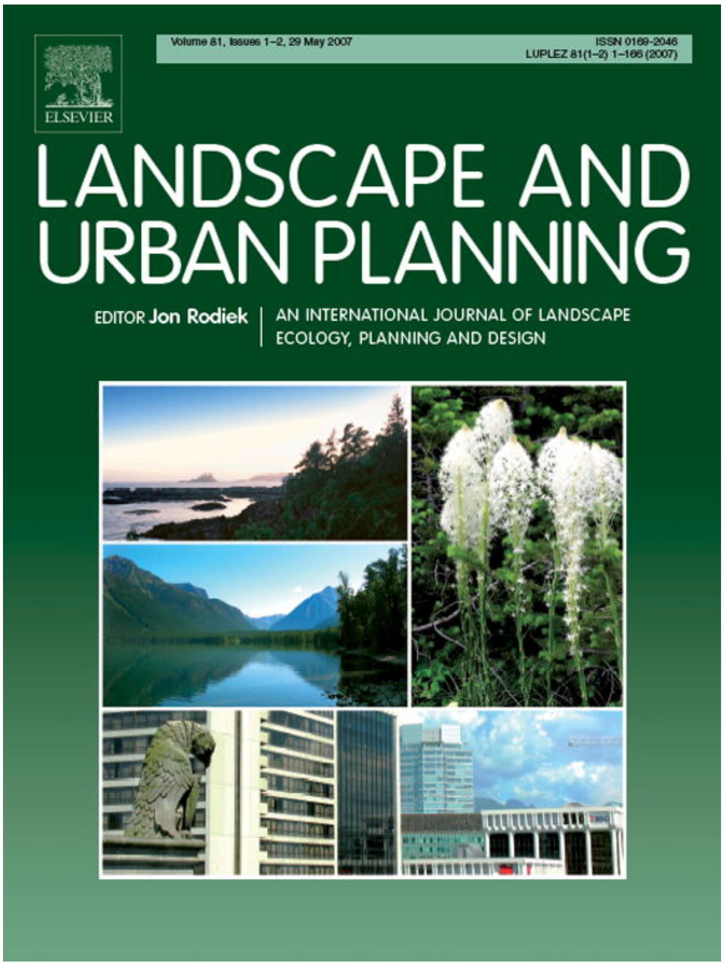
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Comparing forest assessment based on computer visualization versus videography

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Abstract

This study examined the representational validity of computer-visualized forests by comparing them with field-recorded walkthrough videos (field videos) from a timber stand management perspective. Computer-visualized replicas of field conditions at selected locations in loblolly pine (*Pinus taeda*, L.) stands were generated using measured data. Human subjects examined either field videos or computer visualizations and assessed characteristics of five distinct stands which consist of three well managed spacing stands (1.5 m, 2.4 m, and 3.0 m) and two minimally managed stands (immature and mature stands). Subjects viewing computer visualizations tended to estimate lower stem density and higher mean diameter of the well managed stands. Assessed stand structure of the well managed stands through the field videos and computer visualizations were in relatively high level of agreement. In minimally managed stands, significant differences were not found in density assessments including mean spacing, stem density, and mean diameter; however, horizontal crown cover in the immature stand was estimated lower using computer visualizations. Field video and computer visualization groups perceived different stand structure in the mature stand in which hardwoods were present in the mid-canopy.

Keywords: Computer visualization; Forest visualization; Loblolly pine; Forest assessment; Forest management; Human perception

1. Introduction

There is an increasing interest in the use of forest visualizations to assist forest management (Uusitalo and Orland, 2001). Forest visualization has been used to make visual predictions after harvesting practices (Orland, 1997), simulate treatment options (Heasley and McNamara, 1990; Bergen et al., 1995a), and assess landscape changes (Thuresson et al., 1996). Certain types of forest management operations require tree- or location-specific assessments, i.e., removing small trees in release treatments or thinnings in which trees are removed according to crown classes or grades (Smith et al., 1997). Spatially explicit forest visualizations, in which trees are accurately depicted in location and dimensions, have the potential to assist in stand assessments. However, the demonstrated utility of spatially explicit forest visualizations has been limited due to the difficulty of collecting the required information over large areas (Uusitalo and Orland, 2001). In recent years, remote sensing has increasingly been used for forest assessment and inventory as a result of increased data availability and technical advances (McCombs et al., 2003; Persson et al., 2002). Prototypical stand visualizations displaying forest conditions using remotely sensed data are becoming more of a possibility. Using computer visualizations for forest assessments could provide numerous possibilities. Examples might include a heads-up display detailing measurements used to create the scene, the ability to 'fly' into the canopy and assess the stand from there, or color-coding various parts of the forest to illustrate relative density. However, such visualizations are useful for forest assessment only if computer-visualized forests can accurately represent forest characteristics.

