ELSEVIER

Forest Ecology and Management 155 (2002) 223–236

Forest Ecology and Management

www.elsevier.com/locate/foreco

Using Forest Health Monitoring to assess aspen forest cover change in the southern Rockies ecoregion

Paul Rogers*

USDA Forest Service, Rocky Mountain Research Station, 507 25th Street, Ogden, UT 84401, USA

Abstract

Long-term qualitative observations suggest a marked decline in quaking aspen (*Populus tremuloides* Michx.) primarily due to advancing succession and fire suppression. This study presents an ecoregional coarse-grid analysis of the current aspen situation using Forest Health Monitoring (FHM) data from Idaho, Wyoming, and Colorado.

A unique feature of aspen forests in western North America is regeneration primarily by asexual ''suckering'' although rare seeding events do occur. The dominant clonal process provides the basis for this analysis. In essence, the remaining aspen stems of previously large clones provide a window to the past and possibly a view of the future. The author uses baseline observations of aspen and associated tree species regeneration, forest size and structure components, stand age, tree damage, and recent disturbance to assess regional aspen conditions. Analysis of stands where aspen is dominant (aspen forest type) and where aspen merely occurs (aspen present) are presented. Basic groupings within the aspen forest type plots were obtained by cluster analysis of 10 FHM variables derived from tree- and plot-level measurements. Stable and unstable aspen forest types were verified using principal component analysis. A further criterion of at least 25% conifer species present was placed on the unstable group to render a more conservative population estimate of instability.

The unstable aspen forest types, along with the plots having only the presence of aspen, comprise the dynamic portion of the aspen community in this area. These results support the hypothesis of an aspen decline within the past 100 years. However, additional regional plots and long-term remeasurements should provide a clearer picture of the decline's extent. Altering current and future management practices may significantly affect the rate of change. Published by Elsevier Science B.V.

Keywords: Aspen; Ecosystems; Forest health; Forest succession; Forest disturbance; *Populus tremuloides*

1. Introduction

Aspen (*Populus tremuloides* Michx.) is a commercially and aesthetically valuable species throughout the interior west, USA. This tree is the most geographically widespread species in North America and is the predominant deciduous tree of the Rocky Mountain region (Preston, 1976). Recently, the topic of widespread aspen decline has elevated in prominence in both the scientific (Brown, 1995; Kay, 1997; Bartos and Campbell, 1998) and popular media (Frazier, 1996; Sweigert, 1998). Thus far, documentation of aspen decline has been largely anecdotal or on a geographically limited scale (Monte, 1995; Bartos and Campbell, 1998; O'Brien, 1999). Forest Health Monitoring (FHM), along with Forest Inventory and Analysis (FIA), can provide standardized baseline and long-term data sets for large geographic areas.

Aspen forests depend on certain periodic disturbances to regenerate. The primary abiotic disturbances affecting interior west forests are drought, fire, wind,

* Tel.: +1-801-625-5330; fax: +1-801-625-5723.
E-mail address: progers@fs.fed.us (P. Rogers).

0378-1127/02/$ – see front matter. Published by Elsevier Science B.V.
PII: S0378-1127(01)00560-6

and geomorphologic events (gravity driven). Biotic disturbances include timber harvest, other human manipulations (e.g. road building, forest thinning, land clearing), domestic animal grazing, wildlife browsing, insects, and diseases. Some disturbances, such as fire promote aspen regeneration (Jones and DeByle, 1985; Mueggler, 1985), while other disturbances, such as elk browsing (Kay and Bartos, 2000) or disease (Hinds, 1985) have the opposite effect. Long periods (80–150 years) without fire, harvest, or other catastrophic disturbance will likely lead to the decline, and perhaps total loss, of all except the most stable aspen stands (Jones and Schier, 1985; Mueggler, 1985).

This study will examine large-scale (multi-state) baseline FHM data sets and use established principles of aspen ecology to assess aspen cover change in the southern Rockies ecoregion (SRE). Aspen community stability will be examined based on forest composition, structure, tree damage, stand age, and recent disturbance. Discussion of factors affecting decline and suggestions for management are presented.

2. FHM in the southern Rockies ecoregion (SRE)

2.1. The FHM program

FHM is a national program designed to determine the status, changes, and trends in indicators of forest condition on an annual basis (Stolte, 1997). The United States Department of Agriculture (USDA) Forest Service is working closely with state natural resource entities, as well as other federal agencies and universities, to implement FHM at four principal levels, detection monitoring, evaluation monitoring, intensive site monitoring, and research on monitoring techniques. The first level, detection monitoring, involves the implementation of ground and aerial surveys of forest conditions for specific forest health indicators. If unexplained changes are detected, the second level, evaluation monitoring, investigates the extent and severity of changes. The third level, intensive site monitoring, involves establishing a small network of sites nationally for research on ecological processes related to change elements in specific forest types. The fourth level, research on monitoring techniques, develops reliable forest health indicators through experimentation and regional field trials.

The data used in this study were taken from FHM detection monitoring field plots. Potential forested plots are located on a hexagonal grid across the United States approximately 26.5 mile apart (Overton et al., 1990). Plots are located on this standardized grid regardless of ownership or management practices, reducing sampling bias considerably over monitoring systems defined by agency or managerial boundaries. Field crews conduct a baseline sample on each forested plot the initial year the program enters a state. In subsequent years one-fourth of the baseline sample is visited, until the entire grid is remeasured by the fifth year. The plot covers 1 ha and is sub-sampled for a suite of forest health indicators, including traditional tree measures, tree crown conditions and damage, lichen communities, ozone biomonitoring, and soils (USDA Forest Service, 1999).

In the interior west, field plots were first established in Colorado in 1992. Annual measurements in this state, along with the addition of Idaho (1996) and Wyoming (1997), constitute the baseline set of data used here. State FHM baseline reports are compiled after the initial grid is measured (e.g. Rogers et al., 1998). These three states comprise approximately two-thirds of the entire SRE. Future FHM work in Utah, Montana, and New Mexico will complete the measurement of this ecoregion in the interior west.

2.2. Southern Rocky mountain steppe: open woodland, coniferous forest, alpine meadow province (SRE)

When we look at the totality of forest resources, then state, county, agency, and legal designation boundaries may limit landscape assessment. As public entities begin to cooperate at state and regional scales, it seems prudent to approach forest health issues using nonpolitical, ecologically based land divisions (Rudis, 1998). Bailey (1995) presents a hierarchical framework for logically delineating ecological regions based on their unique combinations of physiography, soil type, potential vegetation, and climate. FHM reports large-scale resource status and trends at state, ecoregion, region, and national scales.

