

Interpretation of forest characteristics from computer-generated images

Tara M. Barrett^{a,*}, Hans R. Zuuring^b, Treg Christopher^{b,1}

^a Pacific Northwest Research Station, USDA Forest Service, 3301 C Street Suite 200, Anchorage, AK 99503, USA

^b University of Montana, College of Forestry and Conservation, Missoula, MT 59812, USA

Received 8 March 2006; received in revised form 7 July 2006; accepted 19 September 2006

Available online 6 December 2006

Abstract

The need for effective communication in the management and planning of forested landscapes has led to a substantial increase in the use of visual information. Using forest plots from California, Oregon, and Washington, and a survey of 183 natural resource professionals in these states, we examined the use of computer-generated images to convey information about forest characteristics. Age and density (basal area (BA)) were underestimated for large, old, dense forest and overestimated for small, young, open forest. While accuracy of responses for density, tree size, and age of forest plot images was low, the ordering of such images by these attributes did correspond to the actual forest plot characteristics.

Alterations to the standard image were made for three of the forest plots, including alterations for the area depicted, the incorporation of under-story vegetation and fallen trees, the addition of a truck, and regular and clumpy individual tree spacing. Image alterations did affect some mean responses for tree size, density, fire hazard, vertical stratification, and forest age. Results show managers and planners may need to exercise caution and supplement images with additional information to avoid miscommunication about the nature of current and projected forest landscapes.

© 2006 Elsevier B.V. All rights reserved.

Keywords: Computer visualization; Decision support systems; Vegetation modeling; Public communication

1. Introduction

More than a decade after the compromise Northwest Forest Plan was developed for 9.8 million ha of forest land in California, Oregon, and Washington, intense controversy over forest management in the region continues (Stokstad, 2005). The content of the conflict has broadened from protection of old growth (Thomas et al., 1993) to debate over the merits of salvage logging (Lindmayer et al., 2004) and fuels reduction (Stephens and Ruth, 2005). Because of the many disparate interests involved, effective communication is viewed as critical to addressing contentious issues in management of forest ecosystems (Yaffee and Wondolleck, 1997). Computer-based visualization is increasingly seen as an effective way of involving technical experts, decision makers,

and public stakeholders in forest management (Lewis et al., 2004).

Frequently controversies over forest management are discussed in terms related to forest structural characteristics such as tree size, density, age, species composition, or relative fire risk. For example, the recent reevaluation of late-seral and old growth forests covered by the Northwest Forest Plan presents the status of the forests in terms of average tree size and vertical stratification (Moeur et al., 2005). Fuels reduction to lessen fire hazard is frequently discussed in terms of tree density and vertical stratification, with computer-generated graphic images used to portray patches of forest before and after silvicultural treatments (Johnson and Peterson, 2005).

Following the adage that “a picture is worth a thousand words” planners are increasingly using graphic images to convey the structural characteristics of forests. Whether for public or private forests, management plans now routinely include data-driven graphic images, as do many other publications and presentations. Researchers report positively on this development: visualizations can help managers communicate basic forest dynamics (Twery et al., 2005) or historical changes (Wang et al., 2006); visualizations help to involve the public in

* Corresponding author. Tel.: +1 503 808 2041; fax: +1 503 808 2020.

E-mail addresses: tbarrett@fs.fed.us (T.M. Barrett), hans.zuuring@cfc.umt.edu (H.R. Zuuring), treg.christopher@uvm.edu (T. Christopher).

¹ Present address: Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT 05405, USA.

forest management (Stoltman et al., 2004; Tang and Bishop, 2002); visualization of forests under alternative future planning scenarios is promising for stakeholder involvement when the management issues are contentious (Sheppard and Meitner, 2005); data-driven computer visualizations of possible forest management futures are useful for finding common ground among interdisciplinary teams (Meitner et al., 2005); visualizations can display outcomes for forests that are otherwise inaccessible (Wang et al., 2006).

