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Effects of Timber Harvest on *Cimicifuga elata,* a Rare Plant of Western Forests

Abstract

Cimicifuga elata (tall bugbane) is a Species of Concern with the U.S. Fish and Wildlife Service and it is considered by Natural Heritage programs in Oregon and Washington to be endangered. Since the species occurs in forests, its conservation could conflict with other forest uses such as timber harvest. It has been postulated that the species is dependent on old-growth coniferous forests. The objectives of this study were to compare populations of this species among sites with differing forest-management histories. In contrast to previous reports, we found that *C. elata* in uncut old-growth forest was smaller and less reproductive than in clearcuts, probably because plants responded well to additional light in cut-over areas. Plants in areas with other management histories, such as second growth and thinned stands (both >70 years old), were intermediate in size. Population structure also differed among management types. Herbivory by deer and elk was more frequent in clear cuts and edges than in unmanaged old-growth forests. No populations were known at the time of this study from second growth forests of moderate age (20-30 years), and it is possible that competing vegetation excludes *C. elata* from clearcuts after a few years. Management actions that retain hardwoods, thin stands, or create gaps may improve at least short-term conditions for this species.

Introduction

Timber harvest is a widespread disturbance of forest ecosystems in western Oregon and Washington. According to most estimates, less than 20% of old-growth forest present in the 1880's remains, and these forests are now highly fragmented (Spies and Franklin 1988, Norse 1990). Environmental conditions on the forest floor change substantially when forests are clearcut. Compared to old-growth Douglas-fir forests, for example, clearcuts have lower humidity and higher soil and air temperatures, short-wave radiation, and wind speed (Chen et al. 1993, 1995). In addition, some forest harvest practices can cause soil compaction and erosion (Worrell and Hampson 1997), and change nutrient balances (Knoepp and Swank 1997). Not surprisingly, because of extreme changes in physical and site conditions, removal of overstory trees may reduce understory diversity and negatively affect the abundance of some common forest herbs (Halpern and Spies 1995).

Rare plants frequently have narrow geographic ranges, small population sizes, and/or restricted habitat requirements (Rabinowitz 1981, Rabinowitz et al. 1986), characteristics that may inhibit their recovery from disturbance. In a recent study of a highly disturbed landscape, for example, Fischer and Stocklin (1997) showed that local extinction was most likely for plants with small populations or high habitat specificity. Populations of rare species in ancient forests may be threatened by logging practices that damage established plants and alter habitat conditions. An estimated 38% of rare vascular plants in Oregon are thought to be threatened by logging and associated activities (Kaye et al. 1997), but few studies have quantified the effects of timber harvest on populations of these species.

Cimicifuga elata (tall bugbane) is a plant of forested habitats west of the Cascades in Oregon, Washington, and British Columbia. It is considered endangered by both the Washington (1997) and Oregon (1998) Natural Heritage programs, and it is a U.S. Fish and Wildlife Service Species of Concern (formerly a C2 candidate for listing as threatened or endangered). The presence of the species in federally managed forests, especially in proposed timber sales, creates the potential for population loss due to logging effects (USDA 1994, 1996). Information on how this species responds to forest harvest is, therefore, crucial for its long-term conservation. Previous reports suggested that populations of *C. elata* in or near clearcuts may have reduced vigor compared to those in unmanaged forests (Alverson

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1986), and the same concern has been expressed for *C. laciniata* (cut-leaved bugbane), a related species of northwestern Oregon forests (Siddall and Brown, 1990). The goals of this study were to document differences in *C. elata* plant size and fecundity, population structure, and herbivory in populations with varied histories of timber harvest throughout the geographic range of the species.

