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In-stand scenic beauty of variable retention harvests and mature forests in the U.S. Pacific Northwest: The effects of basal area, density, retention pattern and down wood

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ABSTRACT

Tensions between amenity- and timber-based economies in the U.S. and Canadian Pacific Northwest motivated a study of scenic beauty inside mature forests and timber harvests. A diverse sample of regional forests, measures of forest structure, and large, representative samples of photographs and public judges were employed to measure scenic beauty inside un-harvested mature and old-growth forests, and timber harvests. The latter varied systematically in down wood levels and retention level and pattern. Scenic beauty tended to be optimized at a basal area of 110–155 m^3/ha and/or 700–900 trees/ha. Older forests and those with larger trees were perceived to be more beautiful. In harvests, greater retention levels, less down wood, and dispersed rather than aggregated retention patterns contributed to aesthetic improvements. Green-tree retention harvests offer considerable potential gains in perceived scenic beauty compared to perceived very ugly clearcuts, particularly at higher retention levels. These gains are more reliable from dispersed retention patterns. The silvicultural parameters studied change strength in affecting scenic beauty with changes in retention level. These interactions are explored in relation to a range of scenic quality objectives as an aid to planners, visual impact analysts, and silviculturists.

1. Introduction

Scenic beauty is an important issue affecting socially acceptable forestry and timber harvest decisions (Sheppard et al., 2001; Bliss, 2000). There is an extensive literature about this problem, summarized by Ribe (1989), Rosenberger and Smith (1998), and Ryan (2005), and aesthetic values are regularly considered in forest planning decisions. Some public agencies systematically account for scenic impacts in forest landscapes and timber harvests (USDA Forest Service, 1995; British Columbia Ministry of Forests, 2001), and forest plan optimizations can include measures of scenic production (*e.g.* Alho and Kangas, 1997; Leskinen et al., 2006).

Managing the aesthetics of timber harvests is salient in the U.S. Pacific Northwest and western Canada (Shindler et al., 2002; Sheppard, 2003). Many immigrants and visitors to this region have strong expectations of a high quality of life, scenic amenities, and a non-exploitive relationship with nature (Niemi and Whitelaw, 1999; Durning, 1999). These newcomers often value ecology in forest management (Ribe and Matteson, 2002) and many value perceptions of a naturally healthy regional environment, whether or not they directly use it for recreation or livelihood (Niemi and Whitelaw, 1999). The region's population tends to use simple, affective perceptions of scenic beauty as a cue to landscapes' acceptable management (Ribe, 2002). Scenic beauty also influences cognitive judgments of timber harvests' acceptability, along with information about wildlife impacts, the intensity of harvests, and economic benefits (Ribe, 2006).

The regional conflict between these popular, naturalistic expectations of forests versus traditional, intensive silviculture came to a head in the U.S. via the spotted owl controversy of the late 1980s and early 1990s (Dietrich, 1992; Yaffee, 1994). This conflict proved socially traumatic and very contentious (Carroll, 1995; Durbin, 1996), and produced the Northwest Forest Plan (NFP) (USDA and USDI, 1994). This highly prescriptive plan has substantially modified planning and silvicultural practices in public forests throughout major portions of three U.S. states. The NFP seeks to apply ecosystem management principles (*e.g.* Bormann et al., 1994). These promote "New Forestry" ideas, as opposed to plantation or clearcut-based forestry (Debell and Curtis, 1993; Swanson and Franklin, 1992). The NFP requires variable retention timber harvests (Franklin et al., 1997), which are also gaining favor in western

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Canada in response to growing ecological and aesthetic public concerns (Cashore et al., 2000).

New Forestry principally aims to reduce the ecological impact of timber harvests to better sustain soil, hydrologic, habitat, and plant community functions (Franklin et al., 1989). A major technique is retention of green trees, which may also reduce the "aesthetic dip" associated with harvests (Sheppard et al., 2001; Silvennoinen et al., 2002). This is possible in vista views (Ribe, 2005a; Karjalainen and Komulainen, 1999; British Columbia Ministry of Forests, 1997; Palmer, 2008), and is arguably an ethical intention of New Forestry (McQuillan, 1993).

Forests are also extensively experienced from within, as people travel through, recreate and work in them. In-stand forest scenery is therefore also important, and often a point of affective contention in forest management debates (*e.g.* DeVall, 1994), and the extent of New Forestry's scenic benefits inside forests are problematic. Adverse visual impacts from retention harvests may occur due to high prescribed levels of down wood and snags, too few retained trees, or extensive clearcut areas within harvests (Gobster, 1996, 1999; Sheppard, 2003), or a general appearance of lack of care for the forest (Nassauer, 1995; Sheppard, 2001). Such adverse aesthetic affects inside variable retention harvests have received little systematic investigation.

This study focused on in-stand views of the most contended forests in the controversies outlined above, namely mature forests, timber harvests within these, and old-growth forests. The goal was to better understand, assess and manage the visual impact of transitions among these. Do readily measurable forest and harvest attributes usefully relate to perceived scenic beauty inside forests in the Pacific Northwest? This study sought to model in-stand forest aesthetics to establish regionally useful prescriptive parameters. To this end it employed unusually extensive and diverse samples of forests, forest scenes, and public judges. It employed only common measures of forests' and timber harvests' structure to predict perceived scenic beauty.

2. Background

2.1. Review of in-stand forest scenery findings

A few studies have explored aesthetic perceptions of green-tree retention harvests. Tonnes et al. (2004) used visual simulations to study low levels of retention. They found that a basal area of 3 m^2/ha was a threshold where average ratings began to rise above those for clearcuts, and scenic beauty increased with more retention from there. They found dispersed retention patterns more scenically positive than aggregated patterns, that larger retained trees and trees in better-looking condition also helped, and that retained undergrowth of shrubs and saplings in clearcuts slightly improved scenic perceptions. British Columbia Ministry of Forests (1997) systematically investigated relationships between percent green-tree retention and public scenic quality perceptions, along with expert judgments of achieved visual quality goals. They found that 50% or more retention will most probably achieve high scenic "retention" standards, 30–50% (sometimes 20%) will probably achieve moderate "partial retention" standards, and 0–20% will typically achieve low "modification" scenic standards. They found that dispersed retention patterns are perceived as more acceptable than aggregated patterns, with the latter perceived about equally as clearcuts. Ford et al. (2009), Ribe (2006), and British Columbia Ministry of Forests (2006) studied acceptability perceptions of variable retention harvests but do not report any findings regarding aesthetic perceptions.

Studies exploring scenic perceptions of traditional silvicultural treatments allow inferences about variable retention harvests. Thinnings can produce moderate to high scenic beauty (Silvennoinen et al., 2002; Bradley et al., 2004; Brunson and Shelby, 1992). The size of clearcut "rooms" in in-stand views can matter (Tveit, 2009). Small group selection cuts are scenically preferred to harvests entailing large openings (Bradley et al., 2004; Lindhagen, 1996; Karjalainen, 1996). Shelterwood, seed tree and two-age retention harvests garner similar or better average ratings as selection cuts, depending upon retention density (Bradley et al., 2004; Brunson and Shelby, 1992). Patch cuts producing large, clearcut openings do not generally garner favorable scenic perceptions (Bradley et al., 2004; Brunson and Shelby, 1992; Karjalainen, 1996; Brown and Daniel, 1986; Schweitzer et al., 1976; Echelberger, 1979), but may be scenically better over time (Brush, 1976; Arthur, 1977; Shelby et al., 2003). These findings suggest that New Forestry harvests have much aesthetic potential compared to clearcuts and plantations, but much may depend upon evidence of harvesting "violence" (Chokor and Mene, 1992; Echelberger, 1979; Benson and Ullrich, 1981; Liao and Nogami, 1999).

Because New Forestry harvests can leave a moderate number of standing trees, and more than most traditional harvests, they should be more scenically successful, because both very-high and very-low stand densities tend to produce low scenic beauty perceptions (Silvennoinen et al., 2001; Ribe, 1990; Rudis et al., 1988; Hull et al., 1987; Vodak et al., 1985; Buhyoff et al., 1986; McCool and Benson, 1988; Kaplan and Kaplan, 1989; Schroeder and Daniel, 1981; Daniel and Boster, 1976; Schweitzer et al., 1976; Kim and Wells, 2005). Retaining more of the largest, most commercially valuable trees also adds aesthetic value (Bradley et al., 2004; Silvennoinen et al., 2001; Rudis et al., 1988; Brown and Daniel, 1986; Ribe, 1990; Hull and Buhyoff, 1986; Schroeder and Daniel, 1981; Arthur, 1977; Daniel and Boster, 1976; Pukkala et al., 1988).

The retention of down wood as habitat (Harmon et al., 1986), or for soil maintenance (Stark, 1988) is more aesthetically problematic. It will tend to reduce perceived scenic beauty (Schroeder and Daniel, 1981; Vodak et al., 1985; Brown and Daniel, 1986; Ribe, 1990; Schweitzer et al., 1976; Daniel and Boster, 1976; Arthur, 1977). Snag retention or creation in harvests may be problematic in affecting scenic beauty perceptions (Tonnes et al., 2004; Brunson and Shelby, 1992; Brush, 1979) but can add favorably to informed acceptability perceptions (Brunson and Shelby, 1992; Shelby et al., 2003).

2.2. Harvest design and visual impact assessment and planning

In response to mandates to account for and mitigate visual landscape impacts, the U.S. Forest Service and British Columbia Ministry of Forests have employed and updated visual resource management (VRM) systems (USDA Forest Service, 1995; British Columbia Ministry of Forests, 2001). Among other things, these systems apply scenic standards to harvest designs, which vary by forests' visibility, natural scenic quality, visitation numbers, scenic sensitivity of viewers' activities and forests' importance to public constituencies. These standards are described in Section 5.4.

