Baseline population density estimates of ‘Wyoming range lichens’ 
(Xanthoparmelia wyomingica) relative to mountain goats in the La Sal 
Mountains, Utah, USA

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Abstract. The La Sal Mountains in eastern Utah, USA, contain the only alpine habitat on the Colorado Plateau in Utah. These unique sky island alpine communities are vulnerable to a wide range of disturbances, including factors associated with the recent introduction of mountain goats (O. americanus). In order to monitor the potential impact of O. americanus, and other disturbances on alpine communities in the La Sals, we provide baseline estimate population densities for ‘Wyoming range lichens’ (Xanthoparmelia wyomingica) at two sites near Mount Laurel. Using the point-centered quarter and the quartered-neighbor methods, we estimate ca. 20 individuals/m² at both sites. These estimates provide an important baseline for long-term monitoring of vulnerable alpine sites on the Colorado Plateau.

Key words. Alpine habitats, Biomonitoring, climate change, Colorado Plateau, distance methods, disturbance.

INTRODUCTION

Alpine habitats support unique communities, often harboring a number of rare or sensitive species, including lichens (Imshaug 1957, Billings & Mooney 1968). Members of these communities are vulnerable to a wide range of perturbations including climate change (Wilson & Nilsson 2009, Fowler & Smith 2010, Ernakovich et al. 2014), grazing pressure (Gao et al. 2007, St. Clair et al. 2007), and invasive species (Muñoz & Cavieres 2008), among other disturbances. In 2013, mountain goats (Oreamnos americanus) were released in the La Sal Mountains, on the Colorado Plateau in eastern Utah, USA. The O. americanus population in the La Sals is currently ca.100 animals, and the herd unit management plan has an objective of 200 individuals. However, the potential impacts of the introduced large ungulates in the La Sal Mountains on other components of the alpine community remain unclear, considering the limited availability of suitable habitat, particularly vegetated alpine turf.

Mountain goats may impact lichen communities through density-dependent physical disturbances (Reid 1983; Fig. 1), grazing lichens as a food source (Hjeljord 1973), and indirect impacts through altering alpine community composition (Fox et al. 1989). The mountain goat population in the La Sal Mountains overwinters and grazes on wind swept, high alpine ridges, and may have a disproportionate impact on alpine communities when compared to other ungulate populations that migrate to lower elevations during winter months. However, the potential impact of this introduced goat population on alpine lichens has not yet been evaluated.

To monitor the potential impact of O. americanus, and other potential disturbances on alpine communities in the La Sals, here we provide baseline estimates of population density for ‘Wyoming range lichens’, mycobiont = Xanthoparmelia wyomingica (Gyelnik) Hale, at two sites.
Figure 1. Alpine turf near the summit of Mount Mellenthin (La Sal Range, Utah, USA) with evidence of physical disturbance by mountain goats (*Oreamnos americanus*).

**MATERIALS AND METHODS**

*Site description*—Sites were selected in the ‘middle group’ of the La Sal Mountains on the western side of the locally named Mount Laurel, a minor peak of 3740 m (12,271 ft) in elevation (Fig. 2). This area was selected due to the relatively high density of ‘Wyoming range lichens’ (*X. wyomingica*), frequent use by *O. americanus*, and distinct substrate types supporting ‘Wyoming range lichens’ populations, e.g., rocky hummocks vs. alpine turf (Fig. 2, lower panels). ‘Wyoming range lichens’ were sampled along two, 10 m. transects during the summer of 2019, with sampling points set every 0.5 m. One transect, ‘S1a’, was placed on a rocky hummock at the western base of Mount Laurel (eastern transect point: WGS 84 Lat. 38.45551, Long. -109.2407; western transect point: Lat. 38.45548, Lon. -109.24083) elevation 3625 m.a.s.l. The second transect, ‘S2a’, was placed in alpine sod/soil habitat in the saddle west of Mount Laurel (eastern transect point: Lat. 38.45604, Lon. -109.24326; western transect point: Lat. 38.45606, Lon. -109.24337) elevation 3564 m.a.s.l. While transects were not marked with physical monumentation, GPS and photographic (Fig. 2) monumentation will facilitate accurate transect identification for future re-sampling efforts.

*Population density estimates*—We used the point-centered quarter (PCQM; Cottam & Curtis 1956; Cottam et al. 1953) and the quartered-neighbor (QNM; Krebs 1999; Zhu & Zhang 2009) to estimate population density of ‘Wyoming Range lichens’ at both transects following Leavitt & St. Clair (2011). Initial surveys indicated that the transects were dominated by *X. wyomingica*, with all vouchered specimens containing usnic and salazinic acids (identified using thin layer chromatography). However, no attempts were made to differentiate and exclude the limited number of other closely related *Xanthoparmelia* species from sampling that potentially occur at these sites, e.g., *X. neocumberlandia* T.H. Nash & Elix, *X. coloradoënsis* (Gyelnik) Hale. These two later species tend to be at least partially attached to the substrate, but we did not want to disturb these individuals. We tested for random spatial distribution patterns using Hopkins’ test for statistic for randomness (Hopkins 1954). We used Diggle’s compound estimator (Diggle 1975) calculated from both distance methods to minimize the bias of each method’s sensitivity to spatial patterns.
**Figure 2.** Arial view of the location of the two sampled transects west of Mount Laurel – ‘S1a’ is located on a rocky hummock at the base of Mount Laurel and ‘S2a’ is located in alpine sod at the saddle between Mount Laurel to the east and an unnamed hill to the west; scale bar = 80 m. Lower right panel, transect ‘S1a’, looking northwest towards Gold Basin. Lower left panel transect ‘S2a’, from saddle looking east towards Mount Laurel.
RESULTS AND DISCUSSION

