Soils and rare plant habitat in the Colorado Plateau

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Key words: endemic plant, soil depth, species conservation, rangeland planning

Abstract

It is common for botanists and plant ecologists to study the soil of rare plants by sampling the soil surface horizon and analyzing pH and a few other chemical properties, often looking for a "silver bullet" to explain rare plant distribution. It is rare in these studies to investigate the whole soil in a landscape context. However, multiple pedological studies of rare plants in the arid and semiarid climate of western North America's Colorado Plateau reveal a unique soil physical habitat where few other plants exist. These rare, endemic plants adapted and survived in soil environments and edaphic conditions that most plants are unable to survive in, effectively creating a competition-free zone. Shrubby reed-mustard (*Schoenocrambe suffrutescens*), Jones' waxy dogbane (*Cycladenia humilis* var. *jonesii*), Parachute beardtongue (*Penstemon debilis*), and Debeque phacelia (*Phacelia submutica*) all occur in shallow soils in distinct sedimentary rock strata. In the case of *Schoenocrambe suffrutescens*, the habitat was successfully modelled using remotely sensed and topographic data in order to locate new occurrences, and we believe there is potential for modelling potential habitat for the other species. In some cases, the harsh soil physical environment was also associated with one or more chemical properties that are challenging for most common plants. Understanding where these rare endemic plants occur and how they persist facilitates rangeland planning decisions.

Introduction

It is common for botanists and plant ecologists to study the soil of rare plants by sampling the soil surface horizon and analyzing pH and a few other chemical properties, often looking for a "silver bullet" to explain rare plant distribution. It is rare in these studies to investigate the whole soil in a landscape context. There is a relatively high concentration of rare endemic plants in the Colorado Plateau known only to occur in small, specific geographic areas, generally fragmented into smaller subpopulations.

The Colorado Plateau was a basin subject to more than 300 million years of sediment deposition. About 20 million years before present, the region began uplifting and continues to uplift today, reaching elevations of more than 3000 m. The region of 390,000 km^2, centered at the four corners where the states of Utah Arizona, New Mexico and Colorado meet, was dissected by the Colorado River and its tributaries, resulting in tablelands, plateaus, mesas. The elevation ranges from 750 to 3840, the mean elevation is 1936 m, and the climate is mainly arid to semiarid.

We hypothesize that the uplift and dissection of the Colorado Plateau over 20 million years has led to genetic isolation and speciation of plants. The objective of this study was to determine the soil and landscape habitat of four rare endemic plant species in the Colorado Plateau to develop concepts that can help guide rangeland planning that is compatible with conservation efforts.

Methods

Three of the plant species, *Penstemon debilis*, *Cycladenia humilis* var. *jonesii*, and *Phacelia submutica* are listed by the US Fish and Wildlife Service (USFWS) as "Threatened" and one, *Schoenocrambe suffrutescens*, is listed as "Endangered" (USFWS, 2024). *Penstemon debilis*, commonly known as Parachute beardtongue and thought to tolerate toxic trace elements, is a mat-forming perennial that was reported to occur only in the Parachute Creek member of the Green River Formation in western Colorado (McMullen, 1998). *Cycladenia humilis* var. *jonesii*, commonly known as Jones' waxy dogbane and reported to be a gypsophile (Welsh et al., 2015), sometimes thought to be an indicator of selenium (Se) and/or uranium (U), is a perennial that occurs in several Jurassic and Triassic sedimentary rock formations of southern Utah and northern Arizona. *Phacelia submutica* commonly known as Debeque phacelia and thought to tolerate high shrink-swell capacity in soil, is a tiny, low-growing spring annual that occurs only in western Colorado in the "clay barrens" of the Atwell Gulch and Shire members of the Tertiary Wasatch Formation (Langton, 2015). *Schoenocrambe suffrutescens*, commonly known as shrubby reed-mustard and also classified in the literature as *Hesperidanthus suffrutescens* and *Glaucocarpum suffrutescens* (Lewis and Schupp, 2014), is a perennial that occurs only in northeastern Utah in the Green River Formation.

We investigated the soil and landscape characteristics at five populations for *Penstemon debilis*, four populations for *Cycladenia humilis* var. *jonesii* in southern Utah, five populations of *Phacelia submutica*, and three populations of *Schoenocrambe suffrutescens*. We manually excavated soil pits to 1m depth or to a hard rock contact, whichever was shallower. We described soil morphology and sampled soils following standard methods (Schoeneberger et al., 2012). We sampled soil at least 50 cm away from the rare plant in its habitat. In the case of *Schoenocrambe suffrutescens* we also sampled at least 50 cm away from a similar plant in a similar habitat. We determined selected soil physical and chemical properties in the laboratory, including particle-size distribution, pH, calcium carbonate equivalent, gypsum content (if present), and total elemental composition (Soil Survey Staff, 2014). In the case of *Schoenocrambe suffrutescens* we also modeled topographic and remotely sensed spectral characteristics (Baker et al. 2016).

