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Gnome Sweet Gnome: Supporting Rock Gnome Lichen Conservation in the Southern Appalachians

Elsa Haun
Environmental Studies: Environmental Management and Policy
University of North Carolina Asheville
One University Heights
Asheville, North Carolina 28804 USA

Faculty Advisor: Dr. Irene Rossell

Abstract

The Rock Gnome Lichen (*Cetradonia linearis*) is one of two federally endangered lichens in the U.S. and is endemic to western North Carolina with small populations in southwestern Virginia, eastern Tennessee, and northern Georgia. It is a squamulose lichen inhabiting either partially shaded high-elevation vertical rock faces or cool, shaded lower-elevation rocks. Some of the main threats to the Rock Gnome Lichen include disturbance by climbers and hikers, air pollution from nearby industry, and climate change. The objective of this research was to survey the status of Rock Gnome Lichen populations along the Blue Ridge Parkway, repeating and expanding on a study done in 2008. Each site was assessed using the U.S. Fish & Wildlife Service Rapid Assessment Protocol (RAP) for Rock Gnome Lichen, which entails semi-quantitative measurements of plant cover, and the collected data was compared to findings of the previous study. This was the first inventory of Rock Gnome Lichen populations along the Parkway in 10 years, and results suggest populations are declining. These findings highlight the importance of ongoing conservation work and establish the need for continued monitoring and protection of this species under the Endangered Species Act. Because much of Rock Gnome Lichen habitat is on public lands, there is substantial potential for impact through aggressive conservation efforts within the NPS (National Park Service). This research will provide crucial information to the NPS on the necessity of continued protection for this species. It will also provide a valuable resource for other land managers in the Southern Appalachians who are stewards of Rock Gnome Lichen populations.

1. Introduction

The mountains of western North Carolina, southwestern Virginia, eastern Tennessee, and northern Georgia are home to many unique and endemic species due to their high elevations and relatively moderate climates[1]. Because these mountains and valleys were never covered by glaciers, they have developed exceptionally high soil fertility which has allowed many plant species to thrive[2]. These special conditions create niches for high biodiversity and endemism of both flora and fauna species. Endemic species inhabiting this region often exist in small, isolated populations that are potentially already nearing their environmental limits[3]. High-elevation species are thus especially vulnerable to threats and environmental changes, as their habitats are so specialized that these species can only persist given very specific conditions.

One of these high-elevation southern Appalachian endemic species is the Rock Gnome Lichen *(Cetradonia linearis*), shown in Figure 1. It is a squamulose lichen, meaning that it grows out from the substrate in small, protruding scales. This lichen inhabits vertical or near-vertical rock faces on mountaintops over 5,000 feet in elevation in the southern Appalachian mountains[4]. The U.S. Fish and Wildlife Service range map (Figure 2) broadly shows the geographic area where *C. linearis* can occur. Some of this species' specific habitat requirements include high elevation (over 5,000 feet above sea level), consistent shade, and a constant supply of water through either deep fog or seeping water[5]. It often shares these high-elevation rock outcrops with the common moss *Andreaea* and the sedge *Carex misera*[6], and occasionally with another endangered plant, the spreading avens (*Geum radiatum*)[7].

Figure 1. *Cetradonia linearis.*

Cetradonia linearis was first described by Evans as *Cladonia linearis* in 1947, and later as *Gymnoderma lineare* by Yoshimura and Sharp in 1968[8]. Wei and Ahti further amended this taxonomy to give the species its current name, with their 2002 work designating the new genus *Cetradonia*[9]. Other recent work on this species analyzed genetic patterns of *C. linearis* and found isolation between populations and evidence for a larger geographic range during the last glacial maximum, suggesting that this lichen exhibits smaller ranges under warmer climatic conditions[10].

Due to its highly specific habitat and dwindling populations, the Rock Gnome Lichen was classified as an endangered species by the U.S. Department of the Interior in January of 1995[11]. That designation ranks *C. linearis* as one of only two federally endangered lichens in the United States, along with *Cladonia perforata*, which grows in Florida[12]. With this classification, the species fell under the protection of the Endangered Species Act of 1973[13] and a recovery plan was put into place[14]. A report was initiated to determine if designation of critical habitat would be a reasonable conservation tactic for this species, but in 2001 the U.S. Fish and Wildlife Service determined that designation was not prudent for *C. linearis*[15].