Study Species

Cimicifuga elata is an herbaceous perennial in the Ranunculaceae (buttercup family). It produces sprays of white, apetalous flowers and has a self-compatible, facultatively geitonogamous mating system (Pellmyr 1986a, Evans 1993). The genus as a whole includes 15 species world wide (Mabberley 1993) and has been the focus of research on pollination ecology (Pellmyr 1985, 1986a, Evans 1993), evolution and systematics (Pellmyr 1986b, 1986c, 1987; Ramsey 1965, 1986, 1987; Groth et al. 1987, Compton 1998), seed germination (Baskin and Baskin 1985), and pharmacology (e.g., Shibata et al. 1975, 1977, 1980). Over the majority of its range, *C. elata* occurs on moist north-facing slopes in mixed conifer/hardwood forests, with a canopy dominated by *Pseudotsuga menziesii* (Douglas-fir) and *Acer macrophyllum* (big-leaf maple) (Kaye and Kirkland 1994).

Populations of *Cimicifuga elata* are generally small; more than half have fewer than twenty-five individuals (Kaye and Kirkland 1994). In the United States, the species occurs from northern Washington to southern Oregon, entirely west of the Cascade Range (Figure 1). In Oregon, it is found on federal lands of the Mt. Hood, Willamette, and Umpqua National Forests; the Salem, Eugene, Roseburg, and Medford Districts of the Bureau of Land Management; and Army Corps of Engineers properties associated with dams and reservoirs in the Cascade Range. In addition, a few populations are known from state forests, state and county road rights-of-way and parks, and private lands (Kaye and Kirkland 1994).

Methods

To evaluate the effects of forest management on *Cimicifuga elata*, we conducted an observational study of populations with various land-use histories from northern Washington (Olympic Peninsula) to southern Oregon, and concentrated in

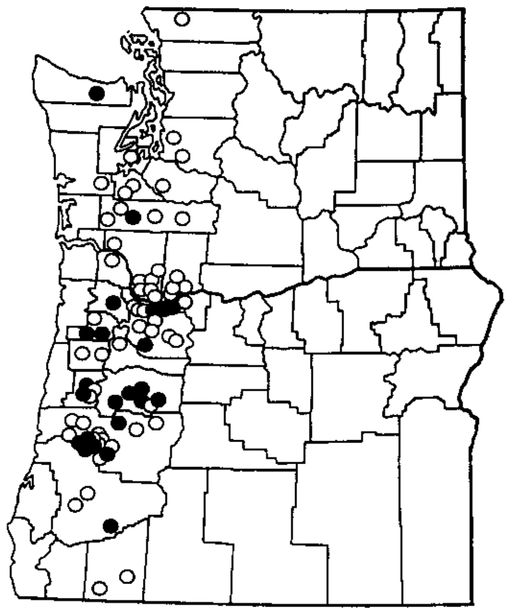


Figure 1. Distribution of *Cimicifuga elata* in Oregon and Washington. Solid dots indicate populations included in this study. Some overlapping dots were omitted to improve clarity.

western Oregon between the Columbia Gorge and Lane County (Figure 1). Information detailing the location of known sites was obtained from the Oregon and Washington Natural Heritage Programs and federal agencies. Populations included in this study ranged in size from 3 to 103 individuals, and averaged 35 plants. Thirty-seven populations were visited in 1992 and 24 of these were revisited in 1993. The land-use histories of these populations fell into six management categories. Ranked from least to most disturbed, these categories were: unmanaged (often old-growth), selectively thinned (more than 70 years ago), second growth (greater than 70 years old), edge between recent clearcut and unmanaged forest (within 15-m either side of edge), recent clearcut (less than five years old), and roadside. Of the 37 study sites visited in 1992 (and 24 resampled in 1993), 15 (8) were undisturbed, 5 (4) thinned, 3 (3) second growth, 4 (4) edges, 4 (3) clearcut, and 6 (2) roadside. Field work took place between late June and early August of both years.

