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Initial Response of Understory Plant Diversity and Overstory Tree Diameter Growth to a Green Tree Retention Harvest

Abstract

The increasing use of harvest techniques other than clearcutting in forests west of the Cascade mountains has created an urgent need to understand the effects of these practices on ecosystem species composition and structure. One common alternative, "green tree retention" (GTR), leaves some live trees on a harvest site to more closely mimic a moderate-intensity fire or wind disturbance. We examined the response of understory plant diversity and basal area increment of retained overstory trees after sixteen months and six years, respectively, in GTR cuts. Understory species cover was sampled on three adjacent treatment areas in the Seattle City Watershed, Washington: a clearcut, a dispersed green tree retention and the intact sixty-five year old forest. The change in basal area increment on dispersed green tree retention cuts was sampled with increment cores collected in six stands and two uncut control stands in the Wind River and H.J. Andrews Experimental Forests in Washington and Oregon, respectively. Herb and shrub species richness and evenness were significantly higher in the green tree retention cut than in the other two understory treatments. Although overall species composition of the GTR was closer to the clearcut than the forest, the GTR retained more species and cover of shade-tolerant plants important for maintaining understory diversity as canopy closure reduces understory light. While the basal area increment response of retained trees varied between stands, the average response for all stands for a six year period following harvest was a 15% reduction in increment growth compared to the control stands. Additional study is needed to determine the persistence of these effects and how basal area growth response varies as a function of tree size and age.

Introduction

In the Pacific Northwest a fundamental change in forest management techniques has occurred in the last several years on Federal, State and some private lands. These changes are often collectively termed "new forestry" (Franklin 1989; Gillis 1990; Hopwood 1991), "new perspectives" (Salwasser 1990; Kessler et al. 1992) or "ecosystem management" (Eubanks 1989; Grumbine 1994; Salwasser 1994). Although variously named, the common goal of all these approaches is to integrate efforts to sustain biological diversity and long-term ecosystem health into forest resource planning and timber management (Lertzman 1990; Swanson and Franklin 1992). One particular change is the increasing use of alternative cutting techniques in forests west of the Cascade mountains of Washington and Oregon where the most common practice has been clearcut harvesting followed by slash burning. One alternative method, referred to here as "green tree retention" (GTR), involves leaving approximately five to 60 large, live trees per hectare on a logging site to persist through the next rotation to increase the structural diversity of the regenerating stand. This structural diversity is intended to retain some later seral conditions such as a multi-layered canopy, provide a future supply of large snags and down logs, and increase microsite variability for a more diverse understory (Franklin 1989; Gillis 1990). In theory, green tree retention harvests are designed to more closely mimic conditions following a moderate-intensity wind or fire disturbance and thereby change the impact of logging on ecosystem structure and function.

As a harvest technique, the concept of "green tree retention" is not a new silvicultural practice. In the Pacific Northwest, alternatives to clearcutting have been proposed and experimentally tried throughout the century under such names as selective harvest (Kirkland and Brandstrom 1936), seed tree cutting (Isaac 1956) or irregular shelterwood (Smith 1986, USDA Forest Service 1979). Although the rationale behind each of the methods may have differed, the common result

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has been to leave some live trees on site after initial harvest. Green tree retention, therefore, may not be a "new" forestry, but it is being applied on a larger scale than previous silviculture alternatives west of the Cascade Mountains. The U.S. Forest Service and Washington State's Department of Natural Resources have adopted green tree retention as a standard harvest practice (Robertson 1992; Washington Forest Practices Board 1993) and some private companies are experimenting with its use (Washington Forest Protection Association 1995). While green tree retention harvests are becoming more common, little is known about how this alternative silviculture will affect ecosystem processes or the structure and composition of the forest community. Research is needed on fundamental ecosystem responses including impacts on the understory plant community and the retained overstory trees.

Current computer models and retrospective studies of multi-cohort stands can provide only limited information on how green tree retention will affect either growth of the overstory trees or the understory plant community. Predicting growth changes in overstory trees using computer models such as DFSIM (Curtis et al. 1981) and ORGANON (Hann et al. 1992) would be difficult because the model algorithms are predominantly based on growth and yield information gathered from even-aged, short rotation practices. Another approach would be to sample existing stands which through past disturbance or silvicultural experiments approximate a green tree retention stand condition. However, most existing multi-cohort stands in western Oregon and Washington have a variable density of residual trees and comparisons between dissimilar sites would be difficult (Thomas et al. 1993).

The effects of a green tree retention harvest on understory diversity are also difficult to predict from existing studies. Changes in understory community composition during natural succession (Spies 1991) and in response to a clearcut and slash burn disturbance (Halpern 1988, 1989) have been studied. However understory plant succession and diversity are influenced by both life history traits of the plants in the community and the disturbance intensity (Connell and Slatyer 1977; Noble and Slatyer 1980; Halpern 1989). By leaving trees on a site, green tree retention attempts to change the nature and intensity of the logging disturbance. To assess whether this change in disturbance affects the understory community, vegetation response on green tree retention sites should be studied. It is important to understand the response of both overstory trees and understory plants to alternative silviculture because these processes will affect the structural and functional development of the regenerating forest.