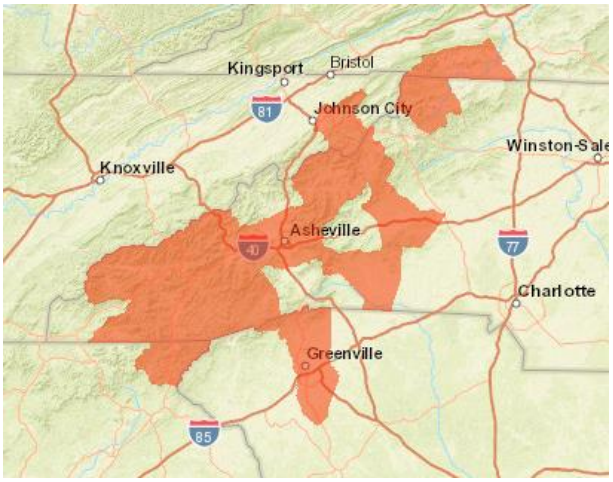

Figure 2. Range map of *Cetradonia linearis*[16].

The main threats to this lichen, as documented in the proposal to classify *C. linearis* as a federally endangered species, include hikers and rock climbers, air pollution, and decreasing forest cover[17]. Hikers and rock climbers can disturb the lichen when they come into contact with growth on boulders or cliffsides. Air pollution from nearby

industry is another potential cause for decline and possible extirpation. *C. linearis* is also vulnerable to changes in high-elevation forest ecology resulting from logging and the decline of the Balsam fir and the endemic Fraser fir. These high-elevation trees are suffering a high mortality rate due to damage from an invasive insect, the balsam wooly adelgid[18]. When these trees die out and the surrounding forest thins, the rock outcrops containing the lichen are exposed to higher temperatures and greater amounts of sunlight. These microclimatic changes can desiccate *C. linearis* populations[19].

This research establishes an updated survey of *C. linearis* populations on the Blue Ridge Parkway, a National Park in western North Carolina and southwestern Virginia. The study area was chosen because the Parkway runs along many of the highest ridgelines in western North Carolina, making it the public land managing entity responsible for the largest proportion of *C. linearis* habitat[20]. The management decisions of the Parkway have a high potential impact on all of the species inhabiting its range. As the country's most popular National Park, the Blue Ridge Parkway hosts 14 million annual visitors[21]. This high volume of visitor traffic can devastate native species such as *C. linearis* if not carefully managed.

As of the 1993 proposal to list *C. linearis* as a federally endangered species, only 7 of the 32 documented populations covered an area greater than 2 square meters (m^2)[22]. The most recent field survey of the total growth area of *C. linearis* was conducted in 2008 by Dr. Chris Ulrey, Plant Ecologist of the Blue Ridge Parkway. In 2013, the U.S. Fish and Wildlife Service conducted a species review and found that while new, larger occurrences of *C. linearis* have been found since the 1993 proposal, the species was still in decline, and *C. linearis* was not considered for downlisting (from endangered to threatened status)[23]. Without ongoing data collection, there is no way to know the present status of the species. This lack of study forms the impetus for this research. This study hypothesized that *C. linearis* populations are still in decline, and that a majority of sites would show a decrease in total area.

2. Methodology

To obtain an updated survey of *Cetradonia linearis* cover, measurements of lichen area were conducted at 12 study sites from May to August of 2019. All sites were located on National Park Service land within the boundaries of the Blue Ridge Parkway in western North Carolina. Eight of the 12 study sites were being re-surveyed following the last field monitoring of *C. linearis* in 2008. Repeating *C. linearis* surveys at known sites allowed for comparison of data to past findings. Four new study sites were identified in locations where *C. linearis* was known to exist but no previous surveys had been conducted. While data from these sites could not be evaluated for trends over time, the new data was submitted to the National Park Service and will serve as a resource for decisions about the management of vulnerable habitat locations.

Each previously surveyed site was identified by an assigned element occurrence (EO) number. Plant biologists use EO numbers in instances where it is difficult or unrealistic to quickly differentiate plant occurrence sites into genetically distinct populations[24]. Therefore, in this study, measurements for each EO were treated as data for a single "population." When referencing USFWS documents such as the 1997 recovery plan for Rock Gnome Lichen, this terminology was used. The EO methodology was consistent with the protocols used by the USFWS in their 5-year reviews[25]. The new sites measured in this study were treated as new EO's but have not yet been assigned numbers. Therefore, these sites were referred to by name.