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Table 1
Means and standard deviations (S.D.) of loblolly pine field measurement in five stands

	Spacing[a] (m)		Stem density[a] (trees/ha)		Height (m)		DBH (cm)		LCR (%)		Crown radius (m)	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1.5 m	2.1	–	2378.8	–	16.9	1.5	15.2	2.7	27.4	4.5	2.7	0.2
2.4 m	3.0	–	1091.7	–	18.1	1.4	20.2	2.8	38.4	6.3	1.2	0.3
3.0 m	3.6	–	792.6	–	18.2	1.8	23.4	3.8	42.9	7.5	1.4	0.4
Immature	2.4	0.5	2005.4	1062.5	8.2	1.8	11.2	4.6	51.7	11.3	1.0	0.5
Mature	7.0	1.3	222.8	86.8	31.1	3.2	36.1	7.5	24.6	7.2	2.3	0.9

[a] Tree spacing and stem density in spacing stands are based on total inventory, so S.D is not included. The spacing differs from initial planting spacing due to dead trees. Spacing for immature and mature stands was estimated from stem density based on plot samples assuming square area occupancy by each tree.

Few studies have examined how well a computer visualization represent forest conditions, therefore the validity of forest visualizations is uncertain (McQuillan, 1998). Bergen et al. (1995b) compared perceived scenic beauty through photographs of real and computer-visualized forest landscapes. They found a moderate to high correlation between the mean ratings of scenic beauty assessed by the human subjects through real and computer-visualized forest images of the same scene. Rautalin et al. (2001) examined correlations between actual and estimated mean age, mean height, mean diameter, basal area, and stem density through computer visualizations. They found that mean tree height and mean diameter were reasonably well estimated while basal area and stem density were not accurately assessed.

The objective of this study was to determine if computer visualizations represented or under-represented actual stand conditions by using field-recorded walkthrough videos (field videos) as the basis for the comparison. Videos were recorded and computer-visualized replicas were generated at selected locations within different types of forest stands. Viewer estimates of stand characteristics through the field videos were compared to those through the computer visualizations. Previous studies indicated that photoreality (House et al., 1998), accuracy of data to render trees (McQuillan, 1998; Uusitalo and Orland, 2001), scale references (Rautalin et al., 2001), and viewing aspects (e.g., viewer location, view direction, and angle) potentially affect viewer perception through computer-visualized forests. These issues were accounted for in preparing experimental stimuli within available computational resources and logistics. The results of this study are expected to provide additional information in using forest visualizations in practice of forest management.

2. Methods

2.1. Study sites and field measurements

Three well managed spacing stands (18 years) in which trees were initially planted at square spacings of 1.5 m, 2.4 m, and 3.0 m and minimally managed immature (8 years) and mature (40 years) stands of loblolly pine (*Pinus taeda*, L.) were selected from the Mississippi State University (MSU) John W. Starr Memorial Forest (33°16′N, 88°52′W). Although the spacing stands have been maintained for research, they have similar characteristics to that of well managed pine plantations. In minimally managed stands, hardwoods were present in mid canopy of the mature stand and underbrush was present in both immature and mature stands.

Field measurements were conducted between March and April 2002. Location (geographic coordinates), species, height, height to the base of live crown (BLC, determined by the presence of the lowest two live branches), crown radius, and stem diameter at breast height (DBH, diameter at 1.37 m above ground) of individual trees were measured in selected portions of the spacing stands and in eight plots in each of the minimally managed stands (5 m radius for the immature stand and 10 m radius for the mature stand), avoiding openings (Table 1).

2.2. Field recording

Previous studies used photographs (Zube et al., 1974, 1975; Bergen et al., 1995b; Daniel and Meitner, 2001) or videos (Laumann et al., 2001; van den Berg et al., 2003) to represent actual scenes. We chose field videos as the control stimuli because overlapping (hidden) trees in a static view may mislead viewers. Field videos were recorded in January 2003 along predetermined transects in the spacing stands, and at plot center with the camera rotating in minimally managed stands. The minimally managed stands were recorded in this manner because walkthroughs were difficult due to the thick underbrush. Stem and canopy views were recorded separately due to the small field of view of the camera. Loss of dimensional information was a concern in using videos as stimuli, so to minimize this problem, scale cues were added before recording. These included 1-in. thick tape at breast height of selected trees and regularly spaced flags on the ground (1.5 m for spacing stands and 3.0 m for immature and mature stands). Duplicate videos were recorded for each scene. The videos were individually evaluated for image quality and disruptions and the best quality video was selected for the study.