At each site, individual *Cimicifuga elata* plants were evaluated for height, number of flowering racemes, and area of the largest (usually lowest) leaf. The tripartite leaves of *C. elata* are roughly triangular, so leaf area was estimated from measurements of leaf length and width, and calculated as length × width × 1/2. We measured all individuals at most populations. In six cases, however, a large sample of individuals (a census of the largest subpopulation) was measured because the populations were so large or scattered that all portions were difficult to reach. Evidence of herbivory by deer or elk was also recorded at 27 and 16 of the sites in 1992 and 1993, respectively. Herbivory was attributed to deer and/or elk based on observations of bite style; cropped stems were broken or torn, which results from the lack of upper incisors in these ungulates (Anderson 1969, Dolbeer et al. 1994). Domestic livestock, which may also leave this type of evidence, were not present at these sites.

We used one-way Analysis of Variance (ANOVA; STSC, Inc. 1991) to test the null hypothesis that management history had no effect on plant height, number of racemes, and frequency of herbivory in 1992 and 1993. Only reproductive plants were considered in tests with the first two response variables to minimize the effects of population structure (which were tested separately, see below), and, in the case of raceme number, improve the fit of our data to a normal distribution. If all plants were included, populations with high proportions of small, newly recruited plants might not be distinguished from those with a high proportion of mature plants with low vigor. Consideration of reproductive plants only reduced sample sizes for some treatments because reproductive plants were absent from some populations. Data for frequency of herbivory were log transformed (after addition of 0.5 to all values) to meet the assumptions of normality and equal variances required by ANOVA. Fisher's Protected LSD was used to compare means (STSC, Inc. 1991) because it is relatively robust to unequal sample sizes.

Finally, we assigned each individual to one of three life-history categories to investigate the effects of timber harvest on population structure. Plants were considered reproductive if they flowered (produced one or more racemes). Non-reproductive plants with area of the lowest leaf >611 cm^2, which was one standard deviation below the 1992 pooled mean for reproductive plants ($\bar{x}$=1311 cm^2, S.D.=700 cm^2, n=380), were arbitrarily classified as medium-sized. Small plants were defined as non-reproductive plants with a leaf area ≤611 cm^2. The importance of identifying medium-sized plants is that they may represent suppressed individuals that are big enough to reproduce but lack sufficient resources, such as light, to flower.

We tested the null hypothesis that the abundance of plants in each stage was independent of management history in 1992 and 1993 using a generalized linear model procedure in SAS (proc genmod; SAS Institute, Inc. 1990). In this analysis, the log of the mean was linearly related to the treatments and variance was Poisson distributed. This loglinear model is appropriate for count data of individuals in different categories (Steel, Torrie, and Dickey, 1997), such as size classes and treatments. A scale parameter was included in the model to allow for greater variation than expected (over-dispersion) from a Poisson distribution, and total population size was included as an offset term to remove effects of population size. To illustrate population structure, we calculated the relative frequency of each life-history stage within each population and estimated the mean and standard error for each treatment. Analyses performed for each response variable are summarized in Table 1, along with the sample size for each management history category in each test and year.