In this paper we examine overstory tree and understory plant response in the first few years after green tree retention harvests. To assess the response of overstory trees, we located the oldest dispersed green tree retention cuts available (harvested in 1988) and compared the change in mean basal area increment for these stands with adjacent stands which had not been cut. To examine the impact of green tree retention on the understory community we compared species composition, richness and evenness on a small, relatively homogenous site where an experimental harvest produced a clearcut (CC), dispersed green tree retention (GTR), and the original forest (FOR) in close proximity. While this study provides information on the initial response of a particular community, responses are likely to vary between sites and with different harvesting methods. This study limits comparisons to a few sites in close proximity and results should not be generalized to conditions for all green tree retention harvests.

Study Areas

The response of understory plants to different harvest methods was studied in the Seattle City Watershed (also known as the Cedar River Watershed), sixty kilometers east of Seattle, Washington. The 26.9 hectare site had been harvested in the summer of 1992, producing three contiguous units: an 8.1 hectare clearcut (all trees felled), an 18.7 hectare dispersed green tree retention (27 live trees per hectare), and a 0.1 hectare patch of retained trees (no cutting). The patch was not included in the analysis because its small size and singularity made understory comparisons unreliable. A survey of the understory community on the CC and GTR sites was not made before harvest. However, an adjacent intact forest of 65 year-old trees was included to compare understory composition and diversity between clearcut, green tree retention and no harvest treatments. Although the study area before harvest was fairly homogenous (McCalmon pers. comm.) differences in the present understory composition may be partially due to pre-harvest differences in understory composition between the adjacent sites.

Basal area, species composition and stocking density of the GTR and clearcut areas were the same as the intact forest before they were cut (City of Seattle Watershed, unpublished data). The study area is flat and at an elevation of 480 meters. The three treatment sites are within 300 meters of each other and represent the *Abies amabilis/ Vaccinium membranaceum* association (Henderson et al. 1992). The average tree diameter in the intact forest and before harvest in the clearcut and green tree retention units was 37 cm, with a total basal area of 66 m^2/ha. The species mix on the site was 65% western hemlock (*Tsuga heterophylla*), 19% Douglas-fir (*Pseudotsuga menziesii*) and 16% Pacific silver fir (*Abies amabilis*). On both the clearcut and green tree retention sites logs were yarded over skid roads using tractors. The green tree retention and clearcut areas were planted in 1993 with a mix of noble fir (*Abies procera*), Douglas-fir and Sitka spruce (*Picea sitchensis*) at 740 trees/ha. The understory plant cover was sampled in September of 1993, 16 months after harvest.

The retained green trees at the Seattle City Watershed site were not sampled for changes in basal area increment because only 16 months of growth response could be examined. Instead, sample stands for overstory diameter response were selected from the oldest green tree retention cuts in the Pacific Northwest which we could find. Four stands in the H.J. Andrews Experimental Forest east of Eugene, Oregon, were selected. Three of these stands were cut in 1988 and logs were hauled to the landings with tractors. The density of leave trees at the three sites was 20, 43 and 45 trees per hectare of mature Douglas-fir. Although sites did have variable retention density, only stands with low densities were used in this study to minimize the effects of stem competition. Retained trees at all sites were widely dispersed and the distance between adjacent crowns was five meters or more. Mortality of retained overstory trees appeared low but was not systematically sampled. The three GTR sites had been burned following harvest and planted with Douglas-fir seedlings. A fourth undisturbed stand, adjacent to the green tree retention stands, was sampled as a control. The dominant Douglas-fir trees at all sites were 120-140 years old, and average site diameter ranged from 65 to 78 cm. The four sites are in *the Tsuga heterophylla/Rhododendron macrophyllum/ Berberis nervosa* plant association (Franklin and Dyrness 1988), range in elevation from 700 to 900 meters and are on moderate slopes of 10-25°.

Tree diameter increment cores were also collected on four stands near the Wind River Experimental Forest north of Stevenson, Washington. Three of these stands were harvested with tractors in 1988 and planted with Douglas-fir. Retention trees at the three sites averaged 16, 20 and 25 trees per hectare of 130-145 year-old, Douglas-fir. Retained trees on all three sites were widely dispersed and tree crowns were separated by at least five meters. A fourth control stand adjacent to the green retention sites was also sampled. All sites are fairly level, near 600 meters in elevation and in the *Tsuga heterophylla/ Polystichum munitum* plant association (Franklin and Dyrness 1988).

