RESEARCH ARTICLE

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Effects of Forest Management Practices on the Federally Endangered Running Buffalo Clover (*Trifolium stoloniferum* Muhl. ex. A. Eaton)

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ABSTRACT: Running buffalo clover (*Trifolium stoloniferum* Muhl. ex. A. Eaton), a federally endangered plant species, often occurs in habitats affected by periodic disturbance such as mowing or grazing. At the Fernow Experimental Forest in West Virginia, USA, it is most often associated with skid roads where uneven-aged silvicultural techniques are being tested. We monitored running buffalo clover population trends for seven years in two research compartments before and after scheduled silvicultural operations. Stem density (stems/m^2) was declining in both compartments prior to planned silvicultural operations, and ground-based skidding caused a further reduction in the number of running buffalo clover locations and stems. Running buffalo clover began to increase in density two years after the logging. Running buffalo clover excluded from ground disturbance increased in the second growing season following tree removal, but had declined by the third season. Running buffalo clover subjected to ground disturbance continued to increase in density during the third growing season. Canopy gaps, leaf area index, associated plants, and abiotic factors were compared between 35 sites supporting running buffalo clover and an equal number of randomly chosen sites in a third research compartment that had not been disturbed by silvicultural operations for 15 years. Running buffalo clover sites had greater gap areas and lower leaf area indexes than average for the whole compartment. Several herbaceous species, including *Panicum* L. spp., *Eupatorium rugosum* Houttuyn, and *Amphicarpaea bracteata* (L.) Fern., were found more frequently at sites supporting running buffalo clover than would be predicted by chance. Preliminary results indicate that controlling the intensity of surface disturbance, combined with the reduction in canopy density associated with uneven-aged silviculture, will help sustain populations of running buffalo clover in managed forests.

Efectos de las Prácticas de Manejo de Bosque en *Trifolium stoloniferum* Muhl. ex. A. Eaton

RESUMEN: *Trifolium stoloniferum* Muhl. ex. A. Eaton, una planta amenazada, a menudo ocurre en hábitats afectados por disturbios periódicos, tales como corte o pastoreo. En el Bosque Experimental Fernow en Virginia del Oeste, USA, está generalmente asociado con caminos temporarios, en lugares donde se testean técnicas silviculturales de diferentes edades. Monitoreamos tendencias poblacionales de *T. stoloniferum* Muhl. ex. A. Eaton, durante siete años en dos compartimentos antes y después de operaciones de silvicultura programadas. La densidad de tallos (tallos/m^2) declinó en ambos compartimentos previo a las operaciones de silvicultura, y la extracción de la madera por tierra causó una disminución mayor tanto en el número de tallos como de lugares. *T. stoloniferum* Muhl. ex. A. Eaton, empezó a aumentar en densidad dos años después de la tala. Las plantas que se mantuvieron sin disturbios aumentaron en la segunda temporada de crecimiento después de la remoción de los árboles, pero disminuyeron en la tercer temporada. Plantas de *T. stoloniferum* Muhl. ex. A. Eaton, sujetas a disturbios en la tierra continuaron aumentando en densidad durante la tercer temporada. Los gaps en el dosel, el índice de área foliar, las plantas asociadas, y factores abióticos fueron comparados entre 35 sitios donde había *T. stoloniferum* Muhl. ex. A. Eaton, y un número igual de sitios seleccionados al azar en un tercer compartimento de investigación que no había sido perturbado por actividades de silvicultura durante 15 años. En los sitios en que se encontró *T. stoloniferum* Muhl. ex. A. Eaton, se encontró una mayor área de gaps y menor índice de área foliar que el promedio para todo el compartimento. Muchas especies herbáceas, incluyendo *Panicum* L. spp., *Eupatorium rugosum* Houttuyn, y *Amphicarpaea bracteata* (L.) Fern., fueron encontradas más frecuentemente en los sitios que contenían *T. stoloniferum* Muhl. ex. A. Eaton que lo que se hubiese esperado por azar. Los resultados preliminares indican que controlando la intensidad de disturbio del suelo, combinado con la reducción de densidad del dosel, asociado con silvicultura de diferentes edades, ayudaría a mantener poblaciones de *T. stoloniferum* Muhl. ex. A. Eaton en los bosques sometidos a manejo.

Index terms: endangered species, leaf area index, running buffalo clover, *Trifolium stoloniferum*, uneven-aged silviculture

INTRODUCTION

In a review of the status of running buffalo clover (*Trifolium stoloniferum* Muhl. ex. A. Eaton) (RBC), Brooks (1983) considered the species to be possibly extinct, noting that it had only been collected five times since 1900, and that no extant populations were known. Bartgis (1985) rediscovered RBC in West Virginia, USA—two individuals at one location in 1983, and two more at a second location in 1984. He referred to the species as "one of the rarest members of North American flora" that "appears to be close to extinction." Additional searches led to the rediscovery

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of the species in Kentucky (Campbell et al. 1988), Ohio (Cusick 1989), Indiana (Homoya et al. 1989), and Missouri (Rowan 1994). The historical range also included Arkansas (Harmon et al. 1990), Illinois (Hickey et al. 1991), Kansas (Harmon et al. 1990, Hickey et al. 1991), and possibly Pennsylvania and New York (Brooks 1983). This species was listed as federally endangered in 1987 (Jacobs 1987).

