R^2
Density (stems/ha)	0.394	0.000	0.793
Proportion of deciduous stems (%)	0.010	0.000	0.806
Mean dbh* total (mm)	0.090	0.000	0.973
Mean dbh* coniferous (mm)	0.165	0.000	0.957
Mean dbh* deciduous (mm)	0.132	0.038	0.489
Proportion of stems with damage (%)	0.006	0.002	0.814
Proportion of stems with "undefined damage" (%)	0.065	0.000	0.830

* Diameter at breast height, stems over 1 cm.

The largest differences in density between the mean results of the cleaners and the "general" simulation occurred in the Skutskär areas. The mean density obtained at SkutskärPine was 3078 (CI_{95} ±509), while the "general" simulation gave a density of 3500 stems per hectare. At SkutskärSpruce the corresponding figures were 3250 (CI_{95} ±1218) and 2500, respectively. Thus, the SkutskärSpruce area also had the largest differences between cleaners.

The proportion of deciduous stems was significantly affected by both method and location (Tables 4–5). The percentage of deciduous stems varied from 3.6% to 15.0% after the "general" simulation whereas the cleaners mean results were significantly higher (Table 4) and varied from 4.0% to 36.7%, and after the "adjusted" simulation the proportion varied from 4.5% to 37.5%. The cleaners' mean results for proportion of deciduous stems were above target in four of the six areas, and all twelve cleaners performed above target in at least one of the two areas they cleaned.

The mean dbh of the remaining stems was significantly affected by location, but not by method (Tables 4–5). However, the mean dbh of deciduous stems after the "general" simulation was within the CI_{95} of the cleaners' mean results only at the SkutskärPine area. The proportion of damaged stems was significantly affected by both method and location (Tables 4–5). The cleaners selected more deciduous stems with damage than the "general" simulation, which influenced the total and deciduous dbh results, as well as the proportion of damaged stems. The proportions of stems selected by the cleaners that were damaged varied from

Table 6. Proportions of stems selected by one, two, three or four of the cleaners in each area (%), i.e. interpersonal reliability, including mean values and 95%-confidence intervals (CI_{95}).

	Proportion of stems selected by cleaners 1 to 4		Proportion of stems selected by cleaners 5 to 8		Proportion of stems selected by cleaners 9 to 12			
	Enköping		Jönköping		Skutskär		Total	
	Pine1	Pine2	Pine	Spruce	Pine	Spruce	Mean	CI_{95}
1 cleaner	35.6	36.6	23.7	15.8	23.7	29.1	27.4	±8.4
2 cleaners	15.1	20.7	18.6	17.5	19.7	27.9	19.9	±4.6
3 cleaners	28.8	18.3	10.2	26.3	30.3	15.1	21.5	±8.6
All 4 cleaners	20.5	24.4	47.5	40.4	26.3	27.9	31.2	±10.9

Table 7. Proportions of stems selected by the simulations and by 0–4 cleaners (%) including mean values and 95%-confidence intervals (CI_{95}).

	Proportion of stems selected by cleaners 1 to 4		Proportion of stems selected by cleaners 5 to 8		Proportion of stems selected by cleaners 9 to 12			
	Enköping		Jönköping		Skutskär		Total	
	Pine1	Pine2	Pine	Spruce	Pine	Spruce	Mean	CI_{95}
"General" simulation								
0 cleaner	28.6	16.3	15.6	17.1	7.1	5.0	14.9	±8.8
1 cleaner	11.9	18.4	8.9	7.3	16.1	10.0	12.1	±4.5
2 cleaners	14.3	14.3	15.6	7.3	17.9	20.0	14.9	±4.5
3 cleaners	26.2	20.4	11.1	24.4	28.6	17.5	21.4	±6.7
4 cleaners	19.0	30.6	48.9	43.9	30.4	47.5	36.7	±12.5
"Adjusted" simulation								
0 cleaner	33.3	26.7	20.0	12.5	6.8	10.0	18.2	±10.8
1 cleaner	8.9	15.6	6.7	10.0	15.9	7.5	10.8	±4.2
2 cleaners	13.3	17.8	15.6	5.0	20.5	30.0	17.0	±8.7
3 cleaners	24.4	26.7	8.9	22.5	25.0	15.0	20.4	±7.3
4 cleaners	20.0	13.3	48.9	50.0	31.8	37.5	33.6	±15.7

6.6% to 41.0%, and after the "general" simulation the proportions were significantly lower (Table 4), varying from 0.0% to 9.5%. The proportions of damaged stems varied from 2.3% to 35.6% after the "adjusted" simulation.

A third of the selected stems were chosen by all four cleaners (Table 6). The amount of unselected stems in the areas varied from ca. 20% to 55%. Three of the cleaners (one in Skutskär and two in Enköping) performed close to the target density, i.e. within 2300 to 2700 stems per hectare. The Jönköping cleaners seemed to agree more about which stems to select. However, they were all below target in the JönköpingPine area, and in the JönköpingSpruce area two were close to the target and the other two were above. Five cleaners (three in Skutskär and two in Enköping) always exceeded the target. In four cases more than 3300 stems per hectare were selected (one cleaner in SkutskärPine, one in SkutskärSpruce, and two in EnköpingPine2).