At the same time, researchers have also recognized that these data-driven images may have limitations. Stone and Porter (1998) advise that relative differences in visual images should reflect the differences in the forests they portray, not just the algorithm used to translate measurements into an image. Used in a biased manner, images can mislead the public or decision makers about the potential impacts of a management proposal (Lewis et al., 2004). Computer visualization of forests can be used to deceive by misrepresenting spatial patterns, portraying stochastic events through averages, presenting a single scale of perception, or simply through the “wow” effect of sophisticated technology (McQuillan, 1998). Even when deception is not intended, images can provide a different impression of a forest than a field visit (Barrett et al., 2002). While designers of software for forest imaging strive for greater realism (e.g., Lim and Honjo, 2003; Kumsap et al., 2005), this may actually exacerbate the ability to create deceptive images (Orland and Uusitalo, 2001).

Although there has been recognition that images could, in theory, create misperceptions, there is almost no information about whether and how this happens for typical visualizations. With the increase in use of images to communicate current and projected forest characteristics, it becomes important to understand more about perception of those forest characteristics. In this study, we used a web-based survey of natural resource professionals to understand more about interpretation of common forest characteristics from data-driven images. Comparisons are made both between perceptions of image and measured forest characteristics, and between different images generated from identical forest data. Specific objectives of the study are to: (1) increase understanding of the accuracy and bias of perceptions

of tree size, age, and density from typical images, (2) examine the interaction between accuracy of perceptions and the nature of the forested areas depicted, and (3) test whether commonly used image alterations affect perception of tree size, layering, age, fire hazard, and density.

2. Methods

2.1. Forest data and image generation

The survey was designed to examine two aspects of visual interpretation. The first aspect, termed the “Image versus Forest” comparison, was the correspondence between peoples’ interpretation of forest attributes from the image and the matching attributes as calculated from field measurements of the trees. For example, did the perception of tree-age match with the field estimate of age? The second aspect of interest, described as the “Image versus Image” comparison, was the variation in response that occurred with different images generated from the same field measurements. For example, how did the presence of a truck affect a person’s tree-size estimate compared to the same image without a truck?

The data set from which the computer-generated images were created came from permanent field plots used to sample all forestland in Oregon, Washington, and California, in the year 2000 for the purposes of monitoring forest health (Alexander and Palmer, 1999). Field measurements included species, tree height, length of tree crown, and stem diameter at breast height (DBH—1.3 m above the ground) for individual trees within a fixed area plot (0.067 ha) of the forest (USDA Forest Service, 2006). From these data, the average DBH of tree stems was recorded in centimeters as a tree-size class attribute. Basal area (BA), the tree stem cross-sectional areas summed over a unit area, was calculated in square meters per hectare as a forest density attribute.

It was desirable to depict forested areas that were structurally diverse, yet keep the number of images small so that survey response time was limited to no more than 20 min. For this reason, the summary attributes were used to partition the forest samples into groups spanning the range of density and tree-size

Table 1

Actual forest characteristics of eight plots representing unique combinations of size, density (BA), and forest type selected for standard 0.4 ha image used in ‘Image vs. Forest’ comparisons

Plot	Combinations		Forest type	Age (years)	Trees (trees ha ⁻¹)	Basal area (m ² ha ⁻¹)	Tree stem diameter (cm)	
	Size	Density					Average	Maximum
1 ^a	Small	Low	Ponderosa pine	6	1512	7.1	9.8	49.5
2	Small	High	Lodgepole pine	55	2931	51.7	17.4	38.6
3	Medium	Low	Ponderosa pine	50	193	11.1	23.5	36.6
4 ^b	Medium	Medium	White fir	95	772	35.1	23.6	74.4
5	Medium	High	Noble fir	70	1352	76.0	25.7	55.6
6	Large	Low	Douglas-fir	60	283	41.9	35.9	73.2
7	Large	Medium	Western hemlock	45	506	87.1	38.8	101.9
8 ^c	Large	High	Western hemlock	250	1364	109.9	45.3	126.5

^a Additional images: (i) 0.07 ha plot; (ii) truck in image; (iii) regular tree spacing; (iv) clumpy tree spacing.

^b Additional images: (i) 0.07 ha plot; (ii) truck in image; (iii) regular tree spacing; (iv) with understory and fallen logs.

^c Additional images: (i) 0.07 ha plot; (ii) truck in image; (iii) regular tree spacing; (iv) clumpy tree spacing.