2.3. Tree models

A forest visualization application that renders individual trees using measured data was developed to create replicas of field conditions. The tree model was a variation of the ‘needle’ model developed to incorporate remotely sensed measurement data and create large-scale forest visualizations (Mohammadi-Aragh et al., 2003). The photorealism of the model was balanced with the

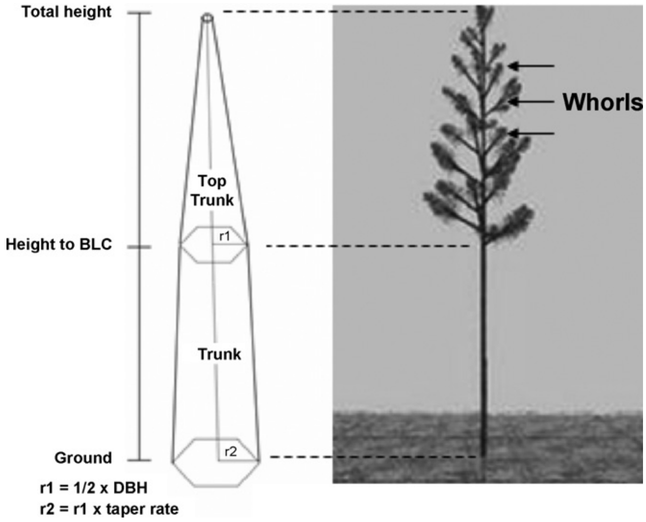

Fig. 1. An illustration of the two-segment trunk (left) and branch whorls (right).

frame rate to maintain interactivity while examining large forest. Since the study used pre-recorded videos, it did not directly rely on interaction speeds; however, interaction speed may be important in future applications with larger data sets. Therefore, we were reluctant to alter the model significantly or use another more realistic tree model designed for static views.

Each stand type had the same basic visual components with slight variations. The stems of the loblolly pine model were centered at each tree location and composed of two upright six-faced polyhedrons (Fig. 1). The base of each trunk was positioned at ground level and had a radius of half of DBH. The top of the trunks had radii of half of DBH times the taper rate (0.8). The trunk heights were set equal to height to BLC. The base of the upper stem was at the height to BLC with a base diameter equal to the top diameter of the trunk.

Branches were drawn in whorls emanating from the upper stem. Whorl spacing, determined automatically based on the live crown ratio (LCR), averaged one whorl per meter except for immature trees, which had one whorl per 0.3 m. Each whorl contained four branches, one in each of the four cardinal directions. The number of branches and sub-branches was automatically adjusted based on the size of the live crown. Branch thickness was based on stem DBH. The branch-to-stem angle was determined based on branch height and varied from 80° at the base of the upper stem to 35° at the top of the tree. Needles were represented with two orthogonal textured quadrilaterals. Randomness was used to prevent rigid repetitiveness in the live crown. For example, every tree had a small probability of having a few dead branches. If a branch was classified as dead, it was not drawn. Branch angles and locations were randomly varied to ensure no two trees were identical.

There was some inconsistency in the tree representations between field videos and computer visualizations because the graphic trees were based only on field measurements. In field measurements, BLC was determined by the presence of at least two live branches; however, dead branches were typically visually present below the BLC. Consequently, the field videos contain dead branches below the BLC, but the computer visualizations do not. However, viewer instructions were consistent: the live crown begins at the height where at least two live branches exist.

Although the scope of this study was limited to pine stands, hardwoods were rendered in the mature stand since their omission could potentially lead to false stand impressions. Hardwood trees were rendered using billboarding. A disadvantage to billboarding is that, sans scaling, every hardwood tree is identical as traditional billboarding involves affixing a single image (texture) to a single quadrilateral (quad). However, to allow both the trunk and crown to be scaled independently for various DBH and crown ratio combinations, our model utilized separate textures and quads for the two tree sections. The trunk and crown billboards were stacked to create a single tree. This simplistic model was used only to provide environment context and the users were not allowed to closely examine these trees, as the viewing location is static in the mature stand.

2.4. Experimental materials

Computer-visualized replicas of the recorded areas were created with approximately the same field of view, viewing position, and viewing angle (Fig. 2). The same scale cues used in the field videos were added to the computer visualizations. Field-recorded and computer-visualized videos, along with user instructions, were combined on a DVD. Approximately 30 s of trunk view were followed by 30 s of canopy view. Total viewing time was two min for the spacing stands (30 s of stem view + 30 s of canopy view per each of the two locations) and seven min for minimally managed stands (30 s of stem view + 30 s of canopy view per each of seven locations).

Both numerical and categorical forest characteristics were estimated. Numerical estimates included mean tree spacing, stem density, mean DBH, mean LCR, mean percent crown cover (the proportion of ground in a given area covered by crowns), and height. Categorical estimates included relative stocking (under stocked, fully stocked, over stocked), rotation stage (establishment, early rotation, mid-rotation, mature), stand structure (even-aged, uneven-aged). Relative hardwood competition (very low, low, medium, high, very high) was asked for the mature stand, as it was the only stand with a significant hardwood component. Estimated mean DBH was also used in comparisons of tree size classes by converting it to one of four classes based on tree size classes defined by the U.S. Department of Agriculture Forest Service (seedling, sapling, pole timber, sawtimber) (Wear and Greis, 2002). Height was estimated numerically, but analyzed as height classes (<7.6 m, 7.6–15.2 m, 15.2–22.9 m, 22.9–30.5 m, ≥30.5 m) due to insufficient height cues.