New Forestry harvests offer options for meeting more demanding visual standards. Scenic impacts inside forests may be partially mitigated by silviculturists and landscape architects in the detailed design of each forest treatment (Rutherford and Shafer, 1969; Brush, 1979; McDonald and Litton, 1998). Policy makers also have an effect by setting harvest parameters that can forecast the general visual impacts of forest plans and help assure achievement of scenic objectives. This study seeks to help set design and planning parameters at a regional scale.

The literature review in Section 2.1 suggests three major New Forestry parameters that affect in-stand, post-harvest scenic beauty: the amount of post-harvest down wood; the level or density of green-tree retention; and the pattern of retention within harvested areas – dispersed throughout, aggregated in clumps, or both (Franklin et al., 1997; Vanha-Majamaa and Jalonen, 2001). These three parameters are the subject of NFP harvest standards (USDA and USDI, 1994): Substantially more down wood from logging, including very large pieces, must be left on the ground than was common before the NFP. Green-tree retention must be at least 15% of each forest's pre-harvest level, and this minimum level is frequently applied. The pattern of retention must be a mix of dispersed and aggregated trees, with no clear policy favoring either pattern for lack of clear scientific direction (Halpern et al., 2005; Aubry et al., 2004).

There are two useful approaches to measuring forest conditions in relation to scenic beauty. One is by combination of the policy parameters described in the previous paragraph. The other is by stand structure metrics regularly employed by silviculturists. Knowledge of the scenic benefits derived from policy parameters can assist visual impact prediction, while structure metrics can assist in forest treatment design. Both were investigated in this study. Structure metrics can allow more precision in as much as, for example, percent retention prescriptions will produce different post-treatment densities depending on pre-treatment densities. Other metrics like down wood volumes, spatial retention patterns, and understory vegetation cover are not usually intensively measured in executing or monitoring forest treatments. The first two of these potentially aesthetically-relevant parameters were investigated here and may be prescribed by silviculturists and forest planners in meeting scenic goals or visual impact standards.

This study explored levels and combinations of forest parameters that may predict levels of perceived scenic beauty, and under what contingencies. Are some forest treatments more reliable at producing scenic beauty than others? Previous studies suggest six postulates: Scenic beauty will increase with (1) higher levels of green-tree retention, (2) dispersed retention patterns that produce the appearance of intact forests, (3) lower levels of down wood, (4) moderate forest densities that produce visual penetration, (5) larger trees, and (6) lower numbers of snags.

3. Methods

3.1. Experimental outline

The experimental design entailed cumulative steps of data development and analysis: (1) A regional variety of forests and variable retention harvests with well measured structures were identified. (2) Unbiased photographic samples were made of these forests and of the scenery produced by harvests' retention patterns and down wood levels. Sub-sets of these photos were randomly sampled to represent each forest treatment in public surveys. (3) Metrics of forest structure were collected for the areas depicted by each of these photos. (4) A variety of adults from the region rated the photographs for scenic beauty or ugliness via mail or slide-viewing surveys; and a psychometric procedure averaged each photo's ratings for reliable measurement of scenic beauty. (5) The reliability of this measurement was tested across the different public survey instruments and against the regional forest sampling frame. (6) Variance in the perceived beauty of the photos was explained by the forests' structure via regression analyses. (7) The regression results were interpreted against commonly applied, conceptual scenery management standards.

3.2. Forest sample

This study was limited to mature forests and harvests within the same. It did not include young forests. Study Photographs were needed inside a variety of mature forests in western Oregon and Washington. The objective was to sample in-stand scenery representative of a regional diversity of un-harvested forests and well-controlled harvests for which a variety of quality data was available. Photographs were sampled from sites of the Demonstration of Ecosystem Management Options (DEMO) study (Aubry et al., 1999, 2004) and the Long Term Ecosystem Productivity (LTEP) study (Homann et al., 2001). Both are large-scale forest harvest experiments conducted in mature, conifer-dominated, Douglas fir (*Pseudotsuga menziessi*) forests in western Washington and Oregon. Both are randomized block designs with a set of harvest treatments replicated one to four times at each of the locations mapped in Fig. 1. The variety of pre-treatment forests found at these sites is described in Table 1.

The DEMO study provided examples of 15% and 40% retention harvests, each with both dispersed and aggregated retention patterns (Halpern et al., 2005). The DEMO "units" in which treatments were executed were 13 ha and square or slightly rectangular. For the aggregated-retention treatments, the percent retention was by area of the unit. For dispersed retention treatments, the percent retention was by basal area of all trees to match that of the corresponding aggregated-retention treatment within the same block. The 15% aggregated-retention treatments contained two one-hectare, 56-meter-diameter, circular aggregates of uncut forest near opposite corners of the unit. The 40% aggregated-retention treatments contained five aggregates of the same size and shape, arranged in a dice-shaped pattern. This unnatural geometry of aggregates was for exact replication across blocks for natural science investigations. It was not obvious in the ground-level photographs sampled for this study. The DEMO blocks and treatments within them retained various amounts of down wood.

The LTEP study provided clearcuts with high and low down wood levels and included 50% dispersed retention treatments (Table 2). In the latter case, wherever tree sampling plots indicated that the forest area depicted in a photograph actually retained close to 40% green trees (See Section 3.6), the corresponding photo was available for sampling into the public perception surveys. These 40% dispersed-retention photos depicted both high and low down wood levels. The LTEP treatment units were 6 ha and square or slightly rectangular.

3.3. Field photography

Within every treatment unit from both studies, a grid of permanent monuments was established. Each grid was smaller than, and roughly centered within, each treatment unit so that photographs from grid points mainly captured the corresponding treatments. Sub-sets of grid points throughout the center of the treatment units were used as photographic sampling points with photos taken in many directions. To ensure unbiased representation of the scenery, photo sampling points and directions were mapped by protocols established prior to field inspection of the forests or any other knowledge of how they would fall within the forest structure, terrain or detailed visual impacts of the harvest treatments. All photos were replicated before and after treatments, and photo counts are listed in Table 2. The DEMO treatments at the Little River site were not executed, so this block only provided photos inside of un-harvested old-growth forests.

All photographs were taken from sampling monuments in specified directions using a 35 mm SLR conventional camera with a 35 mm lens. The foreground-plane's center-perspective vanishing-point of each photo (often at the horizon) was placed as near the center of each image as possible, including photos taken up or down slope. This rule was used to standardize the photos, not to hide the slopes. If a tree, shrub or rock obstructed a photograph from its prescribed point and direction, the photographer moved

Fig. 1. Locations of the ten experimental sites. DEMO study blocks are denoted by circles: CF = Capitol Forest, BU = Butte, PH = Paradise Hills, LW = Little White Salmon, WF = Watson Falls, DP = Dog Prairie, LR = Little River. LTEP study sites are denoted by squares: SP = Sappho (2 blocks used), IB = Isolation Block (3 blocks), SK = Siskiyou (3 blocks).

up to one meter in the shortest possible distance in any direction necessary to minimize the obstruction to the photograph. Photographs were taken within 3 h of noon, standard time. Pre-treatment photos were taken during the same three-month field season as corresponding vegetation structure measurements. Post-treatment photos were taken within 6 months after treatments were completed, and most often within 3 months.

A set pattern of eight grid points was used for photo sampling near all the edges of every DEMO unit's central grid of monuments. One photo was taken at each point in its own unique preset direction toward the middle of the unit. This yielded 48 photos of each treatment across the six study blocks. This pattern of photos was determined for representative sampling of scenery within the 40%, aggregated-retention treatment. This treatment determined the photography protocol because it presented special problems in representative sampling of its most complex pattern of post-harvest scenery. The pattern of photographs was selected by reference to the pattern of felling relative to the sampling grid for this 40%, aggregated-retention treatment. The photo points and directions captured views inside aggregates, across larger areas of harvested matrix, looking at harvested matrix between aggregates, near aggregates with harvested matrix in the foreground, and looking out from just inside aggregates (Tonnes et al., 2004). This overall mix of photos sought to capture views of harvested matrix and retained aggregates in approximate proportion to that encountered hiking through the whole treatment.

There were five preset photo sample points within each LTEP treatment unit. Four photos were taken from each of these in the cardinal compass directions, yielding 20 photos per unit.

Table 1
Selected features and pre-treatment structural characteristics of forests at the ten study sites.

Source study/ Site name	Elevation (m)	Slope (deg)	Stand. age (yr)	Basal area (m^2/ha)	Tree density (no./ha)	Quadratic mean diameter (cm)	No. study replicate blocks
DEMO study[a]							
Watson falls	945–1310	4–7	110–130	36–52	310–500	39.3	1
Little river	1220–1400	14–40	200–520	82–127	255–473	62.6	1
Dog Prairie	1460–1710	34–62	165	72–106	258–475	58.1	1
Butte	975–1280	40–53	70–80	48–65	759–1781	25.6	1
L. white Salmon	825–975	40–66	140–170	61–77	182–335	62.7	1
Paradise hills	850–1035	9–33	110–140	59–87	512–1005	36.0	1
Capitol forest	210–275	28–52	65	54–73	221–562	48.5	1
LTEP study[b]							
Sappho	134–147	3–6	52	197–241	778–1864	48.7	2[c]
Isolation block	482–665	19–48	80–91	53–136	93–962	39.2	3
Siskiyou	836–897	12–58	80–106	21–136	280–2700	26.0	3

[a] Data from trees with a minimum diameter of 5.0 cm.
[b] Data from trees with a minimum diameter of 3.5 cm.
[c] This LTEP site included four replicate blocks but only two were employed in this study due to poor pre-treatment photo quality from the other two.

3.4. Down wood photo sampling

Post-treatment photo samples needed to be sorted by their depiction of high versus low down wood within each treatment. Pre-treatment photos were not sorted by down wood level. Sorting was done by different rules depending on the source study for photos, as follows.

