LICHEN INVENTORY OF WHITE ROCKS OPEN SPACE (CITY OF BOULDER, COLORADO)

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ABSTRACT.—A lichen inventory of White Rocks Open Space (City of Boulder, CO), a unique outcropping of exposed unstable sandstones, is presented. White Rocks is an ecologically important, ~40.5-ha (100-acre) protected area whose biological significance is in part attributable to geological and climatological history as well as degree of preservation, but also because it represents a biodiversity reservoir in a sea of agriculture and urban development. This inventory resulted in documentation of 56 species, including 1 new record to the United States, 1 new record to Colorado, 2 species new to science, and 2 additional species potentially new to science pending further study. Several species, though common at White Rocks, are locally rare within Boulder County and the Front Range Mountains of Colorado owing to a paucity of exposed sandstone. Such species instead have affinities to habitats more typical of eastern and far western Colorado, such as the state's high plains and sage-juniper scrub. A checklist of the 56 species is presented along with an assessment of taxon abundance and preliminary delimitation of 5 lichen communities. General discussion of ecology and management recommendations is provided. The present study is intended to begin the process of more fully documenting the lichen biota of Boulder City, Boulder County, and surrounding areas. Data herein also contribute new knowledge to the North American lichen biota as a whole via a comprehensive inventory of a sandstone formation, of which there exist relatively few. The inventory highlights the ecological significance of Open Space programs nationwide, particularly those in densely populated areas such as the Denver–Boulder–Longmont urban triangle. The discoveries reported here were made within a 10-min drive of the University of Colorado, demonstrating the potential for further discovery in Colorado lichenology.

RESUMEN.—Presentamos un inventario de líquenes de White Rocks Open Space (Ciudad de Boulder, Colorado), un afloramiento único de areniscas blandas expuestas. White Rocks es una área ecológica protegida importante de 40.5 ha (100 acres) de extensión, cuya importancia biológica es atribuible, en parte, a su historia geológica y climatológica, así como a su nivel de preservación, y a que representa una reserva de biodiversidad en un océano de agricultura y desarrollo urbano. Este inventario resultó en la documentación de 56 especies, incluyendo 1 nuevo registro en Estados Unidos, 1 nuevo registro en Colorado, 2 nuevas especies para la ciencia y, a la espera de nuevos estudios, 2 especies adicionales potencialmente nuevas para la ciencia. Varias especies, aunque habituales en White Rocks, raramente se localizan en el Condado de Boulder y en las Montañas Front Range de Colorado debido a la escasez de piedra arenisca expuesta. De hecho, estas especies tienen afinidad con hábitats más típicos del este y el lejano oeste de Colorado, como las llanuras y las arboladas de salvia y enebros del estado. Presentamos un listado de las 56 especies, junto con una evaluación de la abundancia del taxón y la delimitación preliminar de 5 comunidades de líquenes. Se proporciona una discusión general sobre la ecología y proporcionamos recomendaciones para su manejo. El presente estudio tiene como objetivo iniciar el proceso de documentación de la biota de líquenes de Boulder City, el condado y sus alrededores de forma más completa. Los datos que presentamos también contribuyen al nuevo conocimiento de la biota de líquenes de América del Norte a través del inventario completo de una formación de piedra arenisca, sobre las cuales existen relativamente pocos inventarios. El inventario que se describe aquí destaca la importancia ecológica de los programas de Open Space (Espacio Abierto) a lo largo del país, sobre todo aquellos llevados a cabo en zonas densamente pobladas, como el triángulo urbano Denver–Boulder–Longmont. Los descubrimientos aquí documentados se realizaron a una distancia de 10 minutos en automóvil de la Universidad de Colorado, lo que demuestra el potencial de futuros descubrimientos sobre liquenología en Colorado.

