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# Estimating the Minimum Population Size of Dawson's Hookless Cactus (*Sclerocactus dawsoniae*)

## Technical Note 460

June 2024

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**Cover photo:** Researchers sampling a point-in-time macroplot north of De Beque, Colorado.
By Phil Krening, BLM.

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# Estimating the Minimum Population Size of Dawson's Hookless Cactus (*Sclerocactus dawsoniae*)

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# Abstract

In 2021, the Bureau of Land Management assessed the minimum population size of the federally threatened plant Colorado hookless cactus (*Sclerocactus glaucus*), resulting in an estimate of approximately 104,000 individual plants. Since that time, genetic investigation revealed that the northeastern distribution of Colorado hookless cactus, known colloquially as the "northern" or "De Beque" population, represents a distinct species—described as Dawson's hookless cactus (*Sclerocactus dawsoniae*). This technical note describes the results of a sampling-based procedure to estimate the minimum extant population size of Dawson's hookless cactus. Between April 2021 and May 2023, 50 mapped habitat areas were assessed, of which 28 areas were suitable for sampling. The other 22 areas were rejected due to an insufficient number of plants found within the mapped area. Based on the resulting sample, it was determined that the estimated minimum population size of Dawson's hookless cactus is 17,362 individual plants.

# 1. Introduction

Recent indepth morphological and genetic study of the genus *Sclerocactus* has led to an increased understanding of evolutionary relationships within the genus. As a result, the circumscription of several species has been revised, including the segregation of a new taxon, named Dawson's hookless cactus (*Sclerocactus dawsoniae*) from within Colorado hookless cactus (*Sclerocactus glaucus*) (McGlaughlin and Naibauer 2023). Both cactus species are endemic to the high deserts of Colorado's western slope and are allopatric in their relative distributions, with Dawson's hookless cactus occurring to the north and west of the Grand Valley near the town of De Beque and Colorado hookless cactus occurring throughout the Grand Valley and south along the Gunnison River and its tributary canyons.

In 2021, the Bureau of Land Management (BLM) undertook an assessment of the minimum population size of what was known at the time as the "greater-Grand Valley population" of Colorado hookless cactus, which resulted in an estimate of approximately 104,000 individual plants (Krening et al. 2021). The recent recognition of Dawson's hookless cactus as a distinct species raises questions related to its relative abundance compared to its more widespread congener, particularly since the range of the newly described cactus is smaller, subject to different stressors, and was not included in the original study. While the two species share many similarities, the density estimates derived from sampling Colorado hookless cactus do not directly apply to Dawson's hookless cactus. This technical note presents the results of a sampling-based procedure to estimate the minimum extant population size of Dawson's hookless cactus.

The approach summarized herein closely follows the procedure used previously for Colorado hookless cactus (Krening et al. 2021). Since density is the measurement of a given quantity per unit area, it is possible to numerically estimate the size of a population if the density at which it occurs over a defined area is understood. In its most simplistic form, this assessment relies on estimates of mean plant density obtained within sampled macroplots and extrapolated to known habitat areas to derive an estimate of the population size for the species overall. Because each macroplot sampled captured only a portion of the plants within the habitat area assessed, and there were very likely other plants outside the macroplot, it is reasonably certain that estimates of the total number of individuals per habitat area, and therefore, for the species overall, represent the minimum number.

One weakness identified with the original study design was that all mapped habitat areas were treated the same regardless of size. This resulted in an underrepresentation of the small number of large habitat areas in the final sample. Because habitat areas of different sizes may differ in terms of their respective plant densities, adjustments were made in this study to stratify the sample of habitat areas by size. Doing so increases the spatial balance of the sample and therefore its overall representativeness.

## 1.1 Study Species

Dawson's hookless cactus is a small barrel cactus endemic to the semiarid high-elevation deserts of Colorado's western slope (Garfield and Mesa Counties). Plants are usually composed of a single globose or short cylindrical stem, though instances of cactus clusters are relatively common where smaller individuals have established at the base of mature parent plants forming a cluster or "mound" of individuals (Figure 1). Mature plants typically produce pink flowers from late April through May.

Though, despite subtle variation in size and the number of spines per areole, the species is virtually indistinguishable from Colorado hookless cactus of the neighboring greater-Grand Valley region (McGlaughlin and Naibauer 2024).

**Figure 1.** Cluster of individual Dawson's hookless cacti establishing at the base of a parent plant near Molina, Colorado.