Down wood volume data were not available for the LTEP units at the Sappho and Isolation blocks, but the harvests there were intentionally executed to leave substantially different high versus low down wood levels as a key part of this study's protocol. High down wood LTEP post-treatment photos were those taken in units where most harvest residue, including tops, limbs, and many logs remained on site, yielding samples of 160 high down photos for both clearcut and 50% dispersed retention treatments (Table 2). Low down wood LTEP photos came from other LTEP units, wherein most down wood was substantially removed at harvest, again yielding samples of 160 low down wood photos for the same two treatments (Table 2). Among the 50% dispersed-retention photos, 31 high down wood photos and 22 low down wood photos actually depicted 40% retention and became candidates for use in public surveys.

Down wood volume data were available for all DEMO units. To standardize the measures of down wood levels between the LTEP and DEMO studies, volume thresholds for sorting DEMO post-treatment photos were calibrated from down wood volume data available for the units at the LTEP Siskiyou blocks. Among photos that depicted a foreground of 15% dispersed retention, or of harvested matrix within aggregated-retention treatments, those with more than 300 m^3/ha of down wood were classified as high down wood. For photos depicting 40% dispersed retention harvests, the threshold was 200 m^3/ha because fewer harvested trees produced less down wood even when most such wood was left behind. For post-treatment photos depicting foreground un-harvested aggregates, the threshold value was 100 m^3/ha because little down wood from harvesting would find its way inside of these aggregates to be left there.

Down wood levels in post-treatment DEMO photos were identified by field measurements taken within the area depicted by each photo, yielding sample-based estimates of the volume of coarse wood, course litter, and count of snags leaning more than 15° per ha. The course wood (>10 cm diameter) estimates came from the 6 m transect shown in the photo and closest to the photo

Table 2
Selected visual characteristics of pre-treatment forests, and counts of field photo samples by treatment at the ten study sites.

Source study/ site name	Visual penetration[a]	Ground veg. cover[a]	Amount of hard woods[a]	Number of photos by treatments studied[b]								
				Prtr.	15D	15A	40D	40A	CCH	CCL	40DH	40DL
DEMO study[c]												
Watson falls	Medium	Medium	Low	40	8	8	8	8	0	0	0	0
Little River	High	Medium	Low	Old-growth forests with no treatment (40 photos)								
Dog Prairie	High	Low	Low	40	8	8	8	8	0	0	0	0
Butte	Medium	Medium	Medium	40	8	8	8	8	0	0	0	0
L. White Salmon	Low	Medium	High	40	8	8	8	8	0	0	0	0
Paradise hills	High	Low	Low	40	8	8	8	8	0	0	0	0
Capitol forest	Medium	High	High	40	8	8	8	8	0	0	0	0
LTEP Study												
Sappho[d]	High	High	Medium	160	0	0	0	0	40	40	40[e]	40[e]
Isolation block	Low	High	Medium	240	0	0	0	0	60	60	60[e]	60[e]
Siskiyou	Low	Medium	High	240	0	0	0	0	60	60	60[e]	60[e]

[a] Ratings are qualitative and based on inspection of all the photographs taken within each site and serve only to roughly characterize scenic differences.
[b] Abbreviations in list are: Prtr. = photos taken prior to forest treatments, 15D = 15% dispersed retention, 15A = 15% aggregated retention, 40D = 40% dispersed retention, 40A = 40% aggregated retention, CCH = clearcuts with high down wood, CCL = clearcuts with low down wood, 40DH = 40% dispersed retention with high down wood, 40DL = 40% dispersed retention with low down wood.
[c] The DEMO blocks included 75% aggregated-retention treatments not employed in the study here.
[d] The blocks at this site also included treatments with medium down wood levels that were not employed in this study. Half the Sappho treatment units were excluded from this study due to poor photo quality.
[e] At these sites, only a few photos became candidates for inclusion in the public surveys if they depicted sampling plots where approximately 40% of trees were actually retained, instead of the 50% overall target retention level over these entire treatment units. These photos augmented the photo sample of the same 40% dispersed retention treatments derived from the DEMO blocks.

point. The course litter (5–10 cm diameter) estimates came from six 0.2 × 0.5 m microplots along the same transect. The leaning snags estimate came from the 0.08 ha circular plot shown in the photo and closest to the photo point. Leaning, dead trees, not rooted vertical ones, are more likely to adversely affect beauty perceptions (Brush, 1979; Brunson and Shelby, 1992).

3.5. Final photo sampling

A sub-sample was needed from the full set of photos of each combination of treatment and down wood level for use in public survey instruments. These sub-samples needed to be small enough to produce instruments short enough to maximize response rates and avoid taxing respondents with too many, largely redundant photographs. The number of sub-sample photos for each treatment type needed to reliably represent the scenery found there (Palmer and Hoffman, 2001). A small but reliable sample size was not known, *a priori*. Reliability pretests were therefore conducted with sets of 20–40 university students who viewed slides and rated them on the same scale as the study's main surveys. These rating sessions tested even-numbered sample sizes from four to sixteen photos, each repeatedly drawn at random from the 48 photos of the 40% aggregated-retention treatment—the one with the greatest variety of mixed contrasts between harvested and un-harvested areas. The variance in average scenic beauty ratings across samples stabilized at its asymptotically lowest value at twelve or more photos. The smallest reliable sample size of 12 photos was employed to minimize the duration of surveys in order to elicit higher response rates.

Some photos were eliminated from further use. These were of four types: (1) very poor photographic quality; (2) too much plastic flagging in the immediate foreground (used by field researchers); (3) a close-up obstruction (*e.g.* a tree or shrub) filling more than 25% of the field of view; or (4) taken close to and toward the edge of a treatment unit (LTEP photos only) so that it mainly depicted the surrounding forest or a neighboring treatment. This screening eliminated 9% of DEMO photos and 16% of LTEP photos.

The final sampling of twelve photos for each of the ten study treatments ($n = 120$) was by random selection. The first seven photos selected for each of the ten treatments were joined in the sample by the pre-treatment replicates of the same photos ($n = 70$), so as to sample pre-treatment photos from the same forest types and sites as the treated photos. To better represent the full range of pre-treatment forests in the field photo sample, one pre-treatment photo was randomly sampled from each of the six DEMO units or LTEP blocks that happened not to be represented by the above random sampling procedure ($n = 6$). This brought the total sample of un-harvested, mature forest photos to 76. Photos randomly selected from the old-growth forests at the Little River DEMO site ($n = 12$) joined the sample. This yielded a complete sample of 208 photos, as broken down in Table 3. Representative members of this sample are in Fig. 2.

Table 3
Key descriptive statistics for mean ratio scenic beauty estimates across the forest treatments.

Treatment	Mean RSBE	Standard deviation	Standard error	Number of scenes	Standard error as a % of RSBE range across all scenes[a]
Clearcut-low down wood	−110.0	20.3	5.8	12	1.9
Clearcut-high down wood	−109.4	24.6	7.1	12	2.3
15% disp. reten. low dn. wd.	−27.2	38.7	11.2	12	3.6
15% disp. reten. high dn. wd.	−63.7	37.0	10.7	12	3.5
15% agg. reten. low dn. wd.	−31.5	56.2	16.2	12	5.3
15% agg. reten. high dn. wd.	−98.0	40.3	11.6	12	3.8
40% disp. reten. low dn. wd.	74.2	47.4	13.7	12	4.4
40% disp. reten. high dn. wd.	3.5	57.3	16.5	12	5.4
40% agg. reten. low dn. wd.	10.5	95.3	27.5	12	8.9
40% agg. reten. high dn. wd.	−13.1	87.1	25.1	12	8.2
100% reten. mature forest	79.1	33.1	4.3	76	1.4
100% reten. old growth	125.2	32.5	8.4	12	2.7

[a] The endpoints of the observed range of RSBEs across all study scenes were −157.0 (clearcut with high down wood) and +176.1 (un-harvested old growth).

3.6. Measures of stand structure

The main measures of overstory stand structure were basal area and density of trees and vertical snags per hectare within the forest visible in each photograph, exclusive of seedlings and shrubs. Density and dbh distributions by species were also analyzed. This data came from pre- and post-treatment vegetation sampling for the DEMO and LTEP studies, as follows.

The DEMO grid of monuments was placed at 40 m spacing in each 13 ha treatment unit. Circular 0.04 ha vegetation plots were centered on a subset of between 32 and 37 of these, depending on the treatment. The plots were evenly distributed within the dispersed retention treatments. In the aggregated-retention treatments, plots were placed at all grid points inside the aggregates and at an evenly distributed subset of the grid points elsewhere in the harvested matrix areas. Sampling was of all trees greater than 5 cm dbh. Pre-treatment sampling occurred within 4 years prior to treatments and post-treatment sampling occurred in the first growing season after treatment, except at Dog Prairie where hail stripped foliage during the first season.

In the LTEP study, a grid of monuments was placed at 25 m spacing within each 6 ha treatment unit. Five 18 × 18 m (.0324 ha) vegetation plots were placed toward the center of each treatment unit at standardized positions. Sampling was of all trees greater than 3.5 cm DBH. Pre-treatment sampling occurred within 3 years prior to treatments and post-treatment sampling occurred in the first growing season after treatment.

Each study photograph was inspected to estimate the depth of visual penetration and identify which vegetation sampling plots were expected to sample the area visible in the photograph. The content of pre-treatment forest photos was sampled by 1–3 plots. The extent of seen area within post-treatment photos varied greatly, depending on the level and pattern of green-tree retention, such that 2–8 plots sampled the forests and harvested matrix within these photos. One outlier data point, for density at one LTEP Sappho photo, was removed using the Dixon–Thompson test (Dixon, 1953) with a 95% confidence interval.