Methods

Understory vegetation in the uncut forest, clearcut, and green tree retention was sampled with 180 plots taken along randomly placed transects. Plots were placed along three 100 meter transects using a random number generator for values between 0 and 100. At each plot location a two by two meter frame, gridded into 49 squares, was placed over the vegetation. These smaller units, each representing approximately two percent cover, were used to improve the accuracy of visually estimating species cover. Planted trees and coarse woody debris from the logging operation were not included in the analysis. All herbs, shrubs and naturally regenerating trees were identified using Hitchcock and Cronquist (1973) nomenclature. Moss was not identified to genus and species, and bluegrasses (*Poa* spp.), rushes (*Juncus* spp.), wintergreen (*Pyrola* spp.), and willow (*Salix* spp.) were identified only to genus.

Species diversity was analyzed using two measures, richness and dominance (Magurran 1988). Richness was examined at two spatial scales; the total number of species found in each treatment, and the mean number of species per plot. The mean species richness per plot was compared using single-factor ANOVA (Zar 1984). Dominance was evaluated to assess whether a treatment's understory was strongly dominated by a few species or, inversely, whether species were more evenly distributed. To evaluate dominance in understory diversity, the Berger-Parker index (d) was used:

$$d = N_{max}/N$$

N_{max} = total cover of the most abundant species

N= total cover of all species

The conventional practice of adopting the reciprocal form of the measure (1/d) was employed so that the index increases with increasing evenness (Magurran 1988). In this conventional form, high Berger-Parker values indicate cover amongst species is more evenly distributed, and low values indicate dominance by a single species.

Analyzing understory species by their functional role can also provide insight into plant community dynamics and the seral development of a site. Following disturbance in the Pacific Northwest, species richness in forest understory communities greatly increases (Franklin and Dyrness 1988; Schoonmaker and McKee 1988). At the time of sampling, 16 months after harvest, many understory plants are ruderal, non-forest species which rapidly colonize harvest sites. With seral development these invasive species rarely persist through the low-light conditions of canopy closure, and on-site residual forest species regain site dominance. An understory's composition of invasive and residual species can indicate the disturbance intensity and community resilience of a site (Halpern 1988). To examine each treatment's response, species were identified as either residual or invasive depending on whether they are characteristic of undisturbed forest or are commonly restricted to localized disturbed sites. In Pacific Northwest forests this distinction is based on function rather than plant origin because several invasive species are natives (e.g. salmonberry (*Rubus spectabilis*)). Species were classified as invasive or non-invasive following descriptions in regional plant taxonomic guides (Hitchcock et al. 1969; Hitchcock and Cronquist 1973; Klinka et al. 1989; Pojar and McKinnon 1994) and previous studies (Dyrness 1973; Halpern 1988; 1989).

Classifications of the understory data were made using TWINSPAN, a FORTRAN program which uses reciprocal averaging to make divisive classifications of species and plot samples (Hill 1979). The only non-standard option employed in the TWINSPAN program was a change in the pseudospecies cut levels from five (the default) to six to better reflect typical abundance levels at the sample sites (Hill 1979). In field sampling, all species present were recorded even if their coverage was below the minimum coverage value of 0.5%. These trace species were given a coverage value of 0.1%, and a pseudospecies cut level of 0.2% was added to the other values (i.e. 0, 2, 5, 10, and 20) to include the trace species in the classification divisions.

Overstory trees were sampled within each stand by randomly selecting thirty Douglas-fir trees. Each tree was cored on its uphill side at breast height. Cores were mounted, sanded, and measured under a dissecting microscope using the TRIM (Tree Ring Increment Measurement) computer program. Increment cores for each of the eight stands were analyzed separately for the H.J. Andrews and Wind River Experimental Forests areas. The annual change in basal area increment for each tree was standardized by comparing the post-GTR growth each year from 1988 to 1993 to the mean pre-GTR growth for 1983 to 1987 for each tree. This procedure helps control for variation between trees and in site quality between stands (ex. Chen et al. 1992). The annual response for each stand from 1988 to 1993 was calculated using the mean and standard error of the change in basal area increment for all thirty trees.

Results

Understory

Total species richness was highest in the GTR (42 species present), followed by the clearcut (32) and the forest (20) (Table 1). Plot-level species richness (mean number of species in each 4 m^2 sample) was significantly different between treatments ($F_{0.05\,(1),2,179}$= 3.05, P<0.005). Most of the GTR and clearcut's higher richness was due to a greater number of herbs, grasses and shrubs. Both the forest and the GTR had twice the number of fern species of the clearcut.

The most abundant cover in the forest is moss which accounted for 91% of total understory cover, giving a Berger-Parker value of 1.1. The forest's species richness and evenness values may be biased downward because the study did not identify different moss species. Classifying moss to species, however, may not have significantly changed the relative differences in species diversity between

TABLE 1. A comparison of species richness and evenness between the three samples sites, intact forest (FOR), clearcut (CC) and green tree retention (GTR). Species evenness values are for the Berger-Parker (B.P.) index. Higher B.P. values indicate greater evenness. Common and scientific names for the dominant species acronyms are given in Table 2. Acronyms in upper case were classified as invasive and those in lower case as residual.