The entire distribution of Dawson's hookless cactus occurs in an area of only 176 square miles, radiating from the town of De Beque and the Colorado River Valley north along Roan Creek and its Dry Fork tributary, west through Sulphur Gulch as far as Winter Flats, and south throughout the Atwell, Shire, and Jerry Gulch drainages in the Plateau Creek watershed (USFWS 2021). Within the Colorado River Valley, the southern slopes of Mount Logan and the upstream mouth of De Beque Canyon are the species known limits in the northeast and southwest respectively. The majority of occurrences range from approximately 5,000-6,000 ft above sea level, though there are small, scattered occurrences found up to 6,300 ft along the northeast flank of South Shale Ridge.

Occupied sites are typically small and patchy with few, if any, occurrences greater than about an acre. Plants generally occur in gently sloping, stony outwashes at the bottom of steep outcrops of exposed Wasatch Formation (Figure 2). Of the varied sedimentary beds that compose the Wasatch Formation, Dawson's hookless cactus appears to be primarily associated with soils derived from the brown, gray, and tan claystones of the Shire and Atwell Gulch members. Of the many sites surveyed during this assessment, few if any instances of Dawson's hookless cactus were found occupying the variegated red, purple, lavender, and coffee-colored soils that make the formation conspicuous. The species is apparently absent from adjacent areas where the surface geology consists of either Green

River shale or the sandstones of the Ohio Creek Formation (Mesa Verde group). The extent to which Dawson's hookless cactus occupies the suitable habitat available within the immediate De Beque region is tiny when compared to its prevalence. Particularly, it is unclear why Mount Logan is the northeastern extent of the species distribution, given that contiguous areas of apparently suitable, yet unoccupied, habitat underly the Roan Cliffs eastward to Rifle and the Grand Hogback.

**Figure 2.** Researchers surveying a macroplot in a stony outwash typical of Dawson's hookless cactus habitat at Winter Flats.

At the site level, Dawson's hookless cactus requires relatively stable soils. Plants are frequently distributed along the margins of shallow, ephemeral washes at the base of shrubs, which act as nurse plants or otherwise provide some measure of protection from disturbance (Figures 3 and 5). Plants are almost exclusively found in areas where soil crusts are intact or, where erosive forces are stronger, in areas of "desert pavement" where the soil surface is anchored by cobbles and rock fragments (Figure 4). Plants are generally absent from slopes greater than approximately 10˚. At higher elevation sites and those with a northerly aspect, plants are occasionally found scattered throughout sagebrush (*Artemisia tridentata*) flats and growing among duff in woodlands of twoneedle pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*), though these sites appear to be marginal and generally contain only a handful of scattered individuals.

**Figure 3.** The white oval encircles a typical Dawson's hookless cactus microsite. This is a gently sloping, stony outwash below exposed Wasatch Formation (Shire member) near Logan Wash in Colorado.

**Figure 4.** Several small Dawson's hookless cactus individuals emerging from surface cobbles at South Shale Ridge.

Commonly associated species include: shadscale saltbush (*Atriplex confertifolia*), longflower rabbitbrush (*Chrysothamnus depressus*), carpet phlox (*Phlox hoodii*), bulbous springparsely (*Cymopterus bulbosus*), textile onion *(Allium textile)*, basindaisy (*Platyschkuhria integrifolia*), hoary Townsend daisy (*Townsendia incana*), kingcup cactus (*Echinocereus triglochidiatus*), pricklypear (*Opuntia* spp.), and James' galleta (*Hilaria jamesii*). Many sites are quite weedy, featuring an assortment of nonnative and invasive annual plants including cheatgrass (*Bromus tectorum*), annual wheatgrass (*Eremopyrum triticeum*), desert madwort (*Alyssum desertorum*), crossflower (*Chorispora tenella*), curveseed butterwort (*Ranunculus testiculatus*), and redstem stork's bill (*Erodium cicutarium*).

**Figure 5.** Dawson's hookless cactus individual established at the base of a sagebrush.

# 2. Methods

Throughout this technical note, plant density is described at multiple scales. At its most basic level, estimates of plant density were derived from within macroplots and are representative of plant density at a given site. These macroplot density estimates were then converted to estimates of habitat area density by dividing the number of plants estimated in each macroplot by the area of the larger habitat area within which it was obtained, thereby diluting the macroplot (or site-level) densities to approximate the minimum plant density for each habitat area. A ratio estimator was then used to average the plant density for collections of habitat areas of various sizes. These ratio estimator plant densities were ultimately multiplied by the area of the complete collection of habitat areas (mapped occupied habitat) to calculate a minimum population size for the species overall.