2.5. Experimental procedure

Fifty human subjects were recruited from the Department of Forestry at MSU through class announcements and personal contacts. The subjects included undergraduate students ($n = 31$) who had either completed or were attending the forestry summer field program, which involves intensive field measurements and inventory practices, or those who had equivalent experience,

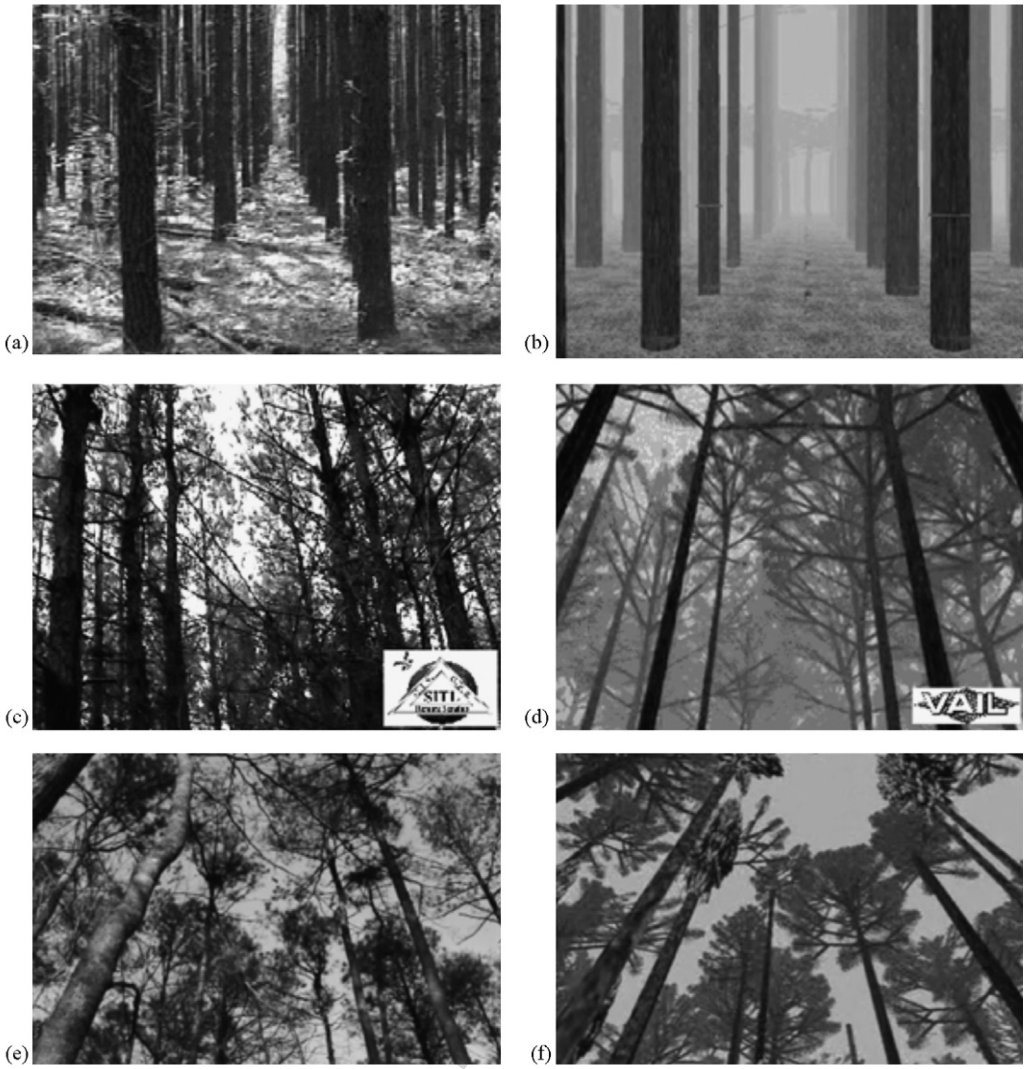

Fig. 2. Examples of the stand images: horizontal views from field video (a) and graphic forest (b) in the spacing stands, canopy views from field video (c) and graphic forest (d) in the spacing stands, and canopy views from field video (e) and the graphic forest (f) in the mature stand.

such as graduate students ($n = 16$), faculty ($n = 2$), and alumni ($n = 1$).