	FOR	CC	GTR
Total number of species (includes moss)	20	32	42
Herbs	9	15	18
Grasses	0	3	5
Shrubs	3	8	9
Trees	3	3	4
Ferns	4	2	4
Mean richness (# species/plot)	4.9	7.0	10.3
Species evenness (B.P.)	1.1	2.3	9.7
Percent of invasive species cover	0	84	68
Dominant cover species	Moss Tshe Abam Madi	SESY Tshe DIPU RUSP	SESY Moss Madi EPAN

the three treatments because of the large stand-level differences in richness between treatments and because moss was abundant on all treatments.

The most common species in both the GTR and clearcut is wood groundsel (*Senecio sylvaticus*), an invasive exotic commonly abundant following timber harvest (West and Chilcote 1968, Dyrness 1973, Halpern 1989). The clearcut is strongly dominated by wood groundsel as indicated by the low Berger-Parker evenness value of 2.3, while species are more evenly distributed in the GTR with a value of 9.7.

No invasive species were present in the forest. The four plants dominating the understory were all shade-tolerant species: moss, western hemlock, Pacific silver fir, and false lily-of-the-valley (*Maianthemum dilatatum*). The forest contained five species unique among the three treatments: oak fern (*Gymnocarpium dryopteris*), wintergreen (*Pyrola* spp.), Pacific trillium (*Trillium ovatum*), western redcedar (*Thuja plicata*) and Pacific silver fir (Table 2).

Most of the understory cover in the clearcut is from invasive species, particularly wood groundsel, foxglove (*Digitalis purpurea*), and salmonberry (*Rubus spectabilis*). In addition, three grasses and four *Rubus* species contributed to make up most of the total invasive cover. The clearcut did not contain any unique species because all species in the clearcut were also found in the green tree retention cut.

Although more than two thirds of the total cover in the GTR was from invasive species, no single species accounted for more than 10% of the total understory cover. While invasive species increased the GTR's total richness, the relatively high Berger-Parker value of 9.7 indicates species were evenly distributed. The GTR contained six unique species, all considered invasive: wall lettuce (*Lactuca* spp.), rush (*Juncus* spp.), running clubmoss (*Lycopodium clavatum*), bluegrass (*Poa* spp.), black cottonwood (*Populus trichocarpa*) and bracken fern (*Pteridium aquilinum*) (Table 2). The GTR and forest share four shade-tolerant species not found in the clearcut.

Eleven of the 47 species were common to all three treatments (Table 2). Constancy values for these eleven non-invasive species are lowest in the clearcut. Constancy values are a measure of the proportion of sample plots within a treatment on which a given species occurs. Constancy values are used instead of cover values to indicate how common or rare a species is within a treatment. Twenty-one species were found only in the CC and GTR. All 21 were classed as invasive species. Sixteen of the 21 species had higher constancy values in the GTR, reflecting its high plot-level richness and low dominance.

The main division in the TWINSPAN classification of the data by species groups (Figure 1) is between shade-tolerant (left side) and shade-intolerant species (right side). This division also separated most of the residual (lower case) and invasive species (upper case). Six residual species were grouped with the other 27 invasive species. Four of these species, false lily-of-the-valley, foamflower (*Tiarella trifoliata*), ladyfern (*Athyrium filix-femina*), and western swordfern (*Polystichum munitum*) are more tolerant of full sunlight than most residual forest species. Two shade-tolerant species, evergreen violet (*Viola sempervirens*) and queen's cup (*Clintonia uniflora*) were also grouped with the invasive species in the classification because both had high frequency and total cover in the clearcut.

The classification of the plots shows a clear division between clearcut and forest plots at the first level of division (Figure 2). While five of

TABLE 2. List of species found in the three sample stands (CC for clearcut, GTR for green tree retention and FOR for the intact forest) in the Seattle City Watershed, by acronym, scientific and common name. Acronyms in upper case were classified as invasive and those in lower case as residual. The species are organized in five groups: found in all three sample stands, found in both the CC and GTR, unique to the GTR, found in both the GTR and the Forest, and unique to the Forest. No species were unique to the CC or common to only the CC and Forest. Values are species constancy (percent frequency of occurrence for the 60 plots in each treatment).