## 2.1 Study Design

This study involved a two-stage sample design, where 28 habitat areas were ultimately sampled using a stratified random sample. Habitat areas were stratified into five discrete groups based on their size (very small, small, moderate, large, and very large). Each of the 28 habitat areas was sampled using a subjectively sited rectangular macroplot. These macroplots were established to capture a portion of the plants within a given habitat area and functioned as the primary sample units in the two-stage design. Each macroplot was then sampled using rectangular quadrats (secondary sample units) selected using a simple random approach, where each quadrat had an equal chance of being selected for sampling. Mean plant density and estimated population totals were calculated for each of the 28 macroplots from the census counts within the nested quadrats.

To prevent overestimation, the procedure assumes that the only plants within each habitat area sampled are those estimated in the macroplot itself. Therefore, the plant density for each habitat area was determined by dividing the estimated number of plants within the macroplot by the area of the larger habitat area within which it occurred. In such case, the resulting density estimates represent ***the minimum number*** of plants per habitat area because they disregard any additional plants that occur in the habitat area and not captured by the macroplot. A ratio estimator was then used to estimate plant density for five size-defined strata. These density estimates were then applied to the complete set of mapped habitat areas that fell into those strata to obtain an estimate of the minimum population size of Dawson's hookless cactus.

## 2.2 Estimating the Area of Occupied Habitat

Any attempt to develop a population size using plant density relies on having a reasonably accurate understanding of where the plant does and does not occur, because the area of occupation is the multiplier to which the density estimates are ultimately applied. To produce a representation of the spatial extent of Dawson's hookless cactus, all occurrence data from Colorado Natural Heritage Program occurrence records were combined with BLM survey data from the Grand Junction and Colorado River Valley Field Offices. The resulting spatial representation consisted of both point data and polygons. In situations where polygon data were concurrent between the two datasets, the union geoprocessing tool in ArcGIS Desktop was used to combine the polygons to ensure that any given area was only counted once. Any additional overlapping areas were manually eliminated in ArcGIS with priority given to the dataset that was most current or complete. As an additional measure, polygons that were clearly derived from a single buffered point were eliminated regardless of their size.

In many cases, point data were clustered in areas of occupation, but because point data are nondimensional, it was not possible to directly apply plant density values to these areas. To obtain a conservative area calculation from the clustered points, these point clusters were converted to polygons using the point density tool in the spatial analyst extension for ArcGIS. The point density analysis used the merged point dataset to perform a density calculation; spatial data points that fell within a search area of 20 $m^2$ were summed and then divided by a search radius of 50 m to derive a point density value for each 20 $m^2$ cell (Silverman 1986). The point density output raster was then reclassified for density values > 0.0005 points/$m^2$ to define the clustered population areas. The resulting raster output was then converted to a polygon layer and unioned with the existing polygon dataset. The resulting output from the GIS exercise was a constellation of 273 individual polygons, each representing a discrete habitat area.

## 2.3 Sample Design

The final spatial layer consisted of 273 mapped Dawson's hookless cactus habitat areas ranging in size from < 1 $m^2$ to 517,869.7 $m^2$ with a mean of 18,453.4 $m^2$ and a standard deviation of 58,057 $m^2$. In order to obtain a spatially balanced sample of these areas, the sample was stratified by habitat area size into five discrete, non-overlapping strata (very small = 2,501–10,000 $m^2$; small = 10,001–50,000 $m^2$; moderate = 50,001–100,000 $m^2$; large = 100,001–200,000 $m^2$; and very large = > 200,000 $m^2$. Habitat areas less than 2,500 $m^2$ were assigned as "no strata," and no sampling occurred within these areas.

The habitat areas (primary sample; n=30) were allocated within the five size-defined strata using a weighted approach based on the amount of variance displayed within each, which was determined by its standard deviation (SD). Such an approach increases sampling intensity within strata that have higher variance in size and approximates an optimum allocation (Neyman 1934). Table 1 shows the optimum allocation of the habitat areas within the five strata. Most of the habitat areas (62.6%) fell into the very small stratum, which had the least amount of variance in size (SD = 2,277.8) and consequently was allocated the lowest sampling intensity (n=6, 5.13%) (Table 1).