Study sites that had been previously surveyed for *C. linearis* were located either with a map with marked coordinates or through guidance by a previous researcher who was familiar with the locations of the lichen populations. The mapped sites located via coordinates obtained from the National Park Service's internal record of *C. linearis* population sites. Researchers used a GPS smartphone application, Avenza, to navigate to these marked sites. The four new population sites surveyed in this study were located by Parkway staff and past volunteers familiar with their locations.

At each study site, the U.S. Fish & Wildlife Service Rapid Assessment Protocol (RAP) for Rock Gnome Lichen was followed to obtain estimates of *C. linearis* cover[26]. The protocol was created by the USFWS to standardize semi-quantitative monitoring of this endangered species. The materials used to collect these measurements included folding centimeter rulers and centimeter measuring tapes (Figure 3). For each occurrence of *C. linearis* within a study site, the RAP involved subdivision into distinct and measurable plots with uniform lichen coverage. The plots were measured for length and width. A coverclass value was assigned to each plot on a scale of 1-10, representing an estimation of the percentage of the plot covered by lichen (Table 1). The true lichen coverage area of each plot was later calculated by multiplying the area of the plot by the percentage at the midpoint of the coverclass. This calculation yielded an area estimation in square centimeters (cm^2) for each plot. These plot measurements were summed to generate lichen area estimates for each study site, and cm^2 measurements were converted to m^2.

An additional estimate was made at each study site to approximate the percentage of the site that was measured. That percentage was used to scale the measurements to include portions of each site where additional *C. linearis* was present but not measurable. This instance occurred where *C. linearis* habitat continued above a reachable height for measurement or in locations where taking detailed measurements would have been unsafe.

Table 1. The coverclass categories used to estimate lichen cover of each plot.

Estimated % of plot covered	0.1%	0-1%	1-2%	2-5%	5-10%	10-25%	25-50%	50-75%	75-95%	95-100%
Coverclass designation	1	2	3	4	5	6	7	8	9	10
Midpoint used for calculations	0.05%	0.5%	1.5%	3.5%	7.5%	17.5%	37.5%	62.5%	85%	97.5%

Figure 3. Measuring *Cetradonia linearis* and estimating a plot.

Figure 3 shows the measurement of a *C. linearis* plot. The lichen appears brown and is visible directly beneath the measuring tape. This instance was small and uniform enough to be measured in just one plot. This plot appears to be about 50 cm by 10 cm, with 60% coverage, corresponding to a coverclass value of 8. In the final calculation, the 500 cm^2 plot area was multiplied by 0.625, the midpoint of the coverclass range, for an estimated total lichen area of 312.5 cm^2.

3. Results

This study found 46.0 m^2 of *Cetradonia linearis* across the eight previously surveyed sites and 5.8 m^2 at the newly surveyed sites, for a total of 51.7 m^2. The 2008 study found a total of 46.9 m^2 across all eight sites. This research found only 0.9 m^2 less coverage at the same sites, indicating a 2% decrease in total area.

Five of the eight previously surveyed sites showed consistent or declining total area measurements. On average, each study site showed a 9% decrease in measured lichen area. Summary data showing total area measured at each study site are shown in Table 2 and Figure 4.

EO 13 showed the greatest measured area of lichen, with an estimated 15.8 m^2 on rock surfaces. The study site at Ube's Cliff showed the smallest measured *C. linearis* population, with just 0.3 m^2 of lichen found on rock surfaces. EO 70 showed the greatest percent change, displaying a 48% decrease in measured area, decreasing from 5.99 m^2 in 2008 to 3.14 m^2 in 2019, a loss of 2.85 m^2.

Table 2. Total *C. linearis* area measurements and percent change by study site.

	2008 Data (m^2)	2019 Data (m^2)	% Change
EO 20	14.52	14.52	-0.01%
EO 13	12.39	15.88	28%
EO 70	5.99	3.14	-48%
EO 19	3.79	2.42	-36%
EO 7	3.24	1.87	-42%
EO 94	1.02	0.73	-29%
EO 69	3.32	3.77	14%
EO 15	2.63	3.63	38%
Ube's Cliff	-	0.32	-
Roan High Bluff	-	1.50	-
Colton's Cliff	-	1.39	-
Reservoir	-	2.57	-
			Mean= -9%