Results

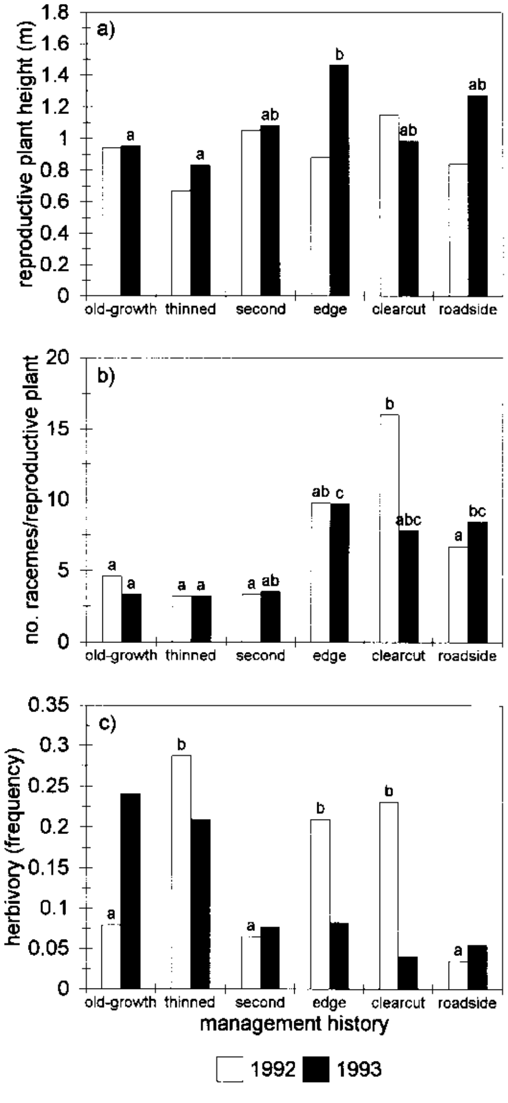
Plant Size and Reproduction

Average reproductive plant size and inflorescence production differed significantly among forest management types, but some of these effects were significant in only one year. Mean height of reproductive plants, for example, differed among forest management types in 1993 ($F_{5,14}$=4.027, P=0.018), but not in 1992 ($F_{5,23}$=1.706, P=0.173). In 1993, plants along clearcut-forest edges were significantly taller (by about 60%) than those in unmanaged forests or selectively thinned stands, while plants in other management types had intermediate heights (Figure 2a).

Management history had a significant effect on average number of racemes per reproductive plant in 1992 ($F_{5,23}$=2.563, P=0.050) and 1993 ($F_{5,14}$=3.698, P=0.024). In 1992, mean inflorescence production was greater in clearcuts ($\bar{x}$=16 racemes per reproductive plant) than in unmanaged forests, selectively thinned stands, second growth, or roadsides (mean range: 3.2-6.7). Raceme pro-

TABLE 1. Dependent variables, analyses and sample sizes for each management history category (independent variables) in 1992 and 1993.

Dependent variable	Reproductive plant height	Racemes/repro. plant	frequency of herbivory	population structure
Analysis:	one-way ANOVA	one-way ANOVA	one-way ANOVA	loglinear analysis
		Sample sizes (1992/93)		
old-growth	11/7	11/7	11/3	15/8
selectively thinned	4/4	4/4	4/3	5/4
second growth	2/2	2/2	3/2	3/3
edge	3/3	3/3	4/3	4/4
recent clearcut	3/2	3/2	3/3	4/3
Roadside	6/2	6/2	4/2	6/2
N	29/20	29/20	27/16	37/24



← Figure 2. Mean reproductive plant height (a), number of racemes (b), and frequency of herbivory (c) in six categories of forest management history in 1992 and 1993. See text for explanation of categories. Means with the same letter in the same year did not differ at the 0.05 level of probability (Fisher's protected LSD); letters are not shown for years where ANOVA did not detect a treatment effect. Herbivory data were log-transformed prior to analysis. See Table 1 for sample sizes.

duction was significantly higher along edges ($\bar{x}$=9.7 racemes) than in unmanaged or thinned forests ($\bar{x}$=3.3 and 3.2 respectively) in 1993 (Figure 2b).

Herbivory

The frequency of herbivory also differed significantly among management histories, but only in 1992 (1992: $F_{5,23}$=7.749, P=0.0003; 1993: $F_{5,10}$=1.039, P=0.446). Herbivory in unmanaged forests, second growth and along roadsides (mean range: 3.4-7.9%) was substantially less than in selectively thinned stands, edges, and clearcuts (mean range: 21-29%, Figure 2c).

Population Structure

Population structure differed among the six forest management types, especially in 1993. Treatment effects in the loglinear models have F=0 and P=1 because total population size was held constant as an offset in the models, making the stage×treatment interaction the effect of interest in this case. Model terms for the interaction between stage and management history in the loglinear analyses (Table 2) were weak in 1992 (P=0.0883) and significant in 1993 (P=0.014).