Heightened awareness of RBC brought about by its federal status has resulted in increased efforts to locate additional occurrences. In 1989, the RBC Recovery Plan acknowledged only 13 element occurrences (EOs) (Bartgis 1989). As of March 1993, about 72 EOs had been located. Additional large populations have been found since then, bringing the total number of known RBC occurrences to 104 (Harmon 1996). The increase in the number of known RBC sites is encouraging, but the biological and environmental factors that significantly influence long-term population dynamics of this species—a key component to recovery and sustainability—are still unknown.

Running buffalo clover is most often found in mesic woodlands where there is a pattern of moderate periodic disturbance for a prolonged period. Disturbed habitats where RBC has been found include floodplains, stream banks, grazed woodlots, mowed paths and wildlife openings, old logging roads, and skidder trails used in logging operations (Harmon 1996). Some have speculated that RBC habitat and dispersal may have once been associated with eastern bison (*Bison bison* L.) activity and seasonal movements (Bartgis 1985, Campbell et al. 1988).

We undertook this study after discovering RBC on the Fernow Experimental Forest (hereafter, Fernow E.F.), West Virginia, in 1993. RBC presence on Fernow E.F. was observed to be in conjunction with soils derived from limestone parent material in areas used for long-term silvicultural studies evaluating uneven-aged forest management. In addition, we found the vast majority of all RBC occurrences on or immediately adjacent (< 1 m) to skid roads within these research areas. Skid roads in these compartments are not surfaced and are only used about once per decade for one to several weeks to skid logs to forest access roads. Consequently, our primary hypothesis was that disturbances associated with uneven-aged forest management practices, specifically within the skidder road environment, were beneficial to sustaining local populations of RBC. In this paper, we describe population dynamics prior to and following logging operations. We also evaluate canopy characteristics, associated vegetation, and abiotic environmental factors in an area that supports abundant RBC occurrences, but which has been relatively undisturbed for 15 years.

METHODS

Study Site

Fernow Experimental Forest (N 39.03°, W 79.67°) is located in north-central West Virginia, in the Allegheny Mountains Section of the Central Appalachian Broadleaf Forest (McNab and Avers 1994). The land type association (LTA) containing Fernow E.F. has been designated as the Allegheny Front Sideslopes LTA (DeMeo et al. 1995), and the vegetation is classified as mixed mesophytic (Braun 1950). Characteristic overstory species include, but are not limited to, northern red oak (*Quercus rubra* L.), sugar maple (*Acer saccharum* Marsh.), yellow-poplar (*Liriodendron tulipifera* L.), and red maple (*A. rubrum* L.) (Schuler and Gillespie 2000). The topography is mountainous; elevations range from 534 to 1113 m above sea level. Mean annual precipitation is approximately 143 cm and is distributed evenly throughout the year (Pan et al. 1997). The growing season is approximately from May through October with an average frost-free period of 145 days. Soils on Fernow E.F. are primarily derived from acidic shales and sandstones, but there is a narrow exposure of limestone outcrops as well. Soils are classified as the Calvin (Typic Dystrochrepts) and Belmont (Typic Normudalfs) series, with only the Belmont soils exhibiting traits common to soils derived from limestone parent material (Losche and Beveridge 1967). RBC is currently known to occur in seven research compartments on Fernow E.F., all of which contain limestone outcrops (Figure 1).

The Elklick watershed (which later became Fernow E.F.) was initially logged between 1903 and 1911 during the railroad-logging era (Fansler 1962, Trimble 1977, Schuler and Fajvan 1999). During this period, some trees were left uncut due to insufficient size, poor form, or species undesirability (Schuler and Fajvan 1999). Since 1915, when the federal government purchased the land, fire has been excluded and grazing discontinued. Chestnut blight (*Cryphonectria parasitica* [Murr.] Barr) resulted in a 25% reduction in the volume of standing timber on Fernow E.F. during the 1930s (Weitzman 1949).

We report our findings from research compartments 8C-D, 9A-B, and 20A (Figure 1). Silvicultural treatments in compartment 8 represent a gradient of management intensity and include a commercial clearcut, diameter-limit harvesting, single-tree selection (8C-D), and an uncut area. In compartment 8, only the single-tree selection subcompartments (8C-D) currently have RBC occurrences. Both subcompartments, each 2 ha in size, were harvested at 10-year intervals following the growing seasons from 1948 to 1998. Subcompartment 8D was also harvested in 1963. Skidder trails in 8C-D also were used occasionally to remove timber from other nearby compartments, probably not exceeding one additional use per decade, although the frequency of such usage was not recorded. The silvicultural guidelines for 8C include (1) a Q factor of 1.3 (Q factors define the change in stem density across consecutive diameter classes and are often used in uneven-aged management to specify stand structure goals, e.g., each consecutively smaller 5-cm diameter class contains 1.3 times more stems than the preceding class for the range of 80 cm–30 cm dbh) (Smith et al. 1997), (2) a maximum dbh of 81.3 cm, and (3) a residual basal area following each harvest of 14.9 $m^2 ha^{-1}$ for trees greater than 27.9 cm dbh. Compartment 8D differs only slightly in that the residual basal area following each harvest was targeted at 19.5 $m^2 ha^{-1}$ for trees greater than 12.7 cm dbh.