For LTEP photos, tree counts for the smallest 3.5–10 cm dbh class were adjusted to remove trees between 3.5 and 5 cm to standardize all photos' data at the 5 cm dbh threshold employed in the DEMO study. This was done by fitting a diameter distribution curve to each LTEP photo's data and using the slope of the curve at the smallest dbh range to estimate how many trees were between 3.5 and 5 cm for subtraction. These corrections were 1–2.5% of total tree densities.

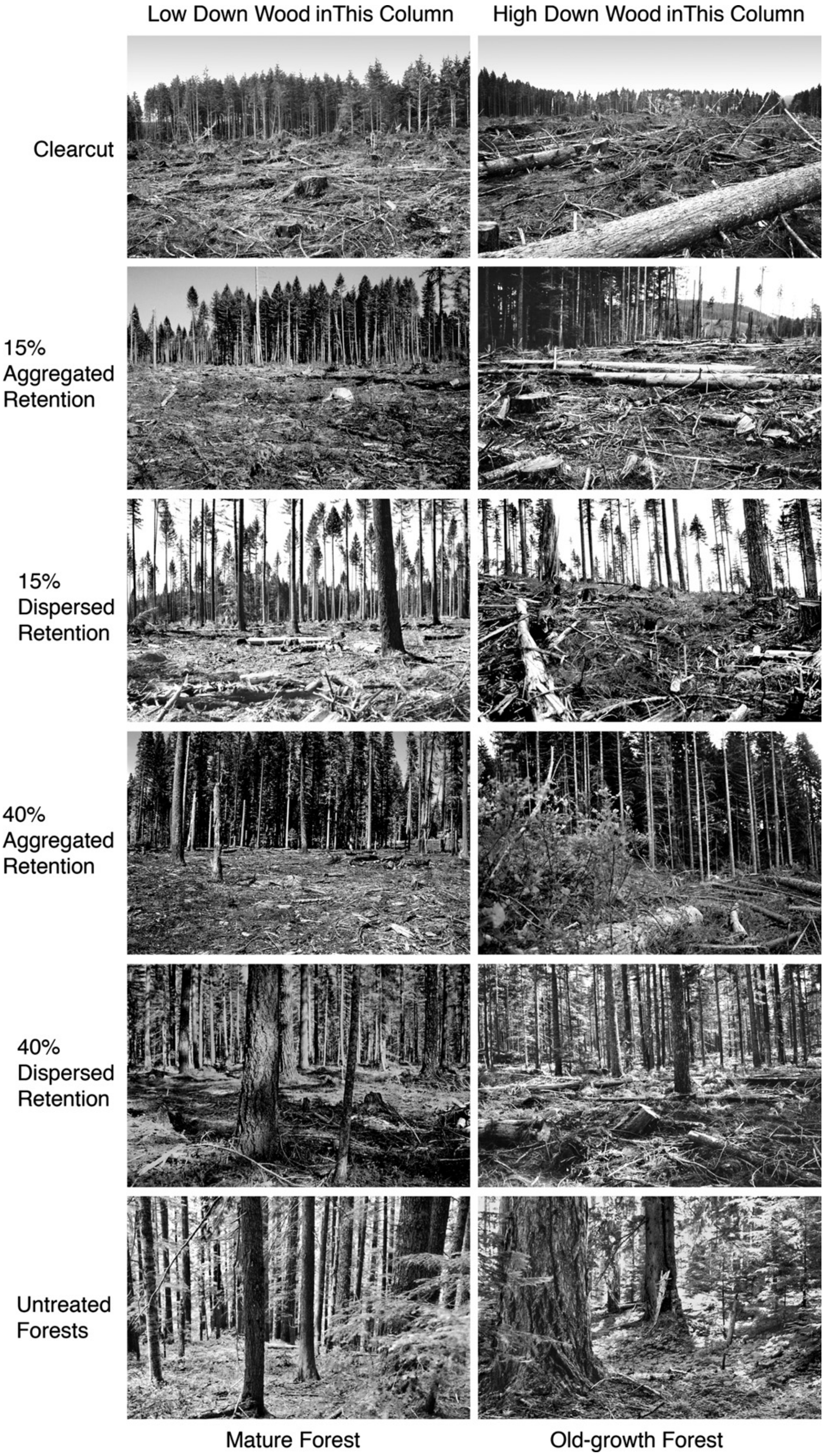

Fig. 2. Example public survey photographs of the 12 forest treatments studied.

3.7. Public perception surveys

The pre- and post-treatment photo samples were distributed into five survey instruments. The large number of study photos, including many forest photos not analyzed here, entailed five instruments to keep each short enough to garner high participation rates. Color photos were printed in two mail surveys, or projected for audiences in three slide-viewing surveys. The sampling frame for the surveys was the regional population, rather than any subpopulation, such as forest visitors or interest groups. This was because regional controversies about public forest management have engaged broad political interest via widely employed forest imagery.

3.7.1. Distribution of photos into survey instruments

The distribution of the photo sample into the five survey instruments achieved six goals: (1) The instruments needed to include photos of young forests and mature forest harvests from the same region that were employed in another study (Ribe, 2005b), but which could not be included in the study reported here for lack of any or adequately similar vegetation structure data. (2) The distribution of photos of forest types needed to be as nearly similar as possible across the instruments to elicit scenic beauty ratings against the same baseline of regional forest scenery (Brown and Daniel, 1990), and help assure inter-instrument reliability. (3) The percent of photos of intact forests, as opposed to that of harvest photos, needed to stay within 10% of 50% to prevent anchoring of ratings by either harvested or un-harvested forests, and also help assure inter-instrument reliability. (4) The mail surveys could only contain 24 photos due to budget constraints in printing large, high-quality color photos in hundreds of surveys. (5) The slide-viewing surveys needed to include 80–100 photos to stay within the time limits imposed by volunteer response groups. (6) No more than five instruments were employed because of the increasing risk of loosing inter-instrument reliability as more instruments were added.

Photos were randomly assigned to the two mail survey instruments, subject to constraints that each mail survey included all ten study treatments. Each mail instrument also included 10 photos of pre-treatment mature forests, one of untreated old-growth forest and 3 of young forests. For the three slide-viewing instruments, photos were randomly selected from the same source sets to fill designed allocations of forest types for each instrument: Slide-set A included 25 slides of pre-treatment, mature forests, three slides of un-harvested, old-growth forests, and three slides of each of the ten study treatments. With 22 additional slides of young forests and other harvests, this set contained 80 slides. Slide-set B included 25 slides of pre-treatment, mature forests, seven of un-harvested, old-growth forests, and two slides of each of the ten study treatments. With 44 additional slides of young forests and other harvests, this set contained 96 slides. Slide-set C included 12 slides of pre-treatment, mature forests, three of un-harvested, old-growth forests and three slides of each of the ten study treatments. With 26 additional slides of young forests and other harvests, this set contained 84 slides.

3.7.2. Conduct of surveys

Each of the two mail surveys began by eliciting scenic beauty ratings for its own set of 24 scenes in random order. Each then queried many attitudes and perceptions related to national forest planning, policy and harvests. The three slide-viewing surveys enabled ratings of the many remaining scenes, but most volunteer respondent groups limited available time to 10 or 15 min, allowing only for instructions, scenic beauty ratings (of no more than 100 slides) and demographic questions, but not the other mail survey questions. This time constraint, together with the large number of slides to be rated, left no room for repeating slide sub-samples of all treatments in every survey – for testing reliability across surveys. Doing so would have entailed a fourth slide rating survey at more risk of reduced inter-survey reliability. Instead, only three slide rating surveys were conducted without repeated slides, but measures taken to sample similar respondent sets across them to promote inter-survey reliability, as described below. That reliability was then tested across the surveys by forest treatments, rather than by scenes, as described below.

The mail surveys were administered in late 2001 and early 2002. A random sample of 1669 registered voters in western Washington and Oregon received letters requesting that they participate. Of these, 702 (42%) volunteered by returning postcards affirmatively as the compliant sample to whom surveys were sent. Each version of the mail survey was sent to half (351) of these people. A prompting letter was sent twelve days later to respondents not yet returning surveys. Another prompting letter was sent along with another copy of the survey 12 days further on to those who had still not returned the survey. Of the volunteers, 325 returned Mail Survey A (93% response rate) and 320 returned Mail Survey B (92%).

Each of the three slide-viewing surveys was administered to a separate set of respondent groups as an activity during their meetings. The groups included various service clubs, neighborhood organizations, state park campfire program attendees, conference attendees, higher education classes, outdoor interest groups, and business clubs. Respondents' demographic attributes were tracked as surveys proceeded. Groups were allocated to the three slide-viewing surveys according to their expected demographic composition to make each survey's respondent sample approximate the demographic composition of the mail surveys with respect to age, urban versus rural residence, and time of regional residence. (Inspection of data for another study (Ribe, 2002) indicated that these traits are most related to small differences in aesthetic perceptions in the same study region, and much more so than gender, education and income.) This demographic consistency among the slide-viewing surveys in concert with the mail surveys helped assure similarly representative sampling of the regional population as the random mail survey so as to achieve inter-instrument and inter-survey reliability in measuring scenic beauty, as explained below in Section 3.8.2. Each slide-viewing survey's sample was deemed complete when at least 200 respondents were acquired and the sample exhibited each demographic characteristic's desired value within 5%. This was achieved at different sample sizes for each survey because these balancing efforts varied in their rate of success. 271 respondents (15 groups) were sampled for Live Survey A, 210 (10 groups) for Live Survey B, and 266 (13 groups) for Live Survey C.

