Research Article

Twenty-Year Trends in Running Buffalo Clover (*Trifolium stoloniferum* Muhl. Ex A. Eaton; Fabaceae) on a Managed Forest in Northeastern West Virginia

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ABSTRACT

Twenty years of monitoring data are assessed for trends in abundance of running buffalo clover (*Trifolium stoloniferum*), an endangered species found on the Fernow Experimental Forest in northeastern West Virginia, where the clover is found under various forest management intensities. Monitored locations were grouped for analysis into sites with common disturbance histories. Of the 13 sites, about half (46%, six sites) were found to have statistically significant trends between numbers of rooted crowns and time. Three out of eight sites with recent and sustained periodic disturbance showed a significant association between time and running buffalo clover counts and the trend is positive. Of the sites with no management or no recent harvest activity, three were found to have negative trends of running buffalo clover counts over time, although at only one site was this statistically significant. This analysis of monitoring data gives some support for previous findings that the number of running buffalo clover rooted crowns is tied to disturbance on the skid roads and increased light conditions created by periodic harvesting.

Index terms: disturbance ecology; Federally endangered plant; silviculture

INTRODUCTION

Running buffalo clover (*Trifolium stoloniferum* Muhl. Ex A. Eaton; RBC) is a perennial plant in the Fabaceae family. Formerly found in Arkansas, Illinois, Indiana, Kansas, Kentucky, Missouri, Ohio, and West Virginia (USFWS 2007), it was listed as a federally endangered species in 1987 (50 FR 21478). Currently, RBC is found in Missouri, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia. Thought to be extirpated from West Virginia, RBC was rediscovered in the state in 1983 with additional populations discovered in 1989 on old roads underlain by Greenbrier Limestone. As surveys continued, many new populations of RBC were discovered across its historical range. In August 2019, RBC was proposed for delisting by the US Fish and Wildlife Service (84 FR 44832 August 27, 2019) and delisting was announced in August 2021 with the final rule effective on 7 September 2021.

As described in Strausbaugh and Core (1977), RBC is smooth stemmed with long runners spreading from a rooted crown; leaflets are broadly obovate and minutely toothed. Flowering and fruiting occur from May to August; flowers are white tinged with purple. Flower-bearing stalks have paired leaflets just below the flower head. Stems are 10–30 cm tall and the round flowers are 9–12 mm in size (USFWS 2007). RBC can reproduce asexually through rooting new plants (also called crowns) off nodes along stolons. This clover does not have a rhizobial association for fixing nitrogen (Campbell et al. 1988). There is circumstantial evidence to link RBC to bison disturbance along trails and wallows (Jacobs and Bartgis 1987). Some researchers suggest that the lack of nitrogen-fixing ability in RBC is linked to its close association with bison, elk, deer, or other ruminants due to the supply of nitrogen available when seeds are passed through animals and excreted (Morris et al. 2002). However, a controlled study with captive white-tailed deer showed low numbers of seeds and low germination after passage (Ford et al. 2003). Numbers of individual RBC rooted crowns in an area can vary greatly year to year (Dart-Padover et al. 2016) leading to difficulty in determining longevity of individuals. Given that reproduction is largely through vegetative means, individual plants can be difficult to identify when monitoring a population.

The past extent of RBC stretches from the Midwest to the mountain forests of West Virginia occurring in a variety of habitat types, including mesic woodlands, stream banks, grazed woodlots, mowed paths, old logging roads, trails, mowed wildlife openings within mature forests, savanna-like woodlands, sandbars, steep ravines, infrequently used UTV trails, hawthorn thickets, and graveled roads and driveways (USFWS 2007). RBC is a disturbance-dependent species that thrives when exposed to periodic disturbance, such as grazing, mowing, trampling, timber harvest with partial canopy removal, or flood-scouring (USFWS 2007). The primary threat to RBC is habitat alteration caused by natural forest succession and subsequent canopy closure, competition by invasive plant species, and permanent habitat loss through development or road construction.

On the Fernow Experimental Forest (Fernow; Figure 1), part of the Monongahela National Forest near Parsons, West Virginia, RBC was first found in 1993 in forested settings. More specifically, the plants are largely restricted to corridors—mainly skid roads—where bare dirt is exposed (Burkhart et al. 2013; Figure 2). Seven years of monitoring RBC numbers on the Fernow before and after research timber harvests determined that immediately after harvest RBC numbers were reduced but