Fig. 1. Three out of eight 1-acre (0.4 ha) images representing unique combinations of size class, density, and forest type for the 'Image versus Forest' comparison: medium size and medium density (left); large size and high density (middle); small size and low density (right).

conditions. The average diameter of tree stems was used to split the forest samples into three equal quantiles, representing forests of varying tree size. Within the size quantiles, the forest samples in the medium and large-size classes were split into three density quantiles, and the small-size class was split into two density quantiles. For the "Image versus Forest" analysis, one plot was chosen randomly from each of the resulting eight strata, to provide a range of forest types (Table 1). A visual image of each forest plot was created from the field measurements of tree species, diameter, and height using the Stand Visualization System (SVS) (McGaughey, 1998), the software most commonly used by forest managers and planners in the United States to depict a representative area of forest. SVS parameters were set to the standard defaults for the program, resulting in an image of 0.4 ha (1 acre) of forest with randomized tree positions (Fig. 1).

For the "Image versus Image" analysis, three of the plots had additional images created: an image of a 0.07 ha (1/6th acre) of forest (Fig. 2), an image including a truck in the foreground, and an image where trees had a more regular distribution. The three plots chosen for these additional images were the small-size low-density plot, the medium-size medium-density plot, and the large-size high-density plot. For this comparison, we looked at whether the choice of image affected perception of stand structure variables of: (1) size, (2) density (basal area), (3) layering, and (4) age. Two additional images with clumped tree distribution, and one image with a forest understory, were gener-

ated. This provided a total of 3 plots $\times$ 5 images/plot = 15 images used in the "Image versus Image" analysis (Table 1).

2.2. Survey and analysis procedures

A web-based questionnaire was built to show each of the images with accompanying questions as a single page. Initially the survey had been designed to show six images of all eight plots. However, pre-testing of the questionnaire with several university classes and a professional group indicated that this number of images would negatively affect the response rate. The number of images was therefore reduced from 48 to the 20 described above.

For each individual taking the survey, the order of images was selected randomly, without replacement, to avoid an ordering bias. Although a participant would have seen both altered and non-altered versions of the same image, the images would not have been visible at the same time. Participants for the project were identified from a list of 600 individuals in Oregon, California, and Washington, who belonged to the primary forestry professional organization for this region, the Society of American Foresters. Implementation was adapted from Dillman (2000) using a combination of email and regular mail initial contact and reminder letters.

A unique login and password for each participant controlled access to the web site. The number of completed responses



Fig. 2. Visual comparison of a 0.4 ha (1 acre) and 0.07 ha (0.17 acre) SVS image using the same plot data for the 'Image vs. Image' comparison.

Table 2

Image vs. Forest: comparison of average perception of patch age and density and field-measured age and density for standard SVS 1.0 acre images (HO: $\mu_1 = \mu_2$; H1: $\mu_1 \neq \mu_2$)

Stand type (size, density)	n	Density (basal area)				Stand Age			
		Average image response ($\text{m}^2 \text{ha}^{-1}$)	Actual value ($\text{m}^2 \text{ha}^{-1}$)	S.E.	p-Value	Ave. image response (years)	Actual value (years)	S.E.	p-Value
Small, Low	179	21.9	7.1	1.8	0.000 ^a	26.3	6.0	2.2	0.000 ^a
Small, High	174	65.0	51.7	3.8	0.001 ^a	76.3	55.0	3.2	0.000 ^a
Medium, Low	183	35.5	11.1	2.1	0.000 ^a	75.6	50.0	4.6	0.000 ^a
Medium, Medium	158	45.3	35.1	3.2	0.002 ^a	84.0	95.0	4.7	0.022 ^a
Medium, High	178	77.1	76.0	4.8	0.832	96.1	70.0	5.1	0.000 ^a
Large, Low	178	59.9	41.9	3.9	0.000 ^a	79.7	60.0	3.7	0.000 ^a
Large, Medium	174	65.9	87.1	3.0	0.000 ^a	89.0	45.0	4.6	0.000 ^a
Large, High	163	68.6	109.9	3.0	0.000 ^a	142.0	250.0	6.5	0.000 ^a

^a Mean survey response differs from field measurement at $\alpha = 0.05$, two-sided *t*-test.

for the 20 images ranged from 158 to 183. Communication with non-respondents indicated a variety of reasons for non-participation, with the most frequent reasons related to troubles with computers and web browsers and, for non-forestry resource professionals, unfamiliarity with terms like basal area. Each image was presented as a separate web page, with the following questions accompanying each image; English units were used in the survey instrument, although we show metric units below.