Subjects were assigned randomly in approximately equal numbers to view either field videos or computer visualizations. Subjects were provided instructions including definitions of terms and reviewed the questionnaire prior to examining the forest scenes. Each subject examined the assigned forest scenes projected on a large screen in this order: 2.4 m spacing, immature, 1.5 m spacing, mature, and 3.0 m spacing. Interweaving of the spacing stand and minimally managed stand image sequences was used to minimize potential bias due to effects of learning. The subjects filled in the questionnaire after each stand.

2.6. Analysis

Significant interaction between stand type and image type were found in some of the variables after preliminary analysis based on t-tests (Mohammadi-Aragh et al., 2005). Therefore, numerical estimates were analyzed as either a two-by-three (spacing stands) or two-by-two (minimally managed stands) factorial arrangement of treatments in a split plot design. The main factor was image type (i.e., field video or computer visualization) and the sub factor was stand type (i.e., three levels for the spacing stands and two levels for the minimally managed stands). Image type by stand type interaction was tested first. If the interaction effect is significant, the effect of image type is considered to depend on the stand type, and then effect of image type was tested at each stand type. If the interaction effect is not significant, overall effect of image type was tested. Wilcoxon sum rank test, the non-parametric equivalent of the two-sample t-test, was used for analysis of ordered categorical variables. Fisher's exact test was used for unordered categorical variables. An α level of 0.05 was used for the test level of significance.

3. Results

Five of the 50 subjects (four with extensive prior knowledge of the study site and one who apparently did not understand the questions) were excluded from the analysis. Results were

Table 2
Means and standard deviations (S.D.) of estimated stand characteristics for the spacing stands by field video and graphic groups

Estimated characteristics, stand type	Field video			Graphic		
	n	Mean	S.D.	n	Mean	S.D.
Mean spacing (m)						
1.5 m[a]	21	2.0	0.6	24	2.6	0.8
2.4 m	21	3.2	1.1	24	3.0	1.1
3.0 m[a]	21	2.6	0.7	24	3.2	0.7
Stem density (trees/ha)						
1.5 m[a]	20	1417.9	722.3	23	951.1	371.0
2.4 m	20	910.6	520.4	23	799.4	502.5
3.0 m	20	1101.6	575.3	24	860.7	321.4
Mean DBH (cm)						
1.5 m[a]	21	20.6	7.2	24	26.2	8.4
2.4 m	21	25.4	5.3	24	26.4	6.5
3.0 m[a]	21	23.9	6.1	24	26.2	7.8
Mean LCR (%)						
1.5 m[a]	20	24.1	7.4	24	29.0	12.0
2.4 m[a]	20	29.3	8.2	24	32.6	8.5
3.0 m[a]	21	30.1	10.0	24	34.6	9.4
Mean crown cover (%)						
1.5 m	21	69.6	18.4	24	80.4	12.5
2.4 m	21	62.0	20.4	24	70.6	16.8
3.0 m	21	71.2	13.9	24	73.5	13.4

[a] Viewer estimates through field videos and graphic forests were significantly different at α level of 0.05.

based on the remaining 45 completed questionnaires of which 21 were based on the field videos and 24 on computer visualizations (graphic). Variations in the number of observations among individual questions are due to missing observations such as unanswered questions and illegible handwriting.

3.1. Numerical estimates

Viewer assessments of the spacing stands and minimally managed stands were analyzed separately (Tables 2–4). Significant image type by stand type interaction was found (i.e., image type and stand type interact to affect viewer estimates) in mean spacing ($p < 0.01$), stem density ($p < 0.01$), and mean DBH ($p < 0.01$) in the spacing stands and mean crown cover ($p < 0.01$) in the minimally managed stands. Effect of image type was tested at each stand type for these variables. Overall effect of image type was tested for other variables in which interaction effect was not significant.

In the spacing stands, significant differences between field videos and graphics were found in mean spacing ($\bar{x}_{\text{field video}} <$

Table 3
Means and standard deviations (S.D.) of estimated stand characteristics for minimally managed stands by field video and graphic groups

Estimated characteristics, stand type	Field video			Graphic		
	n	Mean	S.D.	n	Mean	S.D.
Mean spacing (m)						
Immature	21	3.3	1.7	23	4.0	1.4
Mature	21	6.2	2.4	24	6.1	1.9
Stem density (trees/ha)						
Immature	20	916.3	543.6	23	663.0	435.6
Mature	20	403.8	378.6	23	373.4	176.6
Mean DBH (cm)						
Immature	21	19.8	5.6	24	21.1	7.3
Mature	21	37.3	8.6	24	39.3	7.8
Mean LCR (%)						
Immature	20	44.4	14.4	24	39.2	11.8
Mature	21	26.3	7.5	24	24.4	7.9
Mean crown cover (%)						
Immature[a]	21	58.4	18.2	24	38.8	12.1
Mature	21	35.7	15.4	24	37.1	16.6

[a] Viewer estimates through field videos and graphic forests were significantly different at α level of 0.05.