The Southern Rocky Mountains and adjacent prairies of Colorado (EPA Level III Ecoregions; Chapman et al. 2006) are characterized by a mosaic of environments typical of many montane portions of North America, particularly western North America (Will-Wolf et al. 2006). Boulder County alone ranges in

elevation from under 1524 m (5000 ft) to over 4267 m (14,000 ft), traversing mixed grass prairies (with tallgrass relicts), submontane forested foothills, and alpine environments above treeline. Among these dominant vegetation zones are patches of much rarer habitat types, such as outcroppings of sandstone or

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Fig. 1. Western end of sandstone outcropping at White Rocks Open Space, showing depressions and rises typical of large, upper rock shelf. The iconic "Flatiron" mountains of the City of Boulder toward the west are seen in background.

shale, eastern woodland relict forests, and fens. Given this biological mosaic and the general ecological significance of Colorado's native habitats, the lichen biota of the state is expected to be particularly rich and representative of numerous other ecosystems of western North America. Yet, a comprehensive account of lichens in Colorado is lacking. Instead, most literature on the biota exists as taxon-specific reports of occurrences. Shushan and Anderson (1969) provided the only attempt at a full checklist of the state's lichens (448 species treated), but this work was based entirely on literature reports rather than verification of specimens held in herbaria. Beyond this, there have been a limited number of regional inventory efforts (Anderson 1962, Dakota Sandstone; Egan 1970, Mt. Audubon alpine; Hale 1982, Flat Tops Wilderness Area; McCune et al. 1998, macrolichens associated with the USFS's Forest Health Monitoring Program; Shrestha and St. Clair 2009, San Juan–Rio Grand National Forest; see additional

references listed in Shushan and Anderson 1969, as well as a review of lichenological inventory work in Colorado presented in Shrestha and St. Clair 2009). The present contribution adds to the list of local or regional inventories in the state and serves as initial steps toward a revision of the lichen biota of Boulder County and surrounding areas.

White Rocks Open Space

White Rocks Open Space (Fig. 1) represents an ~40.5-ha (100-acre) ecologically important protected area, situated within and proximal to the eastern limits of the City of Boulder, Colorado. Its biological significance is in part attributable to its geological history, climatological history, and degree of preservation (MacPhail et al. 1970), but also because it represents an important biodiversity reservoir in a sea of agriculture and urban development (i.e., the Boulder–Denver–Longmont urban triangle). White Rocks is a rare and fragile outcropping of sandstone that rises directly

above the northern margin of Boulder Creek. The outcropping itself consists of a large 1- to 2-tiered sandstone shelf, with both horizontal and vertical exposed surfaces, and is ~1000 m in length oriented east–west. This prominent outcropping is flanked by a slightly more minor adjacent sandstone exposure directly to the east, which is some ~800 m in length. The outcrops belong to the Fox Hills Sandstone of the Laramie Formation, dating to ~67 million years (MacPhail et al. 1970, Weimer 1973, Hirschfeld 2013a, 2013b). The sandstone at White Rocks is, as the name implies, very white in color and composed primarily of quartz with minor amounts of montmorillonite clay. The White Rocks outcropping is known in particular for its peculiar jointed polygons or “turtlebacks” that characterize horizontal surfaces of the exposed rock (Fig. 2). These polygons are thought to be derived from fluctuating levels of moisture content in the montmorillonite clay, which combine with other environmental factors to induce stresses and cracks, culminating in polygons (Netoff 1971). The sandstone itself is extremely fragile and susceptible to weathering by foot travel or natural phenomena such as strong rains or high winds, but its erosion is slowed substantially by characteristic “case hardening” of the superficial-most surfaces of the turtlebacks, which derives from hardened clay strengthened by a biotic crust—primarily lichens.