TABLE 2. Effect of management history on the number of individuals in three life-history stages (small vegetative, medium vegetative, and large reproductive) examined by loglinear analysis with data from 1992 and 1993. Numerator and denominator degrees of freedom (NDF and DDF, respectively) are shown for each *F*-ratio.

Source	NDF	DDF	*F*	*P*
1992				
Stage	2	93	16.7088	0.0001
Treatment	5	93	-0.0000	1.0000
Stage*Treatment	10	93	1.7168	0.0883
1993				
Stage	2	54	35.0175	0.0001
Treatment	5	54	-0.0000	1.0000
Stage*Treatment	10	54	2.5316	0.0140

These interactions indicate that the relative number of individuals in each stage depended on management history in 1993 and nearly so in 1992.

In general, populations in all forest management types were dominated by small vegetative plants, except for populations along roadsides, which tended to have few small individuals and a relatively high frequency of reproductive plants (Figure 3). Populations in unmanaged forests and second growth generally had proportions of medium-sized vegetative plants approximately equal to or higher than reproductive plants. For example, the average fraction of medium-sized plants in these management types in 1992 ranged from 27% to 40%, while reproductive plants averaged only 19% to 26% in the same habitats and year. In contrast, reproductive plants tended to outnum-

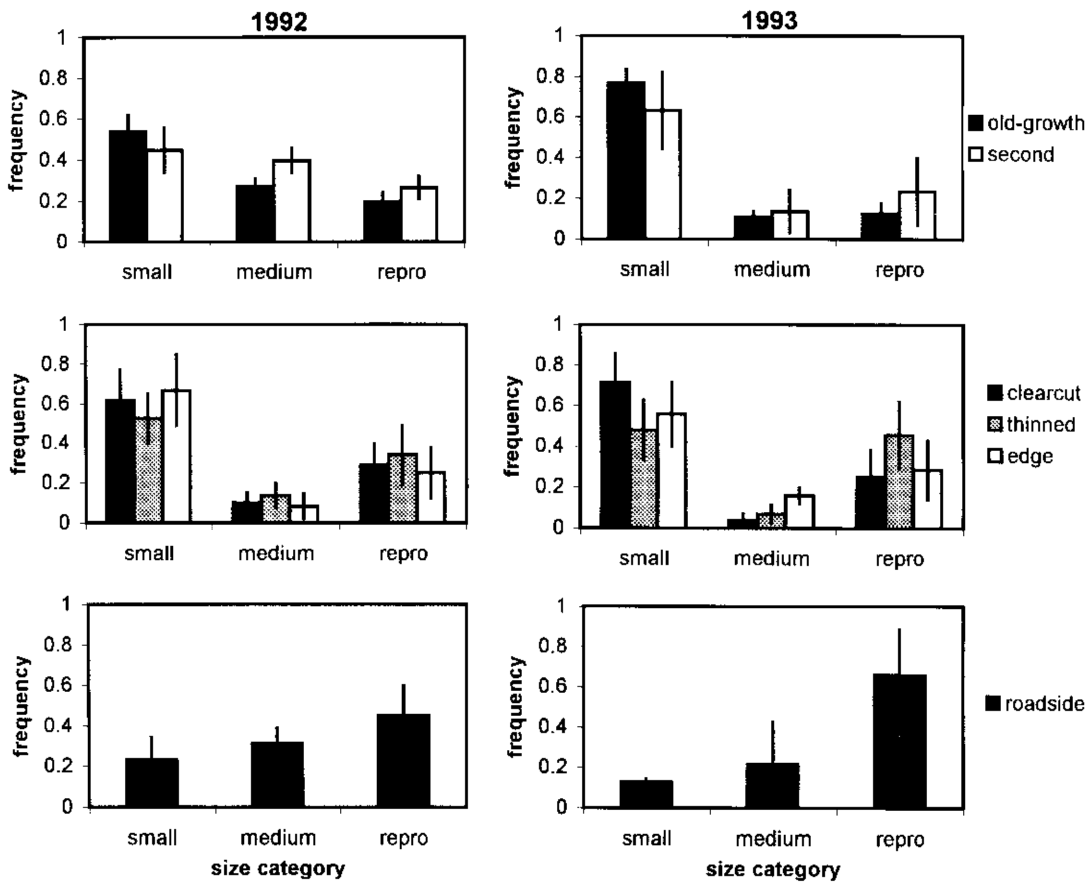


Figure 3. Relative frequency (±1 SE) of life-history stages within each management treatment in 1992 and 1993. Treatments are grouped by types that follow similar patterns. See Table 1 for sample sizes.