Table 4
Summary of p-values of the statistical tests

Estimated characteristics	Spacing stands			Minimally managed stands	
	1.5 m	2.4 m	3.0 m	Immature	Mature
Mean spacing	0.016	0.444	0.010	0.569	
Stem density	0.015	0.480	0.092	0.151	
Mean DBH	0.020	0.597	0.014	0.293	
Mean LCR		0.029		0.297	
Mean crown cover		0.101		<0.001	0.777
Stocking	0.007	0.079	0.008	0.047	0.338
Tree size class	0.025	0.778	0.033	0.392	1.000
Height class	0.012	0.423	0.021	0.821	0.154
Rotation	0.007	0.430	0.018	0.647	0.119
Stand structure	0.544	[a]	[a]	0.102	0.006
Hardwood competition					0.186

Each stand type's p-value is shown for the cases where image type by stand type interaction was significant; otherwise a single p-value is reported.

[a] Fisher's exact tests were not performed since all subjects selected the same class.

$\bar{x}_{\text{graphic}}$), stem density ($\bar{x}_{\text{field video}} > \bar{x}_{\text{graphic}}$), and mean DBH ($\bar{x}_{\text{field video}} < \bar{x}_{\text{graphic}}$) for at least one of the spacing stands (Tables 2 and 4). The effect of image type was significant in mean LCR in the spacing stands ($p = 0.03$, $\bar{x}_{\text{field video}} < \bar{x}_{\text{graphic}}$; Tables 2 and 4). In the minimally managed stands, a significant difference between the field video and the graphic video interpretation was found in mean crown cover in the immature stand ($p < 0.01$, $\bar{x}_{\text{field video}} > \bar{x}_{\text{graphic}}$; Tables 3 and 4).

3.2. *Categorical estimates*

The results of categorical estimates are summarized in Figs. 3 and 4 with the results of statistical tests shown in Table 4. In the spacing stands, significant differences between the two viewer's estimates were found in the 1.5 m and 3.0 m spacing stands in relative stocking ($p < 0.01$ for both), tree size class ($p = 0.2$ for 1.5 m and $p = 0.03$ for 3.0 m), height class ($p = 0.01$ for 1.5 m and $p = 0.02$ for 3.0 m), and time in rotation ($p < 0.01$ for 1.5 m and $p = 0.02$ for 3.0 m). The graphic group tended to perceive sparser stands with larger trees as compared to the field video group.

In the minimally managed stands, significant differences were found in the relative stocking of the immature stands ($p = 0.19$) and stand structure of the mature stand ($p < 0.01$). Likewise, in the spacing stands the graphic group tended to perceive a lower stocking class than did the field video group. The majority of the field video group selected "even-aged" while those in the graphic group selected "uneven-aged" stand structure.

4. Discussion

This study examined representational validity of forest visualization by comparing viewer estimates through field videos and computer visualizations. Instead of comparing viewer estimates through actual forests and computer visualizations, this approach was taken to conduct the experiment in controlled environments. As Rautalin et al. (2001) described, visual estimates and measured values do not necessarily agree. Although a formal statistical test to compare visual estimates and measured values was not conducted, estimates of stem density, DBH, and LCR from measurements were outside of the 95% intervals of the visual estimates by the subjects in the majority of stands. This may suggest inaccuracy of visual estimates despite their prior training and experiences of forest inventory. Therefore, we limit our discussion to the representational validity of computer-visualized stands by comparing visual estimates to field-recorded scenes and not actual stands. It also should be noted that this study is based on a particular forest visualization application. Visualized scenes differ depending on visualization techniques (McGaughey, 1998).

Significant differences in estimates frequently occurred in the spacing stands in which trees are uniform in size and space (Table 4). Overall, higher estimates of spacing and DBH translated to lower estimates of stem density and relative stocking through computer visualizations (Table 2 and Fig. 3). This is consistent with results reported by Rautalin et al. (2001) who found inaccurate stem density estimation through computer visualizations. They suggested that a within-forest view might possibly improve stem density estimation; however, our results did not support this assumption. On average, the graphic group tended to perceive larger trees compared to the field video group. Simplification of the scene due to the omission of underbrush resulted in a lack of partly obscured views in the computer visualizations. This might have led viewers to focus too heavily on the trees leading to inflated diameter estimates. The use of fog also simplified the scene: the background of the video imagery is a solid wall of trees while the background of the computer simulation is a gray haze. Individual trees are essentially highlighted on the bright gray background instead of merging into the surrounding forest. The fog also obscures the simulated underbrush. These factors could have resulted in the overestimation of diameters or underestimation of tree densities. Insufficient use of scale cues is possibly another cause for observed differences.