The ecoregions of the United States are classified, in descending order, by domains, divisions, and provinces. Finer-level ecoregion divisions are available

(McNab and Avers, 1994), but their scale appears inappropriate for the coarse plot density of the FHM grid. This study employs a province-level evaluation of aspen health in Idaho, Wyoming, and Colorado. Specifically, the SRE, described below in detail, is the setting for analysis of FHM plots with aspen dominance (forest types) and aspen presence (Fig. 1). Adjacent ecoregion province descriptions shown in Fig. 1 may be found in Bailey (1995). The subset of aspen forest type plots considered to be unstable, which are shown in Fig. 1, are discussed in (Section 5) of this paper.

The SRE is composed of the major mountain ranges of the southern Rocky Mountains, USA. The area is characterized by high mountains and plateaus regularly dissected by north–south running valleys or parks. Elevations of the highest peaks are over 4200 m and the valley floors range from 1800 to 2100 m. Major highlands include the Salt River and Teton Ranges of southeast Idaho and western Wyoming, the Yellowstone Plateau, Bighorn, and Wind River mountains in Wyoming, and the Front, Sawatch, and San Juan Ranges of Colorado. Climate in this province is highly variable depending on local elevation and

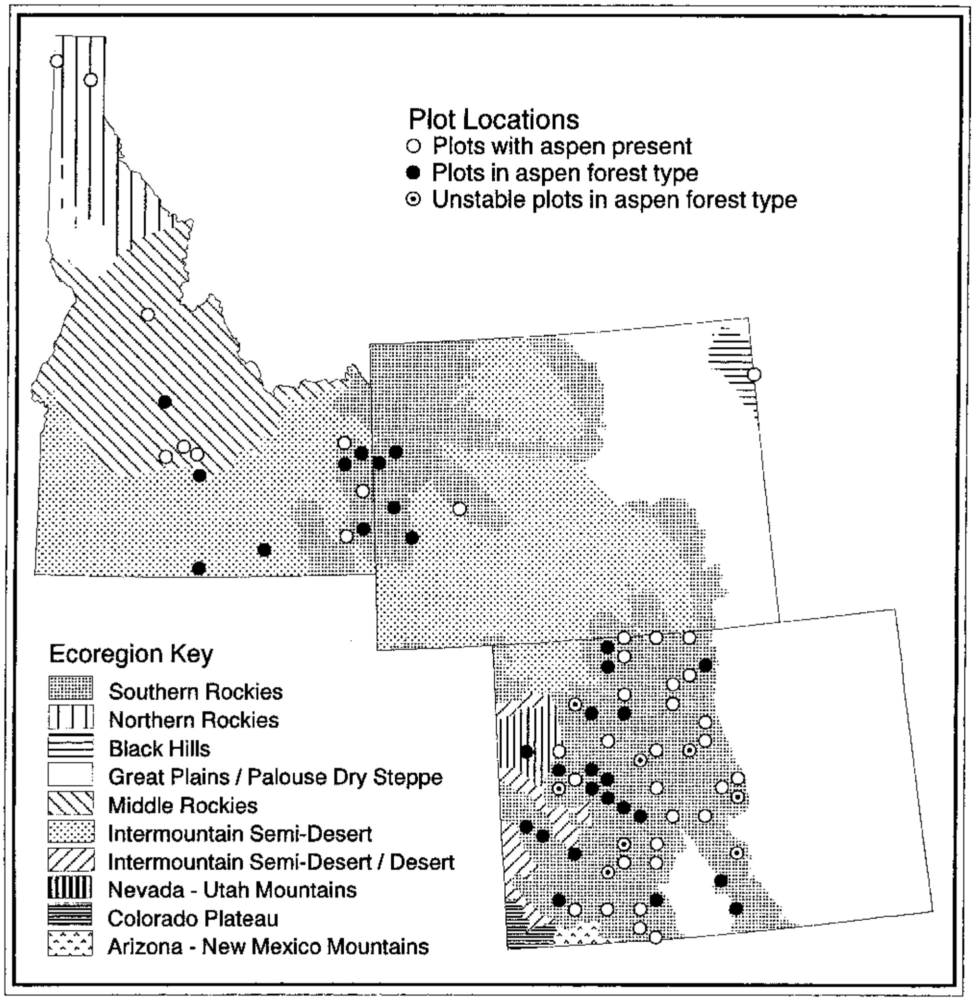

Fig. 1. Sample plots with aspen present, in aspen forest types, and in unstable aspen forest types are shown here by ecoregion. Plot locations shown here represent approximately one-third of the total FHM plots in Idaho, Wyoming, and Colorado. In addition to the cluster analysis done for this study, plots mapped as unstable here had at least 25% of their trees in species other than aspen.

aspect. In general, valleys are warmer and drier than mountains, with annual precipitation of 38–63 cm per year. Higher mountain ranges are much cooler and precipitation is 102 cm, or more, annually. Much of the annual moisture comes in the form of winter snow; however, a northerly flow of summer storms is a common occurrence in the southern portion of the region.

The flora of this province is also highly variable, because of differences in elevation, aspect, soil type, rainfall, and evaporation rate, mountain vegetation resembles a large-scale mosaic of many conifers, few deciduous trees, and some shrub-grasslands. The SRE contains the most forested plots and the greatest diversity of forest types of any interior west ecoregion. Rocky Mountain forests are often depicted in terms of discrete elevation and forest type zones. Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) dominate the highest forested elevations; lodgepole pine (*Pinus contorta* Dougl. ex Engelm.), aspen, and Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) cover the middle montane zone; and ponderosa pine (*Pinus ponderosa* Lawson), pinyon (*Pinus edulis* Engelm.), and Utah juniper (*Juniperus osteosperma* (Torr.) Little) define the mid- and lower-elevation forested zones (scientific names follow Welsh et al., 1987). Exceptions occur based on variations in aspect and presence of less common forest types, such as one-seed juniper (*Juniperus monosperma* (Engelm.) Sarg.), limber pine (*P. flexilis* James), western bristlecone (*P. longaeva* D.K. Bailey), and Gambel oak (*Quercus gambelii* Nutt.).