About a third of the stems selected in the "general" and "adjusted" simulations were also selected by all four cleaners (Table 7). On average more than 80% of the stems that were selected in the simulations were also selected by at least one cleaner. When comparing each cleaner with each simulation, on average, 61.6% (CI_{95} ±3.2%)

Table 8. Mean results of the laymen's "cleaning" and "general" simulation, for each response variable, in the SkutskärPine area.

Variable	Laymen		Simulation
	Mean	CI_{95}	"General"
Density (stems/ha)	3438	±81	3500
Proportion of deciduous stems (%)	3.2	±1.4	4.5
Mean dbh* total (mm)	81.3	±1.5	81.1
Mean dbh* coniferous (mm)	83.4	±0.9	83.4
Mean dbh* deciduous (mm)	16.4	±3.6	17.5
Proportion of stems with damage (%)	3.6	±0.1	3.6
Proportion of stems with "undefined damage" (%)	1.8	±2.3	1.8

* Diameter at breast height, stems over 1 cm.

of the stems selected by a simulation were also selected by a cleaner.

One of the four laymen followed the DSS instructions in all selections. The other three deviated in eight cases; due to miscalculation in six cases, while in one case a damaged stem was selected as if it was undamaged, and the reasons for the other case were unclear. The laymen observed four additional stems with defined damage to those observed in the inventory, and this information was used in the laymen's "cleaning". One of these stems was observed by all four laymen, two by two laymen and one by one layman, causing differences in the results (Table 8).

4 Discussion

This comparison showed that the cleaners' results were similar to the results of the "general" simulations, except in the proportions of deciduous stems and damaged stems retained. However, when the settings were altered in the "adjusted" simulations, there were no significant differences between the DSS and the cleaners. Thus, it was possible to obtain results with the DSS that were comparable to the cleaners' results, when the settings were adjusted in accordance with the stand. Since the DSS was developed to suit stands where coniferous stems are favoured the areas were selected accordingly. The selected areas had either a dominance of pine or spruce regarding the coniferous stems, thus these species were not separated in the current DSS.

In accordance with the DSS settings, the amount of coniferous stems fulfilling the "quality criteria" was allowed to be a major factor for the variations in density after "general" simulation in the different areas. The idea was that the number of undamaged stems would affect the density results of the cleaners. This idea seemed correct for all of the areas except the SkutskärSpruce area. However, the largest differences between cleaners were found here, i.e. a low interpersonal reliability, suggesting that the concept should not be dismissed. The difference between the cleaners and the "general" simulation regarding proportion of damaged stems derives from an underestimation of the cleaners' tolerance for selecting damaged deciduous stems. Furthermore, the cleaners selected double the instructed percentage of deciduous stems, on average.

The reason why the "general" simulation gave a higher mean dbh for deciduous stems than the cleaners was that too few deciduous stems fulfilled the "quality criteria". This caused a selection of available undamaged stems, or if necessary damaged stems, with a preference for larger diameter. The preferred diameter range in the "general" simulation was too high in four areas in comparison with the cleaners' choices, but this did not affect the results. To have altered the range, as in the "adjusted" simulation, in those areas would not have made any difference since all stems, but one, within these new ranges were damaged and thus did not fulfil the "quality criteria".

It was possible for the laymen to perform a "cleaning" using the DSS, and the results were close to the results of the "general" simulation. Their deviations from the DSS-recommendations and the discrepancy regarding damaged stems caused the variations in the laymen's results.

The precision at the single-tree level for the DSS compared with the cleaners seems promising. Daume and Robertson (2000b) present a DSS for palm-top computers that foresters can use on location, as they make thinnings. The accuracy of their model was evaluated with tree-wise comparisons of the actual thinning outcome and the model's predictions; the agreement was 52% (Daume and Robertson 2000a). This is very similar to the results of a study by Kahle (1995), showing that in three repetitions of the same thinning in the same stand by the same forester on average 56% of the trees marked for removal in one thinning were also marked in another. In accordance with the cited studies, the presented DSS gave acceptable results, as more than 80% of the stems selected in the simulations were selected by at least one cleaner. The variations in the cleaners' results also seemed to be within the normal range (cf. Kahle 1995, Zucchini and Gadow 1995, Füldner et al. 1996). The amount of unselected stems depended on the initial number of stems and the proportion of damaged stems. The slightly lower precision in the Enköping areas when comparing the DSS and cleaners' results can to a large extent be explained by the cleaners' high proportion of deciduous stems in EnköpingPine1and the high amount of stems fulfilling the "quality criteria" in EnköpingPine2 (4250 stems per hectare in the "adjusted" simulation). The utilised areas in the "adjusted" simulations were in five cases smaller than the areas utilised by the cleaners causing a slightly lower single-tree precision.