A few statistically significant differences in viewer estimates between the field videos and computer visualizations were found in the minimally managed stands (Table 4). Differences were found in mean crown cover and relative stocking in the

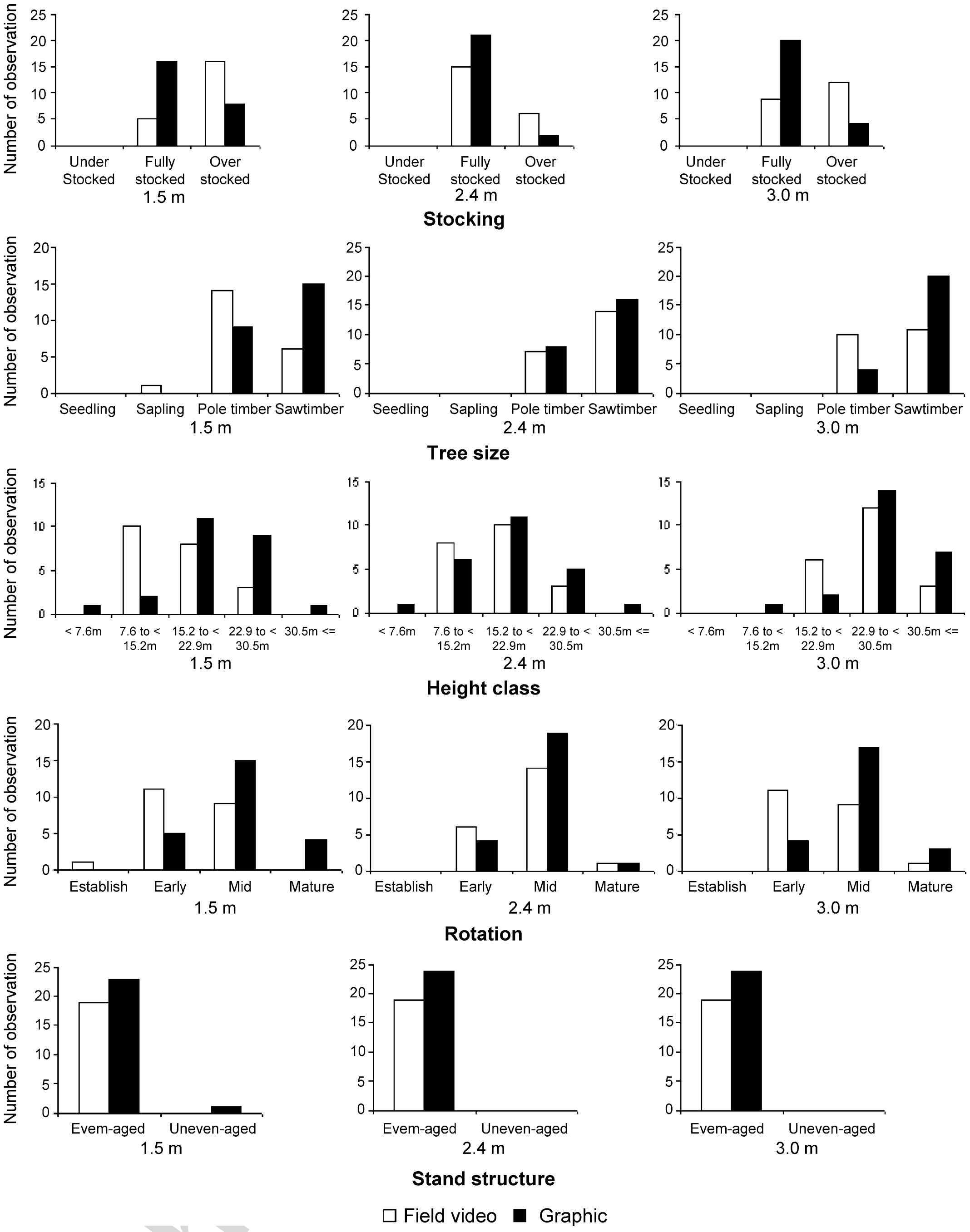

Fig. 3. Results of categorical estimates of the spacing stands by field video and graphic groups.

immature stand (Table 3 and Fig. 4). The presence of understory in the field video may have been a cause for this, since dead branches and vines in the field video can obscure views. This is especially influential in the immature stand because trees are shorter. Insufficient graphical depiction of tree crowns is also another likely cause. Since young pine trees generally have greater LCR, simplification of the crown is more influential on viewer estimates in the immature stand than in the mature stand. Furthermore, there is a slight mismatch in focal length and field of view particularly in canopy views (Fig. 2c–f). The effect of this mismatch was assumed minor, but it might provide viewers with a somewhat different impression and affect their perception of canopy cover. The observed difference in stand structure in the mature stand (Table 4 and Fig. 4) is likely due to the presence of hardwoods which are more distinct in the computer visualizations than in the field videos (Fig. 2e and f).