Despite the small geographic size of White Rocks, the preserve is known to harbor several rare vascular plants as well as invertebrates, likely because of microhabitat diversity therein represented (Byars 1936, Weber 1949, 1970, Clark et al. 2001). Microhabitat differentiation at White Rocks is attributable to small-scale variation in relative humidity and water availability, exposure to wind and sun, mineral content, aspect and steepness of slopes (MacPhail et al. 1970), and the biotic environment itself. Examples of microhabitats represented at White Rocks include (1) large sandstone surfaces exposed to high radiation and winds intermixed with (2) shaded, deep to shallow crevices, (3) steep walls and ledges with overhangs that border riparian forests below, (4) large bowl-shaped depressions and smaller depressions (including turtlebacks) that become short-term catchments for water, (5) regions of sandstone with naturally higher clay content (and thus higher water-holding

capacity), (6) regions of sandstone with greater case hardening attributable to evaporative processes, clay content, and biotic crusts that leave behind a substrate that is more resistant to weathering, (7) bands of separation between Fox Hill Sandstone formations interrupted by exposed Pierre shales, and finally (8) mineral inclusions (chert or calcareous material) that form concretions and are intermixed among sandstones. Based on this diversity of microhabitats, the existing knowledge of the biota of White Rocks, and research elsewhere that has documented rich and unique lichen biotas on comparable sandstone formations (Fink 1904, Gilbert 1980, Showman 1987, Clark et al. 2001), White Rocks is hypothesized to host a unique community of lichens that is unrepresented or underrepresented in Boulder County, as well as across the state. Indeed, other sandstone outcrops in North America host rare or unusual species of lichens such as *Dibaeis absoluta* and *Ramalina petrina* (Skorepa 1973, Showman 1987).

Despite a history of research and general interest in the White Rocks Open Space, no inventory or assessment of lichens of this unique outcropping has been conducted. The most relevant prior works regarding the lichen biota of the immediate area (Colorado’s “Front Range”) are those of Anderson (1962) and Weber (*in* Hogan 1993). Anderson (1962) surveyed lichens of the Dakota sandstone of north central Colorado but excluded many crustose species from that work. Weber (*in* Hogan 1993) provided a synoptic list of the lichens of Boulder’s Mountain Parks, but this list lacks numerous species (especially crustose taxa) and taxonomy therein is outdated. Thus, the objective of the present investigation was to conduct an inventory of lichens of White Rocks Open Space. This inventory builds baseline information about the biodiversity of this important preserve, enables long-term conservation planning and resource management in a data-driven manner, facilitates future lichen taxonomic and ecological research in the area, and improves our capacity to educate the broader public about the importance of lichens in urban environments.

METHODS

Between June and September 2014, a lichen inventory of White Rocks Open Space (City of

Fig. 2. Turtlebacks (polygons) characteristic of horizontal surfaces at White Rocks, derived from fluctuating levels of moisture content in the montmorillinite clay, which combine with other environmental factors to induce stresses and cracks.

Fig. 3. Approximate boundaries of the White Rocks lichen inventory (red outline), which closely mirrors the area delimited by Boulder as the White Rocks Conservation Target.

Boulder, CO) was conducted over the course of 6 site visits. The area covered by this survey was ~40.5 ha (100 acres) (Fig. 3). The inventory was conducted primarily via new field collections rather than existing museum specimens, given the lack of adequate representation of this site among lichen herbaria (www.lichenportal.com), including the University of Colorado Herbarium (COLO). Occasional historical specimens from White Rocks housed at COLO were additionally studied as part of this work but yielded no additional species beyond those discovered during fieldwork (see Results).

Lichens were sampled using standard field collection techniques employed in previous studies (e.g., Lendemer and Tripp 2008, Lendemer et al. 2013). All accessible habitats and substrates contained within the ~40.5-ha (100-acre) preserve were targeted (i.e., the upper and lower flat rock outcrops, the immediately adjacent accessible portions of vertical rock faces, the lower floodplain zone that is densely vegetated and has few exposed rocks, and the adjacent prairie habitats including soil and plant substrates). To capture total diversity as best as possible, terricolous (soil), saxicolous (rock), corticolous (bark), and lignicolous (decaying wood) substrates were sampled. However, given the fragile nature of rock surfaces and the relatively small size of the preserve, care was taken to (1) remove small amounts of material for vouchers and to do so away from a pathway that is used by staff members for tours and monitoring, and (2) make only the minimal number of voucher specimens needed to produce a complete inventory (i.e., a given species was sampled only once unless additional collections were needed to confirm identifications, as in the case for several crustose species). Care was also taken to avoid the general area of a long-term Bald Eagle nest atop a large snag on the northern margin of Boulder Creek. Locality, habitat, substrate, and ecological data were recorded for all vouchers. Additionally, I estimated taxon abundance on a quantitative to qualitative scale with 5 rankings: rare, infrequent, occasional, common, and abundant. A species that was seen only once was considered rare, whereas a species that was seen 2–4 times was considered infrequent. Rankings of occasional, common, and abundant were assessed qualitatively rather than based on the