- Which of the following stand size classes best describes this image?
 - Seedling/saplings (most < 13 cm DBH);
 - small trees (most 13–23 cm DBH);
 - medium trees (most 23–51 cm DBH);
 - large trees (most 51–102 cm DBH);
 - very large trees (most > 102 cm DBH).
- Enter a number for basal area that best describes this image:
- What is your best guess of the age of this stand?
- Which of the following vertical stratifications best describes this stand?
 - Multi-story;
 - single story.
- How would you rate the fire hazard of this image?
 - Fire hazard low;
 - fire hazard med low;
 - fire hazard med high;
 - fire hazard high.

Responses were gathered electronically and analyzed using SAS 9.1 statistical procedures (SAS Institute, 2004). For the multiple category questions, tests for difference included chi-square tests for categorical variables, with use of exact tests for a few instances where more than 20% of the categories had expected values of less than five under the null hypothesis. For the real-valued questions about stand age and basal area, tests of difference used a two-sided one-sample *t*-test for comparison to field-measured attributes or a two-sided two-sample *t*-test for comparison of two images. Comparisons of vertical stratification responses used a two-sample *t*-test for a proportion. All comparison tests set the probability of a Type I error to 5%.

3. Results

3.1. Image versus Forest

This analysis focused on whether people have a tendency to perceive stand characteristics in a computer-generated image to be different than the actual forest characteristics. For basal area and stand age, the null hypothesis was that the mean value given by respondents was the same as the value from field measurements. For basal area (a measure of stand density), mean responses of estimated basal area were significantly different than actual basal area for seven out of eight images of stands (Table 2). For tree age, mean response of estimated stand age was significantly different than actual stand age for all eight stands (Table 2). There was a general pattern of overestimating the density and age of younger, less dense stands and underestimating density and age for older, more dense stands. For the forest stand having a basal area of $77 \text{ m}^2 \text{ha}^{-1}$, there was no significant difference with respondents' estimated basal area. For the two stands with higher basal area than this, basal area was underestimated. For the five stands with lower basal area, basal area was overestimated. Similarly, stand age was underestimated for the 95 and 200-year-old stands, and overestimated for the six younger stands.

If a correct answer were to be defined as being within 20% of the actual value, only 18.6% of respondents' replies would meet that criterion for basal area and 22.9% of replies would meet that criterion for stand age. For large tree stands, the lowest basal area accuracy by this criterion (9.2%) occurred with the high-density stand. For medium and small tree stands, lowest basal area accuracy occurred with the low-density stands (5.5 and 11.7% accuracy, respectively). Age class accuracy by this criterion was between 20 and 29% for each stand with the exception of the small size class low-density stand, for which respondents were 9.0% accurate.

Even with low accuracy, and bias in average responses, the overall ordering of average responses did correspond to the actual ordering of stand attributes such as stand size class (Fig. 3). For example, most respondents successfully classed large-tree stands as being larger than the medium-size class for both high-density and low-density stands, and they

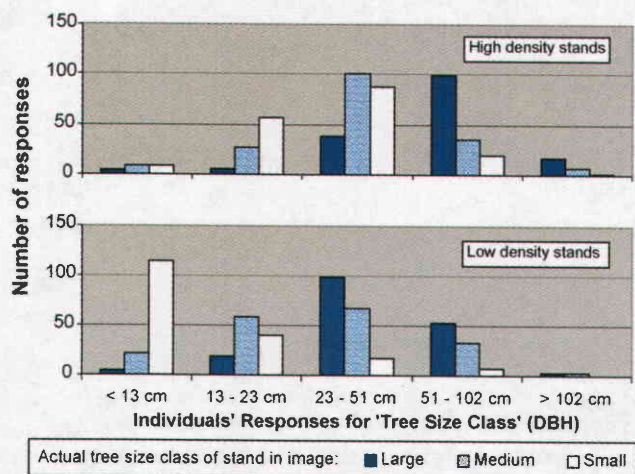


Fig. 3. Distribution of responses for "Which of the following stand size classes best describes this image?" by size class of field plots.

successfully classed medium-tree stands as being larger than small-tree stands. But in low-density stands they tended to underestimate the size class of large trees, and in high-density stands they tended to overestimate the size class of small trees (Fig. 3).