3. Aspen ecology

Aspen is an early colonizer that regenerates quickly following disturbance, but some aspen clones seem to persist for decades even without significant perturbation (Mueggler, 1985). In the interior west, aspen regenerates primarily by vegetative means through adventitious roots, commonly known as suckers (Schier et al., 1985a). Aspen clones may be over 0.5 ha in size and are easily distinguished from adjacent clones by the timing of autumn senescence or spring leaf-out. Although many seeds are produced annually, few instances of sexual regeneration occur in this region, because seedlings require a narrow range of temperatures along with specific soil and moisture conditions (McDonough, 1985; Romme et al., 1997). Although fire is the primary disturbance agent of regeneration, other catastrophic events, such as avalanches, landslides, and forest harvesting may similarly begin the reproductive process. Reproduction from underground root stocks give aspen an advantage over other species whose reproductive parts (i.e. cones and seeds) are often consumed by fire or take longer to establish when they are not burned. In the absence of significant disturbance, aspen clones may deteriorate as longer-lived conifer species establish in the shade of seral aspen stands and eventually dominate the overstory.

Frequent fire events favor a prosperous regional aspen community. However, people have successfully worked to reduce wildland fire in two ways over the past 150 years: (1) through an organized campaign of wildfire suppression led primarily by government land managers; and (2) by systematic elimination of Native American wildland burning practices (Pyne, 1982; Denevan, 1992; Rogers, 1996). It is unclear what the ratio of wildfire to human-set fire was prior to European settlement, but an overall reduction in wildland fire has led to significant changes in post-European settlement disturbance regimes (Gruell, 1983; Baker, 1992; Denevan, 1992; Covington and Moore, 1994; Biasan and Swetnam, 1997). Additionally, less direct human impacts, such as excessive livestock grazing or managed increases in native herbivores, have probably altered understory fuels sufficiently to have greatly impacted fire spread on the landscape (Kay and Bartos, 2000).

A sharp decline in regular fires has resulted in a drop in aspen regeneration in Utah (Bartos and Campbell, 1998). In the absence of fire, disease and advancing succession favor dominance by conifers on many sites when aspen reach 80–150 years of age (Hinds, 1985; Mueggler, 1985). So, while few stands are regenerating due to the lack of fire, older stands of aspen may be replaced by shade-tolerant conifers. In addition, grazing and browsing pressures on new suckers appear to contribute to decline. Moreover, the cumulative effects of aspen loss may lead to a regional decline in biodiversity of aspen-dependent communities. Several authors have discussed the unique fauna and flora supported by aspen cover (e.g. DeByle, 1985; Mueggler, 1985; McCune et al., 1998). While a change in cover seems apparent, the level and geographic extent of aspen change needs further study.

4. Methods

The objective of this study was to document regional aspen community conditions, and possible change, using an initial FHM plot measurement. Three primary steps are used in the methods of this study: (1) data collection using FHM protocols; (2) data summarization by mapping basic groups; and (3) statistical analysis of data to assess aspen forest type stability.

FHM data collection protocols used in the study are described briefly here. FHM field crews measure all trees 12.7 cm (5.0 in.) and greater diameter at breast height (DBH) on four fixed radius 7.32 m (24.0 ft) subplots and saplings 2.5–12.6 cm (1.0–4.9 in.) DBH on four 2.07 m (6.8 ft) radius microplots. Detailed information is gathered on each tree and sapling pertaining to tree growth, mortality, regeneration, crown condition, and damage (USDA Forest Service, 1999). Once established, the plot layout is fixed on the landscape, meaning subplots are not rotated or moved to avoid or concentrate sampling in certain cover conditions. When multiple conditions (either forested or not) are encountered across the plot, field crews will map and tally trees based on their respective conditions (stands). Conditions are distinguished by distinct changes across the plot in any of the five following stand-level variables, land use class, forest type, stand origin, stand size, and recent (past 10 years) disturbance. Two site trees are measured and aged for each forested condition, forming the basis for the stand age in that condition. Variables related to this study are presented in Table 1. Additional information

Table 1
This table lists analytical variables taken from mensuration, crown evaluation, and damage indicators on FHM plots[a]

Name	Type[b]	Name	Type
Plot level			
County number (within state)	Code	Plot status (forest, non-forest)[a]	Code
Elevation (to nearest m)	Num.	FHM region[a]	Code
Hexagon (location number)[a]	Code	Measurement type (first, or revisit)[a]	Code
Panel (year in cycle, 1–4)[a]	Num.	Plot type (subplot, or microplot)[a]	Code
Plot number (if replacement plot)	Code	State (US 50 states)[a]	Code
Condition level			
Condition class[a]	Code	Condition class change (if disturbed)	Code
Density check (overall tree density)	Code	Disturbance year (calendar year)[a]	Num.
Forest type[a]	Code	Land use class (land use type)[a]	Code
Past disturbance (up to three disturbance)[a]	Code	Stand age (in years)[a]	Num.
Stand origin (natural, planted)	Code	Stand size (average tree size, class)	Code
Tree level (trees, saplings, site trees)			
Species[a]	Code	Current tree history (live, dead)[a]	Code
DBH (to nearest mm)	Num.	DRC (diameter root collar, to mm)[a]	Num.
Stem count (DRC, woodland)[a]	Num.	Cause of death (mortality type)	Code
Tree age at DBH (site tree)[a]	Num.	Tree height (site tree, to 1 m)	Num.
Basal area factor (site tree)	Num.	Live crown ratio (estimate %)	Num.
Competing basal area (site tree, m)	Num.	Crown density (estimate %)	Num.
Crown diameter (crown width, cm)	Num.	Crown dieback (estimate %)	Num.
Foliage transparency (estimate)	Num.	Crown light exposure[a]	Code
Crown position (in canopy)[a]	Code	Crown vigor (saplings)	Code
Damage (type, one–three locations)[a]	Code	Location (damage, one–three locations)[a]	Code
Severity (damage, one–three locations)[a]	Code	Tree notes (comments)	Alpha.

[a] Specifically used in this study. Additional FHM indicators and variables can be found in USDA Forest Service (1999).
[b] Num.: numeric value; Code: numeric code; Alpha.: typed description.