The results of both this study, and those by Zucchini and Gadow (1995) and Füldner et al. (1996), show that cleaning and thinning selection is not a "precise science" and the results of humans are not deterministic. The motive for selecting a particular tree is sometimes difficult to predict, although foresters are given the same instructions (Füldner et al. 1996). Incomplete agreement between two thinnings is not necessarily a proof of poor performance, but simply suggest that alternative ways of doing the same thinning exist (Daume and Robertson 2000a). Humans make decisions based on the instruction in combination with their own experience, as argued in Vestlund (2004), and the cleaners' results were therefore dissimilar. One could argue that the deviations from the targets in the results of the cleaners may have reflected "contradictions" in their instructions, which stated that they should select stems as in an actual cleaning and yet consider several desired targets. However, cleaners are always given targets in company-owned forests, which they say they do not always follow (Vestlund 2004), and the results here could be seen as an example of that. An inventory of Swedish cleaning stands by Pettersson and Bäcke (1998) revealed that that generally cleaning sites had 4000 stems per hectare remaining after cleaning, although the requested target is usually 2500 (cf. Vestlund 2004). In contrast, DSS-recommendations are deterministic in the sense that they always follow the given instructions/settings. So it is necessary that the instructions to the DSS are customised to the assigners requests and to the initial state of the stand in order to render satisfactory results. Uniformity could also be a problem, but as the forest varied the results of the DSS also differed. To avoid uniformity, randomness could be built into the system if required.

The attributes diameter, position, and straightness are attributes that should be possible to detect with machine vision and/or laser measurements (cf. Erikson and Vestlund 2003). It should also be possible to identify species and detect the other three defined damage types (cf. Fig. 3) with such approaches (cf. Mattsson 1996, Blackmore et al. 2002, Holmgren 2003). More attributes could be added to the DSS to reduce the differences between the cleaners' and the simulations' results. For example, more types of damage could be defined, as the amount of remaining stems with "undefined damage" was higher for the simulations since the DSS cannot distinguish between such stems and undamaged stems. On the other hand, it is not necessarily essential to conform fully to the cleaners' results, since it is questionable whether all of the cleaners' choices were desirable, even if they were acceptable. It is possible that the forest owners may think that the proportions of deciduous stems retained by the cleaners were too high. Research regarding the effects of the mean spacing of a stand on volume yield and quality parameters such as branch size (e.g. Persson 1976, Pettersson 1992, Nyström 2001) has resulted in recommendations to leave between 1400 and 4000 stems per hectare, depending on site quality and species, when stands with an average height of three metres are cleaned. It should be noted that forest owners could have other desires. The cleaners who selected more than 3300 stems exceeded these recommendations for the sites concerned. The number of stems per hectare after the "general" simulation was also higher than 3300 in the SkutskärPine area, suggesting that the last threshold "valueDefinitive" was set too high. In the "general" simulation "valueDefinitive" was set at 5.5, allowing selection of up to 37.5% more stems than the density target, if there were more stems in the "OK-Tree-list". Nevertheless, the density result for SkutskärPine after the "general" simulation was comparable with the cleaners' results, which was an objective with this simulation, as the cleaners' results are deemed to be acceptable.

It is possible that another DSS with more and/or other attributes could render better economical outcomes, but to be operational and economical a DSS should be as simple as possible, i.e. include as few attributes as possible, without rendering unacceptable results (cf. Daume and Robertson 2000b). The settings in the DSS can be adjusted and more attributes could be added, which are discussed in Vestlund et al. (2005). However, to further evaluate the DSS, and to refine the system if the assigners do not accept the system's selections, comparisons with cleaning researchers or the assigners could be made. The fact that the cleaners sometimes deviated from the general targets does not mean that the assigners do not accept their results. However, cleaning with a DSS will render results in accordance with the given instructions, thus the assigners must state their targets and requests on a more detailed level, if they want variable results in different stands.

The DSS seemed to be quite useful, and it is flexible as it can be adjusted to the results of the cleaners. It is also robust since both of the simulations' and the laymen's results were comparable with the cleaners' choices. Using the DSS in automatic, or semi-automatic, cleaning operations should be possible but only if and when the selected attributes can be automatically perceived. A thorough description of the requirements for e.g. sensors, functions, and base-machine to develop a robot usable in cleanings can be found in Vestlund and Hellström (2005). However, using the DSS as a training-tool for inexperienced cleaners is an interesting option, and with an improved interface the possibility to follow the recommendations of the DSS would rise. The laymen were able to use the DSS, and although they deviated from the DSS-recommendations in some cases their results were close to the results of the "General" simulation. A DSS provides immediate and objective directives about how to proceed, which the cleaners' request (Vestlund 2004). So if this DSS provides correct recommendations and can provide better decisions it can be expected to lead to better outcomes (*cf.* Druzdzel and Flynn 2000). A DSS for humans could include other attributes, as there is no need to be able to sense them automatically. Developing a version that could be used in a Palm-top computer might be a good idea.

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