ber medium vegetative plants in selectively thinned stands, edges, and clearcuts. Populations in clearcuts, for instance, averaged 29% reproductive plants in 1992 and 24% in 1993, while medium-sized plants made up only 10% and 4%, respectively, of the same populations. On average, roadside populations were dominated by reproductive plants ($\bar{x}$=45% and 66%), with respectively lesser amounts of medium ($\bar{x}$=31% and 21%) and small vegetative individuals ($\bar{x}$=23% and 13%).

Discussion

This study detected differences among various habitat-management histories at the level of individuals and populations. *Cimicifuga elata* plants in unmanaged, old-growth forests and mature second growth stands tended to be smaller with fewer racemes than those in some types of disturbed forests, but these differences varied with year of observation. For example, reproductive plants in unmanaged areas were shorter (in 1993) than those along old-growth-clearcut edges, and they had fewer inflorescences than plants in clearcuts (1992) or along edges and roadsides (1993). Population structure also differed among forest management types, especially in 1993. The added light (and possibly heat) reaching plants in thinned stands, edges, and especially clearcuts may have been responsible for their greater size and fecundity, but additional study will be required to test this hypothesis and determine the importance of other resources, such as nutrients and water, as factors controlling the response of this species.

Ecological Implications

These results are inconsistent with the view that *Cimicifuga elata* is old-growth dependent. Instead, the species appears representative of what Collins et al. (1985) termed "light-flexible herbs," which tolerate full sun and shade, but are restricted to neither. Such species respond to canopy disturbances and gaps with increased flowering, seed production, seedling recruitment, and survivorship (Collins et al. 1985, p. 233), largely due to increased light availability. In several respects, *C. elata* is typical of shade-tolerant herbs of temperate deciduous-forests. It is self-compatible and frequently pollinator limited (Pellmyr 1986a), reproduces mainly by seed, lacks specialized seed dispersal appendages (such as pappus or barbs), requires cold stratification for seed germination (Kaye, unpub. data), and generally occurs in populations dominated by small plants, all traits typical of shade-tolerant herbs of eastern North American deciduous forests (Bierzychudek 1982). Seeds of shade-tolerant species are generally heavier than light-demanding herbs (Salisbury 1942), and the seeds of *C. elata* are relatively heavy. The mean dry weight of *C. elata* seeds is 1.9±0.28 mg (Kaye, unpub. data), which is typical of shade tolerant herbs (Bierzychudek 1982) and other species of *Cimicifuga*, such as *C. racemosa* (Abrahamson 1979). These characteristics, combined with our observations of increased size and fecundity in artificial gaps, such as clearcuts, supports the classification of *C. elata* as light-flexible rather than shade restricted (Collins et al. 1985).

Hardwood tree species in western forests of Oregon and Washington are often invaders of moist gaps in coniferous forests (Franklin and Dryness, 1973) because they require the additional light and release from competition available in these sites. The near-constant association of *Cimicifuga elata* with deciduous trees (Kaye and Kirkland, 1994) suggests that it, too, may invade and persist in hardwood-dominated gaps. Hardwoods allow substantial light penetration through the canopy to the forest floor in early spring, prior to leaf expansion (Boyd and Matt 1977), possibly enabling *Cimicifuga* plants to grow rapidly early in the season while moisture is plentiful. If this hypothesis is correct, it may represent a strategy selected in ancestors of *C. elata* from eastern North America. *Cimicifuga* species of that region (including *C. rubifolia*, the closest relative of *C. elata* [Compton et al. 1998]) currently occur in deciduous forests. The fact that medium-sized vegetative plants outnumbered reproductives in uncut stands (at least in 1992, Figure 3) while the reverse was true in disturbed forests may indicate that vegetative plants, though suppressed under a closed canopy, can become reproductive when the canopy is removed and additional light is available. We suspect events that create forest gaps or park-like forest stands allow *C. elata* to regenerate and colonize new sites, and the presence of hardwood trees permits populations to persist.