3.8. Measuring scenic beauty

Each slide-viewing respondent rated the slides privately on their own questionnaire. Each slide was shown once for 6–7 s. The mail survey respondents were instructed to fill in the survey by themselves. All were instructed that the photos included examples of national forests with and without various timber harvests. They were instructed to rate each photo for scenic beauty on a numeric scale from -5 to $+5$, where the scale ranged from "very ugly" (-5) to "very beautiful" ($+5$), with zero value ratings assigned to photos they found neither beautiful nor ugly or were undecided about. To prevent systematic sequencing-effect bias in the ratings of slides seen early or late in the slide rating sessions – as respondents gained familiarity with the range of scenery – each respondent group saw its set of slides in its own unique random order.

A ratio scenic beauty estimate (RSBE) was computed for each scene from all its ratings. Because the respondents used a bipolar rating scale, the resulting RSBE values took on both positive and negative values and are scaled to a zero value where the average respondent changed from negative (ugly) to positive (beautiful) ratings (Ribe, 1988).

3.8.1. The ratio scenic beauty estimate

The scenic beauty estimation method (SBE, Daniel and Boster, 1976) is established and often used to standardize the dispersion, skewness and central tendency of various respondents' scenic beauty ratings to a common, interval scale. It employs a numeric response scale from 1 to 10 and measures one perceptual construct (scenic beauty) while making no distinction between positive versus negative scenic beauty. This is problematic in as much as the U.S. Forest Service Scenery Management System (USDA Forest Service, 1995) does make this distinction – between levels of beauty and levels of unacceptable modification to scenery—to plan and assess visual impacts. The RSBE is a compromise modification of the SBE that measures a dual construct to serve this need.

The RSBE method standardizes people's ratings of beauty and ugliness onto a common scale. Scenic beauty and ugliness may be the same cognitive construct that differs only by valence (Torgerson, 1958); or they might be different constructs, each with a cognitively vague zero value. (Indeed, very few respondents in this study employed the zero rating value on the −5 to +5 scale.) The RSBE is effectively two SBE scales appended back-to-back, one measuring scenic beauty and the other ugliness. The mathematics of the RSBE is almost identical to the SBE and employs a small change to the SBE algorithm (found in Ribe (1988)) that assumes the distribution of responses across the two scales behave as if on one scale, across a gap at the zero value between very cognitively similar constructs differing by valence. Results from Schroeder (1984) indicate that the scaling and reliability of ratings' distributions will be very similar on either scale, supporting the likelihood of a reasonably smooth transition across them. These psychometric uncertainties are offset by the more useful and meaningful values that the RSBE provides for managers.

The zero RSBE value should be understood to apply only within the sampling frame of the landscapes investigated because it is uncertain whether it can be compared to such values derived elsewhere. Consequently, in this study, the RSBE scale, and its zero point, is employed only to interpret findings against scenery management standards as applied to the subject region, for which reliable in-stand forest scene samples were obtained, as described in Section 3.8.3. This is consistent with scenery management systems, which require that visual impacts be judged by reference only to the scenic possibilities characteristic of each region.

3.8.2. Reliability across respondent surveys

Scenic beauty measurement reliability across the five different survey instruments, particularly between the mail versus slide-viewing surveys, was tested by multiple independent samples chi-square tests. These tests could not employ ratings of the same scenes across the five surveys because surveys did not share scenes. (This was because very many scenes needed to be fit into as few surveys as possible to minimize reliability risks and costs associated with more surveys, and surveys needed to be short enough to maximize response rates.) Instead, similar scenes that could be expected to produce similar RSBEs were employed in the tests. Whenever at least one pre-treatment scene from the same experimental block (from the same relatively homogeneous topography and forest structure) had chanced to be assigned to both mail surveys and at least two of the slide-viewing surveys, their ratings were compared, with RSBEs for multiple scenes from the same survey averaged. Similarly, whenever at least one scene of the same clearcut or dispersed retention treatment on mostly level ground had chanced to be assigned to both mail surveys and at least two of the slide-viewing surveys, these were similarly tested for reliability across the surveys. (Photos of these treatments from level sites across blocks tended to exhibit the most scenic homogeneity; and photos of aggregated-retention treatments were too heterogeneous to expect similar RSBEs across the surveys).

Five forest conditions met these eligibility conditions for chi-squared reliability tests (Table 4). The null hypothesis was that the "true" RSBEs for photos of these treatments were nearly the same across the surveys, so that no instrument bias could be attributed to any particular survey(s). A moderately stringent critical probability value of $p = 0.05$ was employed because the somewhat different test scenes were not expected to produce identical RSBEs. All five tests indicated reliable measurement of scenic beauty across the instruments (Table 4). The signs of the chi-squared test values in Table 4 indicate that slide-viewing surveys produced higher RSBEs in two cases and mail surveys produced higher RSBEs in three cases, discounting the likelihood of a consistent bias, however small, between the two survey modes.

3.8.3. Reliability of scene samples

Table 3 lists the standard error of the mean RSBE of the 12 scenes representing each forest treatment. These standard errors estimate the variability expected in mean RSBEs found among other samples of 12 photos that might be taken from regional examples of each treatment. The last column of Table 3 lists these errors as a percentage of the full range of RSBEs observed across all study scenes. All these values are less than 6% except for the two 40% aggregated-retention treatments, which are less than 9% and for which standard errors were minimized as described in Section 3.5. The scene samples are reasonably reliable in representing scenery that might be produced by the study treatments elsewhere in the study region.

3.9. Regression analyses

The regression models reported in Sections 4.2 and 4.3 were identified after extensive exploration of variable combinations and model specifications to identify the best models for explaining variance in RSBEs. Models were not estimated using stepwise procedures. Only post-hoc stepwise regression was used when needed, that forced the final model to be the same as that initially estimated without steps. The best models were those that maximized R^2; that were most efficient by not including factors who's addition increased the standard error of estimate; and that only included factors statistically significant at the 0.10 probability level and that added at least 0.005 to the R^2 (unless such factors had important explicatory value).

4. Analysis and results

4.1. Scope of analysis

This study focused on using attributes of forest structure and timber harvests to explain scenic beauty inside mature forests of the western Pacific Northwest. A repeated-measures study of the scenic effects of the same forest treatments has been published elsewhere (Ribe, 2005b) using a larger set of treatments (some without forest structure data) and testing treatments' photo samples representing equal combinations of high and low down wood. A more-robust repeated-measures study could not be conducted here because photo samples for each of this study's forest treatments included fewer pre-treatment photos (7) than post-treatment photos (12).

Table 4
Chi-squared tests of scenic beauty measurement reliability across the five public survey instruments.

Forest treatments[a]	Level clearcut high down wood	Level 40% disp. ret. high down wood	Little River old-growth forests	Paradise Hills pre-treatment forests	Sappho pre-treatment forests
Survey instrument	Mean within-instrument RSBE values for the above treatments				
Mail survey A	−101.5	−43.8	153.5	77.8	75.7
Mail survey B	−116.1	−27.4	155.3	77.1	82.4
Slide-viewing survey 1	−110.0	−35.3	128.0	73.0	60.3
Slide-viewing survey 2	−108.4	−47.8	120.7	70.5	59.1
Slide-viewing survey 3	−111.1	−33.0	159.2	NA[b]	NA[b]
Degrees of freedom	4	4	4	3	3
Critical Chi-Squared at $p = .05$	±9.49	±9.49	±9.49	±7.81	±7.81
Observed Chi-Squared	−1.01	−7.28	9.27	0.48	5.75
Null hypothesis not rejected, indicating reliable measurement[c]	Yes	Yes	Yes	Yes	Yes

[a] These were the only forest conditions that chanced to be represented in both mail surveys and at least two of the slide-viewing surveys.
[b] Not available because photos of these treatments were not included in slide-viewing survey 3.
[c] The null hypothesis is that the underlying RSBE values are the same for similar photos of the same treatment across the survey instruments. To not reject this hypothesis, each observed chi-squared value needs to be less than the critical value.

4.2. Perceptions of down wood and retention level and pattern after harvests

Table 3 lists the mean RSBEs for the study treatments. The best regression model found to explain RSBEs by forest attributes prescribed by New Forestry is in Table 5. That model was estimated making no distinction between mature and old-growth forests among 100% retention (no harvest) treatments. All three factors significantly explain differences in scenic beauty, and together significantly explain 62% of variance in RSBEs. The standardized coefficients indicate that retention level is the strongest predictor of scenic beauty; which is about four times more powerful in explaining RSBEs than the roughly equal down wood or retention pattern factors.

The mean RSBEs for the study treatments are graphed in Fig. 3. Their pattern indicates that the RSBEs did discriminate among the treatments well. This graph exhibits interesting patterns that can be interpreted to supplement the above interpretation of regression coefficients:

- Down wood level makes no difference in how much ugliness is perceived in clearcuts.
- All four 15% retention treatments are perceived as ugly, but three of these are seen as significantly less ugly than clearcuts.
- The 15% aggregated-retention, high-down-wood treatment is as ugly as clearcuts.
- At 40% retention, only the low-down-wood, dispersed-retention treatment is seen as decisively beautiful, with about the same perceived beauty as untreated, mature forests.
- The other three 40% retention treatments are perceived to be of neutral aesthetic value, neither clearly beautiful nor ugly, and not statistically different from each other.
- Down wood level evidently affects aesthetic perceptions more than retention pattern at the 15% retention level.
- Retention pattern is a bit more important than down wood in affecting RSBEs at the 40% retention level.
- The order of perceived beauty of the forest treatments is the same at both the 15% and 40% retention levels, although these differences are only statistically significant at the extremes, i.e. for the ugliest (aggregated high down wood) 15% retention treatment and the most beautiful (dispersed low down wood) 40% retention treatment.

Table 5
Regression analysis explaining scenes' ratio scenic beauty estimates by means of basic New Forestry harvest parameters.