**Table 1.** Optimum allocation of samples (n=30) based on a stratified sample design.

| | STRATUM | | | | |
|---|---|---|---|---|---|
| | **Very large** | **Large** | **Moderate** | **Small** | **Very small** |
| **Proportion of total** | 2.14% | 1.60% | 7.49% | 26.20% | 62.57% |
| **Standard deviation** | 54,327.1 | 31,109.0 | 9,274.4 | 11,171.5 | 2,277.8 |
| **n allocated** | 3 | 2 | 4 | 15 | 6 |
| **Proportion sampled** | 75.00% | 66.67% | 28.57% | 30.61% | 5.13% |

## 2.4 Habitat Area Assessment

Thirty habitat areas were ultimately selected for sampling from a selection of 60 habitat areas (30 primary sample points and 30 oversample points) using a spatially balanced stratified random design generated by the Shiny spatially balanced sampling application in the Landscape Toolbox (Karl 2007). During field evaluation, a team of trained botanists from the BLM and University of Northern Colorado surveyed each habitat area for Dawson's hookless cactus. If the habitat area contained a sufficient number of plants, an area was subjectively chosen to establish a sample macroplot (see section 2.5 which follows). If a selected habitat area contained an insufficient number of plants, or a spatial configuration of plants that made it impossible to sample, the team navigated to the nearest habitat area belonging to the same stratum and repeated the process. If none of the habitat areas within a given stratum in the immediate region contained a sufficient number of plants for sampling, the point was rejected and an oversample point was chosen to replace it, following the order in which the samples were randomly generated. Eventually, the primary sample and oversample became exhausted in two strata (large and very small) due to high rates of rejection, resulting in a final sample of 28 habitat areas.