Implications for Conservation and Management

The habitat-related differences in plant size, fecundity, and population structure observed in this study varied among sample years, but in no cases were plants in harvested forests smaller or less fecund than in unmanaged habitat. Rather, it appears that timber harvest in or immediately adjacent to existing *Cimicifuga elata* populations has little negative effect on plant size and fecundity, at least in the short term, and could result in population growth. Halpern and Spies (1995) showed that some forest herbs became locally extinct after forest harvest, but others persisted and increased in abundance. Even though *C. elata* occurs in small populations in a specific habitat, characteristics that may make species vulnerable to extinction after disturbance (Fischer and Stocklin 1997), it appears to respond favorably to removal of the forest canopy.

This conclusion is offered with the caveat that no information is available on the long-term viability of populations in managed forests. We could not locate any populations in second growth or plantations of moderate age (20-30 years). It may be that inventories for the species have been inadequate in this age-class (Kaye and Kirkland 1994) or competition for light and other resources excludes the species from habitats with dense tree growth. The short-term effect of timber harvest on *Cimicifuga elata* appears to be positive, but population viability in the long-term, after conifers regrow to shade the forest floor and compete for resources, could be low. In addition, clearcuts pose risks associated with disturbing the forest floor and upper soil horizons that may be harmful to some *C. elata* populations, especially on steep slopes. Therefore, clearcuts may not be the most effective means to improve conditions for the species. Habitat management techniques that retain hardwoods and lead to canopy thinning and small gaps with minimal disturbance of the forest floor may be optimal. Long-term maintenance of *Cimicifuga elata* may require that managers allow natural gap-forming processes to occur or manipulate stands to produce forest gaps that can be invaded by hardwoods. These conclusions concur with recommendations from studies of epiphytic lichens (Neitlich and McCune 1997) and forest floor bryophytes (Rambo and Muir 1998) that suggest hardwoods and small gaps promote species diversity in Northwest forests.

The positive effects of canopy disturbance on plant size may be partially off-set by increases in herbivory by deer and elk. In 1992, for example, the mean frequency of herbivory on *C. elata* in clearcuts, edges, and selectively thinned stands was two to three times greater than in unmanaged forests, second growth, and roadsides. This pattern of herbivory, in which forest openings and edges are preferred for feeding, is consistent with previous studies of the forage behavior of deer (Alverson et al. 1988, Chang et al. 1995) and elk (Schroer et al. 1993). Existing data are insufficient to measure the effect of herbivory on individual *C. elata* plant growth, so solid conclusions regarding the effect of deer and elk must await further study.

Plants on roadsides tended to be larger and more fecund than plants in old-growth forest, but roadside populations tended to have few small plants. This suggests that roadside maintenance activities, such as mowing and spraying, restrict juvenile recruitment, possibly by reducing seed production and lowering survival of small plants. Such populations might be at risk of extirpation if large plants are killed. Delaying maintenance activities until after fruit maturation (usually September) could increase seed dispersal and seedling recruitment and give these populations a more diverse structure.

Rangewide conservation of *Cimicifuga elata* populations will require a coordinated effort by various land managing agencies to maintain appropriate habitat. A Conservation Agreement between several federal agencies for this species identifies populations deemed essential for the long-term viability of the species on public lands, mandates monitoring of several populations, and prescribes conservation measures such as burning and forest density management at selected locations (USDA 1996).

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