Compartment 20A (10.2 ha) also has been

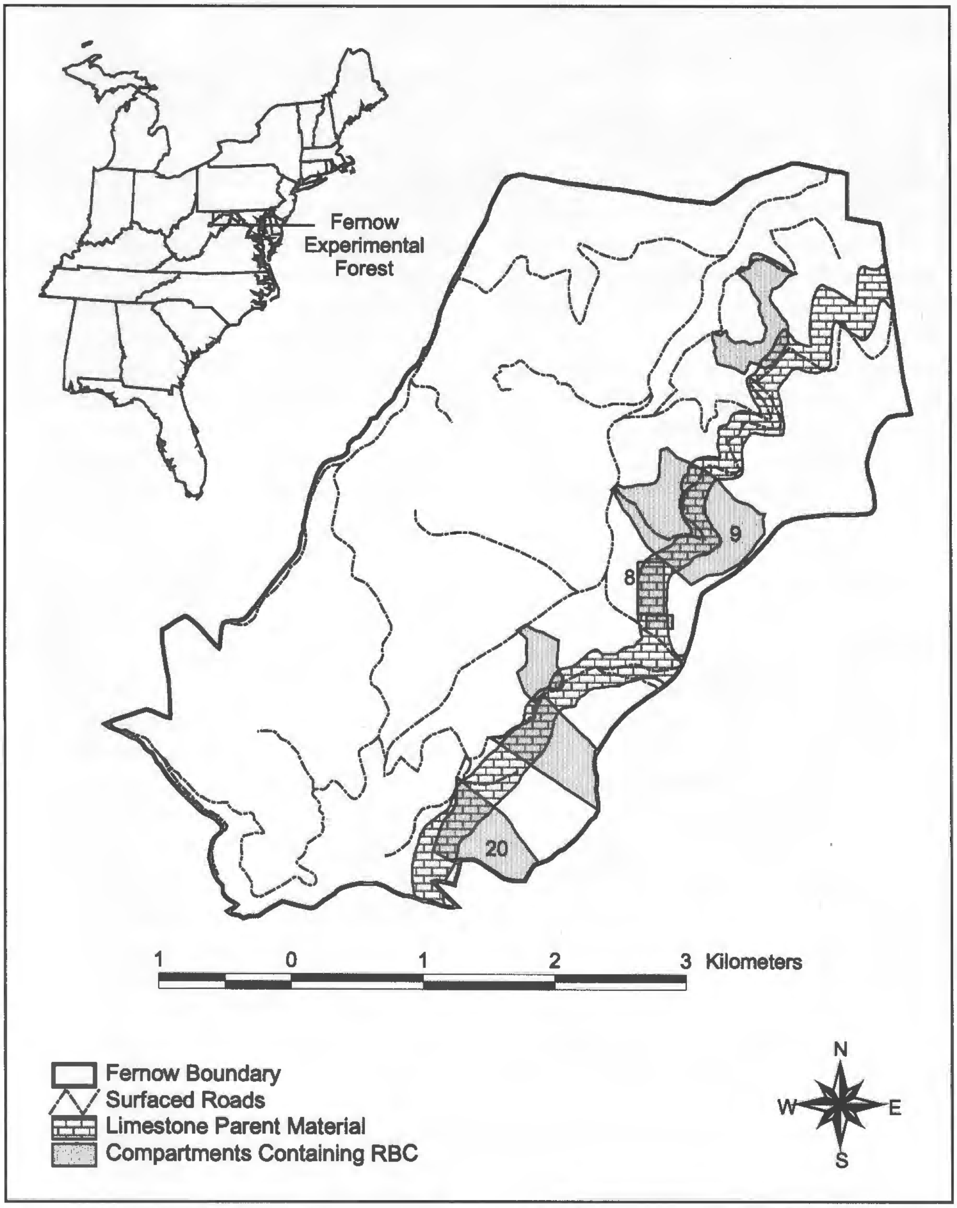

Figure 1. Location of Fernow Experimental Forest, in the Central Appalachian Mountains of West Virginia, and of research compartments where running buffalo clover has been found. In this study, we refer to running buffalo clover in compartments 8, 9, and 20, which have been managed with partial harvesting practices since about 1950.

managed using single-tree selection with essentially the same criteria as used for 8C. Harvests followed the growing seasons of 1951, 1967, 1972, 1977, 1987, and 1997.

Compartments 9A (21.6 ha) and 9B (32.7 ha) were silviculturally treated using a diameter-limit system that removed trees 43 cm and larger; harvests were conducted in 1955, 1970, and 1985. Following harvests, mean residual basal areas were 18.2 m^2 ha^{-1} in 9A and 15.8 m^2 ha^{-1} in 9B for trees with a dbh > 12.7 cm.

Data Collection

In 1994, we established permanent 1-m^2 circular plots for annual monitoring of RBC occurrences in compartments 8C-D and 20A. To ensure that the plot centers could be relocated following disturbance of the roadbed (1998 and 1997 in compartments 8 and 20, respectively), we placed steel-reinforcing rods (to identify plot centers) in protected areas outside the roadbed. Twenty-one plots were located in 8C-D and an equal number in 20A. Twelve of the RBC monitoring plots in 20A and eight in 8C-D were protected from ground disturbance caused by skidder traffic by rerouting of the skid roads around the RBC plots.

We have performed stem and flower counts annually since 1994. Monitoring is done using a circular copper pipe that encloses an area equal to 1 m^2. Three rods, bolted through the pipe, are centrally welded to a metal washer that fits over the reinforcing rods used to mark the plot centers. In this way, the plots were delineated into 1-m^2 areas and subdivided into three smaller units with convenient starting and stopping points for counting the stems and flowers. Rooted crowns, composed of multiple stems originating from one root bundle, have been included in the yearly count since 1998.