3.2. Image versus Image

All of the images used in the above analysis were standard 0.4 ha (1 acre) images of forest plots. The Stand Visualization System allows many types of image variations. Duplicating or grouping of individual tree measurements can be used to vary the stand area portrayed. Tree spacing can be varied between random, regular, or clumpy patterns. View angle, focal length, and distance can be altered, as can vegetation or ground surface coloration. Profile or top down views can be included. Objects such as trucks, canopy cranes, or height poles can be added. Graphical elements representing understory plants or downed logs can be included. We tested only five image alterations against the standard image: adding a truck, depicting a smaller stand, more regular spacing of trees, clumpy tree distribution, and addition of an understory. For real-valued variables, the null hypothesis is that the response mean for the altered image is the same as for the original image. For categorical variables, the null hypothesis is that responses are independent of image alteration. The Large/Dense, Medium/Medium, and Small/Low size/density stands were selected for image alterations, and are referred to as the Large, Medium, and Small stands in the results that follow.

3.2.1. Including a vehicle in an image

The first alteration to the standard image was to include a truck in the foreground. Each altered image also included text drawing the viewers' attention to the fact that there was a truck in the foreground for scale reference. The null hypothesis (that there was no interaction between including the truck and the distribution of responses for tree-size class) was rejected for the Large and Medium stands (p -values = 0.0242 and 0.0030)

but the difference was not statistically significant for the Small stand (p -value of 0.7402). Respondents, on average, recorded a larger tree-size class for images having a truck included.

Adding a truck to the image had no effect on estimates of basal area (p -values = 0.1377; 0.5890; 0.4349) for the Large, Medium, and Small stands, respectively, no effect on estimates of stand age (p -values = 0.1822; 0.7984; 0.5018), no effect on the proportion of respondents who identified the stand as multi-story versus even-story (p -values = 0.8139; 0.1689; 0.6996); and no effect on the distribution of responses for fire hazard rating (p -values = 0.8919, 0.6373, and 0.8766).

3.2.2. Decreased stand area in an image

A second type of image alteration for the three stands was to display an image of a 0.07 ha (1/16th acre) stand instead of a 0.4 ha (1 acre) stand (Fig. 2). For all three stands, the mean basal area estimates were lower for the 0.07 ha plot. However, using a null hypothesis that the average basal area was the same for both types of images, there was a significant difference for the Large stand but not for the Medium and Small stands (p -value = 0.0127; 0.0630; 0.9549, d.f. = 327; 318; 355, respectively). Similarly a null hypothesis of equal tree-size class responses for both types of images yielded a significant difference for the Large stand but not for the Medium and Small stands (p -values = 0.0249, 0.1171, and 0.4035, respectively). A higher proportion of respondents labeled the 0.07 ha image "multi-story" for the Large stand, but no difference in proportions was observed for the Medium and Small stands (p -values = 0.0295, 0.9448, and 0.7103, respectively). There was no difference in mean age estimates for the three stands (p -values = 0.0848, 0.9545, and 0.6730, respectively). The average fire hazard rating was lower for the 0.07 ha image for the Large stand but not significantly different for the Medium and Small stands (p -values = 0.0479, 0.0581, and 0.2174, respectively).

3.2.3. Regular tree spacing in an image

A third image alteration was to create a more regular spacing of individual trees in the image. Using regular tree spacing did not affect the distribution of tree-size class responses for the Small (p -value = 0.3951), Medium (p -value = 0.0854), or Large stands (p -value = 0.1193). Likewise regular tree spacing did not affect the distribution of fire hazard categories for the Small (p -value = 0.4418) or Medium stands (p -value = 0.7111) but did affect the distribution of responses for the Large stand (p -value = 0.0238), with evenly spaced trees resulting in a decrease in the number of respondents classifying the stand as having a very high fire hazard. Using regular tree spacing did not affect mean stand basal area estimates (p -values = 0.4983, 0.5263, and 0.1983 for the Large, Medium, and Small stands, respectively) or mean stand age (p -values = 0.3419, 0.4582, and 0.1163 for the Large, Medium, and Small stands, respectively). Using even tree spacing in the image did not affect the proportion of responses concerning vertical stratification (multi-story or single-story) for the Small or Medium stands (p -values = 0.0621 and 0.6822, respectively), but there was an increase in the proportion of respondents labeling the Large stand single-story (p -value = 0.0076).