precise number of thalli seen. All collections were photographed in the field using a Nikon D7100 digital SLR with a 105-mm 1:1 macro lens and ring flash, in preparation for a field guide (Tripp in press). One to 2 vouchers per collection were made, and the primary set of specimens is deposited at the University of Colorado Herbarium, Museum of Natural History. Taxonomy and nomenclature follow Esslinger (2014) for the most part.

Chemistry was studied using standard spot test reagents as outlined in Brodo et al. (2001). Thin Layer Chromatography was conducted using Solvent C as outlined by Culberson and Kristinsson (1970). Measurements and micrographs of macroscopic and microscope structures were made as needed for identifications using an Olympus SZX10 stereomicroscope and an Olympus BX51 compound epifluorescence microscope equipped with a Retiga 2000R imaging system. Thin sections of thalli and ascomata were made by hand using a razor blade then mounted in water or iodine.

RESULTS

A total of 82 collections were made and photographed in the field, and the collections yielded 56 species of lichens (Table 1). The total number of species on a given substrate was as follows: 50 saxicolous, 4 corticolous, and 2 terricolous. Of the 56 species, 40 were crustose, 11 were foliose, 4 were squamulose, and 1 was fruticose. On an abundance scale with 5 rankings, the number of species per ranking was as follows: 9 abundant, 9 common, 19 occasional, 12 infrequent, and 7 rare (Table 1). These 82 collections also yielded 2 species new to science (Tripp and Lendemer 2015), 2 additional species putatively new to science (currently under further investigation), 1 new report to the United States, and 1 new report to Colorado (Table 1).

DISCUSSION

The present study serves as the first documentation of the lichen biota of a rare sandstone formation in Boulder County, Colorado. Somewhat remarkably, there have been very few lichen inventories of sandstone formations in North America. By far the most relevant to the present study was that of Anderson (1962), who inventoried the Dakota sandstone formation of northern Colorado. He documented

TABLE 1. Checklist of the lichens of White Rocks Open Space, City of Boulder, Colorado. Collection numbers refer to E. Tripp numbers, housed at the University of Colorado Herbarium (COLO). Taxon abundance was measured on a scale with 5 rankings: rare, infrequent, occasional, common, and abundant (see text for further clarification). Notes specific to a taxon report are given following the checklist.