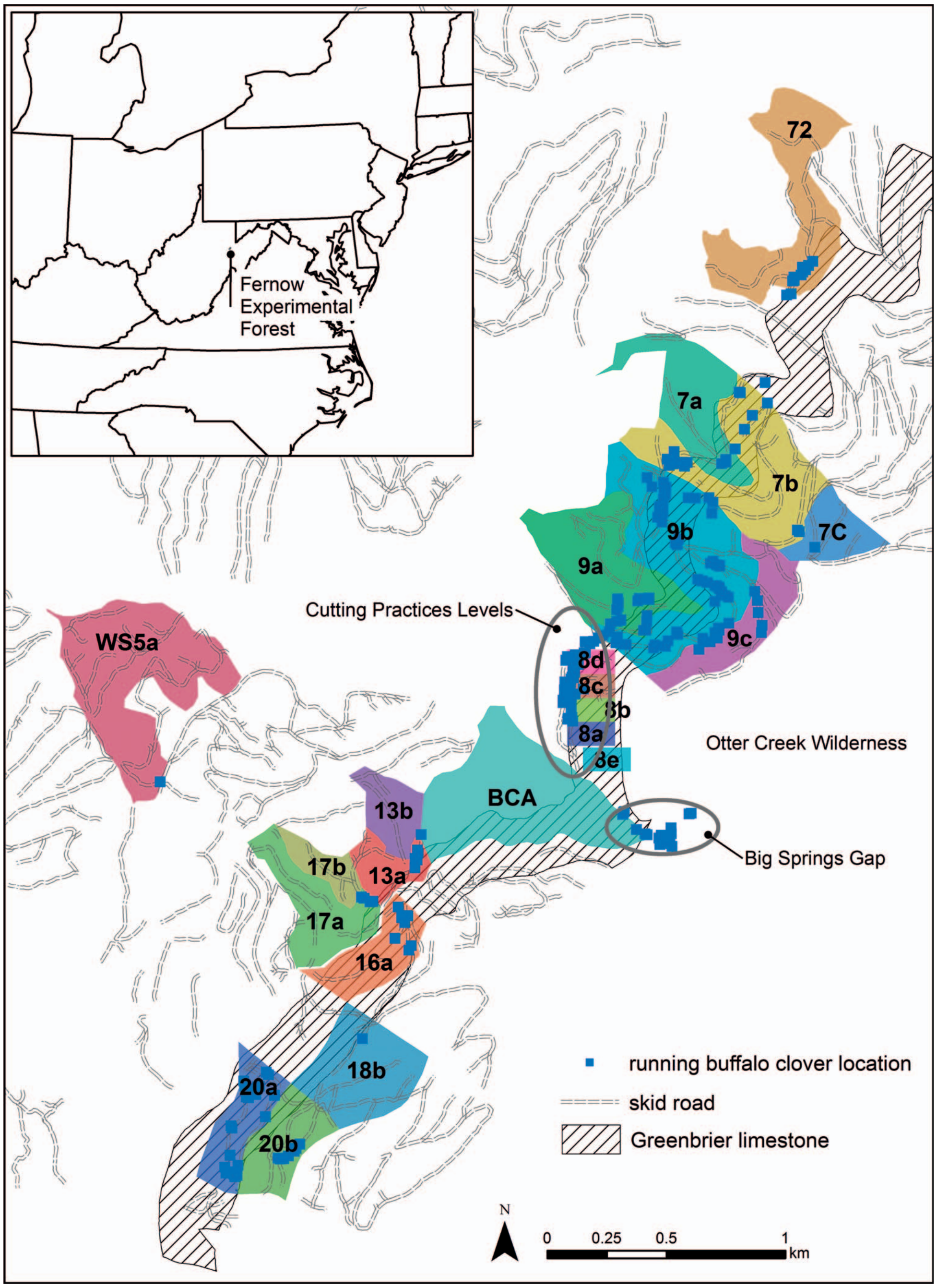

Figure 1.—Vicinity map of study area. Monitoring locations in the Big Springs Gap and Cutting Practices Levels sites are circled; other sites are contained within compartment or watershed boundaries.

began to increase 2 y after logging (Madarish and Schuler 2002). In a subsequent study of disturbance to RBC through logging activities, RBC populations on the Fernow were found to be responsive to recency and frequency of disturbance with five or more harvests since 1948 resulting in a higher likelihood of RBC presence (Burkhart et al. 2013).

The forested habitat required for the species to flourish is often described as hardwood forests with filtered light conditions on nutrient-rich soils (USFWS 2011). These light conditions are found on the Fernow following partial timber harvests. However, plants growing on the skid roads when timber is harvested experience high-intensity disturbance as bare mineral soil is exposed, and plants are crushed or uprooted. RBC plants rarely expand much beyond 2 m from the edges of skid roads on the Fernow even when filtered light conditions are found (Madarish and Schuler 2002).

As the decision to delist RBC continues to work through the regulatory process, management plans are being written for continued management of existing populations. While much is known about RBC ecology and individual population dynamics, more information on the impacts of timber harvesting or lack thereof would be useful in developing improved RBC manage-

Figure 2.—Examples of running buffalo clover plants and habitat on the Fernow Experimental Forest; individual rooted crown in skid road with no recent disturbance (a), individual rooted crown on disturbed skid road (circled; b); multiple rooted crowns delineated for census with red flag pins in a more open area where skid roads join (c).

ment plans. Lack of management is mentioned for several sites as a possible reason for declines in numbers between review periods (USFWS 2011) and RBC on the Fernow is the only population found on sites with long-term management for timber production.

Since its discovery on the Fernow, RBC plants have been systematically censused with consistent methods beginning in 1998. This analysis will present trends in RBC rooted crown numbers across the Fernow with individual RBC locations grouped by site. Each site consists of a variable number of distinct locations where RBC has experienced roughly the same disturbance regime. Building on previous findings on the Fernow, I hypothesize that sites with recent and sustained periodic disturbance will show a significant association between time and RBC counts and that the trend will be positive and, conversely, that for sites without recent and sustained periodic disturbance, the trend in RBC counts over time will be significant and negative.