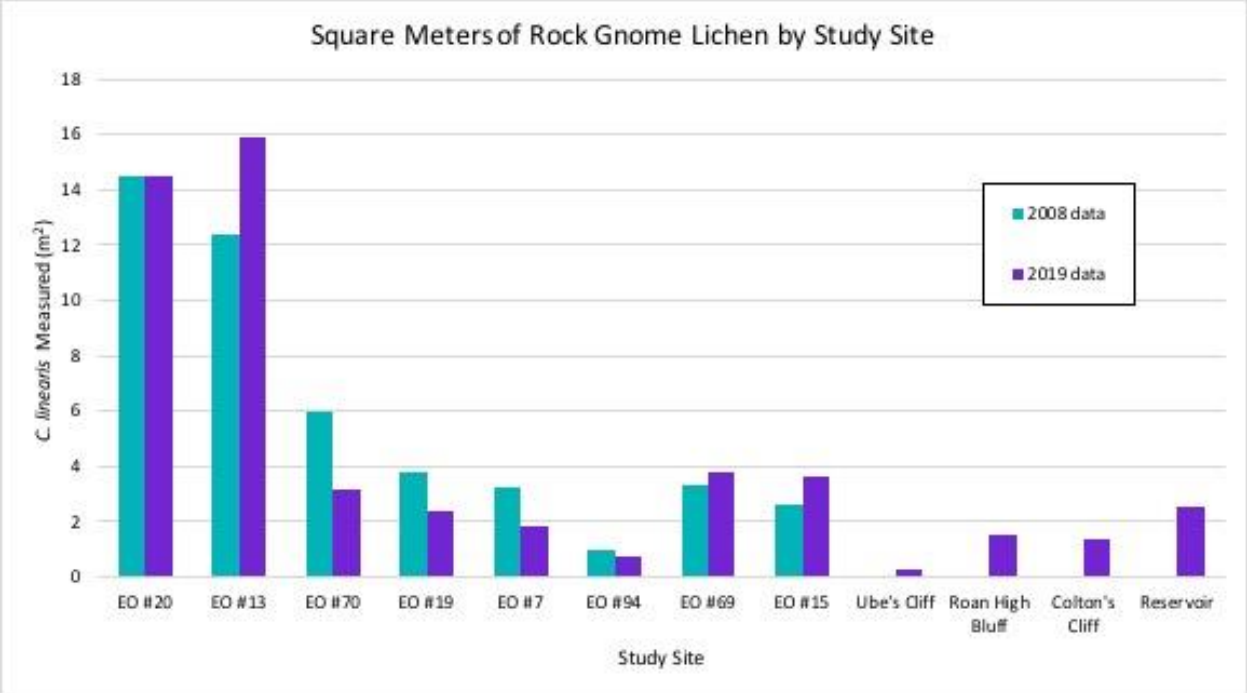

Figure 4. Total m^2 of *Cetradonia linearis* at each study site.

Figure 4 shows total measured area of *C. linearis* at each study site, with sites identified by either their EO number or site name. Green bars show data collected in the 2008 study, and purple bars show data collected in this study. The purple bars on the right side show the measurements collected at the four new sites surveyed for the first time.

4. Discussion

The findings of this study suggest generally decreasing cover area of *Cetradonia linearis*. Measurements that fell above or below this trend could be due to exceptional growth or dieback over the 11-year period since the most recent study or inconsistencies in the study design. The most likely scenario involves a combination of these two factors.

Due to the remote nature of the cliffside study sites, documenting and finding locations when collecting data was difficult and inconsistent. One challenge was the lack of location accuracy available when using the GPS smartphone application to navigate to study sites by coordinate location. This inaccuracy could have been alleviated by using more sophisticated GPS technology, had funding for such equipment been available.

Once study sites were located, a judgement was made as to how far to search in each direction before considering the site completely measured. With no consistent protocol to reference from past *C. linearis* surveys, this survey used a variety of techniques to decide when measurement was complete for each study site. In some cases, the topography of the site provided a clear endpoint, in areas where the researchers could realistically survey the entire potential habitat in the area. This was the case at sites where all rock faces were clearly visible and no more than 3 m tall. When topography limited the readily apparent habitat of a study site, researchers made judgement calls about the possible extent of measurement. Factors involved in these decisions included judgements of the safety of continued searching and the likelihood of additional *C. linearis* growth based on evidence of habitat suitability such as dampness and shade on rock faces. Inconsistencies in decisions between this study and the 2008 survey are likely responsible for some of the differences in measurement between the two. If the author chose to continue measurement in an area where previous researchers chose to turn back, the data would reflect measurement of additional areas not captured in the 2008 survey, and vice versa.