Results

Penstemon debilis occurs in soils formed in shale of the Parachute Creek member of the Tertiary Green River Formation. Plants occurred at elevations ranging from 2425 to 2740 m on steep slopes of 45 to 67% gradient. The soils surface was bare, with very high rock fragment content between very few plants. Soils were shallow, ranging from 17 to 55 cm in depth, and roots were observed in between rock fragments in the fractured shale. In contrast to these similar physical properties, different populations had dissimilar soil chemical properties, with pH ranging from 6.8 to 8.3 and the total elemental content of Se, As, and Hg highly variable. Plants were observed to survive on steep, unstable, shale slopes, with stems appearing to elongate as leaves were buried by shifting talus (McMullen, 1998).

Cycladenia humilis var. *jonesii* soils all had similar site and soil physical properties (Boettinger and Sipes, 1997). The plants occurred on stable slopes of 5 to 50% gradient. Soils were mostly bare, with few plants. Soil parent materials ranged from mudstone to shale to siltstone, all fractured in situ. Soil depth to bedrock ranged from 25 to 50 cm in depth with extremely high rock fragment content in subsoil (90 to nearly 100%

by volume) in the lower part. Roots were observed in between rock fragments in the fractured rock. We were unable to sample sufficient fine-earth fraction material (<2 mm) to characterize texture in the laboratory for most horizons. As with *P. debilis*, the soils at each population had dissimilar soil chemical properties. The soil pH ranged from 6.8 to 8.3. Trace element content of the whole soil (<2-mm and rock fragments) was highly variable. Gypsum was present in soils of only half of the populations – soils in the Castle Valley and Onion Creek populations in southeastern Utah contained gypsum, whereas soils in the San Rafael Swell and Deer Creek populations in southcentral Utah lacked gypsum, which is evidence that *Cycladenia humilis* var. *jonesii* is not an obligate gypsophile.

Phacelia submutica soils all had similar site and soil physical properties (Langton, 2015). Plants occurred on stable slopes of 5 to 85% gradient. Elevation ranged from 1,532 to 1,958 m. Soil were bare with very few plants, and all were less than 30 cm depth to hard bedrock. Soil textures were clay with high clay content ranging from 40 to 85% with a mean of 70%. Soils all had strongly alkaline pH, ranging from 7.7 to 9.7 with a mean of 9.0. The electrical conductivity of some soils was relatively high (3 to 5 dS m^{-1}) in the horizon directly overlying bedrock. The roots of these short-lived annuals did not extend to the bedrock.

Schoenocrambe suffrutescens soils were generally bare with very few plants. The depth to hard bedrock in all soils was less than 59 cm, with most ranging from 9 to 39 cm, and all had high rock fragments (greater than 50% by volume). Soil textures were silt loam to loam. All soils were strongly alkaline, with pH ranging from 8.0 to 9.0, with a mean pH of 8.7. Calcium carbonate equivalent was greater than 50% by mass in the fine earth fraction. Available phosphorus (P) was low (less than <2 mg kg^{-1} soil). The edaphic habitat for *Schoenocrambe suffrutescens* was topographically and spectrally distinct, which facilitated modelling of potential habitat and subsequent identification of new occurrences (Baker et al., 2016).