METHODS

Study Area

The approximately 1800 ha Fernow (39.0543°N, 79.6701°W) is in the Central Appalachian Broadleaf Forest, within the Allegheny Mountains Ecological Section (Cleland et al. 2007; Figure 1). Characteristic tree species currently on the Fernow include northern red oak (*Quercus rubra*), yellow-poplar (*Liriodendron tulipifera*), black cherry (*Prunus serotina*), sugar maple (*Acer saccharum*), hickory (*Carya* spp.), black birch (*Betula lenta*), red maple (*Acer rubrum*), and American beech (*Fagus grandifolia*) (Schuler and Gillespie 2000). The topography is mountainous with elevations ranging from 530 to 1100 m above sea level. Mean annual precipitation is about 1400 mm and is distributed evenly throughout the year (Cleland et al. 2007). The growing season is approximately from May through October with an average frost-free period of 145 d.

Slopes range from 20% to 50% over most of the Fernow and the most common soils mapped are the Calvin and Dekalb series. The Calvin series consists of moderately deep, well-drained acidic soils formed in material weathered from interbedded shale, siltstone, and sandstone. Dekalb soils also are acidic, deriving from acidic sandstones. Belmont soils, which extend along a band on the east side of the Fernow, are formed from weathered limestone of the Greenbrier formation and are much less acidic than the other soils. Soils on the Fernow are derived from a range of geologic formations with the Chemung and Hampshire formations west of Elklick Run and the Hampshire, Pocono, Greenbrier, Mauch Chunk, Pottsville, and Allegheny formations east of Elklick Run.

The majority of the Fernow was initially logged between 1903 and 1911 during the railroad-logging era (Fansler 1962; Trimble 1977). However, many trees were not removed due to undesirable size, species, or form including sugar maple, American beech, black birch, and hickory, resulting in uneven harvest intensity. Only a small portion of the area was farmed, and the forest regenerated following the cessation of logging activities. The federal government purchased the land in 1915 and the Fernow was established and dedicated to forest and watershed research in 1934 with the longest-running studies initiated in 1948 or 1949 (Adams et al. 2012).

Data Collection

The data used in this analysis are not from a designed study but were the result of over 20 y of monitoring surveys. As groups of RBC plants were found on the Fernow, their locations were documented through the establishment of point coordinates and placement of markers (rebar) near the plants. Markers were installed just off the skid or haul road where the plants were found so that use of the road could continue while also allowing for recounting of the plants. Metal tags with location number or name were attached to the markers; markers and nearby trees were marked with plastic flagging during the annual census.

The markers locations were visited in June through early July when plants are flowering and stolons are present. Before 2004, locations were monitored annually; however, starting in 2005, they were monitored once every 2 y including some locations where no RBC rooted crowns have been found in over 5 y. The number of physically monumented RBC locations and total rooted crowns per year on the Fernow has varied through time as new locations are discovered (Table 1 and Figure 3). Rooted crowns were individually censused on the majority of the locations; sampling was used on only two or three locations in any given year. During the tally, individual crowns were determined through a light tug on plants to establish if a crown

Table 1.—Summary of the management history of sites used for the analysis. An asterisk in the trend column indicates statistical significance ($\alpha = 0.10$).

Research status	Site (year first monitored)	Number of RBC locations (as of 2020)	Number of years tallied	Management	Year of last disturbance	Number of research-related disturbance events	Trend
Active	Cutting Practices Levels (1999)	30	14	Mainly single-tree selection, 10-year cycle	Skid roads used in 2019	5	increasing *
	C7c (2000)	1	13	Single-tree selection, 10-year cycle	2012	6	increasing
	C20a (1999)	15	13	Single-tree selection, 10-year cycle	2019	9	increasing *
	WS5a (2008)	1	7	Single-tree selection, 10-year cycle	2019	7	increasing
	C9a-c (1998)	52	15	Diameter-limit harvest, 15- or 20-year cycle	9a: 2016 9b: 2017 9c: 2011	5	increasing *
	C7a-b (2002)	17	11	Patch cutting, 10-year cycle	2009	7	decreasing
	C17a-b (2002)	3	11	Patch cutting, 10- or 15-year cycle	2020	5	decreasing
	C18b (2002)	1	9	Patch cutting, 10- or 15-year cycle	2013	7	decreasing *
Inactive	C16a (2003)	10	10	Single-tree selection, 20-year cycle	1990	6	decreasing *
	C20b (1999)	6	14	Partial harvest, 10-year cycle	2006	6	decreasing
	C72 (2003)	9	10	Strip clearcut	1996	3	Increasing *
	C13a-b (2000)	6	13	Prescribed fire and bat habitat study	prescribed fire 2009	2	increasing
None	Big Springs Gap (1999)	9	14	Mixed – Wilderness, road, control area	Annual road grading affects one location	none	decreasing