Taxon	Collection number(s)	Abundance scale	Notes
<i>Acarospora obpallens</i> (Nyl. ex Hasse) Zahlbr.	E. Tripp & D. Clark 4817; E. Tripp <i>et al.</i> 4830	occasional	
<i>Acarospora socialis</i> H. Magn.	E. Tripp 4806	occasional	
<i>Acarospora</i> sp. nov.	E. Tripp 4820	rare	1
<i>Acarospora strigata</i> (Nyl.) Jatta	E. Tripp <i>et al.</i> 4559; E. Tripp 4808, 4868	abundant	
<i>Aspicilia cinerea</i> (L.) Körber	E. Tripp & V. Díaz 4880	occasional	
<i>Caloplaca atroflava</i> (Turner) Mong.	E. Tripp & D. Clark 4824	abundant	2
<i>Caloplaca decipiens</i> (Arnold) Blomb. & Forss.	E. Tripp <i>et al.</i> 4845	occasional	
<i>Caloplaca pratensis</i> Wetmore	E. Tripp <i>et al.</i> 4836; E. Tripp 4873	occasional	
<i>Caloplaca saxicola</i> (Hoffm.) Nordin	E. Tripp <i>et al.</i> 4838	common	
<i>Caloplaca sideritis</i> (Tuck.) Zahlbr.	E. Tripp <i>et al.</i> 4835	infrequent	
<i>Caloplaca subsclata</i> (Nyl.) Zahlbr.	E. Tripp <i>et al.</i> 4832	occasional	
<i>Caloplaca trachyphylla</i> (Tuck.) Zahlbr.	E. Tripp 4812	abundant	
<i>Candelariella clarkii</i> E. Tripp & Lendemer	E. Tripp & V. Díaz 4876	rare	3
<i>Candelariella rosulans</i> (Müll. Arg.) Zahlbr.	E. Tripp 4809, 4811; E. Tripp & V. Díaz 4877	abundant	
<i>Collema tenax</i> (Sw.) Ach.	E. Tripp & V. Díaz 4878	infrequent	
<i>Dermatocarpon americanum</i> Vain.	E. Tripp <i>et al.</i> 4844	infrequent	
<i>Dermatocarpon moulinsii</i> (Mont.) Zahlbr.	E. Tripp <i>et al.</i> 4828	rare	
<i>Diploschistes scruposus</i> (Schreber) Norman	E. Tripp & D. Clark 4857, 4859; E. Tripp 4867	occasional	
<i>Diplotomma venusta</i> (Körb.) Körb.	E. Tripp <i>et al.</i> 4849	occasional	
<i>Endocarpon pallidulum</i> (Nyl.) Nyl.	E. Tripp <i>et al.</i> 4829; E. Tripp & D. Clark 4850, 4860, E. Tripp 4862	occasional	
<i>Lecanora argophalis</i> (Ach.) Ach.	E. Tripp & D. Clark 4819, 4823	common	
<i>Lecanora garovaglii</i> (Körb.) Zahlbr.	E. Tripp 4813; E. Tripp <i>et al.</i> 4833; E. Tripp & D. Clark 4852	common	
<i>Lecanora muralis</i> (Schreber) Rabenh.	E. Tripp & D. Clark 4822	common	4
<i>Lecanora</i> sp. nov.	E. Tripp & D. Clark 4823	rare	
<i>Lecidea hoganii</i> E. Tripp & Lendemer	E. Tripp 4801, 4805	infrequent	3
<i>Lecidea</i> sp.	E. Tripp & V. Díaz 4881	infrequent	5
<i>Lecidea tessellata</i> Flörke	E. Tripp & D. Clark 4818, 4856	infrequent	6
<i>Lecidella carpathica</i> Körb.	E. Tripp & V. Díaz 4876	infrequent	
<i>Lecidella patarina</i> (A. Massal.) Knoph & Leuckert	E. Tripp 4869, 4870	abundant	
<i>Lecidella stigmattea</i> (Ach.) Hertel & Leuckert	E. Tripp <i>et al.</i> 4846	infrequent	