Table 3
Summary of results for 'Image vs. Image' comparisons

Plot type, response type	Image alterations				
	Including a vehicle	Decreased stand area	Regular tree spacing	Clumpy tree spacing	Understory veg and logs
Small tree-size plot					
Tree-size class	NS ^c	NS ^c	NS ^c	NS ^c	n.a.
Basal area	NS ^c	NS ^c	NS ^c	NS ^c	n.a.
Stand age	NS ^c	NS ^c	NS ^c	NS ^c	n.a.
Vertical stratification	NS ^c	NS ^c	NS ^c	NS ^c	n.a.
Fire hazard	NS ^c	NS ^c	NS ^c	Dependence ^a	n.a.
Medium tree-size plot					
Tree-size class	Dependence ^a	NS ^c	NS ^c	n.a.	Dependence ^a
Basal area	NS ^c	NS ^c	NS ^c	n.a.	NS ^c
Stand age	NS ^c	NS ^c	NS ^c	n.a.	Difference ^b
Vertical stratification	NS ^c	NS ^c	NS ^c	n.a.	NS ^c
Fire hazard	NS ^c	NS ^c	NS ^c	n.a.	Dependence ^a
Large tree-size plot					
Tree-size class	Dependence ^a	Dependence ^a	NS ^c	NS ^c	n.a.
Basal area	NS ^c	Difference ^b	NS ^c	NS ^c	n.a.
Stand age	NS ^c	NS ^c	NS ^c	NS ^c	n.a.
Vertical stratification	NS ^c	Dependence ^a	Dependence ^a	NS ^c	n.a.
Fire hazard	NS ^c	Dependence ^a	Dependence ^a	Dependence ^a	n.a.

^a Indicates response is dependent on default image.

^b Indicates significant difference between mean response of this image and default image.

^c Indicates test not significant.

3.2.4. Clumpy tree spacing in an image

Images with very clumpy tree spacing were created for the Large and Small stands. This affected responses about fire hazard category for both stands, with an increase in the number of high hazard ratings for the clumped tree images. Test statistics for the interaction were $\chi^2 = 11.8$, p -value = 0.0182 for the Large stand, and $\chi^2 = 38.4$, p -value < 0.0001 for the Small stand. Clumpy tree spacing had no effect on responses about stand size class (p -values = 0.4789 and 0.2559 for the Large and Small stands, respectively), mean stand BA (p -values = 0.9688 and 0.4899), stand age (p -values = 0.7140 and 0.0511) or vertical stratification (p -values = 0.0968 and 0.7202).

3.2.5. Including understory vegetation and fallen trees in an image

The final image alteration – including understory plants and fallen trees – was made only for the Medium stand. The image with an understory and fallen trees elicited higher ratings for fire hazard (p -value < 0.0001) compared to the standard image. There was no effect on mean responses about stand basal area (p -value = 0.8053 with d.f. = 317) or the proportion of participants placing the stand in a uneven age vertical stratification. It did increase the mean response for stand age (p -value = 0.0208). It also affected the distribution of size class responses (p -value < 0.0001) with more participants placing the stand in a larger tree-size class for the altered image.

Results for image alteration are summarized in Table 3. Although each of the image alterations resulted on a significant difference for at least one combination of forest characteristic and stand-type, image alteration affected responses most frequently for the large tree-size stand.

4. Discussion

We began the study with three objectives: (1) to increase understanding of the accuracy and bias of perceptions of tree size, age and density from typical images; (2) to examine the interaction between accuracy of perceptions and the nature of the forested areas depicted; (3) to test whether commonly used image alterations affect perception of tree size, layering, age, fire hazard, and density.

No single study will conclusively meet these objectives. The eight stands used in this study are similar to only a tiny fraction of the diverse forest types in existence. Images are used to communicate to audiences more diverse than the forestry professionals who participated in this project; possibilities for image variations are vast. What image creators intend to communicate is typically much more complex and nuanced than the questions used in our survey.