Table 2
The proportion of forested plots in the southern Rockies and all other ecoregions in Idaho, Wyoming, and Colorado

	Southern Rockies		All other ecoregions	
	N	%	*N*	%
Plots with aspen present	29	15	9	5
Plots in aspen forest type	33	17	5	3
Forested plots with no aspen	130	68	153	92
All forested plots	192	100	167	100

(not part of this analysis) is collected on field plots for understory vegetation, lichen communities, soils, and ozone biomonitoring. Field crews are trained and checked for quality according to national protocols (Pollard and Palmer, 1998). All plot procedures and indicator terminology are documented in the FHM Field Methods Guide (USDA Forest Service, 1999).

A map of aspen sample locations within ecoregions of the area is presented in Fig. 1. Revised Bailey (1995) ecoregion boundaries are used in this study, because of their precision at the regional scale of interest employed here (Freeouf, 1999). An overview of forested field locations in this ecoregion and the entire three state area, with emphasis on aspen presence versus forest type, is presented in Table 2. Plots where aspen constitute a majority of tree stocking, as determined by field crew stem counts, constitute an aspen forest type, or aspen dominance. Those plots with aspen present, but not as a majority, were labeled aspen present. I assumed that where aspen is present now, at one time there was a viable aspen stand and perhaps aspen had been dominant. O'Brien (1999), used a similar dichotomy of aspen presence and dominance to characterize change of vegetation in Utah.

Aspen present stands in the region were further examined to gauge the overall condition of stands that appear to have succumbed to conifer dominance. These plots with aspen present were evaluated for their abundance of aspen, DBH, and stand age to gain an idea of current conditions. These plots were estimated to have been in an advanced stage of aspen cover loss already. Other than to gain an overall picture of the regional aspen community, no further evaluation of aspen present stands was performed.

Finally, aspen dominant stands were further analyzed for current stability. Evaluation criteria for plot stability were based on previous work (Mueggler, 1985; Schier et al., 1985b; Jones and Schier, 1985; Bartos and Campbell, 1998) and focused on presence of shade tolerant species, regeneration, structure and health of aspen present, and stand age. The FHM measurements used to evaluate these basic stand attributes were: (1) stand age; (2) other species present; (3) aspen sapling regeneration; (4) other sapling species regeneration; (5) aspen in lower canopy; (6) stand age greater or equal to 90 years; (7) aspen mortality greater than 10%; (8) severe damage (conks, cankers, decays, and open wounds) on >20% of trees; (9) presence of a second condition that was a conifer forest type; and (10) percent of conifer trees and saplings present. Variables 2–9 were derived binary data, all others were actual values.

All aspen forest type plots were examined using divisive cluster analysis (Kaufman and Rousseeuw, 1990) to establish statistical groupings based on these 10 variables. Principal components analysis (Afifi and Clark, 1990) was independently applied to the same data set to examine variance and confirm or reject the clustering process.

5. Results

In Colorado, Wyoming, and Idaho, over half of the total forested FHM plots are in the SRE (Table 2). Additionally, the majority (82%) of the aspen plots in these states are found in the SRE. About one-third (32%) of forested plots within the SRE have some aspen presence and exactly half of these plots are classified as aspen forest types.

An examination of plots with aspen presence reveals a mix of conifer species that appear to have gained dominance over the remaining aspen. Lodgepole pine was the most common forest type in this category, and spruce-fir and Douglas-fir types dominated many stands as well. On plots where aspen is present, but not dominant, stand ages are taken from two trees of the dominant forest type, because aspen is a pioneer species, aspen present in other forest types are likely to be at least the age of the current stand.

Plots currently in aspen forest types were grouped according to cluster analysis by the 10 variables

Table 3
Principal component loadings for 10 FHM variables used to assess aspen forest types[a]

Variable[b]	Component loading									
	1	2	3	4	5	6	7	8	9	10
STAGE	−0.24	0.46	−0.46	−0.16	0.06	0.08	−0.01	−0.38	0.53	0.24
OTHSP	0.51	0.16	−0.26	0.13	−0.03	0.13	−0.22	0.19	0.32	−0.65
ASPREG	0.37	0.27	0.16	−0.34	0.17	−0.20	0.74	0.14	0.08	0.01
OTHREG	0.41	0.29	0.10	0.41	0.09	0.01	0.00	−0.65	−0.37	0.05
LOCAN	0.33	0.31	0.12	−0.51	0.06	0.01	−0.57	0.19	−0.21	0.34
SAGE	−0.28	0.41	−0.48	−0.01	−0.10	0.02	0.14	0.25	−0.62	−0.21
ASPM10	−0.22	0.31	0.19	0.28	0.22	−0.78	−0.21	0.14	0.13	−0.10
ASPD20	−0.12	0.36	0.32	0.43	0.26	0.53	0.05	0.39	0.12	0.20
MULTCON	−0.04	0.30	0.33	0.03	−0.89	−0.02	0.04	0.00	0.12	0.00
PCTOTH	0.35	−0.15	−0.44	0.39	−0.20	−0.22	0.07	0.31	0.06	0.56
Cumulative variance	0.26	0.44	0.58	0.71	0.79	0.87	0.92	0.95	0.98	1.00

[a] Components 1 and 2 describe the greatest variance. The remaining components taper evenly, suggesting similar low levels of contribution by several of the components evaluated.

[b] Variable abbreviations are explained in (Section 4).

described above. The divisive coefficient of 0.69 on a scale of 0–1.0 describes a moderately strong statistical grouping (Kaufman and Rousseeuw, 1990). Principal components analysis was applied to further narrow the factors of variance that explain the groupings. Output from the principal component analysis is shown in Table 3. Component 1 describes the largest portion of the variance (26%) in combinations of the 10 variables used to form initial clusters. The highest standardized values for component 1 are for (1) other species present, and (2) other species regenerating (Table 3). Moderate values for component 1 are for whether aspen is regenerating and the percent of other species in the stem count. These values, overall, imply that component 1 is a surrogate for the amount of other species present.

A look at component 2 reveals that the strongest variables are stand age, stand age over 90, and aspen damage greater than 20% of stems. Because damage tends to increase with age in aspen stands, this variable, along with component 2 more generally, becomes a surrogate for stand age. It should be noted, however, that the relationships found in component 2 are of less importance, statistically, than those found in component 1. In fact, cumulative variances shown in Table 3 illustrate the declining importance of components in explaining variable relevance to aspen stand groupings.