We began intensive monitoring in compartments 9A-B in 1998. Within this compartment, all RBC rooted crowns and flowers were counted. Pin flags were used to mark the locations of each rooted crown. Thirty-three locations with RBC were identified in 1998, and two additional locations were found in 1999. In 1999, 35 points within compartment 9A-B were randomly selected from a grid. We compared canopy characteristics in the random locations to those in the RBC plot locations using Li-Cor® LAI-2000 instruments. Light-detecting sensors were fitted with 90° restrictor caps, which are recommended by the manufacturer in situations where canopy gaps are likely to occur (we expected them on skid roads). Readings were taken in the morning and evening to reduce the incidence of reflected light, and care was taken so that the sun did not shine directly on the sensor. Because 90° restrictor caps were used, measurements were taken in each of the four cardinal compass directions to achieve complete directional coverage. Only one direction was metered during each outing, and the reference sensor, located in a nearby field, was pointed in the same direction. For each point, readings were taken at a height of 1 m (generally above surrounding herbaceous vegetation) and at 15 cm (approximating the height of RBC, which can receive some shade from tall herbs).

Annual monitoring at RBC locations in compartments 8, 20, and 9 also included visual estimates of ground cover by associated plants, as well as the height and identification of the tallest species ≤ 2.54 cm dbh within the plot, with identification and nomenclature following Gleason and Cronquist (1991). Percent cover of rock and coarse woody debris (≥ 10 cm basal diameter), were all estimated for each plot. All estimates were made to the nearest 5% by comparing coverage for each species or parameter with percent coverage charts (Munsell® Soil Color Charts, GretagMacbeth™, New Windsor, NY). Plant species individually comprising < 5% cover were grouped as "other-herbaceous" or "other-woody," and if the tallest species of the plot fell into one of these categories, a note identifying the species was recorded. Species > 2.54 cm dbh growing over the plot but originating from outside the plot were also noted.

Data Analysis

We initially evaluated population trends using repeated measures analysis of variance. However, sphericity tests indicated the covariance structure of the repeated measurements was such that the probabilities from the univariate F tests were not correct (Huynh and Feldt 1970). Rather than adjusting the associated degrees of freedom for the univariate F-tests (Greenhouse and Geisser 1959, Huynh and Feldt 1970), we changed our approach to multivariate repeated-measures analysis using SAS® software. The multivariate approach does not require sphericity and can test for within- and between-subject effects, and also an interaction term (Neter et al. 1990). In compartment 9, where we assessed canopy characteristics and understory vegetation, canopy comparisons were made between RBC and random points using independent *t*-tests ($P = 0.05$), and chi-square analysis ($P = 0.05$) was used to compare occurrence frequencies of associated vegetation (Zar 1999).

It should be stressed that the portion of this work that assesses logging impact refers to a particular set of plants, in a particular location, affected by a particular disturbance. Because we were not able to select a number of sites and randomly assign treatments to those locations, our results do not necessarily represent the usual effect over a large number of occurrences. This is one of the statistical challenges of environmental impact assessment as discussed by Hurlbert (1984) and Stewart-Oaten et al. (1986). In contrast, our canopy analysis did use randomly assigned locations and was well replicated. As such, these results are more generally applicable to other sites.

RESULTS

Population Trends

There were highly significant changes in RBC mean stem densities across time for both compartments ($F_{6,14} = 6.14$, $P = 0.0025_{[8C-D]}$ and $F_{6,14} = 12.48$, $P < 0.0001_{[20A]}$) (Figure 2). The maximum number of RBC stems in 8C-D was observed in 1995, seven years after the previous harvest. Mean stem density per plot declined each year after the peak,