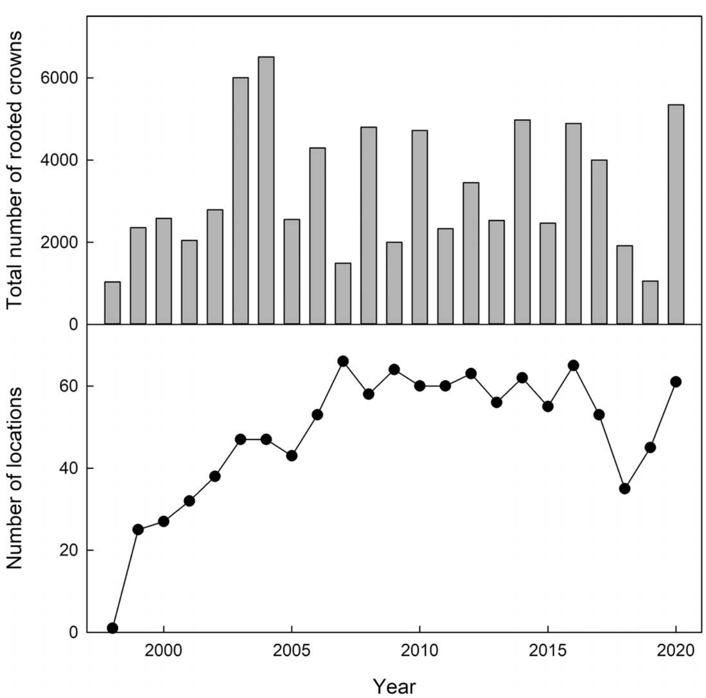

Figure 3.—Number of physically monumented RBC locations and total rooted crowns per year on the Fernow Experimental Forest, all sites combined.

was rooted at the node or was still attached to the parent through the stolon; only rooted crowns were counted in the census. Each individual crown was indicated by a pin flag and when the entire patch was delineated, the pin flags were removed and counted to establish the total census of rooted crowns. For sampling, 1 m^2 plots were located 3 m apart and all rooted crowns were tallied within the plot. To extrapolate the sample to a count of plants, a 2.4 m road width was assumed, and the total length of area sampled was measured. The number of sample plots varied from 2 to 8 by location and year.

RBC Site Descriptions

To display the trends in total numbers of rooted crowns through time, known locations of RBC on the Fernow were grouped into 13 sites across 18 research compartments or watersheds (site names in compartments start with C; watershed sites with WS) and one area not assigned to a research study (Table 1 and Figure 1). Each site consists of distinct census locations where RBC has experienced roughly the same disturbance regime of timber harvest and skid road use under specific silvicultural practices and one site with no timber harvest activities. Specific information on the silvicultural research on the Fernow can be found in Schuler (2014), Schuler et al. (2017), and Thomas-Van Gundy et al. (2018). The sites with silvicultural practices can be further divided into active or inactive studies (Table 1). There are eight RBC sites with active forest management (generally on a 10- or 15-year harvest cycle depending on the study), four RBC sites where research timber harvest took place in the past, but the study is now inactive, and one site where no timber harvest has taken place in many decades. No management specifically for the enhancement of RBC has occurred on the Fernow.

Active Research Sites

The Cutting Practices Levels (CPL) site includes RBC locations in the demonstration blocks (C8a–d) and on the skid roads used to harvest C8a-d, C9a, and C9b (Figure 1). The CPL demonstration blocks have been managed continuously since 1949 with most of the censused locations either along the skid road or within the areas managed by single-tree selection on a 10-year cycle (C8c, d). C7c is composed of only one RBC location and the area is managed through single-tree selection; harvests occurred in 1955, 1970, 1981, 1990, 2002, and 2012. Site C20a is also managed by single-tree selection with harvests in 1952, 1968, 1973, 1977, 1987, 1998, 2006, and 2019. Skid roads in this area were used to access C20b in 2007. In 2008, RBC was found on WS5a—an area managed through single-tree selection with harvests in 1958, 1968, 1978, 1988, 1998, 2007, and 2019.

C9a–c have been managed by diameter-limit harvesting every 10 or 15 y with C9a treated in 1954, 1970, 1985, 2001, and 2016; C9b in 1953, 1970, 1985, 2001, and 2017; and C9c in 1954, 1971, 1992, and 2011. Several sites are managed under patch cutting also called patch clearcutting where small (about 0.4 acre) patches of trees are harvested or felled. C7a and C7b are managed by patch cutting with entries in C7a in 1956, 1967, 1976, 1987, 1995, and 2009; and C7b in 1955, 1967, 1977, 1987, 1995, and 2009. Skid roads in C7a are also used to access another harvest area and were last used in 2008. C17a and C17b are under patch cutting prescriptions on 10- or 15-year rotation harvests in 1957, 1967, 1977, 1988, 1998, 2006, and 2020 for C17a and C17b in 1957, 1971, 1987, 2003, and 2020. C18b is also under patch cutting prescription and was logged in 1952, 1959, 1964, 1974, 1985, 1994, 2005, and 2013. During timber harvests on the sites under silvicultural management, RBC plants are directly impacted by a track-mounted dozer used to open the established skid roads and to establish water control structures when logging is finished.

Inactive Research Sites

C16a was initially managed through single tree selection on a 20 y cycle. Harvests occurred in 1951 and 1970. In 1990 a crop tree release harvest occurred—the last research-related disturbance in C16a. Monitoring notes in 2019 state that the skid road is not as distinct as in the past and that the RBC sites are in deep shade in C16a. Some areas on the Fernow were managed under a variant of diameter-limit harvesting for a study that has ended including C20b with timber harvests in 1952, 1968, 1977, 1987, 1998, and 2006. C72 was managed by strip clearcut with different sections of the area cut in 1977, 1988, and 1996 with no further management or skid road use after 1996. C13a and C13b were originally part of a study that involved partial overstory removal harvests starting in the 1950s and continuing at irregular time intervals through 2003. In 2007 the compartments were included in a prescribed fire study with an emphasis on the creation of bat habitat; herbicides were also used to deaden mature canopy trees. Prescribed fire was applied in 2007 and 2009 although fire did not carry well near the RBC sites.