Parameter	Standard estimate	Standard coeff.	Error	*t* value	Prob.
Intercept	−80.33	−80.33	6.16	−13.04	<0.001
Retention level	1.74	0.78	0.09	18.64	<0.001
Down wood indicator[a]	−21.53	−0.19	4.76	−4.52	<0.001
Dispersed retention indicator[b]	12.69	0.10	5.46	2.32	0.021

Degrees of freedom	R^2	Adjusted R^2	*F*-test	Prob.
Regression statistics 3/204	0.64	0.63	122.20	<0.001

[a] The down wood indicator variable took on a value of 1.0 for scenes of high-down-wood treatments, -1.0 for scenes of low down wood treatments, and 0 for all untreated (100% retention) forests with no down wood produced by timber harvesting.
[b] The dispersed retention indicator variable took on a value of 1.0 for scenes of forest treatments with dispersed patterns of green-tree retention, −1.0 for scenes of treatments with aggregated green-tree retention, and a value of 0 for clearcuts and untreated (100% retention) forests.

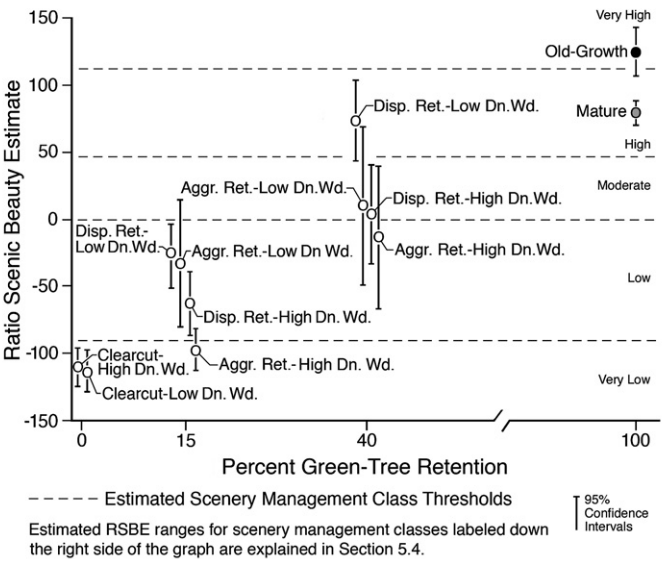

Fig. 3. Mean RSBEs for the forest treatments plotted against retention levels.

- Within either retention level, both low down wood treatments are more beautiful than those with high down wood, but these differences are not usually statistically significant.
- Within the same down wood level at either retention level, the dispersed retention pattern is more beautiful than the aggregated one, but not usually with statistical significance.
- Untreated old-growth forests are perceived as more beautiful than untreated mature forests.

4.2.1. *Reliability of harvest retention patterns in producing scenic beauty*

Some New Forestry treatments may vary in scenic beauty more than others from one viewpoint to another within a forest, or from one forest to another. The RSBE standard deviations in Table 3 measure the treatments' reliability of scenic beauty production, and suggest that aggregated retention and high down wood are associated with more variation in scenic beauty. Differences were tested in the reliability of scenic beauty production between treatments by analyses of variance among these standard deviations (Table 6). Down wood level was never a statistically significant factor in these ANOVAs, indicating more down wood is reliable in reducing scenic beauty across the treatments. All three effects in this ANOVA are statistically significant as they explain RSBE standard deviations by the other two New Forestry parameters. Dispersed retention is more reliable than aggregated retention in producing expected (average) scenic beauty levels, and this difference is greater at 40% retention than at 15% (Table 6).

4.3. *Using forest structure to explain differences in scenic beauty*

Percent green-tree retention is only a rough predictor of actual post-treatment vegetation structure because pre-treatment densities vary considerably, as do decisions about which trees to remove in each stand. A number of measures of actual vegetation structure in post- and pre-treatment forests were therefore explored via regression models to explain variance in forest scenes' RSBEs. The most singularly efficient were stand density (trees per hectare) and basal area (square meters per hectare) as shown in Tables 7 and 8. Quadratic mean diameter (QMD) also proved an effective measure. Density breakdowns by species or by softwood versus hardwood trees were unrelated to RSBEs as were counts of leaning snags. Only the bottom of snags in the foreground of photos were visible and likely not readily identifiable to respondents as dead trees or ugly. Snags further back in untreated forests and in 40% retention treatments often were obscured by live trees. Tree counts in smaller dbh classes were weakly and not significantly related to RSBEs. This is likely because there were similarly low counts of small trees in clearcuts, in 15% retention treatments, and in some mature forests; and this study did not include young plantations and young forests with high densities of small trees. Tree counts in larger dbh classes did not meet the criteria described in Section 3.9 for inclusion in the best regression models. QMD proved to be more efficient, significant, and free of heteroscedasticity errors in modeling the importance of larger trees in producing scenic beauty.

Basal area proved to be strongly correlated to density ($r = 0.77$) because mature forests with more large trees tend to have more

Table 6
Analysis of variance explaining standard deviations of forest treatments' scene sample RSBEs by means of retention level and pattern, excluding clearcuts and no harvest treatments.[a]

Source	D.f.	Mean square	*F*-ratio	Prob.	Power
Retention level (nominal)	1	1650.25	31.36	0.005	0.98
Retention pattern	1	1212.78	23.05	0.009	0.94
Ret. pattern X Ret. level	1	404.70	7.69	0.050	0.56

[a] Data for this analysis are found in Table 3.

Table 7
Regression analysis explaining scenes' ratio scenic beauty estimates by measures of forest structure, here including density, and basic New Forestry harvest parameters.

Parameter	Estimate	Standard coeff.	Standard error	*t* value	Prob.
Intercept	−128.35	−128.35	9.57	−13.42	<0.001
Density/ha	0.49	1.95	0.07	7.25	<0.001
$(\text{Density/ha})^2$	−0.00047	−2.37	0.00012	−3.95	<0.001
$(\text{Density/ha})^3$	1.30E-7	0.93	5.26E-8	2.7	0.014
Down wood indicator[a]	−21.37	−0.19	4.94	−4.32	<0.001
Dispersed retention indicator[b]	22.60	0.17	5.72	3.95	<0.001
Quadratic mean diameter	1.34	0.33	0.20	6.76	<0.001

Degrees of freedom	R^2	Adjusted R^2	*F*-test	Prob.
Regression statistics				
6/200	0.62	0.61	54.86	<0.001

Step	Parameter	Added R^2	Cumulative R^2
Stepwise regression explanation of variance in ratio scenic beauty estimates			
1	Stand density quadratic	0.35	0.35
2	Quadratic mean diameter	0.21	0.56
3	Down wood indicator	0.03	0.59
4	Dispersed retention indicator	0.03	0.62

[a] The down wood indicator variable took on a value of 1.0 for scenes of high-down-wood treatments, −1.0 for scenes of low down wood treatments, and 0 for all untreated (100% retention) forests with no down wood produced by timber harvesting.
[b] The dispersed retention indicator variable took on a value of 1.0 for scenes of forest treatments with dispersed patterns of green-tree retention, −1.0 for scenes of treatments with aggregated green-tree retention, and 0 for clearcuts and untreated (100% retention) forests.

Table 8
Regression analysis explaining scenes' ratio scenic beauty estimates by measures of forest structure, here including basal area, and New Forestry harvest parameters.

Parameter	Estimate	Standard coeff.	Standard error	*t* value	Prob.
Intercept	−108.31	−108.31	8.62	−12.57	<0.001
Basal area m^2/ha	4.10	2.98	0.36	11.24	<0.001
(Basal area $m^2/ha)^2$	−0.02	−4.39	0.004	−6.62	<0.001
(Basal area $m^2/ha)^3$	4.32E-5	1.98	9.77E-6	4.42	<0.001
Down wood indicator[a]	−22.70	−0.20	4.54	−5.00	<0.001
Dispersed retention indicator[b]	24.95	0.19	5.27	4.73	<0.001
Quadratic mean diameter	0.15	0.04	0.20	0.75	0.456

Degrees of freedom	R^2	Adjusted R^2	*F*-test	Prob.
Regression statistics				
6/201	0.68	0.67	71.37	<0.001

Step	Parameter	Added R^2	Cumulative R^2
Stepwise regression explanation of variance in ratio scenic beauty estimates			
1	Basal area quadratic	0.60	0.60
2	Down wood indicator	0.04	0.64
3	Dispersed retention indicator	0.04	0.68
4	Quadratic mean diameter	0.001	0.68

[a] The down wood indicator variable took on a value of 1.0 for scenes of high-down-wood treatments, −1.0 for scenes of low down wood treatments, and 0 for all untreated (100% retention) forests with no down wood produced by timber harvesting.
[b] The dispersed retention indicator variable took on a value of 1.0 for scenes of forest treatments with dispersed patterns of green-tree retention, −1.0 for scenes of treatments with aggregated green-tree retention, and 0 for clearcuts and untreated (100% retention) forests.

basal area. Consequently, they could not be included in the same model without multicollinearity errors. Each of these factors best explained variance in RSBEs via the third-order quadratic specifications illustrated in Figs 4 and 5. Basal area explains substantially more variance in RSBEs ($R^2 = 0.60$ in Table 8) than density ($R^2 = 0.35$ in Table 7) because it better accounts for the scenic affect of larger trees. This is clear in Fig. 4, where many data points at lower densities occur both well below and above the regression function. Quadratic mean diameter is a needed, significant factor only in the model employing density (Table 7), where it accounts for tree sizes. It is not needed in the model employing basal area (Table 8) where basal area adequately accounts for tree size in explaining scenic beauty. Both these models' graphs provide estimates of optimal vegetation prescriptions for scenic beauty, respectively at about 110–155 m^2/ha basal area (Fig. 5) and 700–900 trees/ha (Fig. 4). Figs 4 and 5 show that pronounced increases in scenic beauty can be expected moving up to these optimal ranges, beyond which scenic beauty will likely decline gradually.