Nonetheless, for the stands, images, participants, and questions used here, we can make some general observations. In relation to the first objective, we found that accuracy of tree size, age, and density perception was quite low, and bias was indicated by mean responses that differed significantly from field-measured values. However, viewers can perceive relative differences in tree size, density, and age from images when actual differences are great.

In examining the second objective, we found that the nature of the forest area depicted appeared to strongly influence the expected direction of bias in perception. Directions of the bias reversed as the real forests varied from small to large trees, and from low-density to high-density basal area. Responses were biased toward underestimating age, and density for large, old,

dense forest and overestimating age and density for young open forest. This suggests that interpretation of visual images follows the principal of regression toward the mean—images of young small trees appear larger than their actual size, and images of old large trees appear to be smaller. This is important for planners to know, because some of the most contentious issues for management of forest ecosystems are centered on the extremes of forest structure (e.g., clearcutting, stand-replacing fire, or conservation of old growth).

In relation to our third objective, we found that commonly used image alterations did affect perception of tree size, layering, age, fire hazard, and density. However, there were no clear patterns and in many cases image alterations had no discernable effect (Table 3). Image alterations for the depiction of the old, dense stand most frequently resulted in altered perception. Managers who use computer-generated images should think about the interaction of what they intend to convey and the choice of image style they use.

Collectively, the results that we found provide some corroboration of concerns raised by other researchers (Lewis et al., 2004; McQuillan, 1998; Orland and Uusitalo, 2001) about the use of computer-generated images within a forest planning context. The results also provide evidence for the general usefulness of images to convey differences in density, age, and tree size among forest structures when the actual differences are great.

A caveat is that we used forestry professionals as our target population, and framed survey questions in terms that would be unfamiliar or difficult for others. Although much of the use of computer-generated images in presentations and publications is directed toward other professionals, it is also common to use images for public communication. Indeed, graphic images are often appreciated precisely because they are more accessible to a general audience. It would be useful to confirm that these results hold true for a general population also. However, it seems likely that if professional foresters have difficulty in accurately perceiving forest characteristics from computer-generated images, that the general public would also.

A common base of understanding among individuals is critical to mitigating the contentious nature of disputes over management of forest ecosystems. Agreement on the current state of the forest, and on the potential state of the forest under different futures, allows discourse to move from arguments over facts to issues of substance. Like other models, algorithms for computer-generated images are typically judged on usefulness rather than accuracy. The frequency of appearance of computer-generated images of forests in recent professional communications is a strong argument in favor of their usefulness.

Yet if perception of forest characteristics from images differs from real forests, there is potential for miscommunication. These results suggest that managers and researchers need to exercise caution in using computer-generated images to communicate about current or projected forest characteristics. In some cases, accompanying images with summarized estimates may help in correcting misperceptions. Where possible, supplementing the use of computer-generated images with field visits

and demonstration sites could prove useful in conveying realistic expectations.