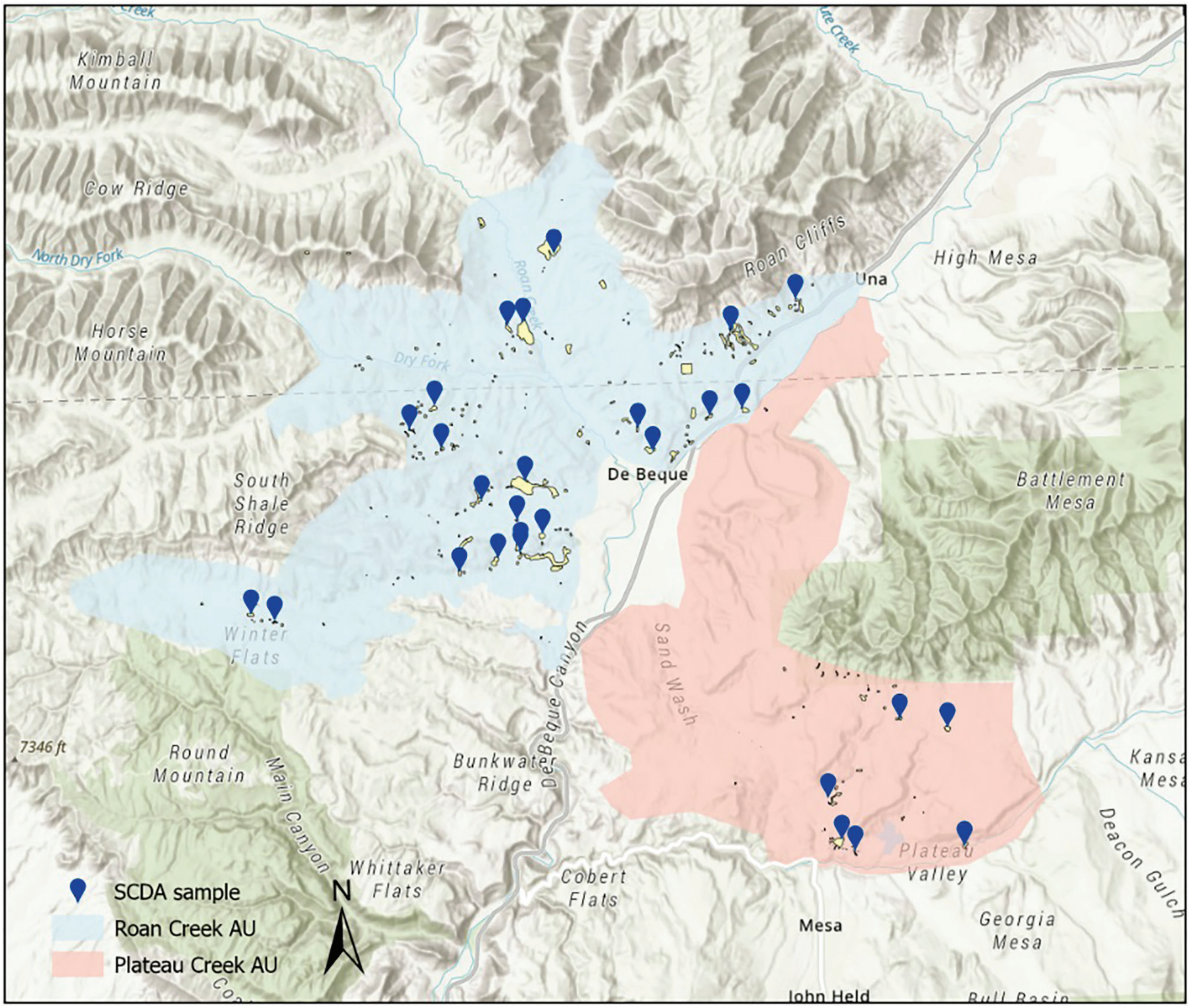


**Figure 6.** Distribution of 28 Dawson's hookless cactus samples. Polygons indicate the extent of two analytical units used in the Colorado hookless cactus species status assessment (USFWS 2021). The northernmost polygon is Roan Creek, and the southernmost polygon is Plateau Creek.

## 2.5 Sample Macroplots

Within each habitat area that contained a sufficient number of plants for sampling, a rectangular macroplot was subjectively sited encompassing a portion of the plants within the habitat area. Generally, areas sampled consisted of core populations with disproportionately high plant density compared to the larger habitat area. While this could lead to the assumption that the resulting density estimates are biased high, the macroplots themselves were many times smaller than the habitat areas they were chosen to represent, capturing approximately 1% of the habitat area on average (Table 2). Each macroplot was divided into a series of even-sized rectangular quadrats for sampling. Within each macroplot, the necessary number of quadrats was selected for sampling using a simple random approach, whereby each quadrat had an equal chance of being selected for sampling. Macroplot density in terms of the number of plants/m$^2$ was calculated. Power analysis was completed at each site to ensure enough quadrats were sampled to be at least 80% confident of obtaining an estimate of the mean density and population size within 30% of its estimated true value (Elzinga et al. 1998).

**Table 2.** Summary statistics for 28 samples of Dawson's hookless cactus. Densities reported per sample are macroplot densities, not habitat area densities. Habitat area densities can be determined by dividing the estimated total by the corresponding habitat area.

| Site | Stratum | Analytical Unit | Macroplot Area (m$^2$) | Estimated Total | Density | Habitat Area (m$^2$) | Quadrat Area (m$^2$) | Mean | Standard Deviation | N | n |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Chevron** | Very Large | Roan Creek | 240 | 67 | 0.279 | 444,206.2 | 40 | 11.2 | 10.1 | 6 | 5 |
| **Black Hills** | Very Large | Roan Creek | 720 | 46 | 0.064 | 517,869.7 | 80 | 5.1 | 6.0 | 9 | 8 |
| **South Shale Ridge** | Moderate | Roan Creek | 840 | 72 | 0.086 | 53,443.3 | 40 | 3.4 | 4.1 | 21 | 14 |
| **N. Pyramid Rock** | Small | Roan Creek | 800 | 146 | 0.183 | 43,895.6 | 40 | 7.3 | 9.8 | 20 | 14 |
| **Interstate** | Small | Roan Creek | 660 | 12 | 0.018 | 41,458.9 | 165 | 3.0 | 3.6 | 4 | 4 |
| **Ant Mound** | Small | Roan Creek | 640 | 56 | 0.088 | 48,799.9 | 80 | 7.0 | 3.7 | 8 | 5 |
| **Well Pad** | Small | Roan Creek | 1,440 | 102 | 0.071 | 15,663.9 | 80 | 5.7 | 6.7 | 18 | 13 |
| **Winter Flats** | Very Small | Roan Creek | 480 | 157 | 0.327 | 9,874.5 | 40 | 13.1 | 12.6 | 12 | 9 |
| **Pond** | Small | Roan Creek | 1,800 | 498 | 0.277 | 39,686.9 | 100 | 27.7 | 28.3 | 18 | 12 |
| **Homer Deep** | Small | Roan Creek | 250 | 41 | 0.164 | 14,758.6 | 50 | 8.3 | 3.2 | 5 | 4 |
| **Hoodoos** | Small | Roan Creek | 672 | 228 | 0.339 | 34,542.4 | 48 | 16.3 | 20.9 | 14 | 11 |
| **C Hollow** | Very Small | Roan Creek | 320 | 63 | 0.197 | 7,589.7 | 40 | 7.8 | 6.7 | 8 | 6 |
| **Racetrack** | Moderate | Roan Creek | 960 | 202 | 0.210 | 63,294.3 | 80 | 16.8 | 32.5 | 12 | 11 |
| **Pyramid Bench** | Very Small | Roan Creek | 480 | 110 | 0.229 | 3,560.0 | 40 | 9.1 | 7.3 | 12 | 8 |
| **Pyramid Rock** | Moderate | Roan Creek | 1,200 | 690 | 0.575 | 56,602.2 | 40 | 23.0 | 22.4 | 13 | 22 |
| **Watertower** | Moderate | Roan Creek | 320 | 19 | 0.059 | 74,327.0 | 80 | 4.8 | 3.8 | 4 | 4 |
| **Logan Wash** | Very Large | Roan Creek | 2,080 | 66 | 0.032 | 474,364.7 | 130 | 4.1 | 2.6 | 16 | 8 |
| **De Beque Bench** | Small | Roan Creek | 780 | 17 | 0.022 | 35,213.0 | 130 | 2.8 | 2.2 | 6 | 5 |
| **The Gulch** | Very Small | Roan Creek | 800 | 16 | 0.020 | 9,210.8 | 100 | 2.0 | 1.7 | 9 | 8 |
| **Powerline** | Small | Roan Creek | 1,024 | 75 | 0.073 | 28,054.5 | 64 | 4.7 | 3.2 | 16 | 9 |
| **Winter Flats 2** | Small | Roan Creek | 960 | 27 | 0.028 | 26,458.1 | 80 | 2.3 | 2.5 | 12 | 11 |
| **Ramp** | Small | Roan Creek | 400 | 19 | 0.048 | 16,817.6 | 100 | 4.7 | 2.3 | 4 | 3 |
| **Atwell Gulch** | Small | Plateau Creek | 1,200 | 135 | 0.113 | 22,342.4 | 80 | 9.0 | 10.9 | 15 | 10 |
| **Jerry Creek** | Very Small | Plateau Creek | 480 | 380 | 0.792 | 9,525.8 | 40 | 31.6 | 28.0 | 12 | 8 |
| **Halfway House** | Small | Plateau Creek | 400 | 12 | 0.030 | 13,722.7 | 80 | 2.4 | 2.6 | 5 | 5 |
| **Indian Peak** | Large | Plateau Creek | 1,200 | 300 | 0.250 | 120,662.5 | 80 | 20.0 | 10.8 | 15 | 7 |
| **Sunnyside** | Small | Plateau Creek | 288 | 47 | 0.163 | 37,703.3 | 48 | 7.8 | 3.4 | 6 | 5 |
| **Molina** | Small | Plateau Creek | 320 | 115 | 0.359 | 27,798.5 | 40 | 14.4 | 18.2 | 8 | 7 |