The models in Tables 7 and 8 include stepwise regression results to aid interpretation of factors' relative strength, because standardized coefficients are difficult to interpret when a factor is expressed via three quadratic terms. In both models the strongest predictor of scenic beauty is to approach the optimal basal area or density ranges noted above. If density is used to model scenic beauty then another important factor is QMD to account for tree sizes, and this factor can be omitted from the model using basal area. In both models, retention pattern and down wood levels are useful factors of equal and lesser value in predicting scenic beauty levels.

4.4. Interpolating results across retention levels

It is helpful to estimate expected scenic beauty levels across a full range of green-tree retention levels and not just at the four levels employed in this study. Fig. 6 shows such interpolations. The functions there were found by two steps: First, a regression model was estimated for the three factors employed in the regression models in Tables 7 and 8, using the data points' observed retention levels as the independent variable. All three resulting models were

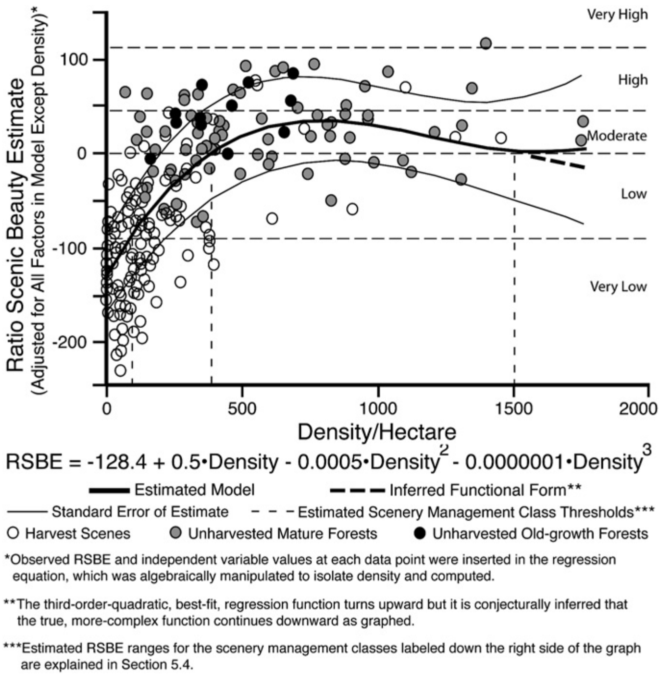

Fig. 4. Estimated regression model of RSBEs as a function of stand density.

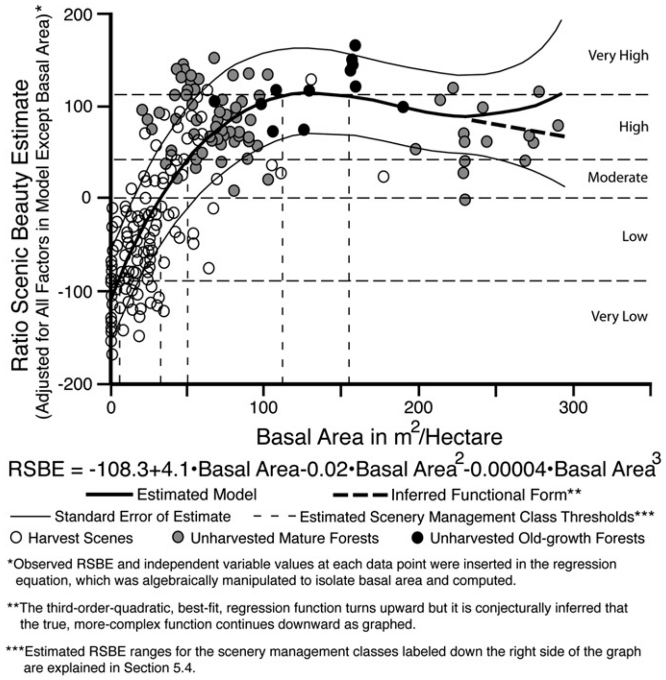

Fig. 5. Estimated regression model of RSBEs as a function of stand basal area.

significant at $p_f < .001$ and all intercepts and coefficients were significant at $p_t < .001$. They were: Trees/ha $= 4.73 + 6.12 \cdot$ Ret. Level ($r^2 = 0.41$); Basal area m^2/ha $= -3.46 + 1.14 \cdot$ Ret. Level ($r^2 = 0.50$); and QMD cm $= 15.13 + 1.44 \cdot$ Ret. Level-0.011 $\cdot$(Ret. Level)^2 ($R^2 = 0.38$). Second, these functions were substituted for the corresponding factors in the models in Tables 5, 7 and 8, along with the required combinations of the down wood and retention pattern indicator variables. The resulting predicted RSBE functions for retention levels 3–97% are graphed in Fig. 6. (The endpoints of possible retention are not plotted because there is no retention in clearcuts and no harvest patterns in 100% retention forests.) The average of the three functions is also plotted at lower right in Fig. 6, as an overall estimate of how retention level relates to scenic beauty.

5. Discussion

5.1. Summary, research needs and limitations

Forest planners can mitigate public controversies by improving scenic beauty. They can substantially predict average, relative scenic beauty levels within such forests by readily measurable and manageable factors. All the postulates in Section 2.2 about how to do so were confirmed, except the last regarding snags. Increased scenic beauty can be expected, in order of importance, with: dispersed rather than aggregated harvest retention patterns, higher harvest retention levels, moderate tree density, larger trees and less down wood. These factors are consistent with public preferences for forests with more coherently natural scenery (Ode et al., 2009). Dispersed retention patterns are more reliable in producing expected aesthetic results than aggregated patterns. More research is needed about harvests' long-term impacts (Shelby et al., 2003) with understory and tree re-growth, and how aesthetic perceptions relate to people's values (Ford et al., 2009).

This study employed a limited sample of forests, focusing on mature forests and harvests of the same. To see how these cases

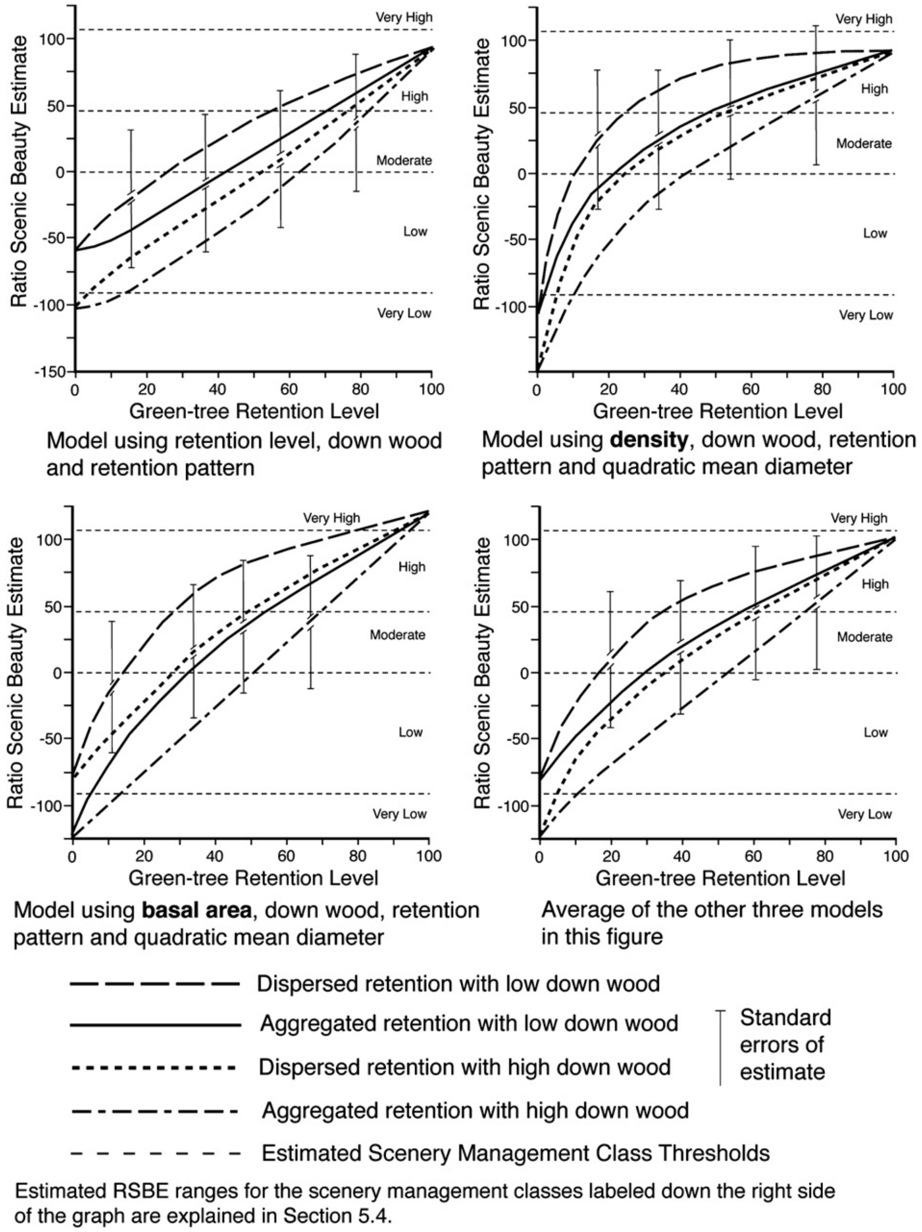

Fig. 6. Interpolated plots of the three scenic beauty regression models across harvest retention levels, and a plot of the functional average of these three models.

compare to young managed forests and old-growth harvests, see Ribe (2005b). Investigation of more levels and combinations of silvicultural parameters is needed, particularly to model scenic beauty inside young forests between 5 and 70 years old. The results provide useful predictions due to the use of reliably measured forest metrics and scenic beauty, and the extensive sample of diverse forests, scenes, and public respondents. The interpretations in Sections 5.2–5.4 are made from the mean values and the regression functions from this study that offer evidence-based predictions of average differences in in-stand scenic beauty. These predictions are subject to the ranges of uncertainty indicated by the errors graphed in Figs. 3–6.