No Planned Active Management

No planned disturbance related to timber harvests occurs at the Big Springs Gap site. The locations were grouped by their proximity to the Big Springs Gap area on the Fernow including locations in the Otter Creek Wilderness, the Biological Control Area (BCA), and a few locations along the main road (Figure 1). In terms of tree canopy disturbance, occasionally trees are cut for safety purposes along the road and the parking area at the wilderness trailhead.

Data Analysis

The 13 sites created by grouping RBC locations by disturbance history were used as the analysis unit (Table 1). Monitoring of RBC plants on the Fernow has resulted in a dataset with varying numbers of locations by site and variations in years tallied between sites, making comparisons between sites at any given time difficult. A simple method for determining significance of RBC counts over time was desired for this analysis of monitoring data. Univariate analysis showed the variance was much larger than the mean for most sites. The counts of RBC over time are not independent as counts occurred on the same locations, near the physical monuments, each year, making analysis by linear regression inappropriate. Given these factors, I chose to explore the relationship of RBC counts over time (year) through correlation analysis and the Mann-Kendall test for significance (Proc CORR; SAS 2019) with significance set at $\alpha = 0.10$. I also report the Kendall Tau-b correlation coefficient computed for the Mann-Kendall test to describe the strength of the trend with a coefficient of -1 indicating complete negative correlation, $+1$ complete positive correlation, and 0 indicating no correlation. This method has drawbacks for testing trends in RBC as the Mann-Kendall test is best for data with monotonic trends. Given the observed dynamics in RBC counts after disturbance from timber harvest—near zero counts immediately after harvest and recovery to increases over pre-harvest numbers a few years after harvest—the trend may not be strictly monotonic depending on numbers of disturbance events and length of census record. In contrast, on those sites with no recent disturbance, the expected trend would be negative and monotonic.

RESULTS

Trends by Site and Management

Of the 13 sites identified, six (46%) showed statistically significant trends of RBC counts over time. Of eight sites under active management, four were found to have statistically significant relations between counts of RBC and time (Figures 4 and 5). Of those four, three sites show positive trends—CPL (Figure 4a), C20a (Figure 4c), and C9a-c (Figure 5a)—and are under either single-tree selection or diameter-limit harvest prescriptions. The strongest positive correlation between counts and time was found in C20a, under single-tree selection, with a Kendall Tau-b of 0.487. The three sites displaying negative trends in counts over time—C7a-b (Figure 5b), C17a-b (Figure 5c), and C18b (Figure 5d)—are under patch cutting prescrip-