Even given the monitoring of new population sites of this species, it continues to fail to meet the conditions to downlist the species from endangered to threatened status, as per the USFWS recovery plan. The recovery plan states that, to be considered for downlisting, there must be evidence of at least 30 stable populations of *C. linearis* over a 5-year period, and that each stable population must exhibit no more than a 10% cumulative decline in coverage[27]. These conditions are not met by this study, due to the fact that it did not survey 30 sites. However, analysis of the smaller sampling of sites would still fail to suggest downlisting, because multiple sites show greater than 10% declines in area.

The results of this study agree with declining trends identified by previous research on the condition of *C. linearis.* The results also partially support the hypothesis; the average 9% decrease shows evidence of decline, but the study did not find that a majority of sites showed a decrease in area. Only half of the sites showed significant decreases in area.

5. Conclusion

Conserving endemic species such as this lichen will become an increasingly difficult task as the progression of global climate change transforms habitats worldwide. There is evidence to suggest that a species limited by geography is more vulnerable to global climate change[28]. This species is at particular risk because its specific habitat requirements mean it can only thrive in the southern Appalachians.

Some fast-growing plant species threatened by climate change can be translocated to areas where they could continue to thrive[29]. However, the slow growth rate of *C. linearis* makes it unsuitable for this approach[30], with an estimated generation time of 33 years[31]. Lichens are difficult to cultivate artificially, making them poor candidates for propagation and translocation options[32].

Ultimately, federal policy will guide the decisions of land managers towards the conservation of acceptable levels of *C. linearis*[33]. The species is not yet eligible for consideration of downlisting from endangered to threatened, according to the guidelines set forth in the recovery plan[34]. At present, *C. linearis* is protected as a federally endangered species, with the legislative backing of the Endangered Species Act to limit further disruption of its current range. However, without any data collection to verify its condition since 2008, additional studies are needed.

The data from this study were submitted to the National Park Service and may be used by the U.S. Fish and Wildlife Service as they complete the next 5-year review of *C. linearis* in the upcoming year[35]. These findings suggest that the Rock Gnome Lichen continues to require stringent protections wherever possible to slow its pattern of decline.

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7. References

1. Ford, W.M., Odom, R.H., Hale, P.E., and B.R. Chapman. 2000. Stand-age, stand characteristics, and landform effects on understory herbaceous communities in southern Appalachian cove-hardwoods. Biol. Conserv. 93: 237-246.
2. Ulrey, C. 2002. The relationship between soil fertility and the forests of the southern Appalachian region. Ph.D. dissertation, North Carolina State University, Raleigh, North Carolina.
3. Estill, J.C. and M.B. Cruzen. 2001. Phytogeography of rare plant species endemic to the Southeastern United States. Castanea. 66:3-23.
4. U.S. Fish and Wildlife Service. 1997. Recovery plan for the Rock Gnome Lichen (*Gymnoderma lineare*) (Evans) Yoshimura and Sharp. U.S. Fish and Wildlife Service, Southeast Region, Atlanta, GA. https://ecos.fws.gov/docs/recovery_plan/970930b.pdf. Accessed 01 March 2019.
5. USFWS, Recovery Plan. 1997.
6. Department of the Interior: U.S. Fish and Wildlife Service. Proposed Rule. "Endangered and Threatened Wildlife and Plants; Proposed Endangered Status for Gymnoderma Lineare." Federal Register 58, no. 247 (December 28, 1993): 68623-68627. https://ecos.fws.gov/docs/federal_register/fr2487.pdf. Accessed 01 March 2019.
7. Ulrey, C., Quintana-Ascencio, P.F., Kauffman, G., Smith, A.B., and E.S. Menges. 2016. Life at the top: Long-term demography, microclimatic refugia, and responses to climate change for a high-elevation southern Appalachian endemic plant. Biol. Conserv. 200: 80-92.
8. Dept. of Interior, Final Rule. 1995.
9. Wei, J. and T. Ahti. 2002. Cetradonia, a new genus in the new family Cetradoniaceae (Lecanorales, Ascomycota). Lichenologist 34: 19–31.
10. Allen, J.L., McKenzie, S.K., Sleith, R.S., and S.E. Alter. 2018. First genome-wide analysis of the endangered, endemic lichen *Cetradonia linearis* reveals isolation by distance and strong population structure. Am. J. Bot. 105: 1556-1567.
11. Department of the Interior: U.S. Fish and Wildlife Service. Final Rule. "Endangered and Threatened Wildlife and Plants; Gymnoderma Lineare (Rock Gnome Lichen) Determined To Be Endangered." Federal Register 60, no. 11 (January 18, 1995): 3557-3562. https://www.govinfo.gov/content/pkg/FR-1995-01-18/pdf/95-1174.pdf#page=1. Accessed 01 March 2019.
12. Gordon, R.E., Lacy, J.K., and J.R. Streeter. 1997. Conservation under the Endangered Species Act. Environ. Int. 23: 359-419.
13. Dept. of Interior, Final Rule. 1995.
14. USFWS, Recovery Plan. 1997.
15. Department of the Interior: U.S. Fish and Wildlife Service. Notice of Finding. "Endangered and Threatened Wildlife and Plants; Determination That Designation of Critical Habitat Is Not Prudent for the Rock Gnome