5.2. *Scenic beauty in mature forests*

The most efficacious way of achieving scenic beauty in mature forests is by basal area, particularly at lower forest densities. The closer forests approach 110–155 m^2/ha basal area the more beautiful they will tend to be. If circumstances entail an emphasis on forest density, a useful but less effective strategy is to manage forests toward 700–900 trees/ha and to increase average tree size. These two routine measures of forest structure, alone or together, provide good rules of thumb, while infrequently measured factors, such as vegetative ground cover or vision-blocking shrubs and seedlings, likely also affect forests' scenic beauty.

5.3. *Scenic beauty in timber harvests*

The relative importance of factors that explain perceptions of post-harvest scenic beauty varied among the models in this study, and these are systematically resolved in Section 5.4. But, there is a general consensus across the models shown in Fig. 6. The strongest rule is that the greater the level of post-harvest green-tree retention the greater the scenic beauty. Clearcuts are perceived as very ugly irrespective of the level of post-treatment down wood (Fig. 3). Dispersed retention patterns are more reliable at producing expected scenic beauty levels than aggregated patterns, particularly at higher retention levels, producing fewer ugly "surprises".

At lower levels of green-tree retention, such as 15%, reducing down wood levels is the most important factor in improving scenic beauty, but such harvests will still be seen as ugly. Such harvests have become more common in the U.S. Pacific Northwest, and this may prove problematic for perceptions of public forests there. For example, harvests substantially exhibiting 15% aggregated retention and substantial down wood are not an uncommon NFP prescription and these are seen as not much less ugly than clearcuts. 15% retention harvests with low down wood and dispersed retention are significantly less ugly than clearcuts, but still ugly.

At higher levels of retention, such as 40%, favoring dispersed instead of aggregated retention patterns is the most important factor in producing scenic beauty. Reduced post-harvest down wood levels are also effective. Dispersed, 40% retention, low-down-wood harvests are seen as beautiful, on average, as the average, un-harvested, mature forest in the region. Other 40% retention prescriptions are perceived to be scenically neutral, neither beautiful nor ugly.

As shown in Fig. 6 across retention levels, dispersed-retention, low-down-wood harvests are estimated to exhibit the highest comparative scenic beauty, aggregated-retention, high-down-wood harvests tend to have the lowest relative scenic beauty, with other harvests in-between. To further refine scenic beauty production, particularly when employing dispersed retention harvest patterns, silviculturists may aim for the basal area and density targets described in Section 4.3, which may often be achievable at 40% retention. If only one of these optimum ranges can be approached, that for basal area is more effective. Retaining larger trees increases scenic beauty and the basal area target may often be achieved at silviculturally desired post-harvest densities.

5.4. Interpretations against conceptual visual impact standards

The findings in Sections 5.2 and 5.3 can be usefully interpreted for forest planners by an evidence-based, approximate translation to reference VRM standards (USDA Forest Service, 1995; British Columbia Ministry of Forests, 2001). This entails a rough interpretation of numeric RSBE ranges to correspond to VRM standards' conceptual definitions. This is not scientific interpretation but a way to make this study meaningful to planners and impact analysts who must use VRM methods and need such a translation of the findings. The RSBE ranges corresponding to VRM standards are explained below by reference to the USDA definitions, are listed in Table 9, and shown in the vertical divisions of Figs. 3–6. In each case, the New Forestry parameters studied here are discussed, but managers may also seek to target the densities or basal areas in Table 9. The relationship between retention levels and VRM standards is contingent on retention patterns and down wood, as shown in Figs 3 and 6.

5.4.1. High or retention scenic quality

The reference scenic standard is the "high" scenic integrity level (USDA) or corresponding "retention" scenic quality class (BCMF). This standard includes forests where "the valued visual character appears intact." This is consistent with the range of scenic beauty observed for mature, un-harvested forests, or the RSBE range of one standard deviation (33.0) on either side of the mean (79.1) for the untreated, mature forest scenes in the study (Table 9). Managers seeking to implement this high/retention scenic standard should either extend rotations without harvesting, or employ harvests with dispersed retention patterns that retain 40% or more trees with low down wood levels (Fig. 6), closely consistent with findings in BCMF (1997).

5.4.2. Very high or preservation scenic quality

The "very high" scenic integrity level (USDA) or corresponding "preservation" scenic quality class (BCMF) is higher than that above. It applies to forests where 'valued scenic character and sense of place is intact and is expressed to the highest possible level.' This is consistent with all RSBE values above the high/retention levels discussed above (Table 9), to include most of this study's old-growth forest scenes as well as a few mature forest scenes with very high RSBEs. Such scenery is highly valued as iconic of regional sense of place (Dietrich, 1992; Durbin, 1996) and for conservation (Ribe and Matteson, 2002). Managers seeking this very-high/

Table 9
Rules of thumb identifying the highest scenery management standard for which forest treatments and conditions will typically be acceptable for short-term, in-stand scenic impacts.

USDA	BCMF scenic standard	Approx RSBE range	Density range trees/ha[a]	B. A. range m^2/ha[b]	Forest treatments from this study that have acceptable visual impacts[c,d]
Very high	Preservation	>112	700–900 with disp. retention & high QMD	110–155	Many old-growth forests, Some mature forests
High	Retention	46–112	700 to 900 with disp. retention	50–110 and >155	Most mature forests, 40% disp. ret.- low dn wd harvests
Moderate	Partial retention	0–46	400–1500	30–50	40% disp. ret.- high dn wd harvests 40% agg. ret.- low dn wd harvests
Low	Modification	−90–0	100–400 and >1500	10–30	40% agg. ret.- high dn wd harvests 15% disp. ret.- low dn wd harvests 15% agg. ret.- low dn wd harvests 15% disp. ret.- high dn wd harvests 15% agg. ret.- high dn wd harvests
Very low	Maximum modification	<−90[e]	0–100[e]	0–10[e]	Clearcut-low-down-wood harvests[e] Clearcut-high-down-wood harvests[e]
Unacceptably low	Unaccept. modific.	<−90[e]	0–100[e]	0–10[e]	Clearcut-low down wood harvests[e] Clearcut-high-down-wood harvests[e]

[a] Ranges are estimated from the fitted curve in Fig. 4 and are subject to the errors shown there.
[b] Ranges are estimated from the fitted curve in Fig. 5 and are subject to the errors shown there.
[c] Threshold values for high down wood were 300 m^3/ha for clearcuts, all 15% retention harvests, and 40% aggregated-retention harvests (within the harvested matrix area); and 200 m^3/ha for 40% dispersed retention harvests.
[d] Interpretations in this column are made by reference to the lower-right graph in Fig. 6, with cross-reference to Figs. 3–5, and are subject to the errors shown in all three of these figures.
[e] The application of the very low versus unacceptably low scenic impact standard to forests in this RSBE range is a matter of policy choice that can not be interpreted from the results of this study.

preservation scenic standard should retain old-growth forests and retain or treat mature and old forests to approach the density and basal area ranges indicated in Table 9.

5.4.3. Moderate or partial retention scenic quality

The "moderate" scenic integrity level (USDA) or corresponding "partial retention" scenic quality class (BCMF) is just below the high/retention standard discussed in Section 5.4.1. It applies to forests where valued scenic character "appears slightly altered" and where "noticeable deviations must remain visually subordinate" to the valued forest character. This is consistent with forest scenery that is aesthetically impacted by disturbances but remains of positive perceived scenic beauty, corresponding to the range of RSBEs below that for high/retention but above the zero RSBE value (Table 9). Managers seeking to just meet this moderate/partial-retention scenic standard should employ harvests of 20–40% retention (Fig. 6), either in a dispersed pattern with high down wood, or an aggregated pattern with low down wood. British Columbia Ministry of Forests (1997) found that 20% is the minimum green-tree retention level needed to potentially meet this moderate/partial-retention standard in the dispersed-retention, low-down-wood forests they studied, and this is closely corroborated by the 17% retention level indicated for this transition point in such forests in the lower-right graph of Fig. 6.

5.4.4. Low or modification scenic quality

The "low" scenic integrity level (USDA) or corresponding "modification" scenic quality class (BCMF) is just below the moderate/partial-retention standard discussed above. It applies to forests where valued scenic character "appears moderately altered" and "deviations begin to dominate" the scenery. Such deviations from valued forest scenery should nevertheless be "compatible or complimentary" to such scenery. This can be interpreted as consistent with negative RSBEs but only for scenes that retain visually clear forest attributes, i.e. those derived from at least some significant green-tree retention. The lower limit of this moderate/partial-retention RSBE range can reasonably be set at an RSBE value of −90 (Table 9), just above which almost all scenes were awarded with ratings of −2 or higher by at least a majority of study respondents. Managers seeking to just meet this low/modification scenic standard may employ 40% aggregated-retention harvests with high down wood, or any of the 15% retention harvests studied here (Table 9), similar to BCMF's (1997) less than 20% retention finding.

5.4.5. Very low or maximum-modification scenic quality

The "very low" scenic integrity level (USDA) or "maximum modification" scenic quality class (BCMF) is below the low/modification standard above. It applies to forests where valued scenic character "appears heavily altered" and where "deviations strongly dominate." This can be interpreted as consistent with RSBEs below −90 (Table 9), below which a majority of respondents almost always awarded scenes with ratings of −3 to −5. Managers permitted to meet this very-low/maximum-modification scenic standard may employ clearcuts with any level of down wood. This very low perceived scenic beauty might instead be interpreted as consistent with the lowest possible "unacceptably low" (USDA) or "unacceptable modification" (BCMF) standard, which would render clearcuts impermissible anywhere subject to scenic standards.

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