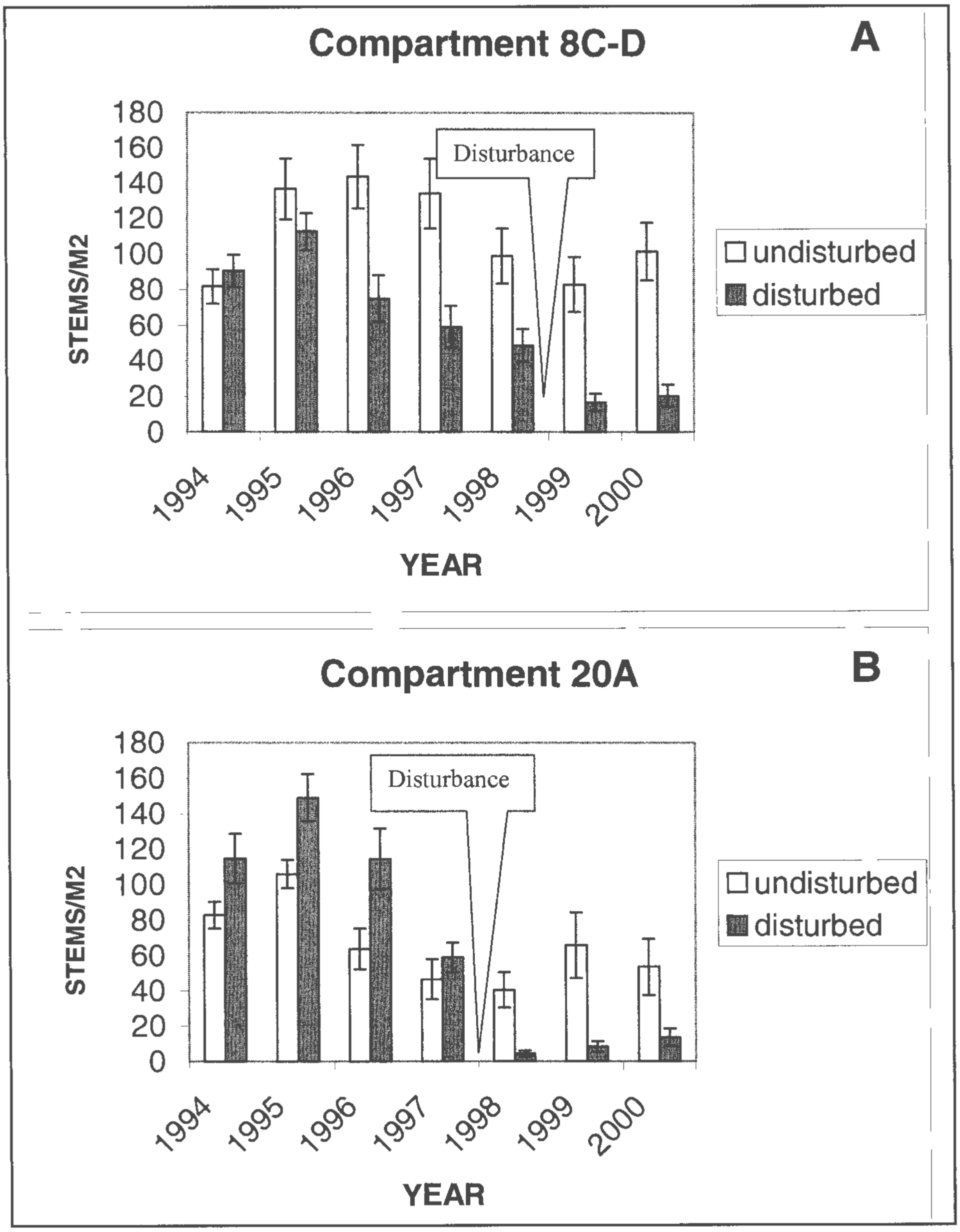

Figure 2. Mean number of RBC stems per plot (m^2) in compartments 8C-D and 20A of Fernow Experimental Forest, West Virginia. Each bar (± 1 SE) represents the mean stem density stratified according to planned disturbance level.

through 1999; however, in 2000 (two years after logging), the number of stems began to increase. In 8C-D there were highly significant linear ($F_{1,19} = 8.81$, $P = 0.0079$) and cubic ($F_{1,19} = 29.05$, $P < 0.0001$) changes in stems across time, indicating a curvilinear response (Figure 2A). There was also some evidence that the pattern of change across time differed for the two disturbance categories as supported by tests of significance for linear ($F_{1,19} = 3.65$, $P = 0.0712$) and cubic ($F_{1,19} = 4.27$, $P = 0.0526$) interaction terms with disturbance level. In 20A there were highly significant linear ($F_{1,19} = 12.25$, $P = 0.0024$), cubic ($F_{1,19} = 20.97$, $P = 0.0002$), and quartic ($F_{1,19} = 17.80$, $P = 0.0005$) changes in stems across time, indicative of both a maximum and minimum, as is suggested graphically (Figure 2B). There was strong evidence that the temporal change in RBC stem densities differed by disturbance category, as indicated by a highly significant cubic interaction term with disturbance level ($F_{1,19} = 8.30$, $P = 0.0096$). Mean stem density peaked in 1995 in 20A then declined through 1998. Similar to the trend in 8C-D, there was an increase in mean stem density in 1999, two years after logging activity. In 2000, the RBC occurrences subjected to skidder traffic continued to increase, whereas the RBC not affected by ground disturbance declined slightly.

Leaf Area and Canopy Characteristics

The RBC sites consistently exhibited lower leaf area index (LAI) and higher percentage of open sky than the randomly selected points within the same management unit (Tables 1 and 2). LAI differences between RBC and random points were most prominent to the south and west when the light measurements were stratified by cardinal direction (Table 1). The angle of light, as measured by the concentric light sensors, showed the most contrast between point types in the upper rings (rings 1–3, or light from an angle of 0°–38°) (Table 1). As expected, LAI was somewhat greater and percent open sky somewhat less when estimated from 15 cm than when estimated from 1 m due to shading by tall herbs; however, the overall differences were not significant ($t = -0.7631$, df = 68, $P = 0.4480_{[LAI]}$; $t = 0.4303$, df = 68, $P =$

Table 1. Leaf area index (LAI) is compared by direction and light angle from points supporting RBC and randomly selected points. Ring 1 measures light directly overhead (0–7°) while Ring 5 measures light closer to the horizon (54–68°). Measurements are averages of RBC points (n=35) and random points (n=35) in the same management unit (9A-B). Aspects of the sampled points range from northwest to southwest (* indicates difference significant at $P < 0.05$ and ** $P < 0.01$).