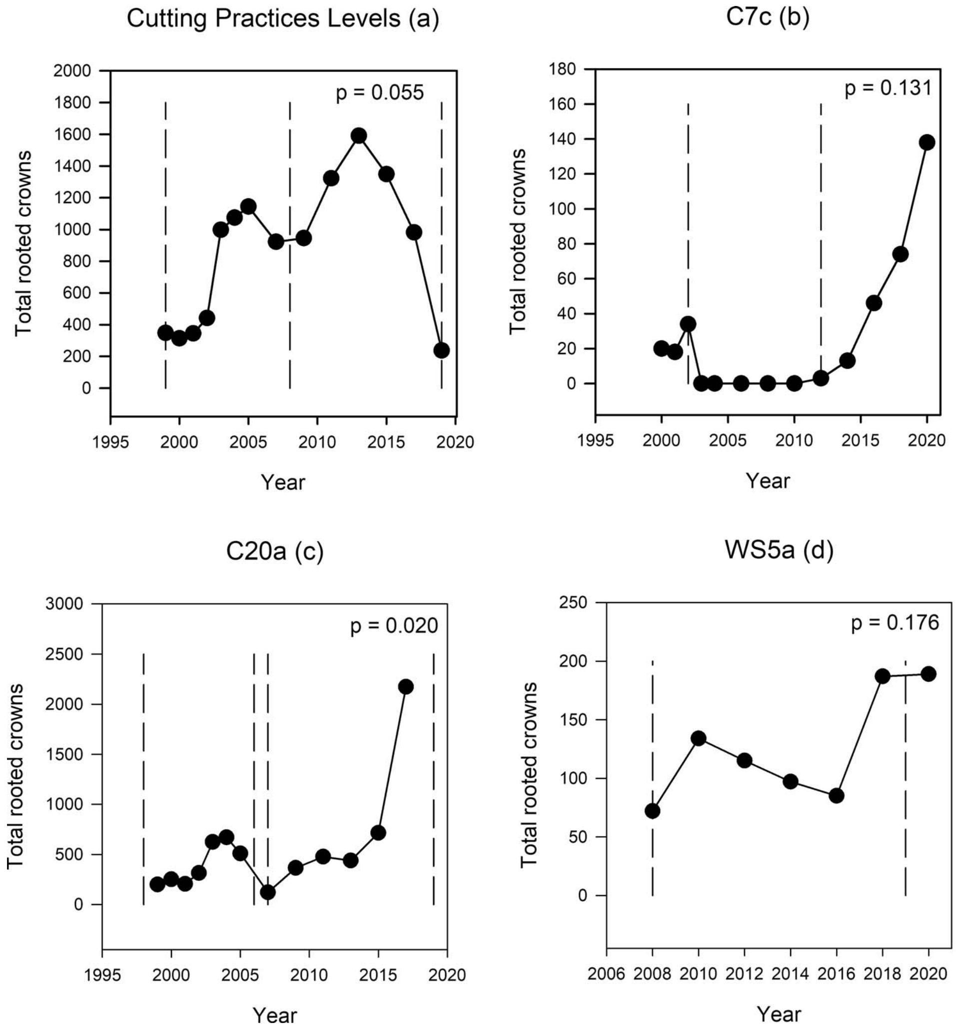

Figure 4.—Scatter plots of RBC total rooted crown counts over time for Cutting Practices Levels (a), C7c (b), C20a (c), and WS5a (d) sites. All sites are in active management. Dashed lines signify disturbance event. Note the differences in year and count scales for each site.

tions although only one site (C18b) was found to have a statistically significant trend and the largest coefficient of correlation (Kendall Tau-b = –0.559).

Two of the five sites either in inactive research studies or no planned management were determined to be statistically significant (Figure 6). Of those two, one shows a strong negative trend (C16a [Figure 6a; Kendall Tau-b of –0.911]) and one displays a positive trend (C72 [Figure 6c; Kendall Tau-b of 0.511]). Those sites with negative trends were under single-tree selection (Compartment 16a), patch cutting (C20b), or had no timber harvest (Big Springs Gap). Interestingly, two sites in inactive research studies showed positive trends in counts over time—C72 and C13a-b (Figure 6d)—although only the relationship in C72, harvested under a three-stage strip clearcut, was statistically significant.

DISCUSSION

A previous study of disturbance and RBC abundance on the Fernow determined that skid road use and timber harvest with a return interval of 8–14 y favored RBC (Burkhart et al. 2013). Further, this work determined that in areas with no timber harvest–related disturbances in 14 y, RBC numbers declined, and in areas with no disturbances in 20 y, no RBC clover was found (Burkhart et al. 2013). The results presented here with RBC sites determined by disturbance history show support for those findings with three sites with recent and sustained periodic disturbance showing significant and positive associations between time and RBC counts. Of the sites with no management or no recent harvest activity, only one was determined to have a significant and negative trend for RBC counts over time. These results cover 23 y at maximum, with many sites being monitored for less than that amount of time. Given the 20 y threshold for RBC persistence, the number of sites with significant negative trends is expected to increase if no management is introduced on those sites.

Of the six sites determined to have significant trends, two stand out as examples of the relationship of RBC numbers and disturbance—C16a for the lack of disturbance and C20a for sustained periodic disturbance. In C16a, no timber harvest and no skid road use has occurred since 1990. The plot of RBC counts over time (Figure 6a) shows the rapid decrease in