## 2.6 Ratio Estimator

Because of the uneven sizes of the 28 habitat areas sampled, a ratio estimator was used to estimate the density and variance (Stehman and Salzer 2000). The following ratio estimator was used:

$$\hat{D} = \frac{\bar{y}}{\bar{a}}$$

where $\hat{D}$ is the estimated density, $\bar{y}$ = sample mean number of plants per habitat area, and $\bar{a}$ = sample mean area per habitat area sampled (Thompson 2012; Stehman and Salzer 2000). Krening et al. (2021) provides a detailed description of the ratio estimator and formulas used to calculate variance and construct confidence intervals. In the previous study, $\bar{y}$ corresponded with the lower 90% confidence level of each of the samples. This was done as an additional conservative measure because the samples were predominately derived from smaller areas and applied as a single blanket density to all mapped habitat areas, regardless of their size. For this study, the total estimated number of plants per sample was used, as opposed to the values corresponding to the lower 90% confidence level. This was done due to the more robust, stratified nature of the sample design, which is inherently more conservative by applying relevant densities to areas of different sizes.

The ratio estimator was completed using the samples taken within the five strata resulting in five separate density estimates. These estimates were then multiplied by the area of the complete collection of habitat areas within each stratum.

# 3. Results

## 3.1 Macroplot Densities

Twenty-eight sites were sampled between April 2021 and May 2023. The sampling success rate was 56%. Both the very small and large strata fell short by one sample due to high rates of rejection, ultimately reducing the final sample from 30 to 28. Macroplot densities ranged between 0.018 and 0.792 plants/$m^2$ based on an average study site area of 760 $m^2$. The average of the 28 macroplot densities was 0.178 plants/$m^2$. Estimated macroplot totals ranged from 12 to 690 individual plants based on the same series of variously sized macroplots (Figure 7).