A scatter plot of components 1 and 2 shows the influence of other species in the clustering of aspen forest type groups (Fig. 2). Cluster 1, the unstable group, is found almost exclusively on the right hand side of the graph, signifying the strong relationship to the presence of other species. A somewhat weaker relationship is found in component 2, along the *y*-axis. Stand age is only slightly higher, on average, for the unstable (cluster 1) group than the stable (cluster 0) group.

Those plots labeled unstable in Fig. 1 represent a conservative subgrouping, emphasizing other species presence, of the clustering process in aspen forest types. Within the aspen forest type group about half of the plots sampled fall into each of the two clusters described above (Fig. 2). Though the two clusters were strongly supported by the principal components, evidence was inconclusive for calling all of these stands unstable. In fact, it appeared that plots having only one or two other species tallied may be unduly placed in the unstable group based on examination of the other nine variables (which appeared more similar to the stable group). For this reason the unstable cluster was further limited to only plots with at least 25% other species present. Three additional plots were eliminated from the unstable group because too few trees were sampled to clearly discern their stability based on percent of stems. The unstable group,

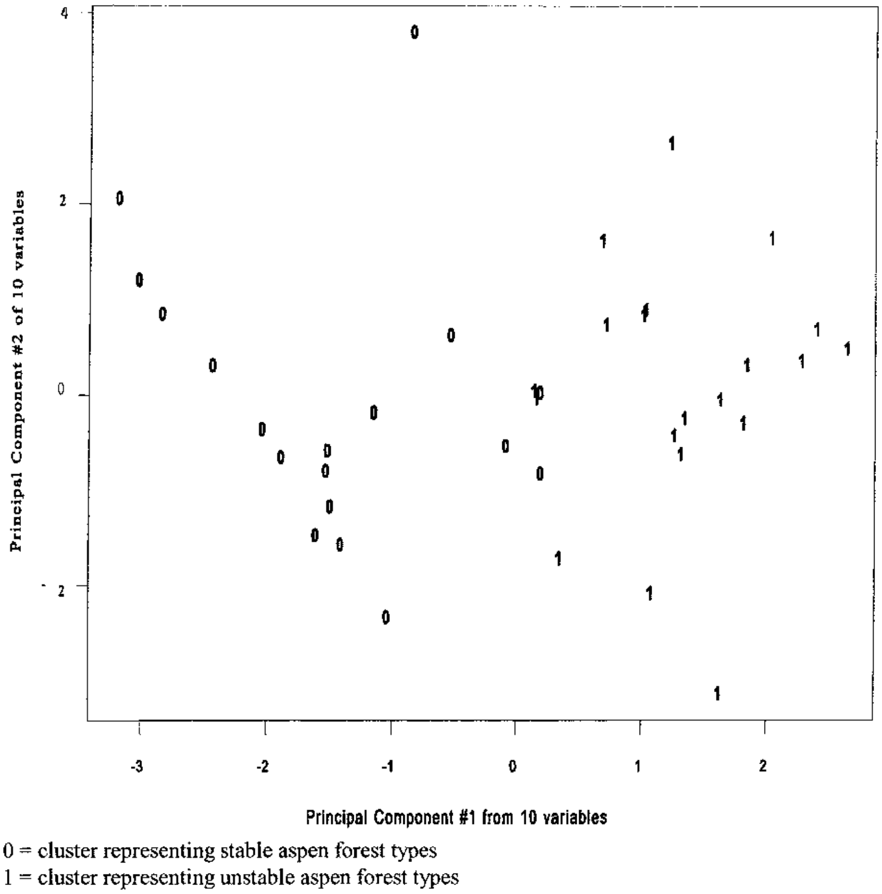

Fig. 2. Principle components 1 and 2 are plotted on the *x*- and *y*-axes, respectively. Component 1 represents the amount of species besides aspen present on sample plots and component 2 represents stand age. All plots shown here are aspen forest type (cluster 1 represents the unstable group, cluster 0 the stable set of aspen forest types).

mapped in Fig. 1, amounts to 21% of all aspen forest type samples in the three-state region (11% of all aspen plots evaluated). All unstable plots are located in the SRE.

Throughout the three-state region, aspen trees were associated with the highest rates of damage overall and the highest rates of severe damage among all species (Table 4). Other deciduous species had a higher percentage of damage, but the sample size was too small to be conclusive. Overall, conifers (80%) have more trees with no damage than deciduous species (62%). This pattern is supported by FHM data across the United States (Stolte, 1997). Much of the damage to aspen in the interior west may be attributed to naturally higher levels of damage among deciduous trees, but at least some of this high incidence rate, most prominently infection by cankers and decay, is likely related to the aging aspen population in this region (Hinds, 1985).

Disturbance is a final important factor to examine in the FHM data set. Eleven (14%) of the 76 plots with aspen present, including those in aspen forest type, showed past evidence of disturbance. Of the eight unstable plots, none were classified as having disturbances within the previous 10 years. Among the stable portion of the aspen forest type plots, five had some recent disturbance. Of these plots, two had selective harvesting, two showed signs of livestock grazing, and one had evidence of excessive elk browsing.

Table 4
Distribution of damage types by species for trees (≥12.7 cm DBH) on Colorado[a], Idaho, and Wyoming plots[b]

Species group	Trees with no damage (%)	No. of damages recorded[c]	Cankers	Conks and dacays	Open wounds	Resinosis	Broken bole	Brooms on bole	Broken roots	Loss of apical dominance	Broken branches	Excessive branching	Damaged shoots	Discolored foliage	Other
Softwoods															
Douglas fir	883 (86)	164	10	37	12	8	1	0	0	56	17	20	3	0	0
P. Pine	234 (81)	66	0	21	17	0	0	0	0	15	5	2	4	1	1
Lodgepole pine	1267 (74)	552	48	103	187	6	1	3	0	98	17	67	8	13	1
Subalpine fir	801 (83)	202	33	44	39	2	2	2	1	54	16	5	2	2	0
Engelmann spruce	702 (88)	108	4	13	22	11	2	0	2	29	16	6	2	1	0
Other softwoods	819 (85)	179	5	60	33	1	1	2	0	53	11	2	1	9	1
Softwood woodland	484 (62)	420	0	158	80	5	0	0	2	21	138	5	1	7	3
Subtotal, softwoods	5190 (80)	1691	100	436	390	33	7	7	5	326	220	107	21	33	6
Hardwoods															
Aspen	410 (59)	375	143	132	53	7	0	0	0	22	16	0	2	0	0
Cottonwood	39 (76)	13	0	2	1	0	0	0	0	3	7	0	0	0	0
Other hardwoods	8 (47)	10	0	2	1	0	0	0	0	4	3	0	0	0	0
Hardwood woodland	115 (66)	76	0	19	5	0	1	0	0	10	40	0	1	0	0
Subtotal, hardwoods	572 (62)	474	143	155	60	7	1	0	0	39	66	0	3	0	0
Totals	5762 (77)	2165	243	591	450	40	8	7	5	365	286	107	24	33	6

[a] There are 1025 trees from Colorado plots in 1992 that are not included in this tally because of changes in the damage system since that time.
[b] Compare aspen (below, under hardwoods) to other species tallied in this region.
[c] No. of damages recorded may include multiple damages, up to three, for individual trees.