TABLE 1. Continued

Taxon	Collection number(s)	Abundance scale	Notes
<i>Montanella tominii</i> (Oxner) Divakar	<i>E. Tripp et al.</i> 4842	occasional	
<i>Phaeophyscia nigricans</i> (Flörke) Moberg	<i>E. Tripp</i> 4865	rare	
<i>Physciella melanchra</i> (Hue) Essl.	<i>E. Tripp</i> & <i>D. Clark</i> 4854; <i>E. Tripp</i> 4871	abundant	
<i>Placidium squamulosum</i> (Ach.) Breuss.	<i>E. Tripp</i> & <i>V. Díaz</i> 4882	occasional	
<i>Polysporina simplex</i> (Taylor) Vězda	<i>E. Tripp et al.</i> 4841	common	
<i>Psora tuckermanni</i> R.A. Anderson ex Tindal	<i>E. Tripp</i> 4804, <i>E. Tripp</i> & <i>V. Díaz</i> 4879	occasional	
<i>Rhizocarpon disporum</i> (Nägeli ex Hepp) Müll. Arg.	<i>E. Tripp</i> & <i>D. Clark</i> 4861	occasional	
<i>Rhizoplaca chrysoleuca</i> (Sm.) Zopf	<i>E. Tripp</i> & <i>D. Clark</i> 4816	common	
<i>Rinodina pyrina</i> (Ach.) Arnold	<i>E. Tripp</i> 4872	common	
<i>Rinodina straussii</i> J. Steiner	<i>E. Tripp</i> 4814	occasional	
<i>Rinodina venostana</i> Buschardt, & H. Mayrhofer	<i>E. Tripp</i> & <i>D. Clark</i> 4858	rare	7
<i>Stauriothele areolata</i> (Ach.) Lettau	<i>E. Tripp</i> 4802, 4803, 4863	abundant	
<i>Verrucaria beltraminiana</i> (A. Massal.) Trevis.	<i>E. Tripp</i> 4810	common	8
<i>Verrucaria furfuracea</i> (B. de Lesd.) Breuss	<i>E. Tripp et al.</i> 4831	infrequent	
<i>Verrucaria glaucovirens</i> Grunmann	<i>E. Tripp</i> 4851	infrequent	
<i>Xanthomendoza fallax</i> (Hepp ex Arnold) Søchting, Kärnefelt & S.Y. Kondr.	<i>E. Tripp</i> & <i>D. Clark</i> 4853	abundant	
<i>Xanthomendoza galericulata</i> L. Lindblom	<i>E. Tripp et al.</i> 4827	abundant	
<i>Xanthoparmelia coloradoensis</i> (Gyelnik) Hale	<i>E. Tripp et al.</i> 4840; <i>E. Tripp</i> & <i>D. Clark</i> 4855	occasional	
<i>Xanthoparmelia lavicola</i> (Gyelnik) Hale	<i>E. Tripp et al.</i> 4839, <i>E. Tripp</i> & <i>V. Díaz</i> 4874	occasional	
<i>Xanthoria elegans</i> (Link) Th. Fr.	<i>E. Tripp et al.</i> 4843	occasional	

Notes

1. An undescribed taxon that is still under investigation; a manuscript reporting this species is forthcoming.
2. Most material resembling this taxon (i.e., red apothecia, inconspicuous thalli) within North American herbaria is identified as *Caloplaca arenaria* (Pers.) Müll. Arg. The collection from White Rocks has a definitive, albeit thin, gray thallus that reacts K+ purple in water mount and does not appear to be obviously parasitic on other lichens. As such, the name *Caloplaca atrofaca* is here applied to this collection, instead of *C. arenaria* or *C. epithallina*.
3. The manuscript reporting these 2 new species includes molecular exploration of evolutionary relationships to close relatives (Tripp and Lendemer 2015).
4. This is an usnic-acid containing species that is not readily ascribable to anything in Shiwa's monograph (2007) of the *Lecanora dispersa* complex. S
5. Similar to *Lecidea hoggii*, this collection has a hymenium variably stained with a pink pigment; it however differs from *L. hoggii* by its turquoise ephymenium, 1- medulla, and much thinner thallus. More collections of the *Lecidea* and *Lecidella* community are needed to gauge the commonness of this taxon. It is included in the above checklist because it represents a different entity from congeners present at White Rocks.
6. The name *Lecidea tessellata* is unsatisfactory for this taxon; for example, collections from White Rocks have an 1- medulla, a dark gray thallus, and lack a black prothallus. However, until the genus or this species is fully revised in western North America and the many entities contained within *L. tessellata* are separated out, this is the most suitable name for White Rocks material.
7. *Rinodina venostana* was recently reported as new to North America, from a sandstone formation in Saskatchewan (Freebury 2014). This collection reported here serves as the first documentation of *R. venostana* in the United States, although there is some possibility that eventually, it might be separated out as a taxon new to science (J. Sheard, personal communication).
8. This record represents the first confirmed report of this species for Colorado.