NORTH

	15 cm Height			1 m Height		
Ring #	RBC Mean	Random Mean	*P*	RBC Mean	Random Mean	*P*
1	7.3	8.2	0.0639	7.4	8.1	0.1248
2	6.9	7.6	0.1248	6.9	7.5	0.2400
3	6.4	7.2	0.0376*	6.3	7.0	0.1056
4	5.3	5.9	0.0451*	5.2	5.7	0.0935
5	3.6	4.0	0.1036	3.5	3.9	0.1022
All	4.9	5.4	0.0439*	4.8	5.3	0.0851

EAST

	15 cm Height			1 m Height		
Ring #	RBC Mean	Random Mean	*P*	RBC Mean	Random Mean	*P*
1	7.4	7.9	0.4581	7.3	7.7	0.3701
2	7.3	7.9	0.1849	7.0	7.6	0.2182
3	6.8	7.6	0.0446*	6.5	7.2	0.0895
4	6.2	6.5	0.3953	5.8	6.3	0.1286
5	3.9	3.9	0.7906	3.8	3.9	0.5064
All	5.3	5.6	0.2512	5.1	5.5	0.1419

SOUTH

	15 cm Height			1 m Height		
Ring #	RBC Mean	Random Mean	*P*	RBC Mean	Random Mean	*P*
1	6.2	7.4	0.0084**	6.3	7.3	0.0241*
2	5.7	7.5	0.0004**	5.6	7.5	0.0003**
3	6.1	7.1	0.0128*	5.9	7.0	0.0100*
4	5.6	5.9	0.3611	5.5	5.7	0.4462
5	3.9	4.0	0.4026	3.8	3.9	0.2901
All	4.9	5.3	0.0528	4.8	5.3	0.0510

WEST

	15 cm Height			1 m Height		
Ring #	RBC Mean	Random Mean	*P*	RBC Mean	Random Mean	*P*
1	7.3	8.3	0.0487*	7.3	8.0	0.1680
2	6.6	8.4	0.0002**	6.6	8.1	0.0010**
3	6.3	7.3	0.0087**	6.1	7.2	0.0030**
4	5.3	5.9	0.0191*	5.1	5.8	0.0084**
5	3.5	3.8	0.0293*	3.4	3.7	0.0237*
All	4.8	5.4	0.0016**	4.7	5.3	0.0017**

ALL DIRECTIONS

	15 cm Height			1 m Height		
Ring #	RBC Mean	Random Mean	*P*	RBC Mean	Random Mean	*P*
1	7.0	7.9	0.0180*	7.1	7.8	0.0472*
2	6.6	7.8	0.0001**	6.5	7.7	0.0005**
3	6.4	7.3	0.0005**	6.2	7.1	0.0014**
4	5.6	6.0	0.0282*	5.4	5.9	0.0204*
5	3.7	3.9	0.0633	3.6	3.8	0.0347*
All	5.0	5.5	0.0036**	4.8	5.3	0.0047**

Table 2. The gap area (% of open sky) is compared by direction from points supporting RBC and from randomly selected points. Measurements are averages of RBC points (n=35) and random points (n=35) in the same management unit (9A-B). Aspects of the sampled points range from northwest to southwest (* indicates difference significant at $P \leq 0.05$ and ** indicates $P \leq 0.01$).

	15 cm height			1 m height		
Cardinal Direction	**RBC Mean (%)**	**Random Mean (%)**	***P***	**RBC Mean (%)**	**Random Mean (%)**	***P***
North	3.7	1.9	0.2679	4.4	2.3	0.3342
East	3.0	1.4	0.1901	3.8	1.7	0.1871
South	4.0	1.8	0.0119*	4.5	1.9	0.0157*
West	3.0	1.4	0.0195*	3.2	1.5	0.0243*
All directions	3.4	1.6	0.0281*	4.0	1.9	0.0500*

$0.6683_{[GAP]}$). There were five random points that occurred on skid roads, and the average LAI at 1 m for these points was 5.43, which is even greater than the random point mean LAI (Table 1). The random points that fell on skid roads had an average 3.4% open sky at 1 m, which is less than the RBC percent open sky. These results point to light as a critical limiting factor for RBC viability in forested environments.

Associated Vegetation

The comparison of percent coverage of other plant species, rock, coarse woody debris (CWD), and open ground recorded at RBC points and random points appears in Table 3. Hog peanut (*Amphicarpaea bracteata* [L.] Fern.), white snakeroot (*Eupatorium rugosum* Houttuyn), and sedge (*Carex* L. spp.) were significantly more abundant at RBC points. Grasses, especially *Panicum* L. spp., were also noted as significant associates of RBC. Japanese stilt grass (*Microstegium vimineum* [Trin.] Camus), an invasive grass native to Asia, was identified at one plot in compartment 9 but represented less than 5% of the cover at that location and was not found elsewhere within the compartments used for this research. Ferns were not significantly different at RBC and random sites, but differences may have been obscured by an insufficient sample size to account for the variability encountered with this group of species. Species encountered were glade fern (*Athyrium pycnocarpon* [Sprengel] Tidestrom), Christmas fern (*Polystichum acrostichoides* [Michx.] Schott), broad fern (*Thelypteris hexagonoptera* [Michx.] Weatherby), and New York fern (*Thelypteris noveboracensis* [L.] Nieuwl.). Height of the tallest herbaceous layer plants was significantly greater at the RBC points (t = 3.345, df = 68, P = 0.0013). White snakeroot, grass, wood nettle (*Laportea canadensis* [L.] Wedd.), and blackberry (*Rubus* L. spp.) were most frequently the tallest taxa with a mean of 51.4 cm. The tallest herbaceous layer plants at the random points was commonly a woody species such as red maple, striped maple (*Acer pensylvanicum* L.), rhododendron (*Rhododendron maximum* L.), or greenbrier (*Smilax* L. sp.) with a mean of 33.3 cm. Other herbaceous plants that occurred at the random sites but not at the RBC sites included black cohosh (*Cimicifuga racemosa* [L.] Nutt.), honewort (*Cryptotaenia canadensis* [L.] DC), enchanter's nightshade (*Circaea* L. sp.), and bellwort (*Uvularia* L. sp.). The amount of CWD and cobble- to boulder-sized rock was significantly greater in random plots. The amount of ground not covered by rock, woody debris, or living vegetation also was greater in the random plots, but the difference was not significant (Table 3).