Acronym	Scientific Name	Common Name	CC	GTR	FOR
Common to CC, GTR and FOR					
atfi	*Athyrium filix-femina*	Lady fern	6.7	31.7	15
clun	*Clintonia uniflora*	Queen's cup	5	16.7	6.7
madi	*Maianthemum dilatatum*	False lily-of-the-valley	31.6	75	51.7
moss	----	Moss	55	91.7	100
pomu	*Polystichum munitum*	Sword fern	10	21.7	21.7
titr	*Tiarella trifoliata*	Three leaved foam-flower	3.3	8.3	5
tshe	*Tsuga heterophylla*	Western hemlock	66.7	70	85
trla	*Trientalis latifolia*	Western starflower	1.6	3.3	3.3
vaal	*Vaccinium alaskaense*	Alaska blueberry	15	41.7	41.7
vapa	*Vaccinium parvifolium*	Red huckleberry	3.3	16.7	33.3
vise	*Viola sempervirens*	Evergreen violet	3.3	5	5
Common to CC and GTR					
AGOR	*Agrostic oregonensis*	Oregon bentgrass	25	30	
ANMA	*Anaphalis margaritacea*	Pearly everlasting	11.7	25	
CAME	*Carex mertensii*	Merten's sedge	30	31.6	
CIAR	*Cirsium arvense*	Canada thistle	3.3	1.7	
DIPU	*Digitalis purpurea*	Common foxglove	48.3	53.3	
EPAN	*Epilobium angustifolium*	Fireweed	43.3	71.6	
EPWA	*Epilobium watsonii*	Purple-leaved willowherb	3.3	8.3	
HYRA	*Hypochaeris radicata*	Hairy cat's-ear	5	6.7	
LUCA	*Luzula campestris*	Many-flowered wood-rush	13.3	36.7	
PREM	*Prunus emarginata*	Bitter cherry	23.3	51.7	
PSME	*Pseudotsuga menziesii*	Douglas-fir	18.3	78.3	
RULA	*Rubus laciniatus*	Evergreen blackberry	3.3	3.3	
RUPA	*Rubus parviflorus*	Thimbleberry	1.6	3.3	
RUSP	*Rubus spectabilis*	Salmonberry	51.7	51.7	
RUUR	*Rubus ursinus*	Trailing blackberry	33.3	36.6	
RUAC	*Rumex acetosella*	Sheep sorrel	1.6	21.6	
SALIX	*Salix* spp.	Willow	5	6.7	
SARA	*Sambucus racemosa*	Red elderberry	50	51.6	
SESY	*Senecio sylvaticus*	Wood groundsel	88.3	85	
SOAS	*Sonchus asper*	Prickly sow-thistle	21.7	21.7	
VEOF	*Veronica officinalis*	Speedwell	5	31.7	
Unique to GTR					
LAMU	*Lactuca muralis*	Wall lettuce		5	
JUNCUS	*Juncus* spp.	Rush		3.3	
LYCL	*Lycopodium clavatum*	Running club-moss		3.3	
POA	*Poa* spp.	Bluegrass		10	
POTR	*Populus trichocarpa*	Black cottonwood		1.7	
PTAQ	*Pteridium aquilinum*	Bracken fern		48.3	
Common to GTR and FOR					
blsp	*Blechnum spicant*	Deer fern		33.3	20
rupe	*Rubus pedatus*	Five-leafed bramble		3.3	1.6
stam	*Streptopus amplexifolius*	Clasping twistedstalk		5	10
vaov	*Vaccinium ovatum*	Evergreen huckleberry		10	15
Unique to FOR					
abam	*Abies amabilis*	Pacific silver fir			63
gydr	*Gymnocarpium dryopteris*	Oak fern			8.3
pyrola	*Pyrola* spp.	Wintergreen			3.3
thpl	*Thuja plicata*	Western redcedar			1.7
trov	*Trillium ovatum*	Western trillium			10