130 species over a stretch of ~105 km (65 mi), ranging from Boulder northwards along the Front Range of the Rocky Mountains (see additional reports of psammophilous species added by Anderson and Carmer 1974). Beyond Anderson's study, Hale (1982) studied the lichens of Flat Tops Wilderness Area in Routt and White River National Forests, Colorado, but only a portion of the survey area contains exposed sandstone. Fink (1904) studied the lichen composition of sandstone riprap habitat in Iowa, an artificial habitat some 30 years old at the time of Fink's work. Showman (1987) studied the macrolichens of Crane Hollow in Ohio, but that site was mostly forested and contained only very small outcroppings of sandstone. Finally, Rushforth et al. (1982) studied the lichens of Zion National Park and found that species diversity was highest on sandstone boulders, but that study was ecological rather than taxonomic and no checklist was presented. Thus, the present contribution fills a niche among modern lichen checklists within North America.

Lichen Communities of White Rocks

A preliminary circumscription of lichen communities present at White Rocks is presented below. These communities are not based on quantitative composition data (e.g., see Will-Wolf et al. 2006), nor are they interpreted in light of environmental variables and variation present at White Rocks. Rather, it is intended that the discussion below serves as a first pass at understanding general community types, which can then be used by ecologists during future attempts to more quantitatively define lichen communities at the site. These preliminary community circumscriptions can also be used by Open Space management staff in conservation or other ecological studies of the White Rocks lichen biota.

Five lichen communities present at White Rocks are described below; the first 3 are relatively common, whereas the last 2 are minor. Conspicuously absent from White Rocks were common species of the lower montane foothills of Boulder County with affinity to moister environments (e.g., north-facing slopes) such as *Nephroma parile*, *Parmelia saxatilis*, *Peltigera canina*, *Physconia enteroxantha*, *Physconia muscigena*, and *Protoparmelia badia*.

HORIZONTAL, LOOSE SANDSTONE (HLS).—This was by far the most commonly available

surface and also represents the most diverse lichen community at White Rocks. The fragile nature of this community suggests that several of the constituent lichens could be thought of as biotic soil crusts with important ecological roles in slowing erosion. The following species are common constituents of HLS: *Aspicilia cinerea*, *Acarospora strigata*, *Caloplaca atroflava*, *Caloplaca pratensis*, *Candelariella rosulans*, *Lecanora argopholis*, *Lecanora garovaglii*, *Lecanora muralis*, *Lecidea patavina*, *Xanthoparmelia coloradoënsis*, *Xanthoparmelia laviicola*. This community is dominated by *Candelariella rosulans* and *Lecidea patavina*.

TILTED, HARD SANDSTONE (THS).—Boulders of varying sizes and consisting of sandstone that is conspicuously harder in texture than HLS dominate portions of the upper shelf at White Rocks. Lichens within this community occur on tilted to vertical surfaces, or on the tops of these boulders. The following species are common constituents of THS: *Acarospora obpallens*, *Acarospora socialis*, *Caloplaca saxicola*, *Caloplaca trachyphylla*, *Dermatocarpon americanum* (usually in rock crevices), *Diploschistes scruposus*, *Diplotomma venustum*, *Lecanora flowersiana*, *Lichinella stipatula*, *Montanelia tominii*, *Polysporina simplex*, *Psora tuckermanii* (always in rock crevices), *Rhizocarpon disporum*, *Rhizoplaca chrysouleuca*, *Rinodina straussii*, *Staurothele areolata*, and *Xanthomendoza trachyphylla*. This community is dominated by the small but pervasive crustose species *Staurothele areolata*.

SHADED ROCK OVERHANG (SRO).—This habitat is limited in both size and lichen diversity at White Rocks. The only species that is dominant in large, shaded rock overhangs is *Lepraria finkii*.