Woody species greater than 2.54 cm dbh that either were in the plot or extending over the plot were also noted if present, but the numbers of stems were not quantified. Accordingly, chi-square tests indicated bitternut hickory (*Carya cordiformis*

Table 3. Percent coverage of the most common vegetation (in at least one category) and physical characteristics at sample points with running buffalo clover (n = 35) and an equal number of randomly selected points in the same management unit (9A-B) (* indicates difference significant at $P \leq 0.05$ and ** indicates significant at $P \leq 0.01$).

Parameter	**RBC Point Mean (%)**	**Random Point Mean (%)**	***P***
asters (*Aster* L.sp.)	0.657	0.286	0.5650
blackberry (*Rubus* L. spp.)	0.286	0.857	0.3100
clearweed (*Pilea pumila* [L.] A. Gray)	0.571	0.714	0.8659
fern spp.	0.714	2.429	0.1651
grass spp.	7.37	0.57	0.000245**
hog-peanut (*Amphicarpaea bracteata* [L.] Fern.)	2.51	0	0.004**
sedges (*Carex* L. spp.)	3.74	0.29	0.0387*
violets (*Viola* L. spp.)	1.426	1.143	0.7338
white snakeroot (*Eupatorium rugosum* Houttuyn)	2.77	0.286	0.00122**
wood nettle (*Laportea canadensis* [L.] Wedd.)	7.657	6.429	0.6567
wood sorrel (*Oxalis* L. sp.)	0.143	0.286	0.6561
coarse woody debris	0.714	2.571	0.034*
rock	1.486	12.429	0.00902**
open ground	49.2	60.857	0.0604

[Wangenh.] K. Koch) and yellow-poplar were significantly more frequent at RBC plots ($\chi^2 = 4.5$, df = 1, $P = 0.03389_{[hic]}$ and $\chi^2 = 5.1$, df = 1, $P = 0.02364_{[pop]}$) whereas red maple, chestnut oak (*Quercus prinus* L.), and hemlock (*Tsuga canadensis* [L.] Carrière) were present less frequently ($\chi^2 = 7.0$, df = 1, $P = 0.0082_{[map]}$; $\chi^2 = 4.0$, df = 1, $P = 0.0455_{[oak]}$; $\chi^2 = 4.0$, df =1, $P = 0.0455_{[hem]}$).

DISCUSSION

The first growing season after logging, we found that many of the plots disturbed by skidding were nearly devoid of vegetation. In compartments 8C-D, 7 of the 13 plots intentionally disturbed by skidding contained no RBC, or other vegetation, in June following dormant-season logging. In 20A, 9 of the 12 plots affected by skidder activity did not contain RBC at the start of the first growing season after dormant-season harvesting. In most cases, all pre-logging vegetation had either been incidentally destroyed or displaced by logging equipment. Here we refer to such plots as "totally disturbed," while plots that retained any amount of RBC due to incomplete ground disturbance are referred to as "partially disturbed."

In an a posteriori analysis of disturbance plots, we found that almost all of the post-logging RBC recovery in both compartments originated from plots that received only partial surface disturbance and as a result retained some RBC. In compartment 20A, the partially disturbed plots have increased steadily from 51 total stems (1998) to 100 (1999) to 163 (2000), whereas those plots receiving total disturbance declined from 603 to 0 total stems in the year following disturbance and have not recovered. Plots that received no surface disturbance increased initially (365 total stems in 1998 to 582 stems in 1999), but declined in 2000 (483 stems). In 8C-D, the partially disturbed plots increased from 218 total stems in 1999 to 265 in 2000, while those plots receiving total disturbance declined from 193 to 0 in the year following disturbance (1999) and increased to a single crown of 3 stems in 2000, apparently from a new germinant. Plots in 8C-D that received no surface disturbance increased from 665 stems in 1999 to 813 in 2000. It is clear that RBC sites that either received no disturbance or were only partially disturbed (i.e., retained existing RBC plants) were virtually the sole source of the increase in RBC stems following disturbance. New RBC sites (from displaced plants or new germinants) outside our original sample locations were not incorporated into our assessment, which perhaps points to a deficiency in our impact assessment design, although they do not yet appear to be a key factor in the RBC response to disturbance.

The degree of surface disturbance within the context of the experimental design was related to the location of the sample point. As may be expected, the partially disturbed plots were mostly along the edge of the road where log-skidding and post-logging mitigation practices had less of an impact. In addition, a few outlying plots on the skidder road network in compartment 8C-D showed evidence of skidder tracks and log removal, but not complete surface disturbance. These plots were within the group not protected from disturbance, but because of their location, they received less intensive disturbance. We questioned, although were not able to assess, whether post-logging road recovery work such as road grading and water bar construction was a factor in the overall level of disturbance. In one case, it was clear that such practices were involved because a water bar was unknowingly built on top of two previously existing RBC occurrences. A review of operational records for compartments 8 and 20 during the last 50 years indicates a variety of conditions during past logging from wet to dry to frozen conditions; however, all of the logging during this time has occurred during the dormant season.