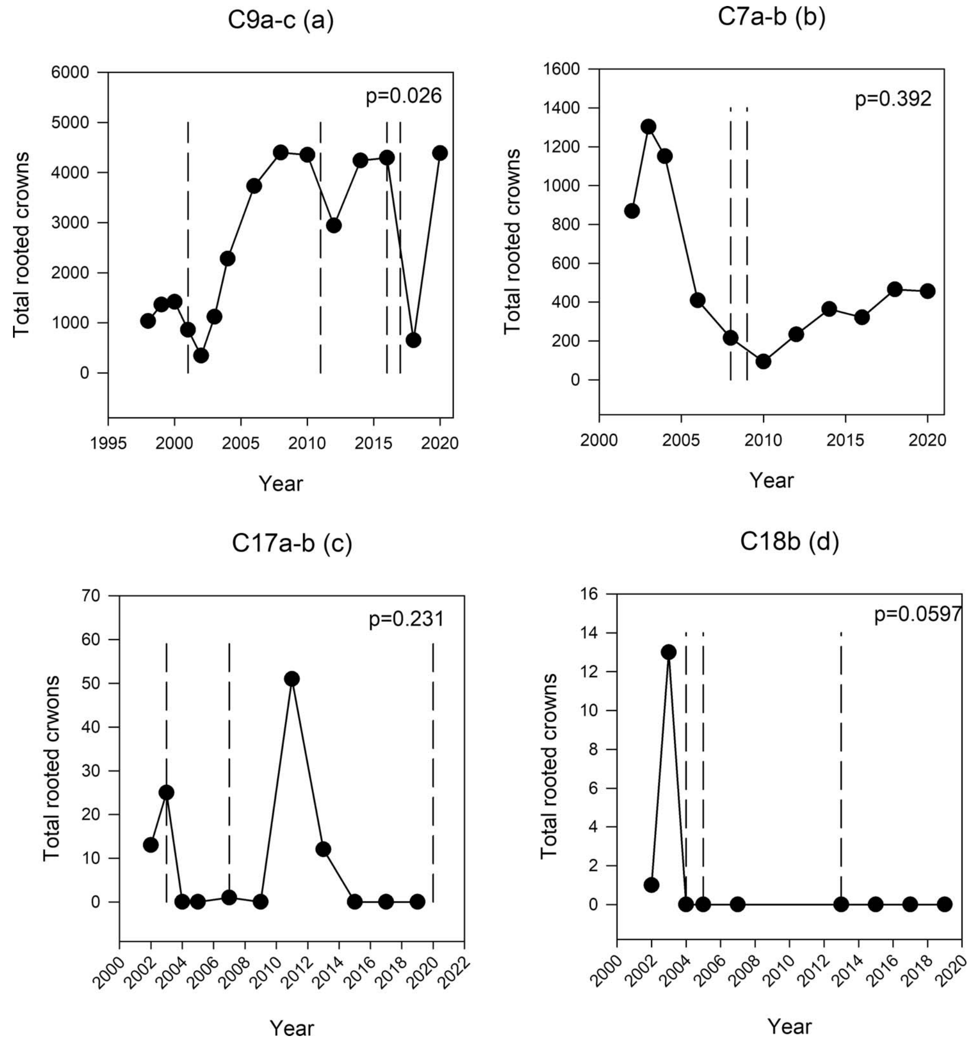

Figure 5.—Scatter plots of RBC total rooted crown counts over time for C9a-c (a), C7a-b (b), C17a-b (c), and C18b (d) sites. All sites are in active management. Dashed lines signify disturbance event. Note the differences in year and count scales for each site.

numbers since last disturbance down to no plants found in the last census. The changes in canopy cover created by single-tree selection at this site alone were not suitable for sustaining RBC. In C20a the plot of RBC count over time (Figure 4c) shows the response of RBC numbers to skid road use and the recovery after harvest. The 2021 census will be the first tally since the last harvest, and it is likely that RBC numbers have recovered somewhat.

The expected trend in C72 is negative given that no harvest or skid road use has taken place since 1996; however, the trend in RBC counts is positive and significant. The numbers of rooted crowns peaked in 2014, which is 18 y since last disturbance and the last census showed a drop in RBC numbers (Figure 6c). On this site, RBC may be persisting because the strip clearcut in three stages over 22 y created suitable canopy closure conditions. The RBC plants making up this site are all found along the main skid road off the log landing on the haul road and are not dispersed throughout the harvested areas (Figure 1).

While the management practice of patch cutting has one element of habitat disturbance for RBC—periodic skid road use—suitable tree canopy closure conditions required are not met with complete canopy openness in cut patches and nearly complete canopy closure in unharvested areas. Additionally, the pattern of skid road reuse differs with patch cutting as the harvest areas are discrete areas and all skid roads are not used each entry, compared to single-tree selection or diameter-limit harvesting where the harvest is dispersed, and the entire skid road system is more likely to be reused each entry. Even with high soil moisture and richness, patch cutting does not appear to be a successful strategy for perpetuating RBC based on the negative trends found in C7a-b, C17a-b, and C18b, although only C18b was statistically significant and this very small population may have been impacted by factors other than forest management such as herbivory, disease, or nonnative invasive species.

That only six of the 13 sites showed statistical significance may be a limitation of the statistical analysis technique attempted here. The dynamics over time for RBC are not monotonic nor linear with sustained disturbance and the sites and methods used here were developed for monitoring and not research. I also explored the use of mixed general linear models with repeated measures with all sites and counts for all years. A classification variable of active or inactive treatment was added to determine if