6. Discussion

6.1. Aspen community health in the SRE

Results presented here support some level of regional aspen cover loss. In an examination of stand structure, regeneration, age, damage, and recent disturbance, indications are that a large proportion of aspen stands in this analysis should be considered either already converted to other types or unstable in aspen forest types. The composition and structure of aspen present and unstable plots show advancing succession by a variety of conifer species, an unstable set of aspen forest types with little regeneration or understory in aspen, and few young aspen stands that were likely initiated by significant disturbance.

Stand age plays an important role in aspen community conditions. Some aspen communities seem to be quite stable for several generations, while the majority of western aspen communities are considered seral (Mueggler, 1985). Some of the stable plots sampled by FHM appear to represent those very stable populations, which are characterized by multi-layered stands with no active conifer invasion. The average age of aspen forest types was 68, while aspen present stands averaged 88 years.

A large percentage (41%) of individual aspen trees had some form of damage, probably related to their advancing community age. Not only was damage in this species common, but the types of damages tended to be more severe, overall, than those of associated species. All aspen forest types greater than 90 years of age had >20% of their aspen stems with severe damage. Of the seven aspen plots over 90 years, all but one had greater than 10% mortality. Moderate rates of disease leading to mortality may not be coded as plot-level disturbances, but they do affect long-term change where conifer species are establishing. Recent disturbance, perhaps the most critical factor affecting aspen cover, was generally absent. Where disturbance was present, the disturbance types are not the sort that promote stand rejuvenation (e.g. fire, wind/weather related damage, or significant tree harvesting).

In the SRE, forest cover change appears to be more acute in the eastern half of the ecoregion (Fig. 1). This may be a reflection of combined human influences (e.g. fire suppression and ungulate grazing) plus the physical limitations on a species near the edge of its regional ecological range. In contrast, FHM data reflect a greater relative aspen stability in both the north central part of Colorado and in southeast Idaho and western Wyoming. Beyond the SRE, plots in central and northern Idaho may represent remnant aspen dominance in the interior west. In peripheral areas of a species range other factors, such as marginal soil or climate conditions, may cause further stress to declining populations.

6.2. Disturbance ecology and aspen management

Disturbance ecology-based management seeks to understand long-term and large-scale disturbances to effectively manage landscapes in alliance with ecosystem functions (Noss, 1990; Veblen et al., 1994; Zimmerer, 1994; Franklin, 1995; Rogers, 1996). This approach contrasts with management practices that pit people against natural disturbances in attempts to accomplish management goals while tightly controlling outcomes (Frome, 1962; Holling and Meffe, 1996).

The unstable plots, in combination with the aspen present plots, represent the dynamic population of the aspen community regionally. Presumably, there has always been a dynamic subset of the aspen community overall. Without catastrophic disturbance some stands are always moving toward dominance by conifers. Rare seedling establishment events may balance out the loss of some aspen clones (Romme et al., 1997). This scenario suggests a long-term relative equilibrium to maintain a viable aspen population regionally. Of course, other disturbances impact this scenario to increase the complexity of the aspen story. For example, forests often burn coincidental to drought. In less severe drought years, some forests burn because of previous damage or mortality caused by insects and diseases. Exceptions to interactive disturbance models occur when direct human impacts, such as harvesting or other treatments, including prescribed fire, are implemented. Note that people are considered part of a biotic system of disturbance factors.

In this region, as throughout much of North America, indigenous people practiced some level of intentional manipulation of vegetation. Native burning of forests was implemented across the continent, although the level of that activity is often debated (Pyne, 1982; Denevan, 1992; Vale, 1998). Aspen stands burned much more frequently prior to European settlement and implementation of fire suppression (Gruell, 1983; Romme et al., 1995). Aspen stands must burn at moderate to high intensity to stimulate successful regeneration (Bartos et al., 1994). High forb content limits the flammability of aspen stands during peak growing season. Kay (1997) suggests that burning of the type to gain adequate regeneration was done in early spring or autumn by indigenous Americans to improve specific plant stocks for food. In the past century, human-set fires have been virtually eliminated and fire suppression has diminished the possibility of conifer fires spreading to aspen forests.

Wildlife browsing, predominantly by elk, has also played an important role in the success or failure of aspen regeneration (DeByle, 1985; Bartos et al., 1994; Romme et al., 1995; Kay, 1997, Suzuki et al., 1999). Kay (1997) suggests that elk populations are unusually high compared to historic levels in the Yellowstone National Park area. In Rocky Mountain National Park, Suzuki et al. (1999) found aspen regeneration reduced in areas of heavy elk use, while in the rest of their study area aspen appear to be regenerating successfully. Livestock grazing may have similar effects on new stems when other forage is limited. Additionally, heavy grazing will limit the spread of fire when fine fuels are consumed in, or adjacent to, aspen forests (DeByle, 1985; Bartos and Campbell, 1998; Kay and Bartos, 2000).

Tree harvesting is often considered a surrogate for stand-replacing fire to stimulate regeneration (Schier et al., 1985b; Bartos and Campbell, 1998). However, commercial cutting differs from other disturbances in that considerable biomass and carbon are taken out of the local system, rather than left in place to recycle. Unlike environmental disturbances, harvesting is often undertaken with less regard for the seasonality of the disturbance it is mimicking. Additionally, precautions should be taken when aspen stands are cut, as mortality on uncut trees can be quite high following mechanical injury because of associated infection by cankers (Walters et al., 1982). More broadly, we tend to think of the aspen forest of 1900 or 1850, as being "the natural state," when in fact there probably is no natural "state" per se, but rather a continuum of conditions along which the forests of 100 years ago are merely a single point in time (Vale, 1988; Tausch, 1996; Shinneman and Baker, 1997). It is likely that forests of 200, 300 or 1000 years past were markedly different from those of today and those of 100 years ago. Changes in climate (e.g. the "little ice age") and probable changes in scale of native burning based on huge disease-related losses to human populations, have had subtle and dramatic consequences on forest change over the millenia. Similar to the management practices of the 20th century, except perhaps in scale, people and environmental factors have shaped different aspen forests for different times. Managers should be forthright in their reasoning when it comes to manipulating aspen toward a desired condition. A presumption of management toward a "natural" or "presettlement" condition should be viewed with caution.