Our results in compartments 8 and 20 indicate RBC population declines were occurring toward the end of a 10-year period free of timber removal. However, it would be premature to conclude that 10-year disturbances are needed to maintain RBC populations. For example, in compartment 9, where we conducted leaf area measurements in anticipation of timber harvesting activities in 2001 and 2002, a declining trend in RBC numbers from 1998 to 2000 was not evident. The last harvesting in compartment 9 occurred during the 1985–86 dormant season, although some roads within this compartment were used in 1994–95 for access into an adjacent research area. In a comparison between roads last used in 1994–95 and 1985–86, both sets of roads had net increases in RBC. This seems to represent population dynamics different from those in compartments 8C-D and 20A, although it is only based on a three-year observation period.

One obvious consequence of logging operations is the change in environmental conditions for understory plants. Our leaf area index data indicate that RBC road sites are less shaded than random sites within the same research area and, possibly, even random sites on the road. Some have speculated that RBC is best suited to sites with 40%–80% shade (Campbell et al. 1988, Cusick 1989). The overall mean LAI of RBC-associated sites, 4.98, represents approximately 83% of the typical maximum projected LAI of 6.00 for temperate deciduous forests (Kramer and Kozlowski 1979). These measurements were conducted 15 years after the last timber removal. Thus, the 15-year cutting cycle and the level of growing stock present for the last 15 years may have roughly followed the desirable levels of shade suggested by Campbell et al. (1988) and Cusick (1989). However, we have observed RBC at other locations on Fernow E.F. growing and flowering in nearly full sunlight within forest openings (ca. 0.15 ha in size). We suspect that in forest openings large enough to establish a new cohort of woody plants or those within the stand initiation stage as defined by Oliver (1981), the persistence of RBC may be limited by vigorously competing vegetation.

RBC may indirectly benefit from a series of infrequent disturbances because competing vegetation is removed. Perhaps most striking in our analysis was the association of RBC with *Panicum* spp. and the lack of grass elsewhere within the compartment. Morris et al. (in press) found RBC presence associated with deertongue (*Panicum clandestinum* L.), a perennial graminoid noted for having significant rhizome development (Hitchcock 1951, Strausbaugh and Core 1978). The rhizomatous trait of deertongue is similar in structure and function to the stoloniferous trait of RBC. Rhizomes and stolons may confer similar competitive advantages in colonizing sites that have compacted soil conditions, little surface organic material, or depositional overburden. One report suggests deertongue may be capable of growing through several centimeters of depositional sediment (Hanlon et al. 1998). Deertongue grass is much more common than RBC in the eastern and central United States and is a constituent of balds in the southern Appalachians (Knoepp et al. 1998) and remnant prairies in the central United States (Hitchcock 1951), both of which were historically associated with frequent surface fires (McNab and Avers 1994). The functional relationship between surface fires and RBC habitat suitability is an interesting research question, also posed by the RBC recovery plan (Bartgis 1989) and others (Homoya et al. 1989). The historical role of fire in shaping eastern forest ecosystems has gained much attention, particularly with regard to present day oak regeneration problems (Crow 1988, Abrams 1992) in forests that have had oak constituents for thousands of years (Larabee 1986, Delcourt and Delcourt 1987). In all of the research compartments we utilized in this study, oak species contribute significantly to the makeup of the overstory but are virtually absent in the understory.

Forestry practices and other ground-disturbing operations can lead to the establishment of invasive exotic species, which can displace native species (Williams 1996). Most exotic plant species on Fernow E.F. are currently associated with permanent roads and high-light conditions. However, Japanese stilt grass, a common exotic species in the eastern United States and recently found on Fernow E.F., can tolerate low-light conditions (Winter et al. 1982). This species threatens native understory vegetation and, similar to RBC, is most common in areas that have been disturbed by natural and anthropogenic sources (Redman 1995). Japanese stilt grass was found at only 1 of 77 RBC monitoring stations referred to in this paper, but was abundant at a site elsewhere on Fernow E.F. used in 1984 as a concentration point for log removal. This site is characterized by a 0.1-ha canopy gap and compacted soil conditions. Japanese stilt grass has not yet become invasive in the adjoining forest understory, but its interaction with native flora is of considerable interest and will be monitored. Fernow E.F. is somewhat protected from invasive exotics, relative to many other forests in the eastern United States, because it is embedded in a much larger forested landscape. In areas prone to invasive exotics such as fragmented forests, establishing silvicultural techniques for management of RBC may be more problematic. In such cases, ground-disturbing manipulations of extant RBC occurrences may aggravate RBC management issues. In areas with both RBC and Japanese stilt grass, appropriate control measures for Japanese stilt grass (Tu 2000) should be implemented prior to any ground-disturbing operations.

CONCLUSIONS

This study is the first to track the federally endangered running buffalo clover, a species hypothesized to be disturbance-dependent, through common forest management disturbance cycles. Before we began this study, it appeared that RBC populations on Fernow Experimental Forest indirectly benefited from timber harvesting and ground-based skidding. Our results indicated that two years following timber removal, previously declining RBC occurrences began to increase in density. However, we did not expect the initial impact caused by logging operations to result in the elimination of a majority of RBC sites where skidder traffic was allowed. Accordingly, at this time it seems prudent to limit the amount of ground disturbance in existing RBC populations to mitigate the initial negative impact of uneven-aged timber harvesting. This could be done by avoiding RBC where skidder traffic is expected to be most concentrated—for example, by relocating skid roads where feasible and ensuring that post-logging practices such as road grading are balanced with the need to conserve existing RBC. The longer term benefits of partial harvesting may stem from the creation of small canopy gaps that result in increased solar radiation reaching the herbaceous layer. It remains to be explained how RBC survived repeated ground disturbances in the past. Experimental work and continued monitoring are needed to clarify why forest roads ostensibly contribute to RBC ecology and management.

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