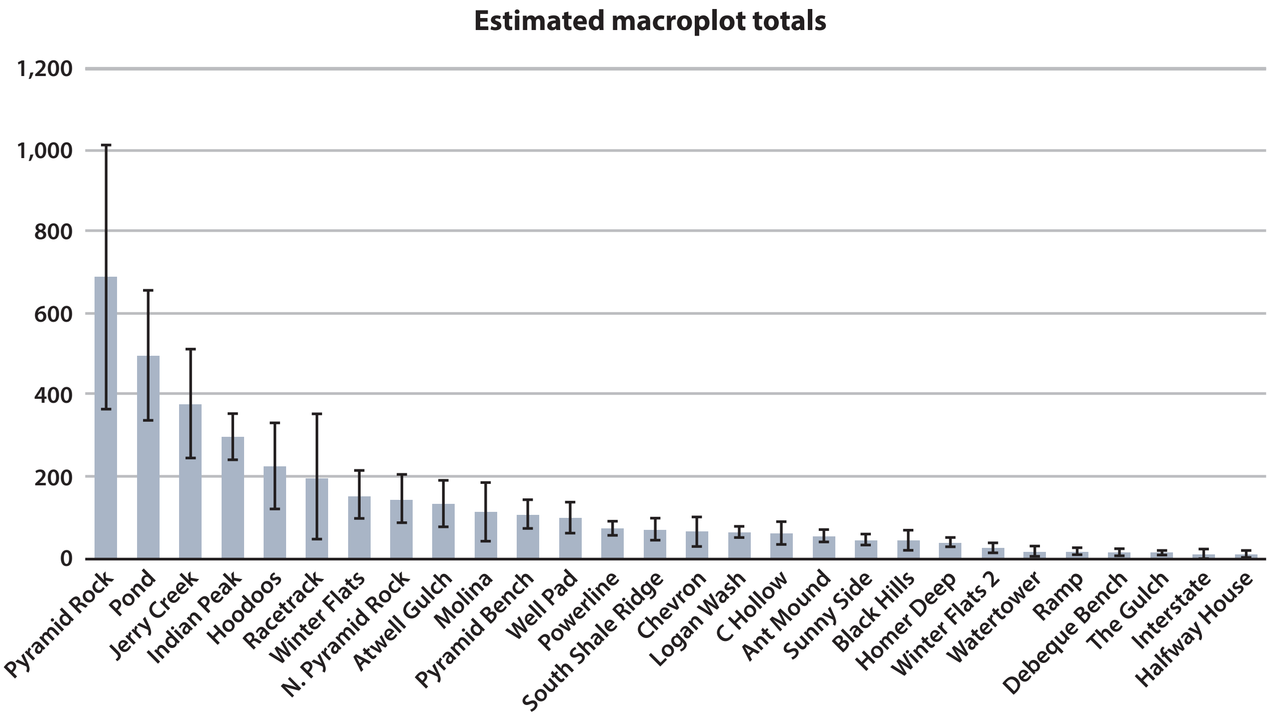


**Figure 7.** Estimated number of Dawson's hookless cactus per macroplot (n=28). Bars are 80% confidence intervals.

## 3.2 Ratio Estimation

The mean estimated plant totals from each macroplot sample and the mean habitat areas within which the mean estimated plant totals were obtained were used with a ratio estimator to calculate estimated plant density for each stratum. These five resulting density estimates were then applied to the area of the total collection of habitat areas within each stratum to obtain a conservative estimate of the number of plants per stratum (Table 3).

**Table 3.** Output statistics resulting from the ratio estimation procedure using the estimated totals from the 28 macroplots.

| | Stratum | | | | |
|---|---|---|---|---|---|
| | **Very large** | **Large** | **Moderate** | **Small** | **Very small** |
| **n sampled** | 3 | 1 | 4 | 15 | 5 |
| **Density (plants/m$^2$)** | 0.0001 | 0.0025 | 0.0040 | 0.0034 | 0.0183 |
| **Standard error** | 0.00002 | N/A | 0.00262 | 0.00104 | 0.00764 |
| **Area (m$^2$)** | 1,824,984.5 | 120,662.5 | 691,277.3 | 734,210.0 | 634,036.9 |
| **Estimated number of plants** | 227 | 300 | 2,744 | 2,514 | 11,577 |

## 3.3 Area Multiplier

As an additional measure to ensure a conservative estimate, the habitat areas that were rejected based on an insufficient number of plants were removed from the final area multiplier for each stratum. While it would be nearly impossible to confirm that these areas were entirely absent of the target species, they did not contain enough plants (or a spatial configuration of plants) that lent themselves to sampling. Generally, these areas contained a handful of scattered individuals occurring over large distances. In combination with areas designated as "no strata," which cumulatively accounted for 65,622.5 m$^2$, approximately 20% of the total area of occupation was ultimately removed from final calculations. The resulting estimated minimum population size for the species overall is 17,362 individuals.