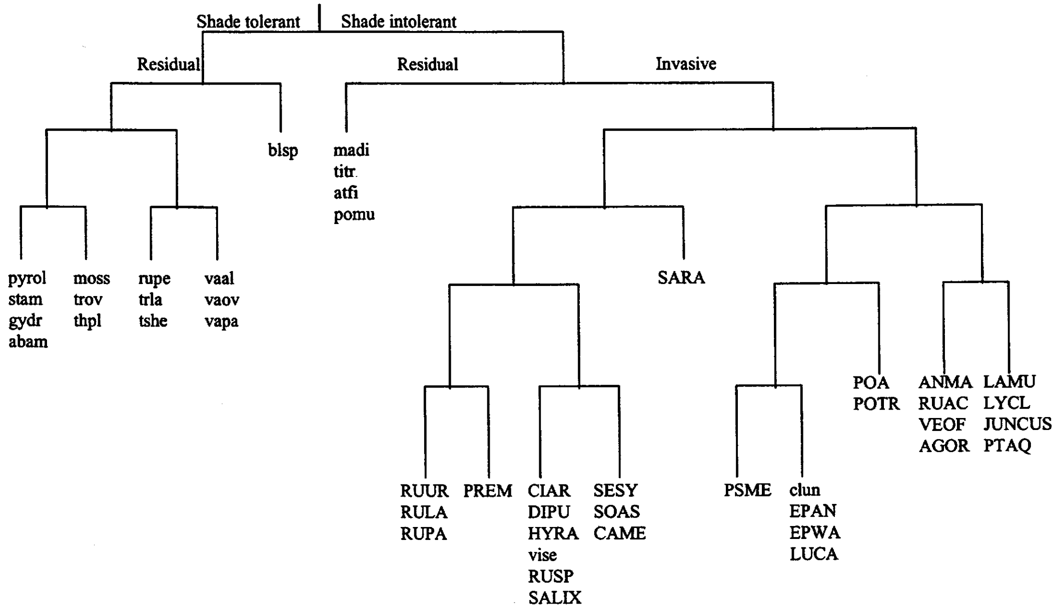

Figure 1. A dendrogram of all species using TWINSPAN. Acronyms in upper case were classified as invasive and those in lower case as residual. Note that most shade-tolerant, residual species are classified in the left branches of the dendrogram and most of the shade-intolerant species are classified in the rightside branches. Common and scientific names for the acronyms are given in Table 2.

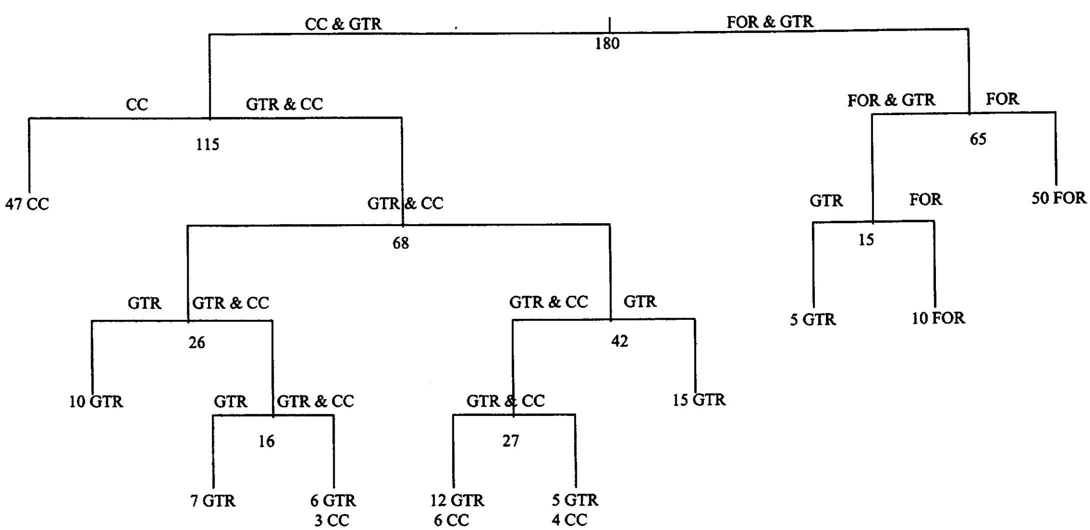

Figure 2. A dendrogram of all sample plots using TWINSPAN. The terminal branches of the dendrogram indicate the number of plots which are from the intact forest (FOR), clearcut (CC), and the green tree retention (GTR). Higher branches indicate which treatments the plots come from and the total number of plots. Classifications were truncated when all plots were in one treatment.

the GTR's 60 plots are classed with the forest plots, most of the GTR plots are grouped with clearcut plots. At the second division level, 55 GTR plots and 13 clearcut plots form a group distinct from most (47) of the clearcut plots. At the lower divisions the 13 clearcut plots are split into three groups shared with 23 GTR plots.

Overstory

Green tree retention stands in both the Wind River and H.J. Andrews areas generally show a decline in basal area increment growth (Figure 3). At Wind River the uncut control stand's annual basal area increment (BAI) has increased an average of 9%