Overall, *p*-values varied widely between assessed characteristics and stand types (Table 4). For those where significant differences were not observed, the absence of a difference does not imply equivalence in estimates made through field videos and computer visualizations. However, viewer estimates were in exact or nearly exact agreement for some of the categorical estimates (e.g., tree size class in the mature stand and stand structure of the spacing stands) (Figs. 3 and 4). These can be

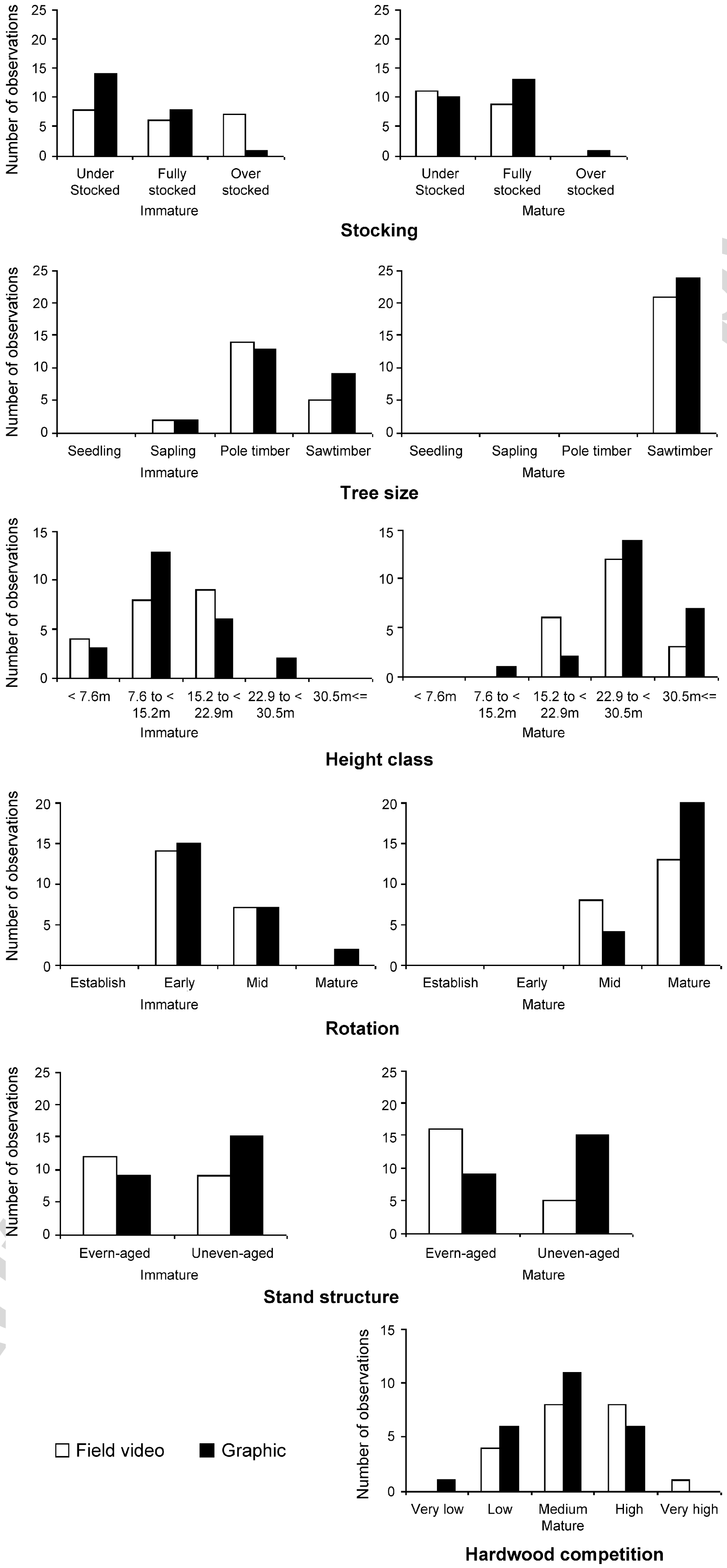

Fig. 4. Results of categorical estimates of the minimally managed stands by field video and graphic groups.

viewed as positive indications of representational validity of the computer visualizations.

5. Conclusion

The presence of differences in estimated stand characteristics through field videos and computer visualizations depends on assessed stand type and characteristics. Differences in viewer estimates more frequently occurred in the spacing stands in which trees are more uniform in size and space than minimally managed stands. Further studies are needed to identify factors which caused these differences and consider whether these factors are accountable for future development of forest visualizations. In particular, we purposely limited realism in an effort to have an interactive model for future applications; however, realism may have a greater effect on perceived stand characteristics than interaction and should be further examined.

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