Lichen." Federal Register 66, no. 195 (October 9, 2001): 51445-51452. https://www.govinfo.gov/content/pkg/FR-2001-10-09/pdf/01-24660.pdf#page=1. Accessed 15 November 2019.
16. Environmental Conservation Online System. 2019. Species profile for Rock Gnome Lichen (*Gymnoderma lineare*). U.S. Fish and Wildlife Service, Southeast Region, Atlanta, GA. https://ecos.fws.gov/ecp0/profile/speciesProfile;jsessionid=AF381B80DDE165DD90EA74D8C676CB95?spcode=U001. Accessed 01 March 2019.
17. Goelz, J.C., Burk, T.E., and S.M. Zedaker. 1999. Long-term growth trends of red spruce and fraser fir at Mt. Rogers, Virginia and Mt. Mitchell, North Carolina. For. Ecol. Manage. 115: 49-59.
18. Dept. of Interior, Proposed Rule. 1993.
19. Dept. of Interior, Final Rule. 1995.
20. Anderson, C.C., and A. Rex. 2019. Preserving the scenic views from North Carolina's Blue Ridge Parkway: A decision support system for strategic land conservation planning. Appl. Geogr. 104:75-82.
21. Anderson and Rex, Preserving the scenic views. 75-82.
22. Dept. of Interior, Proposed Rule. 1993.
23. U.S. Fish and Wildlife Service. 2013. Rock Gnome Lichen (*Gymnoderma lineare*) 5-year review: Summary and Evaluation. U.S. Fish and Wildlife Service, Southeast Region, Atlanta, GA. https://ecos.fws.gov/docs/five_year_review/doc4142.pdf. Accessed 01 March 2019.
24. USFWS, 5-year review. 2013.
25. USFWS, 5-year review. 2013.
26. USFWS, Recovery Plan. 1997.
27. USFWS, Recovery Plan. 1997.
28. Thuiller, W., Lavorel, S., and M.B. Araújo. 2005. Niche properties and geographical extent as predictors of species sensitivity to climate change. Global Ecol. Biogeogr. 14: 347-357.
29. Schwartz, M.W. and T. G. Martin. 2013. Translocation of imperiled species under changing climates. Ann. N.Y. Acad. Sci. 1286: 15-28.
30. Allen, McKenzie, Sleith, and Alter. First genome-wide analysis. 1556-1567.
31. Allen, J., Lendemer, J., and T. McMullin. 2015. Cetradonia linearis: The IUCN Red List of Threatened Species 2015. International Union for Conservation of Nature and Natural Resources. http://dx.doi.org/10.2305/IUCN.UK.2015- 4.RLTS.T70386009A70386019.en. Accessed 15 November 2019.
32. Allen, McKenzie, Sleith, and Alter. First genome-wide analysis. 1556-1567.
33. Jackson, B.C., Pittillo, J.D., Allen, H.L, Wentworth, T.R., Bullock, B.P., and D.L. Loftis. 2009. Species diversity and composition in old growth and second growth rich coves of the southern Appalachian Mountains. Castanea. 74: 27-38.
34. USFWS, Recovery Plan. 1997.
35. Department of the Interior: U.S. Fish and Wildlife Service. Notice of initiation of reviews; request for information. "Endangered and Threatened Wildlife and Plants; Initiation of 5-Year Statues Reviews for 36 Southeastern Species." Federal Register 84, no. 70 (April 11, 2019): 14669-14672. https://www.govinfo.gov/content/pkg/FR-2019-04-11/pdf/2019-07175.pdf#page=1. Accessed 15 November 2019.