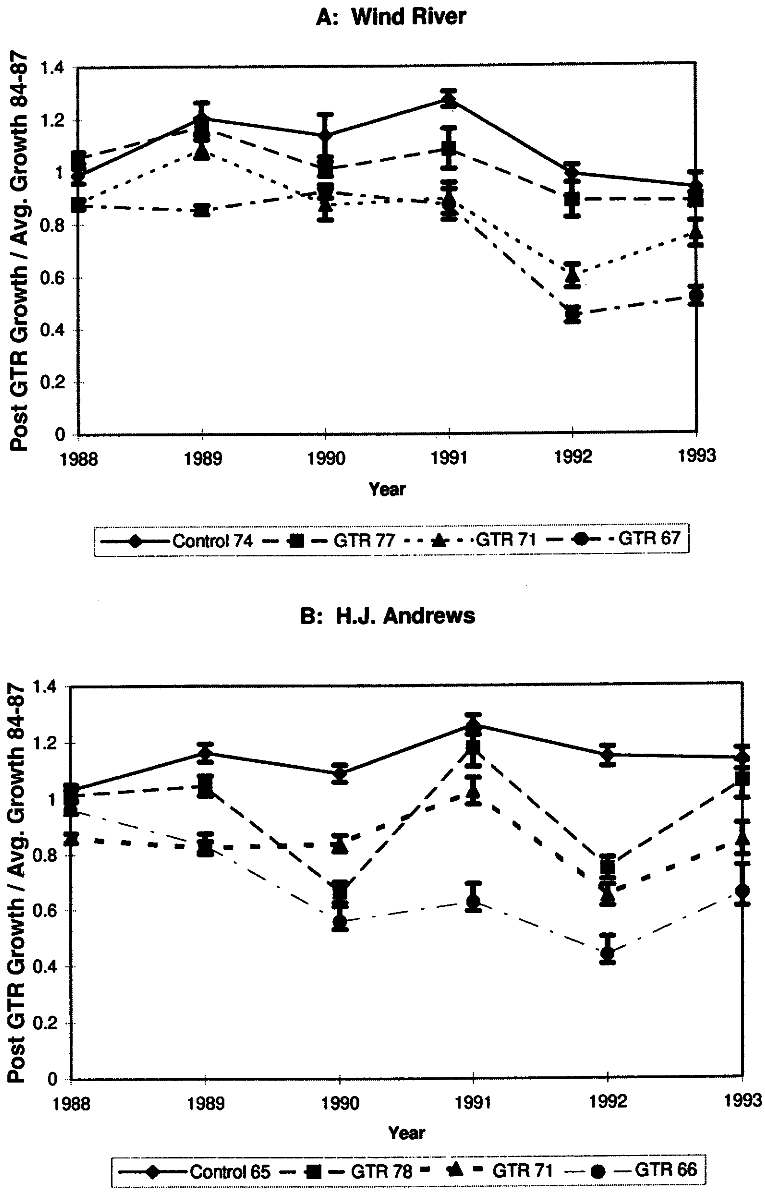

Figure 3. The change in basal area increment for each year of 1988-1993 divided by the average basal area increment for 1984-1987 at (A): Wind River and (B): H.J. Andrews. Each graph shows the control stand and three GTR stands. In the legend, the numbers following the stand type indicate the mean diameter at breast height (dbh). Graph values are the mean and standard error (shown with error bars) for 30 increment cores collected in each stand.

above the mean increment from 1983-1987. In contrast, the three GTR stands, with average retained tree diameters of 77, 71 and 67 centimeters (GTR 77, 71 and 67, respectively), have BAI changes which average 1.02, 0.85 and 0.75 of their mean increment from 1983-1987, respectively. In GTR 77 in 1988, 1989 and 1993, the overlap in standard error with the control indicates that there is not a statistically significant difference in BAI. All other GTR sample points are less than the control, and the three GTR stands average change in BAI is 13% less than their 1983-1987 average increment.

At the H.J. Andrews the control stand's annual BAI has increased 14% over the mean increment from 1983-1987. However, the three GTR stands with average diameters of 78, 71, and 66 centimeters, have changes in BAI of 0.95, 0.85 and 0.68 compared to their means from 1983-1987, respectively. The standard errors for GTR 78 and the control overlap in 1988, 1991 and 1993. All other GTR sample points are less than the control, and the three GTR stands average change in BAI is 17% less than their 1983-1987 average increment.

Discussion

The increasing use of green tree retention harvests has created an urgent need to understand the effects of this new harvest method on ecosystem processes. The intention of both dispersed and clumped green tree retention is to alter the nature of the timber harvest disturbance by retaining some of the original stand structure. Whether the impact of this altered disturbance regime achieves its objectives needs to be closely monitored. Many management objectives for GTR, such as speeding up recovery of habitat for late seral species or accelerating stand structural diversity can only be assessed with long-term and large-scale sampling and monitoring. In the interim, this study was designed to provide information about the early ecosystem response of a few stands to a GTR harvest.

The initial understory response on the study sites was a higher richness and evenness of species on the GTR than the forest or clearcut treatments. The GTR has more total species, a higher average number of species per plot and understory cover is more evenly distributed among species. However, while diversity measures are an important metric for comparing understories, a numerical index alone does not consider the functional role of individual species in seral development.

The understory study sites were sampled within 16 months after the harvest disturbance when invasive species peak in understory dominance (Franklin and Dyrness 1988; Halpern 1988). In 15-20 years after cutting, light levels are reduced as the regenerating forest creates a closed canopy. Residual shade-tolerant species from the pre-harvest stands which persist until canopy closure often begin to dominate the understory as shade-intolerant species die out. Most of the invasive species sampled in this study, which are shade intolerant, will not persist with seral development. The number and constancy of shade-tolerant species therefore provide some indication of the potential future understory diversity as light levels decrease with canopy closure. Furthermore, understories which presently have higher species evenness are less dominated by shade-intolerant, invasive species and therefore retain species which may survive the future reduced light levels of canopy closure. The longevity of shade-tolerant herbs during the stem exclusion stage (Oliver and Larson 1990) of forest development, however, has not been well studied, and in very low light conditions all herbaceous plants may die (e.g. under dense stands of shade-tolerant western hemlock foliage (Alaback 1982)).