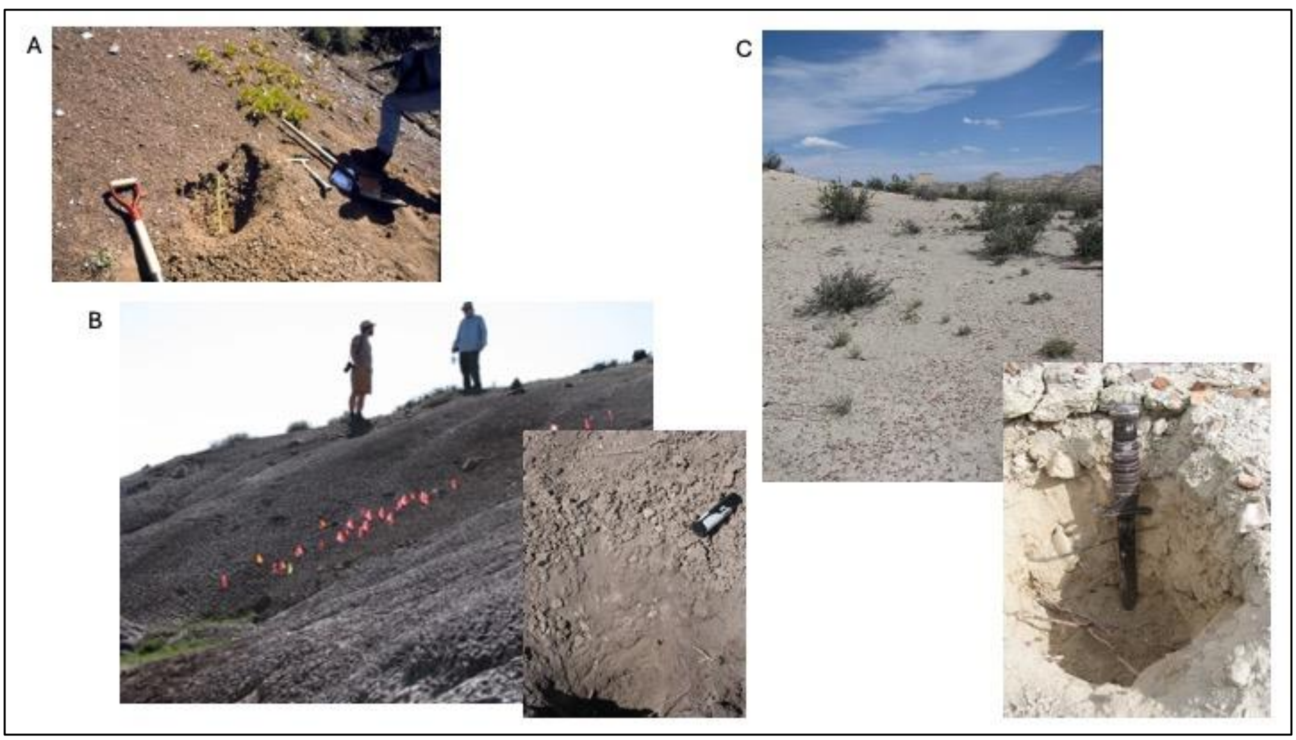

Fig. 1. Typical landscapes and soils of rare endemic plants of the Colorado Plateau. A) *Cycladenia humilis* var. *jonesii* plants (top) and high rock fragment soil on a steep slope in southeastern Utah; depth of soil is 35 cm. B) Red flags mark locations of *Phacelia submutica* on a steep slope in western Colorado; depth of

soil is 30 cm (inset photo). C) *Schoenocrambe suffrutescens* landscape on slope in northeastern Utah; depth of soil is 29 cm (inset photo). All photos by senior author.

Discussion

The key commonality is that all four endemic plant species of the Colorado Plateau can clearly tolerate harsh physical soil conditions. All soils were shallow and the rock fragment content for three of the four species (*Phacelia debilis*, *Cycladenia humilis* var. *jonesii*, *Schoenocrambe suffrutescens*) was very high (50 to 100% by volume). All species were able to tolerate steep slopes and *Phacelia debilis* appeared to have adapted to survive by stem elongation as rock fragments creep downslope due to gravity. The high clay and low rock fragment contents of the *P. submutica* soils were unusual, but still physically challenging for perennials. However, this very shallow-rooted annual is not adversely affected by shallow soils and completes its life cycle in spring when soils are moist, thus avoiding the damaging effects of shrink-swell.

Some endemic plant species of the Colorado Plateau can tolerate gypsum, high concentrations of calcium carbonate, and relatively high concentrations of potentially toxic trace elements such as Se, As, and Hg. However there appears to be no “silver bullet” in terms of a soil chemical property or set of properties that “restricts” these plants to a particular habitat; these species appear to tolerate these chemical conditions rather than require them. In addition, strongly alkaline soils with high pH and/or high concentrations of calcium carbonate have low nutrient availability (e.g., P), adding stress to the harsh soil and landscape physical environment.

These rare, endemic plant species are clearly stress tolerators able to survive in soil and landscape conditions where competitively dominant plant species cannot. We suggest that conservation of rare plant species that occur on otherwise bare areas, on steep slopes, and in shallow soils depends on habitat conservation of these small geographic areas. The occurrence of these plants on bare soil surfaces on distinct geologic formations and often steep slopes can facilitate spectral and topographic modeling of potential plant habitat, which can help locate additional plants and delineate specific geographic areas for conservation.

Acknowledgements

We thank the US Department of Interior Bureau of Land Management, US Fish and Wildlife Service, US Fish and Wildlife Foundation, and the Utah Agricultural Experiment Station for funding this work. Many Utah State University students and volunteers assisted with field and laboratory work. While portions of this work were presented previously in theses, publications, and reports, we hope that presenting our findings from four rare endemic plant species in one presentation/paper will facilitate rangeland planning decisions for conservation throughout the Colorado Plateau.

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