6.3. Management suggestions

Holling and Meffe (1996) point out the pitfalls of managing to "command and control" environments rather than managing to work with them. Lack of consideration for disturbance processes will likely result in continued loss of aspen forests. Before management actions are taken, a better understanding of the scale of historic disturbance is needed. Management actions should be balanced by no management control tracts of similar size. An adaptive management approach will allow for changes to be implemented as new research becomes available.

Managers of sustainable aspen communities in the interior west should consider these basic elements: (1) background research in long-term disturbance regimes and interactions for specific areas; (2) an explicit statement of what disturbances are being "restored" and what conditions are being targeted; (3) a reduction in fire suppression that will allow natural regeneration of aspen where feasible; (4) use of prescribed burning, possibly supplemented by forest harvesting, to stimulate regrowth in areas of documented cover change; (5) a more critical evaluation of wildlife management policies that may be having dramatic affects on forest health (Kay, 1997; Kay and Bartos, 2000; Suzuki et al., 1999); and (6) continuing long-term monitoring with standard measurements across agency, ownership, and political boundaries to understand large-scale change.

6.4. Regional assessments

Regional monitoring, in conjunction with site specific research, can provide vital information to land managers. Managers regularly commission resource studies to answer local questions of concern. While these studies are useful for answering short-term questions, data collected are often incompatible with similar studies on adjacent lands, between measurement cycles, or across scales of interest. The utility of standardized data collection procedures which cross agency and ownership boundaries, over large areas, can not be overemphasized. Both the FHM and FIA programs within the USDA Forest Service collect these types of data.

This study has taken a relatively small number of samples over a large area to examine regional aspen community dynamics. The FHM plot grid is extensive, though the systematic sampling scheme increases the power of data by reducing plot location bias. Moreover, the "broad net" approach of FHM is designed to detect change and to implement more intensive surveys where abnormalities arise.

The SRE is an important forest province in the interior west, and the majority of its range falls in the three states where FHM data are currently available. Additional plot establishment will be needed in surrounding states to assess the geographic extent of decline among aspen in the SRE. This work is not intended to replace geographically specific research, its purpose is to use a coarse-grid plot network in conjunction with localized studies to increase understanding of aspen community health over the entire area. Bailey (1995) ecoregions provide an avenue for this type of hierarchical data linking.

7. Conclusions

Aspen cover change has been evaluated here in the context of a regional forest health assessment. Data from baseline measurements of FHM plots in the SRE support that of more localized studies where aspen cover appears to be changing to coniferous species (Bartos and Campbell, 1998). About 61% of all plots with aspen present, including unstable aspen forest type plots, should be considered in transition away from long-term aspen forest sustainability. Though it is unlikely that all low-level occurrences of aspen on plots today signifies each plot was once dominated by aspen, overall the FHM data suggest declining populations at the regional scale. Repeat measurements and further basic research on clonal viability with low stem counts will yield greater understanding of change estimates regionally.

Acknowledgements

The author would like to thank the field crews, trainers, and quality assurance personnel involved in the 1992–1997 FHM field seasons in Colorado, Idaho, and Wyoming for their hard work. David Turner, Rocky Mountain Research Station, and Susan Durham, Utah State University, provided invaluable statistical consultation in manuscript revisions. Additional thanks go out to all reviewers for their helpful comments and suggestions to improve this paper.

References

Afifi, A.A., Clark, V., 1990. Computer aided multivariate analysis, 2nd Edition. Van Nostrand Reinhold, NY, pp. 371–394.

Bailey, R.G., 1995. Descriptions of the ecoregions of the United States. Misc. Publication no. 1391, 2nd Edition. USDA Forest Service, p. 108.

Baker, W.L., 1992. Effects of settlement and fire suppression on landscape structure. Ecology 73, 1879–1887.

Bartos, D.L., Campbell Jr., R.B., 1998. Decline of quaking aspen in the interior west, examples from Utah. Rangelands 20, 17–24.

Bartos, D.L., Brown, J.K., Booth, G.D., 1994. 12 years biomass response in aspen communities following fire. J. Range Man. 47, 79–83.

Biasan, C.H., Swetnam, T.W., 1997. Interactions of fire regimes and land use in the central Rio Grande valley. Research Paper RM-RP-330, USDA Forest Service, p. 20.

Brown, M., 1995. Aspen decline in the inland northwest: a review of some relevant literature. Report on file at USDA Forest Service, Pacific Northwest Research Station and the Smithsonian Institution, p. 28.

Covington, W.W., Moore, M.M., 1994. Southwestern ponderosa forest structure: changes since European–American settlement. J. For. 92 (39), 39–47.

DeByle, N.V., 1985. Wildlife. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 135–152.

Denevan, W.M., 1992. The pristine myth: the landscape of the Americas in 1492. Ann. Assoc. Am. Geogr. 82 (3), 369–385.

Franklin, J.F., 1995. Scientists in wonderland: experiences in development of forest policy. Biosci. Supp. S-74-78.

Frazier, L., 1996. Keeping the range fires. The Herald Journal, Logan, Utah, pp. 13–14.

Freeouf, J., 1999. (Maps in digital form) Ecoregion modifications to Bailey's ecoregions of the United States (Bailey, 1995): subsection boundaries. USDA Forest Service, Rocky Mountain Region, Denver, Colorado.

Frome, M., 1962. Whose woods these are: the story of the national forests. Doubleday, Garden City, NY, pp. 360.

Gruell, G.E., 1983. Fire and vegetation trends in the northern Rockies: interpretations from 1871 to 1982 photographs. Gen. Tech. Rep. GTR-INT-158, USDA Forest Service, pp. 117.

Hinds, T.E., 1985. Diseases. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 87–106.