References

- Alexander, S.A., Palmer, C.J., 1999. Forest health monitoring in the United States: first four years. *Environ. Monit. Assess.* 55, 267–277.
- Barrett, T.M., Schurr, F.G., O'Hara, K.L., 2002. Classifying stand structure: a comparison of SVS images with plot visits and FVS-generated metrics. In: *Proceedings From the Second Forest Vegetation Simulator Conference*, USDA Forest Service RMRS-P-25, Ogden, UT, pp. 31–37.
- Dillman, D.A., 2000. *Mail and Internet Surveys; The Tailored Design Method*, second ed. John Wiley and Sons, New York, 464 pp.
- Johnson, M.C., Peterson, D.L., 2005. Forest fuel treatment in Western N. America: merging silviculture and fire management. *Forest. Chron.* 81 (3), 365–368.
- Kumsap, C., Borne, F., Moss, D., 2005. The technique of distance decayed visibility for forest landscape visualization. *Int. J. Geogr. Inf. Sci.* 19 (6), 723–744.
- Lewis, J.L., Sheppard, R.J., Sutherland, K., 2004. Computer-based visualization of forest management: a primer for resource managers, communities, and educators. *BC J. Ecosyst. Manage.* 5 (2), 5–13.
- Lim, E.M., Honjo, T., 2003. Three-dimensional visualization of forest of landscapes by VRML. *Landscape Urban Plan.* 63 (3), 175–186.
- Lindmayer, D.B., Foster, D.R., Franklin, J.F., Hunter, M.L., Noss, R.F., Schmiegelow, F.A., Perry, D., 2004. Salvage harvesting policies after natural disturbance. *Science* 303 (5662), 1303.
- McGaughey, R.J., 1998. Techniques for visualizing the appearance of forestry operations. *J. Forest.* 96, 9–14.
- McQuillan, A.G., 1998. Honesty and foresight in computer visualizations. *J. Forest.* 96 (6), 15–16.
- Meitner, M.J., Sheppard, S.R.J., Cavens, D., Gandy, R., Picard, P., Harshaw, H., Harrison, D., 2005. The multiple roles of environmental data visualization in evaluating alternative forest management strategies. *Comput. Electron. Agric.* 49, 192–205.
- Moer, M., Spies, T.A., Hemstrom, M., Martin, J.R., Alegria, J., Browning, J., Cissel, J., Cohen, W.B., Demeo, T.E., Healey, S., Warbington, R., 2005. Northwest Forest Plan—The first 10 years (1994–2003): status and trend of late-successional and old-growth forest. *Gen. Tech. Rep. PNW-GTR-646*. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 142 pp.
- Orland, B., Uusitalo, J., 2001. Immersion in a virtual forest—some implications. In: Sheppard, S.R.J., Harshaw, H.W. (Eds.), *Forests and Landscapes, Linking Ecology, Sustainability and Aesthetics*. CABI Publishing, New York.
- SAS Institute, Inc., 2004. *SAS/STAT 9.1 User's Guide*. SAS Institute, Inc., Cary, NC.
- Sheppard, S.R.J., Meitner, M., 2005. Using multi-criteria analysis and visualization for sustainable forest management planning with stakeholder groups. *Forest Ecol. Manage.* 207, 171–187.
- Stephens, S.L., Ruth, L.W., 2005. Federal forest-fire policy in the United States. *Ecol. Appl.* 15 (2), 532–542.
- Stokstad, E., 2005. Forest conservation: learning to adapt. *Science* 309 (5735), 688–690.
- Stoltman, A.M., Radeloff, V.C., Mladenoff, D.J., 2004. Forest visualization for management and planning in Wisconsin. *J. Forest.* 4, 7–13.
- Stone, J.N., Porter, J.L., 1998. What is forest stand structure and how to measure it? *Northwest Sci.* 72 (2), 25–26.
- Tang, H., Bishop, I.D., 2002. Integration methodologies for interactive forest modeling and visualization systems. *Cartogr. J.* 39 (1), 27–35.
- Thomas, J.W., Raphael, M., Antony, R., Forsman, E., Funderson, G., Holthausen, R., Marcot, B., Reeves, G., Sedell, J., Solis, D., 1993. *Viability Assessments and Management Considerations for Species Associated with Late Successional and Old-Growth Forests of the Pacific Northwest*. USDA Forest Service, Washington, DC, [http://pnwin.nbi.gov/nwfp/viability/\[7/7/06\]](http://pnwin.nbi.gov/nwfp/viability/[7/7/06]).

- Twery, M.J., Knopp, P.D., Thomasma, S.A., Rauscher, H.M., Nute, D.E., Potter, W.D., Maier, F., Wang, J., Dass, M., Uchiyama, H., Glende, A., Hoffman, R.E., 2005. NED-2: a decision support system for integrated forest ecosystem management. *Comput. Electron. Agric.* 49, 24–43.
- USDA Forest Service, 2006. Forest Inventory and Analysis Phase 2 Field Guide., <http://www.fia.fs.fed.us/library/field-guides-methods-proc/> [7/7/06].
- Wang, X., Song, B., Chen, J., Zheng, D., Crow, T.R., 2006. Visualizing forest landscapes using public data sources. *Landscape Urban Plan.* 75 (1–2), 111–124.
- Yaffee, S.L., Wondolleck, J.M., 1997. Building bridges across agency boundaries. In: Kohn, K.A., Franklin, J.F. (Eds.), *Creating a Forestry for the 21st Century*. Island Press, Washington, DC, pp. 381–396.