At the time of sampling, the GTR and clearcut were dominated by invasive, shade-intolerant species creating a species composition distinct from the forest. The TWINSPAN classification of plots, however, also indicates that the composition of most GTR plots is distinct from the clearcut. The main difference in the GTR is the higher richness and evenness of species in each plot (Table 1), and the presence of more shade-tolerant species. For the species common to all three treatments, all of which are shade tolerant, constancy values are higher in the GTR than in the clearcut (Table 2). Four shade-tolerant species were only found in both the forest and GTR. Although there are many species common to the GTR and clearcut which were not found in the forest, species composition in GTR plots was more varied. Five of the GTR plots were classed with the forest plots in the first division of the TWINSPAN classification, while 23 GTR plots have a composition similar to clearcut plots in the final division.

Several hypotheses might explain the GTR's higher diversity and more variable plot-level species composition than the clearcut. The retention of trees on the harvest site may provide greater microsite variability than would be present in a clearcut. Logging disturbance may be more variable in a GTR because areas around the base of retained trees would have less yarding damage than the typical impact found in a clearcut. The partial retention of the overstory canopy may also affect understory microclimate, providing a mosaic of light and moisture conditions (Childs and Flint 1987; Hungerford and Babbitt 1987). The species unique to the GTR are associated with fairly dry (running club-moss) to very moist (rush), and shaded (wall lettuce) to full sunlight (black cottonwood) conditions (Klinka et al. 1989). The GTR, however, does not have two species, oak fern and Pacific trillium, which are sensitive to soil disturbance common with log yarding. Both plants were found only in the forest.

In the six GTR overstory retention stands there is a general decrease in basal area increment six years after harvest. This result was unexpected as studies in younger-age forests show basal area increment increases after trees are released from density-dependent competition (Worthington and Staebler 1961, Reukema 1975, Oliver and Larson 1990). Few studies, however, have examined the release response of mature trees which have been thinned to the low density common in green tree retention cuts. Newton and Cole (1987) found diameter growth continued to increase in two Douglas-fir stands of 120 and 140 year-old trees for 70 years after each was thinned in 1914 to about 75 dominant trees per hectare. Thinning research in 96 year-old Sitka spruce and western hemlock stands in southeast Alaska to about 300 trees per hectare, found diameter growth increased while unthinned stands showed decreasing diameter growth (Farr and Harris 1971). Old-growth Douglas-fir and western hemlock on the edge of a clearcut were found to have increased growth rates of 33% and 150% respectively, for a ten year period following the clearcut harvest (Chen et al. 1992). However, a study of the initial response of 70-150 year Douglas-fir with 60% removal found that the rate of diameter growth response decreased as the age of retained trees increased (Williamson and Price 1971). In mature and old-growth Douglas-fir stands where an average of 36% of the volume was removed, Isaac (1956) found a decline in diameter growth.

It is difficult to compare the response of GTR overstory trees with these studies because of variation in their retention densities, tree ages, species composition and location. The basal area increments for the control sites indicate growth has increased by 9 and 14% in adjacent uncut stands of the same age. Therefore it appears unlikely that climate conditions for growth during 1988 to 1993 were responsible for the GTR's decreased basal area increment. One hypothesis may be that the older trees sampled in this study may experience thinning shock (Oliver and Larson 1990) and initially respond by allocating more resources to below-ground growth. Size also appears to have some effect on response, as BAI in stands with larger average diameter did not decline as much as smaller diameter stands (Figure 3). The reasons for this pattern are not clear. Larger trees may be less stressed by changes in microclimate conditions which occur when the surrounding canopy is removed. Although a decrease in retained tree growth will not effect the "new forestry" objectives of increasing structural diversity and providing a source for large snags and logs, the unexpected result warrants further study.

The effects of new harvest techniques on retained overstory trees and the understory community will vary both with plant communities, geographic area, physiographic features and through time. Our results indicate an initial trend toward higher richness, evenness and number of shade-tolerant species, and reduced basal area growth in retained overstory trees following a green tree retention harvest. We suggest that further research is needed to investigate the effects of green tree retention, particularly:

- a permanent plot study of understory response, monitoring species composition before and after a green tree retention harvest
- monitoring of understory response through canopy closure
- a large-scale comparison of sites in the same plant association, including undisturbed old growth
- changes in overstory basal area increment over long post-harvest periods
- variation in overstory response with diameter, age, dominance, density and vigor of retained trees

Careful monitoring of harvest sites and broad-based, long-term studies are the only means of assessing the full impact of green tree retention harvests on the forested ecosystems of the Pacific Northwest. We recognize, however, that policy makers and forest managers can not wait the several decades needed to get the results of these studies. In the meantime, we hope this study begins to provide information about the effects of these new management practices, until longer-term and more extensive monitoring of the effects of green tree retention harvesting can be completed.

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