Holling, C.S., Meffe, G.K., 1996. Command and control and the pathology of natural resource management. Conserv. Biol. 10 (2), 328–337.

Jones, J.R., DeByle, N.V., 1985. Fire. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 77–81.

Jones, J.R., Schier, G.A., 1985. Growth. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 19–24.

Kaufman, L., Rousseeuw, P.J., 1990. Finding groups in data: an introduction to cluster analysis. Wiley, NY, p. 342.

Kay, C.E., 1997. Is aspen doomed? J. For. 95 (5), 4–11.

Kay, C.E., Bartos, D.L., 2000. Ungulate herbivory on Utah aspen: assessment of long-term exclosures. J. Range 53 (2), 145–153.

McCune, B., Rogers, P., Ruchty, A., Ryan, B., 1998. Lichen communities for forest health monitoring in Colorado, USA. A report to the USDA Forest Service, on file at Rocky Mountain Research Station, Interior West Resource Inventory, Monitoring, and Evaluation Program, Ogden, Utah. p. 29.

McDonough, W.T., 1985. Sexual reproduction, seeds, and seedlings. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 25–28.

McNab, W.H., Avers, P.E. (Eds.), 1994. Ecological subregions of the United States: section descriptions. Administrative Publication WO-WSA-5. USDA Forest Service, p. 267.

Monte, D., 1995. History and current conditions of the aspen ecosystem. In: Camas Creek Watershed Landscape Analysis: a Look at the Changes in the Ecology of the Camas Creek Watershed Over Time—Draft. USDA Forest Service, Targhee National Forest, pp. 18–21.

Mueggler, W.F., 1985. Vegetation associations. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 45–55.

Noss, R.F., 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conserv Biol. 4 (4), 355–364.

O'Brien, R.A., 1999. Comprehensive inventory of Utah's Forest Resources, 1993. Resource Bulletin, RMRS-RB-1, USDA Forest Service, p. 105.

Overton, W.S., White, D., Stevens, D.L., 1990. Design report for EMAP (Environmental Monitoring and Assessment). EPA/600/3-91/053, US Environmental Protection Agency, p. 42.

Pollard, J.E., Palmer, C.E., 1998. Forest Health Monitoring 1998 Plot Component Quality Assurance Implementation Plan. Report on file at USDA Forest Service, National Forest Health Monitoring Program, Research Triangle Park, NC, p. 17.

Preston, R.J., 1976. North American Trees. Iowa State University Press, Ames, p. 399.

Pyne, S., 1982. Fire in America. Princeton University Press, Princeton, NJ, p. 654.

Rogers, P., 1996. Disturbance ecology and forest management: a review of the literature. Gen. Tech. Rep. INT-336, USDA Forest Service, p. 16.

Rogers, P., Schomaker, M., McLain, W., Johnson, S., 1998. Colorado Forest Health Report 1992–95: a baseline assessment. Colorado State Forest Service, and USDA Forest Service, Rocky Mountain Research Station and Rocky Mountain Region, p. 44.

Romme, W.H., Turner, M.B., Wallace, L.L., Walker, J.S., 1995. Aspen, elk, and fire in northern Yellowstone National Park. Ecology 76 (7), 2097–2106.

Romme, W.H., Turner, M.G., Gardner, R.H., Hargrove, W.W., Tuskan, G.A., Despain, D.G., Renkin, R.A., 1997. A rare episode of sexual reproduction in aspen (*Populus tremuloides* Michx.) following the 1988 Yellowstone fires. Nat. Areas J. 17, 17–25.

Rudis, V.A., 1998. Regional forest resource assessment in an ecological framework: the southern United States. Nat. Areas J. 18, 319–332.

Schier, G.A., Jones, J.R., Winokur, R.P., 1985a. Vegetative regeneration. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 29–33.

Schier, G.A., Shepperd, W.D., Jones, J.R., 1985b. Regeneration. In: DeByle, N.V., Winokur, R.P. (Eds.), Aspen: Ecology and Management in the Western United States. Gen. Tech. Rep. RM-119, USDA Forest Service, pp. 197–208.

Shinneman, D.J., Baker, W.L., 1997. Nonequilibrium dynamics between catastrophic disturbances and old-growth forests in ponderosa pine landscapes of the Black Hills. Conserv. Biol. 11 (6), 1276–1288.

Stolte, K., 1997. 1996 National Technical Report on Forest Health. FS-605, USDA Forest Service, p. 47.

Suzuki, K., Suzuki, H., Binkley, D., Stohlgren, T., 1999. Aspen regeneration in the Colorado Front Range: differences at local and landscape scales. Landscape Ecol. 14, 231–237.

Sweigert, S., 1998. Dying of the Light?: The decline of aspen in Utah. Catalyst, Salt Lake City, Utah, 17(10), 13–14.

Tausch, R.J., 1996. Past changes, present and future impacts, and the assessment of community or ecosystem condition. In: Proceedings of the Shrubland Ecosystem Dynamics in a Changing Environment, Las Cruces, NM, 23–25 May 1995.

Gen. Tech. Rep. GTR-338, USDA Forest Service, pp. 97–101.
USDA Forest Service, 1999. Forest Health Monitoring 1998 Field Methods Guide. USDA Forest Service, National Forest Health Monitoring Program, Research Triangle Park, NC, p. 340.
Vale, T.R., 1988. Clearcut logging, vegetation dynamics, and human wisdom. Geogr. Rev. 78 (4), 375–386.
Vale, T.R., 1998. The myth of the humanized landscape: an example from Yosemite National Park. Nat. Areas J. 18, 231–236.
Veblen, T.T., Hadley, K.S., Nel, E.M., Kitzberger, T., Reid, M., Villalba, R., 1994. Disturbance regime and disturbance interactions in a Rocky Mountain subalpine forest. J. Ecol. 82, 125–135.
Walters, J.W., Hinds, T.E., Johnson, D.W., Beatty, J., 1982. Effects of partial cutting on diseases, mortality, and regeneration of Rocky Mountain aspen stands. Research Paper RM-240, USDA Forest Service, p. 12.
Welsh, S.L., Atwood, N.D., Higgins, L.C., Goodrich, S., 1987. A Utah Flora. Brigham Young University, Great Basin Naturalist Memoirs, Vol. 9, p. 894.
Zimmerer, K.S., 1994. Human geography and the ''new ecology'' the prospect and promise of integration. Ann. Assoc. Am. Geogr. 84 (1), 108–125.