SOIL CRUST (SC).—At White Rocks, there is a conspicuous community of lichens that only inhabit the junction where sandstone and vegetation meet. These species also extend onto terricolous substrates of vegetated soils. This community represents biotic soil crusts in the strict sense of the phrase, but note that numerous species of the HLS community also fall under the scope of biotic soil crust communities given the extremely loose and fragile nature of those horizontal sandstone surfaces. The SC community consists primarily of *Endocarpon pallidulum* and *Placidium squamulosum*.

CORTICOLOUS SURFACE (CS).—The corticolous biota at White Rocks was, together

with SROs, the most species-poor of all 5 communities (corticolous substrates were similarly poor in McCune et al. 1998). *Celtis reticulata*, *Oligosporus filifolius*, and *Rhus trilobata* were the most important vascular plant substrates. The following 4 species dominate the CS community: *Physciella melanchra*, *Rinodina pyrina*, *Xanthomendoza fallax*, and *Xanthomendoza galericulata*.

Rare and Unusual Lichens at White Rocks

Although many species found at White Rocks are relatively common in similar habitats of western North America, sandstone outcroppings are unusual in the Front Range Mountains of Colorado. Given this, species such as *Acarospora obpallens*, *Endocarpon pallidulum*, *Lecidella carpathica*, *Lecidella stigmathea*, *Lichenella nigritella*, *Lichenella stipatula*, *Phaeophyscia nigricans*, and *Verrucaria furfuracea* are relatively uncommon elements of the local lichen biota and can be found more commonly in more arid portions of the state, such as prairies and sagebrush or juniper scrub.

Four species at White Rocks represent taxa unknown to science or putatively unknown to science. Two of these, *Candelariella clarkii* and *Lecidea hoganii*, were treated in detail in Tripp and Lendemer (2015). Two others (*Acarospora* sp. and *Lecanora* sp.) are under further investigation and will be treated in a future manuscript. Both the new *Candelariella* and the new *Lecidea* are extremely rare at White Rocks: the former was found only once and the latter only twice. Extensive searches through suitable named and unnamed material in the COLO Herbarium failed to produce further specimens that can be attributed to these species. As such, it is likely that both species are rare locally and globally, and we have recommended that both be considered Critically Endangered under current IUCN conservation assessment guidelines (Tripp and Lendemer 2015). Recent work at other exposed sandstone sites of the Fox Hills Formation has similarly yielded new, rare species (Westberg et al. 2011). Finally, *Rinodina venostana* represents the first report of this taxon from the United States, and *Verrucaria beltraminiana* represents the first confirmed report of this species for Colorado (see Table 1).

This inventory demonstrates that sandstone habitats in the Southern Rockies are

underexplored lichenologically yet host diverse and unique communities. Moreover, these discoveries were made within a 10-min drive of the University of Colorado, whose herbarium hosts one of the largest and most active collections of lichens in western North America. This demonstrates the potential for discovery that remains in Colorado, even within or near dense urban areas.

CONCLUSIONS

The present study represents one of the most comprehensive, modern lichen inventories of a site within or around the Southern Rocky Mountain ecoregion. The primary purpose of this research was to provide a checklist of the lichens of this unusual habitat that can be used by the City of Boulder's Open Space and Mountain Parks research and administrative staff in managing, protecting, and continuing to learn from our local biological resources. It is anticipated that this study will open additional avenues of lichen research and conservation at White Rocks. With a baseline now in place, these data will for example enable a study of lichen succession in an area with already higher-than-average rates of erosion. Additionally, as comprehensive inventories of additional sites are made and become available, these data will contribute to future calculations of biodiversity statistics across the state (e.g., levels of alpha and beta diversity and impacts of ecological and climatological gradients on lichen biodiversity).

White Rocks hosts a rich and, within Boulder County, unique lichen community. Sandstone formations are particularly sensitive landscapes. Excessive foot traffic, thin soils, and high rates of erosion create a relatively unstable environment and one with potentially slower rates of regeneration. Given recent development and continued habitat destruction throughout North America, the lichen inventory described herein is particularly timely and highlights the ecological significance of Open Space programs nationwide, particularly those in densely populated areas such as the Denver–Boulder–Longmont urban triangle.

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