Population density of ‘Wyoming range lichens’ was estimated to be ca. 20 individuals/m² (Diggle’s compound estimator) at both sites, ranging between ca. 12 individuals/m² for the PCQM at ‘S1a’ to 33 individuals/m² using the QNM at the same site (Table 1). PCQM and QNM estimates were more consistent at ‘S2a’, with between ca. 15 individuals/m² (PCQM) to ca. 25 individuals/m² (QNM). The Hopkins test rejected the null hypothesis of randomness in favor of a clumped pattern at both sites; hence, Diggle’s compound estimator likely provides more accurate estimates of population density. The population density estimates at the two sampled sites in the La Sals are in line with estimates from other X. wyomingica populations in the nearby Aquarius Plateau in southern Utah (Leavitt and St. Clair 2011).

Table 1. Population density estimates at two sites near the base of Mount Laurel in the ‘middle group’ of the La Sal Mountains, Utah, USA. Estimates included the point-centered-quarter (PCQM) and quartered neighbor (QNM) methods; Hopkins test of random spatial patterns (h); and Diggle’s estimator of population density. PCQM, QNM and Diggle’s estimates are individuals/m², with standard error for PCQM and QNM estimates in parentheses.

<table>
<thead>
<tr>
<th>Site</th>
<th>PCQM (mean ± SE)</th>
<th>QNM (mean ± SE)</th>
<th>h (mean ± SE)</th>
<th>Diggle’s estimator (mean ± SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘S2a’</td>
<td>15.31 (0.048)</td>
<td>24.96 (0.078)</td>
<td>1.63</td>
<td>19.55 (4.90)</td>
</tr>
<tr>
<td>‘S1a’</td>
<td>11.88 (0.037)</td>
<td>32.52 (0.102)</td>
<td>2.74</td>
<td>19.65 (5.57)</td>
</tr>
</tbody>
</table>

Little is currently known in regard to how soil-dwelling Xanthoparmelia populations respond to disturbances such as grazing pressures and changing climate. Mountain goat behavior often promotes site instability through intense use of conspicuous beds and wallows in alpine areas (Figs. 1 & 2). Continued use of these sites has been shown to eliminate vegetation (Reid 1983). With the limited amount of alpine turf in the La Sal mountains, we predict that X. wyomingica population density will decrease through time due to physical disturbances from O. americanus. Xanthoparmelia species are unlikely to be a major food sources, despite their relatively high abundance and biomass. In fact, the closely related tumbleweed lichen (reported as X. chlorochroa) has been implicated in the mass deaths of elk and domesticated sheep (Cook et al. 2007, Dailey et al. 2008, Raisbeck et al. 2011), although toxicity and pathogenesis of poisoning by Xanthoparmelia spp. in O. americanus has not been documented to our knowledge. Norstictic acid-containing ‘Wyoming range lichens’ appear to be less palatable than those containing usnic and salazinic acids/or acid deficient (Rosentreter personal communication), and future studies will be required to elucidate the influence of secondary metabolite variation in ungulate grazing behavior.

For steppe specialists, such as X. chlorochroa and X. wyomingica (frequently occurring at higher altitude steppe and alpine communities), abundance may be related to grazing intensity, with moderate disturbances likely promoting lichen abundance (MacCracken et al. 1983, Rosentreter 1993). We predict that while moderate grazing pressure may increase Xanthoparmelia spp. abundance at the upper rocky hummock site, ‘S1a’, populations in alpine sod (‘S2a’) may be more vulnerable to physical disturbances from O. americanus due to inherently more fragile nature of the soil-dominated substrate (Fig. 2).

In addition to physical disturbances in alpine communities, lichens may be disproportionately impacted by stochastic events caused by climate change (Jentsch et al. 2007, Bokhorst et al. 2008, Bokhorst et al. 2009). Increased frequency of winter thaw and ground-icing events accompanying warmer winters will likely have a detrimental impact on some lichens (Bjerke 2009, Bjerke 2011). Ground-dwelling Xanthoparmelia populations may be particularly susceptible to ice encapsulation at mild subfreezing temperatures (Leavitt and St. Clair 2011). In addition, vagrant lichens appear to be better adapted for utilization of liquid water than air humidity (Rosentreter 1993, Pérez-Ortega et al. 2012). Increasing snowpack variability and summer
precipitation events associated with changing climate will impact hydrologic and ecologic systems in montane regions throughout western North America (Scalzitti et al. 2016). However, specific responses of most lichens, including *Xanthoparmelia* species, to projected warmer and more unstable climatic conditions on the Colorado Plateau remain unknown.

**Future prospects**— The results presented here provide an important baseline for monitoring vulnerable alpine sites on the Colorado Plateau. Ongoing, long-term monitoring at sites with established baseline estimates of population density will be crucial to understanding the impact of physical disturbances from grazing and factors associated with climate change throughout this region. However, additional research characterizing the response of *Xanthoparmelia* species, and other lichens, to physical disturbances and changing climatic conditions will be required to effectively interpret potential changes in population density in alpine habitats in the La Sal Mountains.

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**LITERATURE CITED**