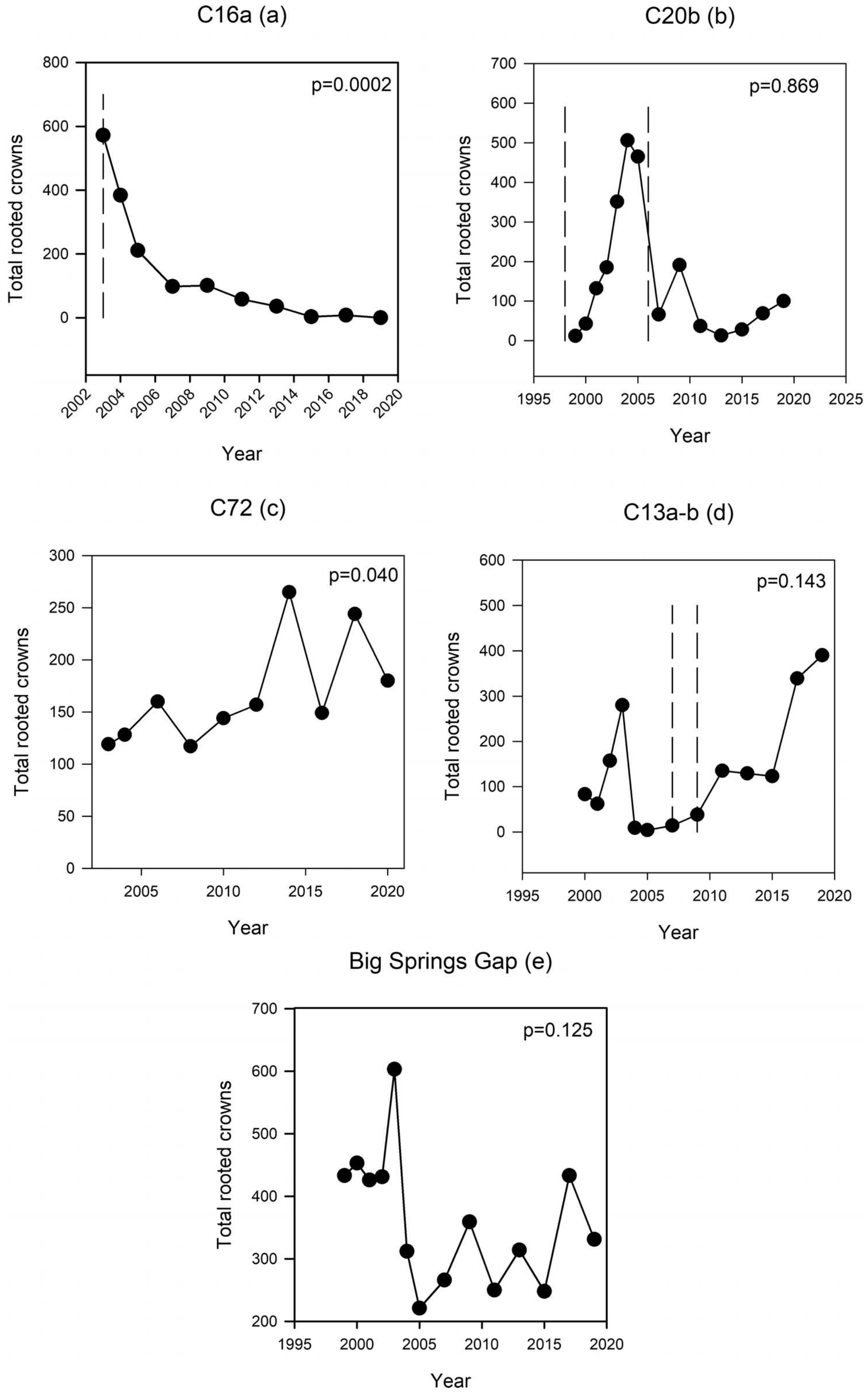

Figure 6.—Scatter plots of RBC total rooted crown counts over time for C16a (a), C20b (b), C72 (c), C13a-b (d), and Big Springs Gap (e) sites. All sites are in inactive studies or have no planned research actions. Dashed lines signify disturbance event. Note the differences in year and count scales for each site.

significant differences between management could be determined. While one model did converge, the residuals were not normally distributed, therefore those results were not included in this analysis. As seen in the scatter plots of the count data, there is variation over time by site as management occurs but also there is high variability in count totals between sites even with sustained disturbance. For example, C20a (Figure 4c) shows a peak of around 2100 crowns and C9a-c has totals over 4000 crowns for several survey years (Figure 5a). C9a-c has the longest census record as well as the first RBC to be found on the Fernow was found in this area.

The disturbance ecology principle of "form follows function, pattern follows process" (Engstrom et al. 1999) can be useful in illustrating the dynamics of the Fernow population. RBC can use all three strategies available to plants to avoid competition—vertical growth, shade tolerance, and lateral growth to escape. However, exploratory measurements on one site (C20a) found no relationship between incoming light (maximum 654–8185 $\mu mol/m^2/s$; mean 4316, SD 2760.9 $\mu mol/m^2/s$) and the number of stolons, length of stolons, or height of tallest shoot, although ordination analysis did show that the presence of tall herbaceous competition is strongly related to stolon length and number (LaBella et al. in press). Genetic studies illustrate genetic variability within RBC populations indicating they were not perpetuated solely by clonal growth from one or a few individuals; however, the species still has low overall genetic diversity (Crawford et al. 1998). Stolon growth may be a response to release from competition when bare soil is exposed, and the individual plant increases site occupation, or be based on plant age as older plants have accumulated carbohydrate root reserves. The measurements taken at C20a were made in the months before a scheduled harvest so very little of the skid road surface was in bare soil (LaBella et al. in press).

The single-location site WS5a dates to 2008 and is the only known RBC site on the Fernow far removed from the influence of limestone geology. This site is very likely the result of a skidder or dozer moving plants or plant parts from the east side of the Fernow to the western side. The presence of RBC on the Fernow follows the pattern of the skid roads with the process of timber harvest and logging replacing the theorized process of bison-created trails and grazing (Jacobs and Bartgis 1987), although not all site trends show statistical significance.

The response of RBC to disturbance is an example of the ecology of clonal plants with stolons as an adaptation to a heterogeneous environment (Liu et al. 2016). Also, as others have found, long-term monitoring of RBC has shown fluctuating population size (USFW 2007; Dart-Padover et al. 2016). The Fernow data are of rooted crowns, individual plants and not unrooted plantlets found along stolons, however the counts over years are a result of those plantlets establishing a new plant. Clonal plants produce stolons to forage for key resources in heterogeneous environmental conditions and to avoid direct competition (Liu at al. 2016). As has been noted, quantifying plant population biology is hindered by two interwoven traits—plasticity and vegetative reproduction (Harper 1967)—both of which are present in RBC.

CONCLUSIONS

The trends documented on the Fernow may help in the development of management plans for this rare plant. However, as others have stated, the disturbance return intervals on the Fernow are based on the needs of the silvicultural studies and not the biology of RBC (Madarish and Schuler 2002) and suitable disturbance frequencies for RBC are likely not absolute. While this monitoring data covers about 20 y for many sites on the Fernow, continued monitoring is needed to validate these trends. However, results from the Fernow show that some forms of timber harvest with skid road use are compatible with the perpetuation of RBC. Additional research is needed into whether RBC habitat can be created away from skid roads by deliberate ground disturbance and timber harvest with partial canopy removal.

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