# 4. Discussion

A combination of three factors contribute to the minimum population size of Dawson's hookless cactus being lower than its greater-Grand Valley counterpart. These factors are: (1) Dawson's hookless cactus occupies fewer sites covering a smaller total area; (2) on average, Dawson's hookless cactus occurs in lower site-level densities; and (3) the sample was drawn from a stratified design, whereby a representative proportion of the final sample was drawn from areas of different sizes—including large areas. Ultimately, the stratified sample was very conservative with respect to large, mapped areas which have been the subject of skepticism related to the accuracy of their mapping. Taken together, these factors result in a lower estimate of Dawson's hookless cactus compared to Colorado hookless cactus in the neighboring greater-Grand Valley.

Based on observations in the field, the finding that Dawson's hookless cactus contains fewer individuals than Colorado hookless cactus was expected. Many of the sites visited contained few, if any, plants, as exemplified by the high rate of sample point rejection. Core population areas, where plants were relatively abundant, were predominately limited to the vicinity of Pyramid Rock, South Shale Ridge, and Atwell Gulch. It appears likely that these three areas alone harbor a significant portion of the total population. Across much of its range, occurrences of Dawson's hookless cactus are small and scattered and contain only a handful of individuals.

It is important to note that while 17,362 plants represents the minimum number of extant Dawson's hookless cactus, the true population size is very likely larger. Though, exactly how much larger is difficult to say. The stratified nature of the sample and the method by which the resulting density estimates were applied reduces or eliminates issues with large areas and their potential to inflate numbers identified in the original study (Krening et al. 2021). On-the-ground observation confirmed the hypothesis that the large, mapped areas in the spatial layer and area multiplier are not, in fact, biologically relevant and representative of continuous occupation by the species. Ultimately, the densities applied to these areas are very conservative, leading to a conservative, if not plausible, estimate of the population size for the species overall.

While it was not explicitly factored into the study design, there is vested interest in understanding how the population is distributed between the two analytical units used during the most recent status review of Colorado hookless cactus. These analytical units divide the species range north and south of the I-70 corridor along the Colorado River, with Plateau Creek in the south and Roan Creek in the north (Figure 6). Based on the application of five stratified densities to mapped habitat areas in each analytical unit, the vast majority of the population is estimated to occur in the Roan Creek analytical unit (14,901 plants), while Plateau Creek is estimated to contain at least 2,461 plants.

It is beyond the scope of this assessment to determine whether Dawson's hookless cactus naturally occurs in such rarity, or if its small population size is the product of a historic or ongoing decline. What is apparent, based on this assessment, is that moderate to high densities of plants are almost exclusively found in areas where the soil surface is durable and resistant to erosion and disturbance. Outside of areas that fit this description, plants are limited to sites where soil crusts are intact and/or sheltered underneath the canopy of shrubs, which provide protection from disturbance. This pattern of occurrence suggests that areas with loose soils, where erosional forces are high, or where land-use activities result in disturbance to the soil surface are likely incompatible with the proliferation of Dawson's hookless cactus.

# 5. Conclusion

This study demonstrated that site-level densities of Dawson's hookless cactus (0.18 plants/$m^2$) are lower on average than those of Colorado hookless cactus (0.24 plants/$m^2$) in the neighboring greater-Grand Valley, and subsequently that its overall population size is many times smaller. The species also lacks ecological representation and redundancy given that a majority of its total population (86%) occurs in a single management unit (the Roan Creek analytical unit contains an estimated 14,901 plants while the Plateau Creek analytical unit contains an estimated 2,461 plants). These attributes—small population size, a high degree of habitat specificity, and a narrow geographic distribution—are characteristics shared by the rarest plant species (Rabinowitz and Synge 1981). During the course of this assessment, a large amount of habitat was surveyed revealing that many of the large, mapped occurrences of Dawson's hookless cactus are not representative of the species' actual occupation on the ground. These areas, which are concentrated at the northeastern extent of the species range, should be the focus of remapping efforts. An apparent lack of recruitment was also noted over portions of the species range, suggesting that degraded land health may be impacting seed production and seedling recruitment in marginal sites that contain a proliferation of nonnative, invasive plants or where the habitat characteristics required by the species have otherwise been altered. Additional investigation of these demographically depauperate patches would help shed light on possible factors inhibiting population growth. In 2023, the U.S. Fish and Wildlife Service proposed the delisting of Colorado hookless cactus from the federal list of threatened and endangered species and found that Dawson's hookless cactus was not warranted for listing. Both species will be retained as designated sensitive species by the BLM Colorado State Director.

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